Resilient Sites & Connected Landscapes

For Terrestrial Conservation in Alaska

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at The Nature Conservancy

Resilient Sites and Connected Landscapes for Terrestrial Conservation in Alaska.

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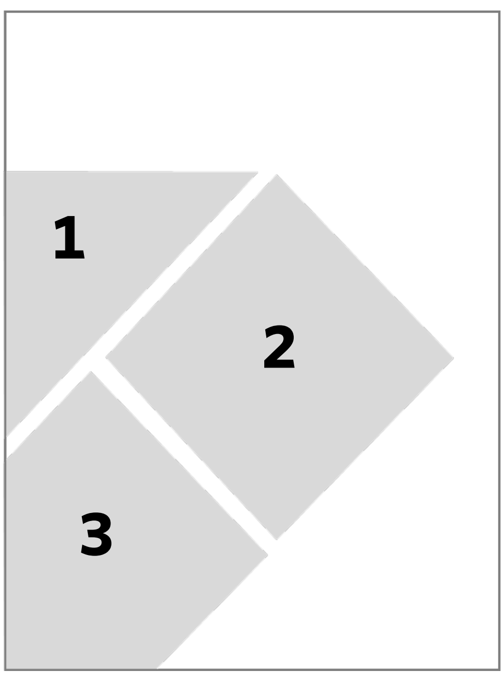

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3. Denali National Park, Alaska. © Charlie Ott

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CHAPTER

INTRODUCTION 1

This report presents the results of a 2-year project to identify and map climate resilient sites across the state of **Alaska** in the U.S. This work was made possible by a grant from the Doris Duke Charitable Foundation, along with contributions from the Alaska Chapter of The Nature Conservancy (TNC). It is part of a set of analyses to identify a comprehensive and connected network of resilient lands across the U.S.

Project History and Scope

TNC has been working for over ten years with support from the Doris Duke Charitible Foundation to identify climate resilient sites in the United States. The Conserving Nature's Stage (CNS) approach has been applied to the U.S. Northeast, Southeast, Great Lakes and Tallgrass Prairie, Great Plains, Rocky Mountains, Desert Southwest, California and Pacific Northwest regions (Anderson and Ferree 2010; Anderson et al. 2012; Anderson et al. 2014a; Anderson et al. 2016a; Anderson et al. 2018a; Anderson et al. 2018b., Anderson et al. 2019, Buttrick et al. 2015). Each of these geographies were analyzed using CNS methods pioneered by TNC's Center for Resilient Conservation Science team led by Dr. Mark Anderson and further refined in each geography by teams of TNC scientists supported by regional Steering Committees. Our goal was to complete this work in Alaska and add it to the Resilient Sites and Resilient and Connected Networks data for coterminous US. Hawaii will be the final geography/state to be competed.

In this project, we expanded the CNS approach to Alaska, identifying the enduring geophysical drivers of biodiversity and the land characteristics that create resilience, and mapping a suite of places that capture these features across the region. We also identified important pathways that connect these places to allow for dispersal and migration of organisms and natural communities. We developed a blueprint for conservation priorities across this broad region, creating a resilient network that can link to similar networks previously identified the conterminous US and ultimately supporting strategies and investments that enhance the resilience of biodiversity as climate changes.

All results in this report are presented within a framework of **ecological regions** or "**ecoregions**" as defined by "Ecoregions of Alaska and Neighboring Territories" developed by Greg Nowacki (USFS), together with Page Spencer (NPS), Terry Brock (USFS), Michael Fleming (USGS) and Torre Jorgenson (ABRI) (Nowacki et al. 2001). Because each ecoregion represents an area of similar physiography and landscape features, it is an appropriate natural unit in which to evaluate geophysical representation and to compare sites. This study includes all of Alaska but does not include portions of the ecoregions that cross into Canada (Figure 1.1). Within each ecoregion, the final datasets map resilience at the scale of 30-meter cells.

Scientists and conservation planners from these states served on our Steering Committee and played an essential role in helping us to adapt the CNS methods to ecological drivers, biodiversity patterns, and land use characteristics that define this geography. Please see the Acknowledgements section for a list of all contributors.

Figure 1.1: Study Area. The 30 ecoregions in Alaska. The Canada portions of each ecoregion were not included in this analysis.

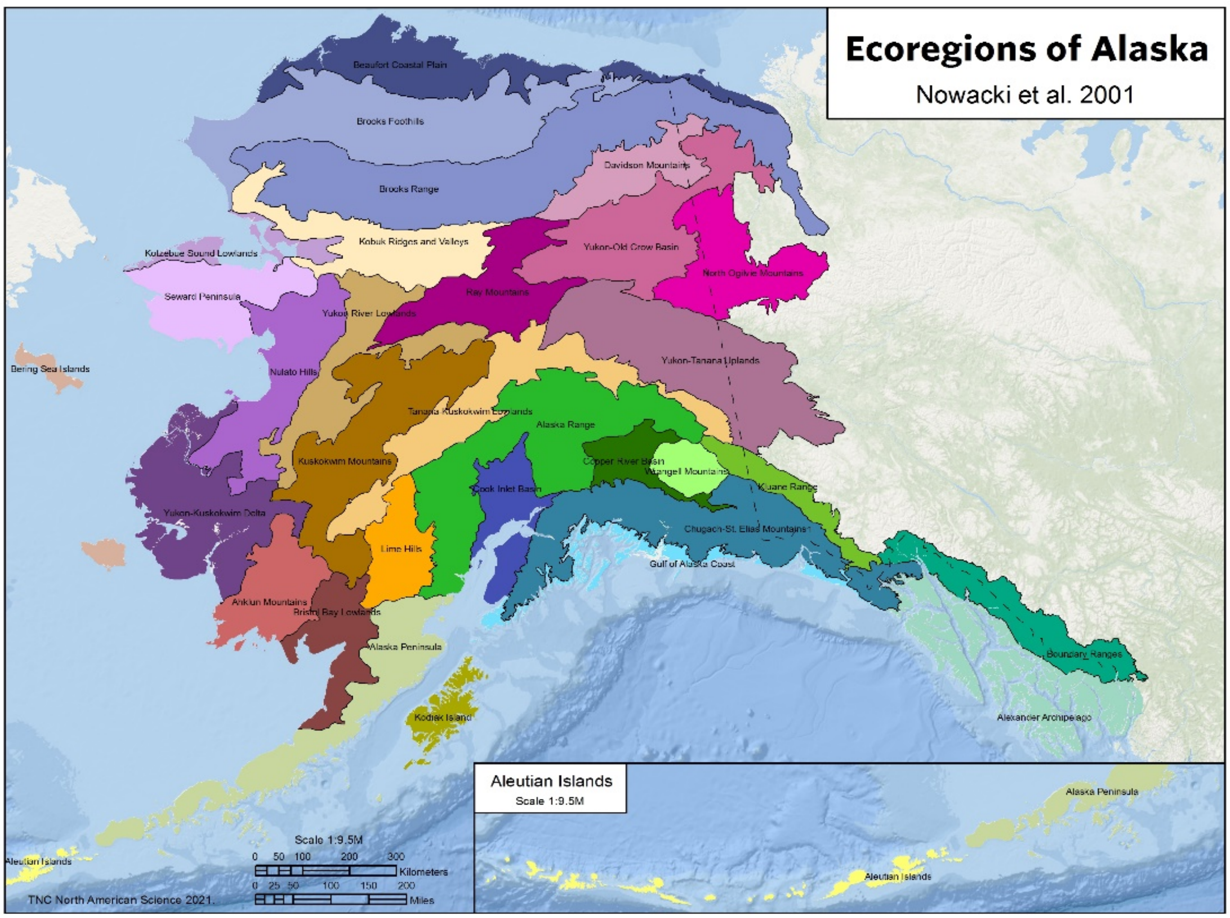
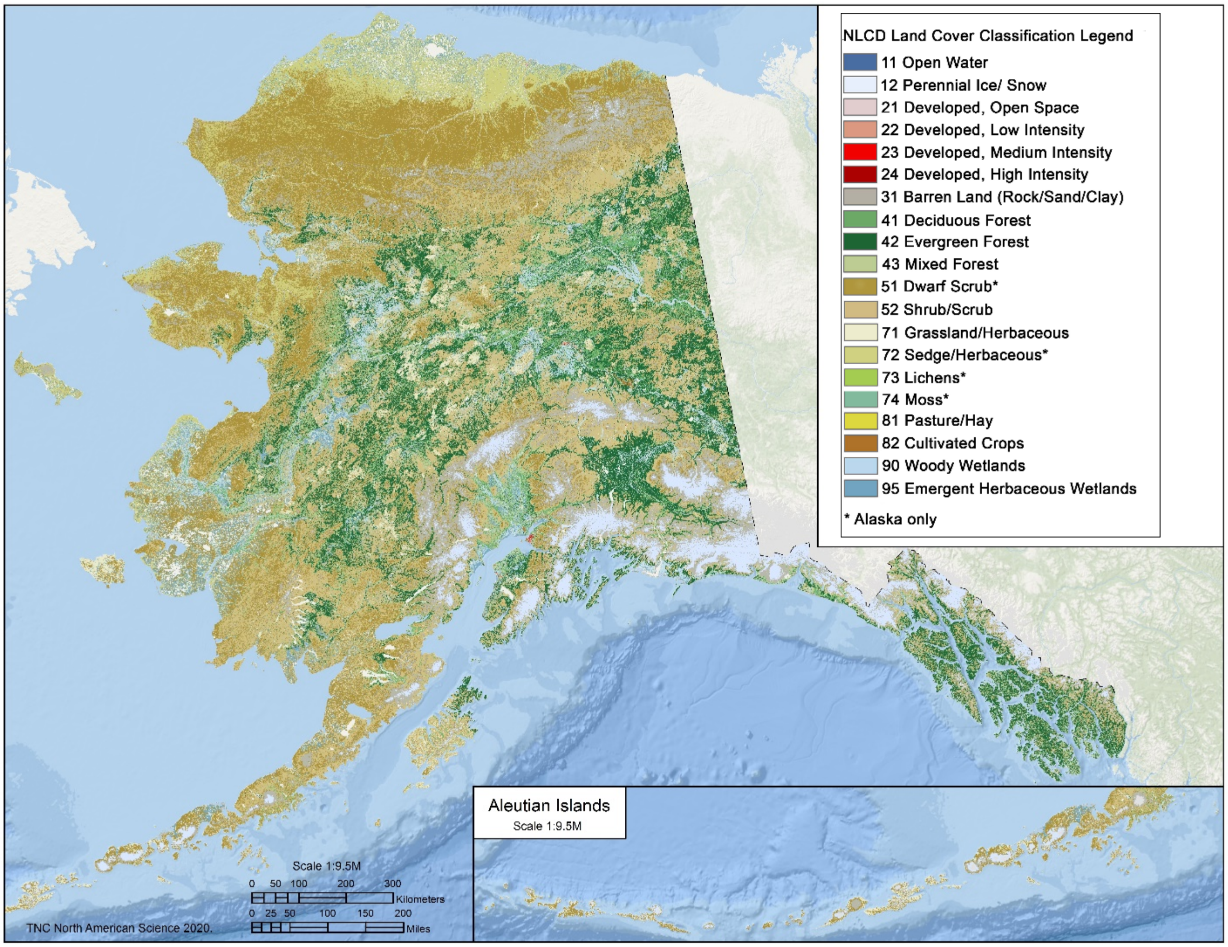


Figure 1.2: Land Use in the Alaska. The region predominately natural with tundra, boreal forests, coastal rainforests, rivers and lakes, wetlands and mountain ranges.



Secured Lands

We compiled information on tracts of permanently protected conservation in Alaska. The information is part of TNC's "secured land" dataset defined as land that is permanently secured against conversion to development. This definition was developed by an international group of scientists to differentiate "secured land" from the International Union for Conservation of Nature (IUCN) term "protected areas" which refers to land with a formal designation of conservation value (Dudley 2008).

The secured lands dataset includes many tracts of land with no formal designation but substantial conservation value, such as reserves held by The Nature Conservancy or "forever wild" easements held by a non-governmental conservation entity. In contrast, the dataset excludes some designated protected areas such as world biosphere preserves, as these areas are not formally protected from development.

To classify secured lands, we used a modified version of USFWS' GAP Status (Crist et al. 1998). Our version (TNC GAP) was similar in concept but used criteria that can be applied more easily than the USFW criteria (Table 1.1). The criteria were:

1) Intent: the degree that owner, or managing entity is focused on maintaining natural diversity.
2) Duration: the owner or managing entity's temporal commitment to maintaining the land.
3) Effective management potential: the apparent capability of a managing entity to implement the intent and duration based on governance, planning, and resource levels. In the US, local, state and federal agencies, conservation NGOs, and land trusts are considered as effective managers.

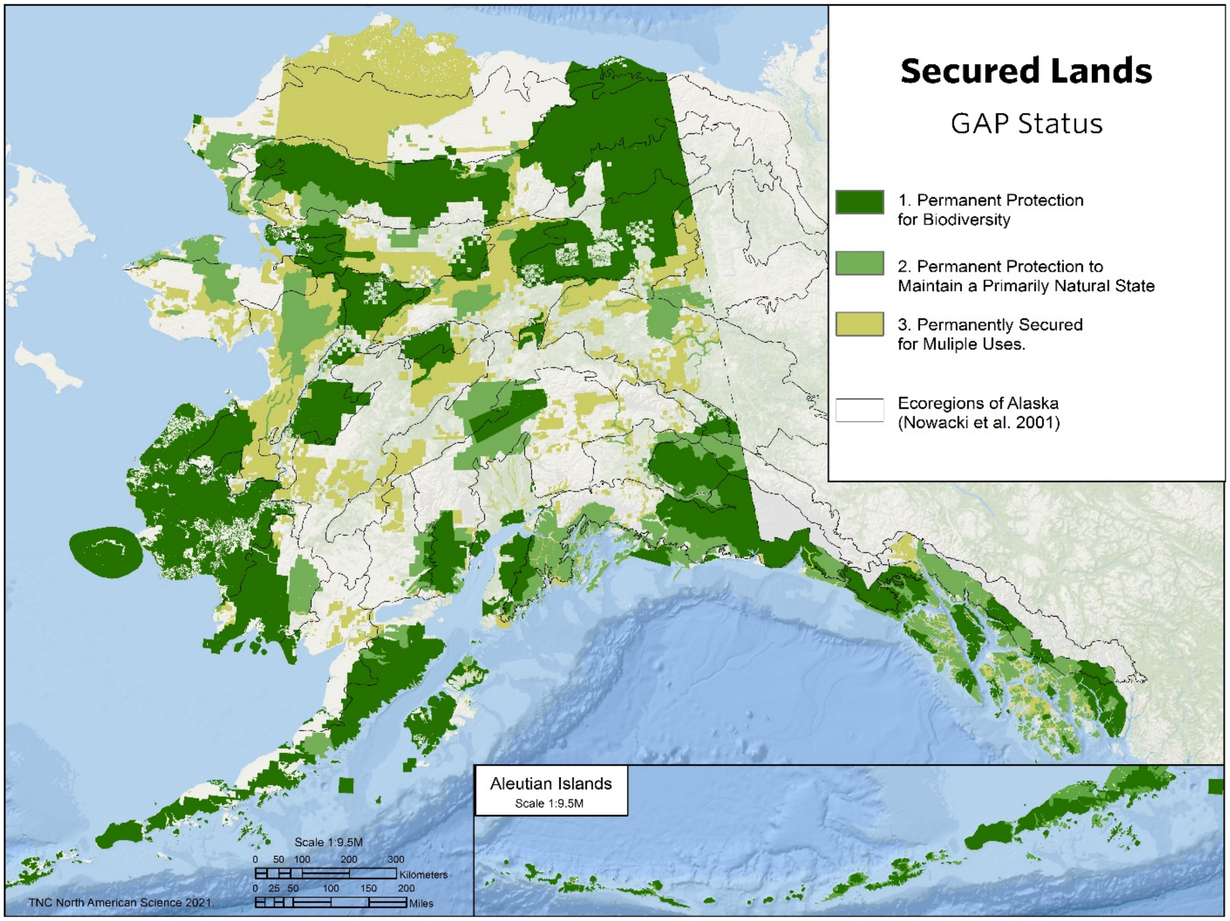
TNC GAP is a land classification system and it does not necessarily describe how protected the contained conservation targets are within a secured area (Table 1.1). For example, a species breeding on a secured parcel may be only partially conserved if their conservation calls for securement of multiple breeding areas and enough winter habitat. In this case, meeting the species conservation goal would require a network of secured lands each with the appropriate level of securement.

The main source of the secured lands dataset is the USGS Protected Areas Dataset of the United States version 2.0 published in 2018 (USGS 2018). In addition, Lands with TNC interests (fee, easements, transfers, assists) were appended to the datasets. Only parcels with permanent ownership duration were included in the mapped dataset. All parcels were assumed to meet the criterion of effective management. With consultation from the steering committee, we reviewed the GAP status of the major designation types. Management intent can change over time and it is not uncommon for conservationists to have a goal of moving the GAP status of a parcel from GAP 3 (secured for multiple-uses) to GAP 1 (secured for nature) (Figure 1.3).

Table 1.1: Comparison of GAP status, IUCN and TNC GAP status definitions.

TNC GAP	GAP STATUS	IUCN	Selected Examples
TNC GAP 1 **Intent:** Nature conservation with little human interference **Duration:** Permanent	**GAP 1:** Areas having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events can proceed without interference or are mimicked through management.	**Category Ia**: Strict Nature Reserves set aside to protect biodiversity **Category Ib:** Wilderness Areas are usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, which are managed to preserve their natural condition.	Research Natural Areas (RNA) Some TNC preserves where TNC controls management Wilderness Areas and Wilderness Study areas Forever wild easements
TNC GAP 2 **Intent:** Nature conservation with heavy management where needed **Duration**: Permanent	**GAP 2:** Areas having permanent protection from conversion of natural land cover and a management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance.	**Category III**: Natural Monument or Feature protected areas **Category IV**: Habitat/species management protected areas aim to protect species or habitats and management reflects this priority.	National Wildlife Refuges Areas of Critical Environmental Concern Some National Parks and county open space lands US Forest Service Special Interest Areas Some TNC conservation easement lands and preserves
TNC GAP 3 **Intent:** Multiple Uses. Typically, resource extraction, recreation and nature conservation **Duration:** Permanent.	**GAP 3** Areas having permanent protection from conversion of natural land cover for most of the area, but subject to extractive uses of either a broad, low-intensity type (e.g., logging) or localized intense type (e.g., mining).	**Category V:** Protected landscape/seascape where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value. **Category VI**: Protected area with sustainable use of natural resources, generally large, with much of the area in a more-or-less natural condition and where a proportion is under sustainable natural resource management and exploitation is one of the main aims of the area.	State Forests and State Wildlife Areas US Forest Service and BLM land Most TNC Easements Most National/ State/ City /County Parks National Recreation Areas Open Space and Natural Areas

Figure 1.3: Secured lands. This map shows the secured lands in the study area by GAP status (see Table 1.1).



Process

To complete this study, we formed a core team of TNC scientists to complete the technical analysis and enlisted a Steering Committee of seven academic specialists on Alaska's unique ecology to work with us to co-develop the analyses and map products. The role of the Steering Committee included:

- Advising the core team on the most appropriate regional data sources and approaches for CNS implementation, promoting confidence in methods.
- Providing technical review of results and products (tools, maps, and reports).
- Connecting the TNC team with existing and future conservation applications.
- Assisting with outreach to to seek input and promote use of products.

The committee met during bi-monthly 2-hour online conference calls. We used an interactive format, in which preliminary results from the spatial analysis were shown and each participant was offered a time to comment on specific pre-identified questions and topics.

Summary of Concepts and Approach

The CNS approach to developing a network of resilient sites for the U.S. is based on several key observations. First, species diversity is highly correlated with geophysical diversity (Anderson and Ferree 2010, Lawler et al. 2015). We know abiotic factors, like soils and geology, shape ecosystems and their biodiversity, and historic evidence, along with studies from other climatic regions, suggest that these drivers will continue to influence the distribution and abundance of species even as climatic conditions change (Beier et al. 2015). Second, under a changing climate, species take advantage of local microclimates to persist in the landscape (Weiss et al. 1988, Suggitt et al. 2011, Roth et al. 2014, Albano et al. 2015). Yet, species populations can use microclimates and adjust to change only if the area is permeable and well connected (Heller and Zavaleta 2009). The idea of protecting examples of all geophysical settings, prioritizing those sites with the most microclimate diversity, and highest landscape permeability is the core concept of this project. Background on the approach and detail on how the results relate to current biodiversity patterns can be found in Anderson and Ferree (2010), Anderson et al. (2014a, 2014b), Anderson et al. (2016a) and the papers included in Beier et al. (2015).
We use the term **site resilience** to refer to the capacity of a site to adapt to climate change while maintaining diversity and ecological function (modified from Gunderson 2000).

Site Resilience

We define **site resilience** as ***the capacity of a site to maintain biological diversity, productivity and ecological function as the climate changes*** following Anderson et al. (2014b). This means that the character of the existing ecosystem, such as species assemblages and biotic structures, may change even as the core functions and biodiversity of the evolving ecosystem continue to provide the ecosystem services we value. Site resilience differs from the classic definition of resilience in the ecological literature, which holds that an ecosystem demonstrates resilience if it quickly returns to a steady-state equilibrium after a disturbance (Holling 1973). Under changing conditions, however, there is no steady-state to return to. Over time, the definition of resilience in the published literature has evolved to include change—for example Gunderson's (2000) definition, *"the capacity for renewal in a dynamic environment."* The meaning also varies depending on the object being impacted (e.g., wildlife species, plant communities, human communities). The *American Heritage Dictionary* defines **resilience** as "*the ability to recover quickly after change or misfortune*." Our definition of resilient sites, actual mapped places, revives an idea of land health that originated with Aldo Leopold (1949): *"Health is the capacity of the land for self-renewal. Conservation is our effort to understand and preserve this capacity."*

We assume that if conservation succeeds, each geophysical setting will support species that thrive in the conditions influenced by the physical properties of the setting, although the site may contain different species in the future than are present now. For example, sandy sites would continue to support species that benefit from well-drained, nutrient-poor conditions, while sites in fertile calcareous loams would support species that thrive in alkaline nutrient-rich conditions. **Geophysical setting** is thus broadly defined either based on bedrock or surficial soil texture, depending upon soil depth. We look to the current distribution of species, communities, and terrestrial system types, including wetlands, to help us understand what key characteristics are shifting across the landscape and could thus be captured by this coarse filter, but expect that the specific species and communities on a given example of setting will change over time.

A climate-resilient conservation portfolio includes sites representative of all geophysical settings selected for above-average levels of microclimatic variation and proportion of natural land cover. Chapter 2 describes how we mapped geophysical settings across the entire study area, using data on geology and soil characteristics, as well as information on soil depths. To guide this process, we refer to spatial data on the occurrence patterns of rare species and natural communities, as these data help us identify relationships between the geophysical settings, and distinct patterns of biotic expression. In the Rocky Mountain-Southwest Deserts region, this involved delineating the region into areas most influenced by surficial sediments (e.g., calcareous loams, deep loess, sand), and areas more closely tied to underlying geology (e.g., acidic granite, circumneutral sedimentary, calcareous sedimentary).

The value of conserving a spectrum of physical settings is based on empirical evidence that this approach will help us meet goals of representation, i.e., protection of the breadth of existing biodiversity (Anderson and Ferree 2010), but there are many choices to make to determine how this is accomplished. For example, of all the possible sand plains that could be conserved, which ones are the most likely to remain functional and sustain biological diversity into the future? Chapter 3 describes the site-based characteristics that promote sustained ecosystem function and diversity, and the methods we used to assess and map them. The first characteristic, **landscape diversity**, is an estimate of the number of microclimates and climatic gradients available within the local area. It is measured by counting the variety of landforms (e.g., hillsides with different slopes and aspects; dry, moist, or wet flats), and the density, configuration, and connectivity of wetlands. South-facing slopes will typically be warmer and drier than similar slopes that face northeast; these types of differences provide local variation in climate that provide additional climate "niches" relative to areas without topographic variation. We expect that microclimate diversity buffers species against regional climatic effects by providing them with a range of local climates, many of which might be suitable for extending a species' ability to persist at a site. By this logic, we expect that the diversity and persistence of species within a local area increases with high landscape diversity relative to other examples of the same geophysical setting (Weiss et al. 1988).

Local connectedness, the second site-based characteristic we use as an indicator of sustained ecosystem function and diversity, is defined as the number of barriers to species movement and the degree of fragmentation within the local area. A highly permeable landscape has no or few barriers (low habitat fragmentation) and promotes resilience by allowing plant and animal movements and the reorganization of communities. Roads, development, agriculture, dams, and other structures create barriers, or resistance, that interrupts or redirects movement and, therefore, lowers the permeability. Maintaining a connected landscape is the most widely cited strategy in the scientific literature for building resilience (Heller and Zavaleta 2009). Connectivity has in fact been hypothesized to explain why relatively few extinctions occurred during the Quaternary (2.5 million years BCE to present), another period of rapid climate change (Botkin et al. 2007)—albeit not as rapid as the current climate change (Holocene/Anthropocene; Masson-Demotte et al. 2013).

Initial sections of this report are focused on mapping site resilience. In Chapter 2, we describe mapping and classification methods used to identify all the distinct geophysical settings in the region. Chapter 3 introduces methods designed to quantify the physical and structural aspects of landscapes using models that measure a site's physical complexity including variety of microclimates (landscape diversity), natural cover (local connectedness), and combined resilience factors (integration of landscape diversity and connectedness). In Chapters 4 and 5 we present the results, identifying resilient sites across individual ecoregions and the full study area, respectively. Subsequent chapters focus on linking resilient areas into a conservation network based on climate flow and biodiversity values.

Importantly, the use of geophysical settings and ecoregions ensured that landscape diversity and local connectedness were ranked relative to sites of the same underlying type within an ecoregion. Thus, the resulting maps of resilient sites are always relative to the setting and ecoregion. Some geophysical settings, such as calcareous loams, have subtler microclimates and are more fragmented (i.e., have less site resilience) than other settings, but our goal was to identify the most resilient sites for each geophysical type. This ensured that we were mapping a blueprint of resilient sites that could sustain all biological diversity and was not biased towards a soil or bedrock. The analysis was performed within each of the 12 ecoregions, and the regional map is a composite of the individual ecoregion maps.

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DEFINING THE GEOPHYSICAL SETTINGS

CHAPTER 2

This chapter describes our process to characterize and classify the Alaskan study area into distinct geophysical “stages” based on the elevation, geology and soils. Our premise is that the characteristics of a geophysical setting represent enduring features that influence biotic differences in the flora, fauna, and natural communities (e.g. due to differences in pH, nutrients, drainage, erodibility) now, and these differences will continue to favor or select against different subsets of species under future climates. These physical characteristics often also correlate with human land use patterns because properties such as bedrock type, soil texture and chemistry contribute to the value and suitability of sites for agriculture, development, or mining.

In addition to shaping parent materials and soils, geophysical environments tend to share topographic characteristics and land use properties, both of which are key components of our site resilience metric (Chapter 3). Typically, bedrock-based environments are more topographically complex and have more intact natural landcover than deep soil environments, which are flatter and more likely to be converted.

The correlation between the geophysical settings and our site resilience factors highlights the important roles that settings play in this study. Geophysical settings are key drivers of biological diversity, so representation of the full range of settings is a critical conservation goal. Further, the correlation between setting types, topography, and land use suggests that direct comparisons of our site diversity metrics would favor some settings over others if they are not used as a stratification. Without a stratification to ensure “apples to apples” comparisons, our results would be biased towards bedrock-based settings and their associated flora and fauna due to the higher topographic relief and lower conversion rate on those settings.

As we determined how to partition the study area into geophysical settings, we considered these dual roles as

(1) “coarse filters” for capturing the full range of abiotic conditions that support biodiversity,
(2) a spatial stratification prior to identifying examples of sites that have the most microclimatic variety and natural cover.

Ecoregions

We assessed the geophysical settings within the larger context of natural ecoregions. Ecoregions are large contiguous units of land with similar environmental conditions (landforms, geology, and soils) which share a similar climate and a distinct assemblage of natural communities and species. The term "ecoregion" was coined by J.M. Crowley (1967) and later popularized by Robert Bailey of the US Forest Service (USFS). In recent decades, ecoregions have become a defining construct of larger conservation efforts because they provide an ecological context for understanding landscape-scale conservation activities by enabling the evaluation of properties considered critical to conserving biodiversity such as representation, complementarity, redundancy, ecological function, and endemism.

The ecoregions map we used (Nowacki et al. 2001) was created to incorporate recent biophysical datasets and an interagency approach to mapping and managing Alaska's lands and resources. It combined the expertise and approach used in ecosystem mapping efforts in the early 1990's (Gallant et al, 1995, Nowacki and Brock, 1995) and used a combination of the approaches of Bailey (hierarchial), and Omernick (integrated). It provides a widely used and accepted ecological foundation for studying, managing and understanding the ecosystems of Alaska and their driving processes. The thirty-two Nowacki ecoregion of Alaska are used as stratification units throughout this resilience analysis. The Nowacki (2001) ecoregions also underpinned TNC's effort to develop ecoregional plans for several sections of Alaska, where the ecoregions were grouped into larger regional study areas (Table 2.1.)

Figure 2.1: Ecoregions. Ecoregions in the study area.

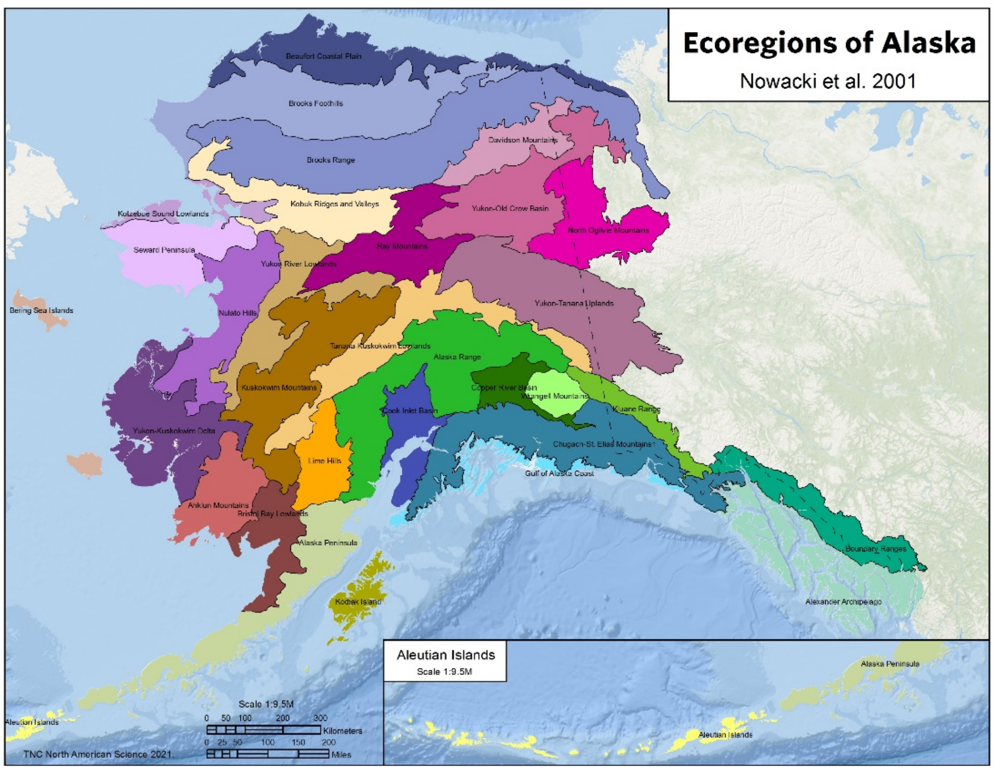


Table. 2.1. Comparison of TNC Ecoregion groups and Nowacki Ecoregions.

Ecoregion Group (TNC)	Nowacki Ecoregions of Alaska	Acres
Alaska Peninsula	Alaska Peninsula	15,868,738
Alaska Range	Alaska Range	25,542,290
	Copper River Basin	4,728,842
	Kluane Range	1,241,328
	Wrangell Mountains	3,536,968
Alaska-Yukon Arctic	Beaufort Coastal Plain	14,690,382
	Brooks Foothills	28,489,299
	Brooks Range	31,809,485
Bering Sea And Aleutian Islands	Aleutian Islands	2,673,856
	Bering Sea Islands	2,321,333
Beringian Tundra	Kotzebue Sound Lowlands	3,753,298
	Nulato Hills	14,466,976
	Seward Peninsula	11,708,228
	Yukon-Kuskokwim Delta	19,420,704
	Ahklun Mountains	9,577,230
	Bristol Bay Lowlands	7,892,753
	Cook Inlet Basin	7,220,094
Gulf Of Alaska Mountains And Fjordlands	Chugach-St. Elias Mountains	19,561,084
	Gulf of Alaska Coast	4,753,121
	Kodiak Island	3,181,872
Interior Alaska Taiga	Kobuk Ridges and Valleys	13,626,154
	Kuskokwim Mountains	21,091,239
	Lime Hills	7,095,207
	Tanana-Kuskokwim Lowlands	15,817,402
	Yukon River Lowlands	12,781,826
S.E. Alaska - B.C. Coastal Forest And Mountains	Alexander Archipelago	13,527,807
	Boundary Ranges	5,019,999
Yukon Plateau And Flats	Davidson Mountains	7,167,238
	North Ogilvie Mountains	3,144,477
	Ray Mountains	12,661,541
	Yukon-Old Crow Basin	13,991,772
	Yukon-Tanana Uplands	15,757,984
	TOTAL	374,120,526

Geophysical Settings

Geophysical settings represent *enduring features* that influence biotic differences in the flora, fauna, and natural communities. These differences will continue to favor or select against different subsets of species under future climates. We define geophysical settings as unique combinations of Geology-Soil type and Elevation Zone. Because geophysical settings are key drivers of biological diversity, a representation of the full range of settings is a critical conservation goal. To ensure this representation in our analysis, our final resilience scores are stratified by each geophysical setting to ensure the most resilient portions of each geophysical setting are identified.

We used a variety of bedrock surficial soils, glacier, and elevation data to define geophysical settings in Alaska. The sections below describe our methods for:

1. Classifying and Mapping the Bedrock Geology
2. Classifying and Mapping the Surficial Sediments
3. Integrating Bedrock Geology and Soil Texture
4. Integrating Above Tree-line Elevation Zone
5. Confirming the relationship with Natural Communities and Plant Species

Classifying and Mapping the Bedrock Geology

Bedrock influenced settings are found in shallow surficial soil areas where bedrock characteristics more strongly influence the pH, nutrients, drainage, and erodibility (Fig 2.2). The natural communities, associated species, and ecological processes differ markedly between areas of shallow bedrock vs. deep surficial sediments. These two major environments separate the deep soil valleys and plains from the areas of shallow soils found in bedrock outcrops, bluffs, mountains, and slope-based landscapes.

Bedrock geology was mapped using **Wilson, F.H., Hults, C.P., Mull, C.G., and Karl, S.M., comps., 2015, Geologic map of Alaska:** U.S. Geological Survey Scientific Investigations Map 3340, 197 p., 2 sheets, scale 1:584,000 http://dx.doi.org/10.3133/sim3340

Bedrock polygons from this dataset were placed into a simplified set of ecologically relevant classes following the scheme of Anderson and Ferree (2010) which focuses on key ecological properties of the bedrock's rock type, genesis, chemistry, weathering properties, and texture. Using attribute data from the geology dataset, we reviewed each geologic taxonomic type based on name and description, and we assigned it to one of the 6 simplified major bedrock ecological classes.

The resultant classes of bedrock included

1. Calcareous Sedimentary: alkaline sedimentary or metasedimentary rock with high calcium content. Limestone, dolostone, marlstone, calcarenite, carbonite, chalk, coquina, marble and marl.

2. Moderately Calcareous Sedimentary: moderately alkaline sedimentary or meta-sedimentary rock with some calcium but less than rocks in the calcareous rock class.

Calcareous shales, mixed sedimentary rocks with calcareous components, calcium-silicate, and calcium-silicate schist rocks, usually in the minor components of the rock.

3. Acidic to Neutral Sedimentary: Fine to coarse grained neutral or acidic sedimentary/metased rocks. Sandstone, sandstones, arenite, arkose, conglomerate mudstone, claystone, shale, siltstone, schist

4. Granitic- Intrusive and Extrusive Felsic : Intrusive felsic igneous rocks rich in silica. Granite, granodiorite, gneiss, tonalite, migmatite, quartzite, mylonite, latite , syenite, quartz monzonite. Extrusive rocks rich in feldspar or quartz: rhyolite, trachyte, basanite

5. Mafic and undifferentiated volcanics: Extrusive igneous rocks rich in magnesium and iron. Basalt, andesite, diorite, gabbro, anorthostie, tectonite, hornfels, amphibolite, amphibole schist, dioritic, monzodiorite.

6. Ultramafic: magnesium-rich alkaline igneous and meta-igneous rock. Serpentine, pyroxenites, peridotites, komatiite and kimberlite.

Figure 2.2 Examples of Alaskan Bedrock Influenced Natural Communities. Photos from Boggs et al. 2019.

Classifying and Mapping the Surficial Sediments

Surficial soil settings are found in areas with deep surficial mineral or organic substrates. These areas with deeper more developed soils are usually flatter and less topographically diverse than bedrock settings.

We created a spatially comprehensive dataset of surficial texture for the study area by using 1) the GIS dataset **Permafrost Database Development, Characterization, and Mapping for Northern Alaska** (M. Torre Jorgenson, 2015) in the three most northern ecoregions (Beaufort Coastal plain, Brooks Foothills, Brooks Range) and 2) **STATSGO2: 1:1,000,000** for the rest of the state. Surface soil texture class names were provided in the Jorgenson 2015 dataset while surface soil texture class was generated for each STATSGO2 polygon using the NRCS Soil Data Development Toolbox_20200311.

Alluvial soils were a class in Jorgenson 2015 in northern Alaska, but were not an available mapped class in the STATSGO2. Because alluvial soils harbor such unique ecological communities and ecological processes influenced by riverine ecosystems, we decided to augment the Jorgenson alluvial soils to be able to map alluvial zones in the rest of the state. Alluvial zones were augmented throughout the state by using 1) GIS delineated Floodplain Riverscapes (Whited et al. 2012) which mapped river floodplain patches, and by developing a 2) new continuous delineation of low-lying floodplain and riparian areas along all rivers >100 sq.km in drainage area following methods of Active River Area assessment (Smith et al. 2008).

For the Active River Area delineation, small to large river centerlines were generated using the 30m statewide DEM and a "Flow accumulation" function. The small to large streams were placed into 5 size classes based on upstream drainage areas: 100-500 sq.km, 500-2,500 sq.km, 2,500-10,000 sq.km, 10,000-25,000 sq.km, and >25,000 sq.km. For each size class, a "cost-distance" function was run to map a relative "cost" of water to travel upslope out and away from the streams. The cost considers both the slope due to elevational change and distance from the channel, with higher costs for greater slopes and distances from the stream. This analysis outputs a continuous grid of cost as one moves upslope and away from the river centerline. To define a cost threshold that approximated the extent of the alluvial zone or floodplain, we used the mean and other descriptive statistics for costs found under confirmed floodplain riverscape patches from Whited (2012). We overlaid the patches and sampled the cost surface within each ecoregion. As a conservative estimate of floodplain extent, all those cells in the cost distance output less than or equal to the mean of "known floodplain patch" for each river size in each ecoregion were extracted. This area was combined with the Riverscape Floodplain polygons (Whited et al. 2012) and the Jorgenson (2015) alluvial polygons to form the total extent of Alluvial and low-lying riparian floodplain settings for the state.

The final classes of surficial soils included:

1. Sand: Sand, Loamy Sand: Sand is a coarse-grained substrate composed of loose rock particles smaller than gravel but larger than silt (>0.2 mm). Sand substrates are typically well drained and nutrient poor

2. Loams: Loam and Sandy Loam: Loam is a relatively fertile soil reflecting a mixture of sand, silt and clay. It yields the highest availability of water to plants.

3. Fines: Silt and Silt Loams: Silts are fine-grained substrates of a size between sand and clay. Silts typically transported by water and are deposited during evaporation. Soils with a high silt content have an increased nutrient and water holding capacity and are often poorly drained.

4. Peat: Peat is an accumulation of partially decayed vegetation or organic matter. It is unique to natural areas called peatlands, bogs, mires, moors, or muskegs. Peat is characterized by a low density and high organic matter. It has high porosity with with a dominance of macropores which facilitate water movement and solute transport.

5. Alluvial Sediments: Alluvium is made up of a variety of materials, including fine particles of silt and clay and larger particles of sand and gravel. These sediments are carried by rushing streams and deposited where the stream slows down. Alluvium and alluvial influenced settings are areas are found in the floodplain, river deltas, and low lying riparian areas.

Figure 2.3: Examples of Alaskan Surficial Influenced Natural Communities. Photos from Boggs et al. 2019

Integrating Bedrock Geology and Surficial Substrates

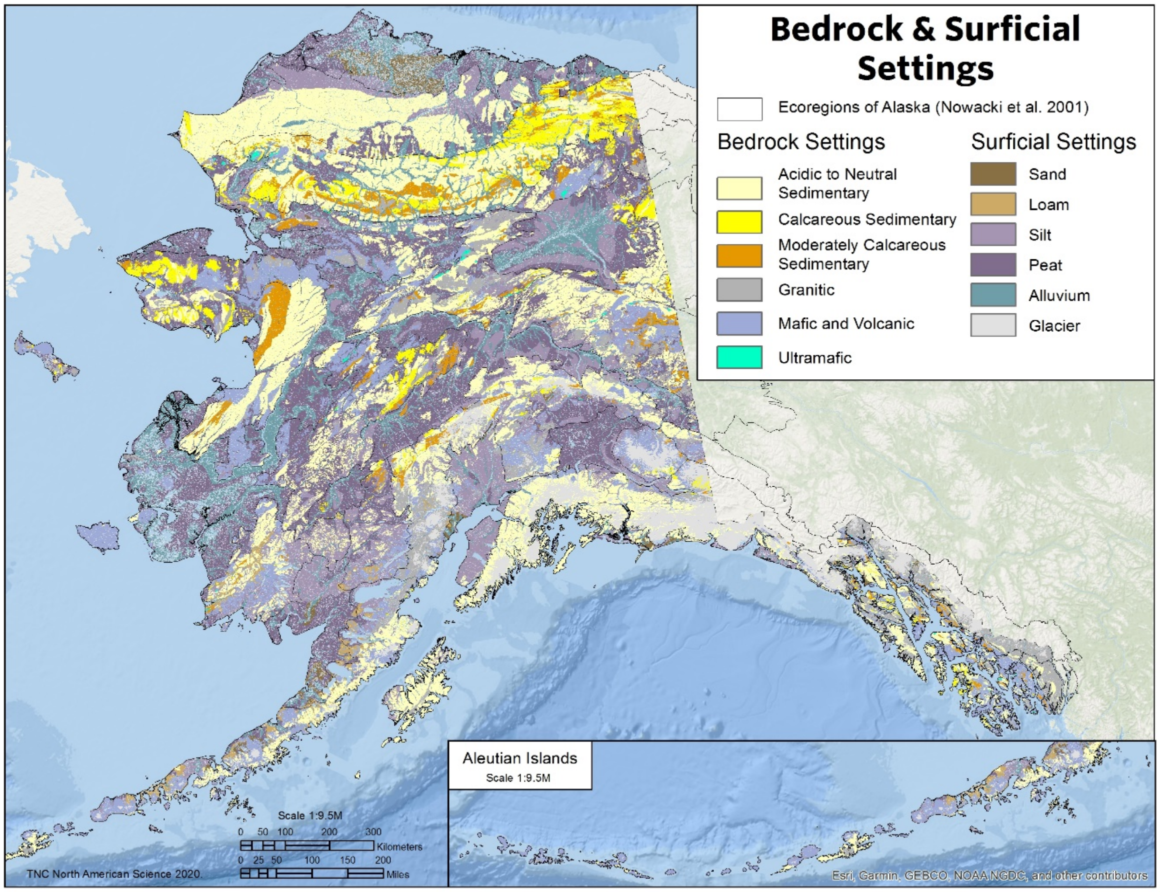
To create the final geology setting map for the study area, we combined the surficial classes and the bedrock classes to fully cover the study area with the appropriate bedrock or surficial settings. Where there were small gaps in the data set due to differences in edges and scales between the bedrock and surficial data, we filled the areas using and expansion of the surficial classes in the flats to gentle slopes while using an expansion of the bedrock classes in the higher sloping areas where we would expect less soil development. To smooth and further generalize the geologic settings, we then eliminated small occurrences of individual polygons less than 1000 acres in size by filling them with a Euclidean distance function which assigned the nearest geologic type to theses areas. This simplification was done to focus our final setting layer on mapping larger patches of each setting. We hypothesize that these larger patches themselves are more likely to support the suite of representative suite of flora and fauna typical of the setting and serve as a better coarse level stratification.

The bedrock settings represent 48% of the study area and the surficial settings represent another 48%, with the remaining 4% glaciated (Table 2.2). The two most common bedrock settings were Acidic to Neutral Sedimentary (25%) and Mafic and Volcanic (10%). The two most common surficial settings were Peat (22%) and Silts (13%).

Table 2.2: Acres of each Bedrock and Surficial Setting.

Geologic Setting		Total Acres (land)	Percent
Bedrock	Acidic to Neutral Sedimentary	86,677,496	25
	Calcareous Sedimentary	12,445,338	4
	Moderately Calcareous Sedimentary	10,442,673	3
	Granitic	19,591,361	6
	Mafic and Volcanic	35,647,576	10
	Ultramafic	400,156	0
Surficial	Alluvium	40,158,722	12
	Peat	75,664,219	22
	Loam, Sandy Loam	2,746,578	1
	Sand	3,880,945	1
	Silt, Silty Loam	43,642,664	13
Other	Glaciated	15,462,476	4
	Grand Total	346,760,203	100

Figure 2.4: Bedrock and Soils. The twelve major geology settings in Alaska

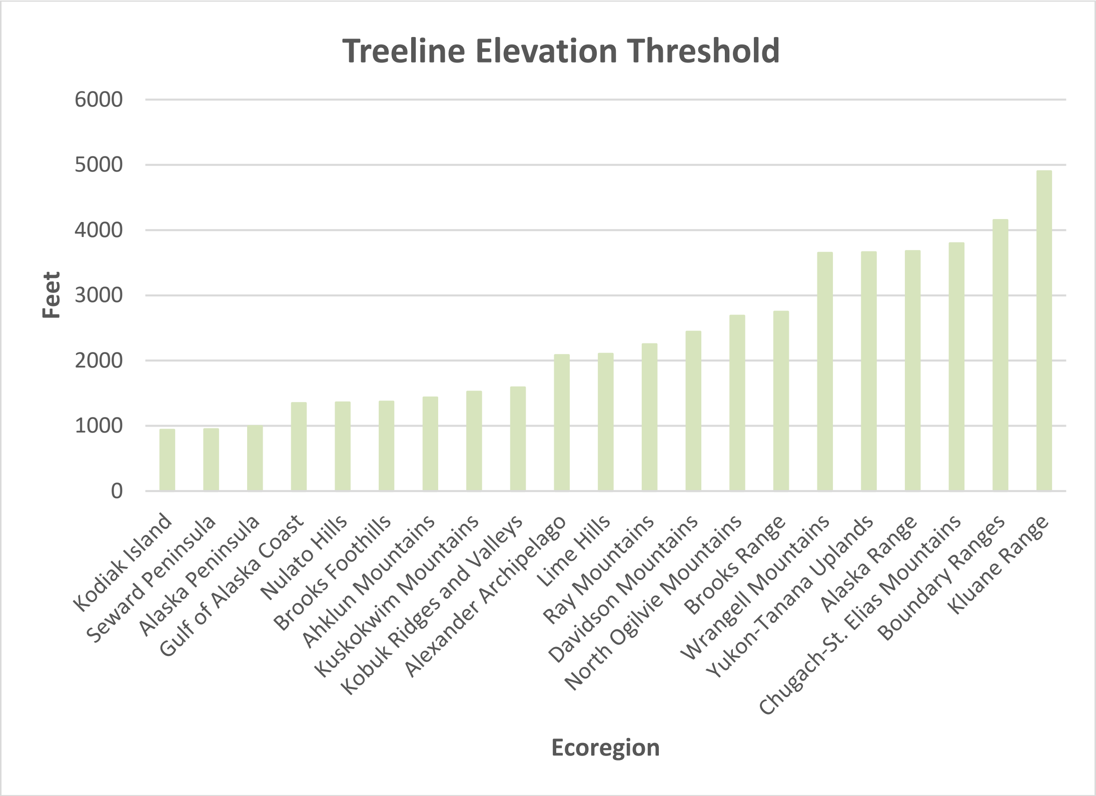


Integrating Glaciers and Above-Treeline Elevation Zone

An upper elevation zone above treeline and/or covered with glaciers was defined to represent these areas covered by ice and/or barren of trees. This zone was highlighted by the review team as an extreme habitat for most biota in comparison to areas of similar underlying geology "below treeline". To be able to compare the resilience of geologic settings below this zone to each other and similarly compare geologic settings above treeline zone to each other (e.g. apples to apples comparison), we delineated this zone and treated it separately.

Treeline elevation varied across the state, so to map the above-treeline zone, we sampled elevation under the known extent of Deciduous, Mixed, or Coniferous tree cover in NLCD (2016). We identified the mean and standard deviation of the elevation of trees within each Ecoregion and then identified areas that were more than 2 SD above the mean tree elevation for each ecoregion, an area that would represent 97% of tree distribution (Figure 2.5). We visually studied the land areas identified as above treeline to QC the analysis and determine which ecoregions had substantial areas above treeline and which did not. No above treeline elevation zone was found or used in the following ecoregions: Aleutian Islands, Beaufort Coastal Plain, Bering Sea Islands, Bristol Bay Lowlands, Cook Inlet Basin, Copper River Basin, Kotzebue Sound Lowlands, Tanana-Kuskokwim Lowlands, Yukon River Lowlands, Yukon-Kuskokwim Delta, and Yukon-Old Crow Basin.

Figure 2.5. Elevation Threshold by Ecoregion: Below this value land were assigned to Below Treeline Zone. Areas above this elevation were assigned to "Above Treeline".



To this elevation derived above-treeline zone, we then added the extent of glaciers given this was also barren land. Glaciers were taken from the GIS dataset Randolph Glacier Inventory (RGI 6.0) for Alaska (RGI Consortium 2017).

Although the treeless zone was patchy in its distribution, we smoothed the resultant dataset by removing patches <500 acres to focus on larger distinct areas that were likely more enduring and representative of the full expression of this kind of setting.

Integrating Elevation Zones and Geology into Geophysical Settings

Results showed that the Above-treeline zone made up 23% of the state (Figure 2.6) We combined the 2 elevation zones with the 12 geology and soils types which created create 23 geophysical settings (Table 2.3, Figure 2.7).

Figure 2.6: Elevation Zones. Red shows the area above treeline.

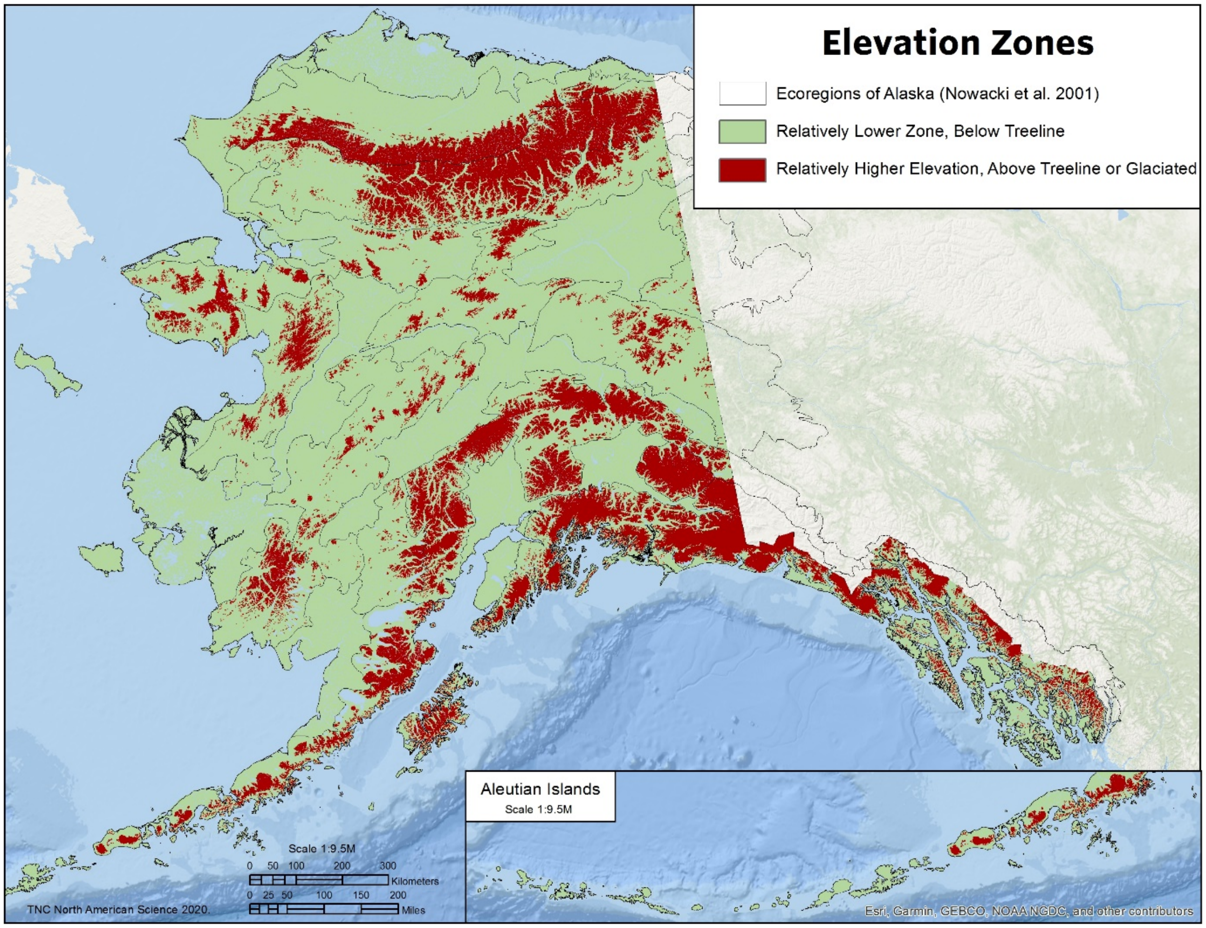
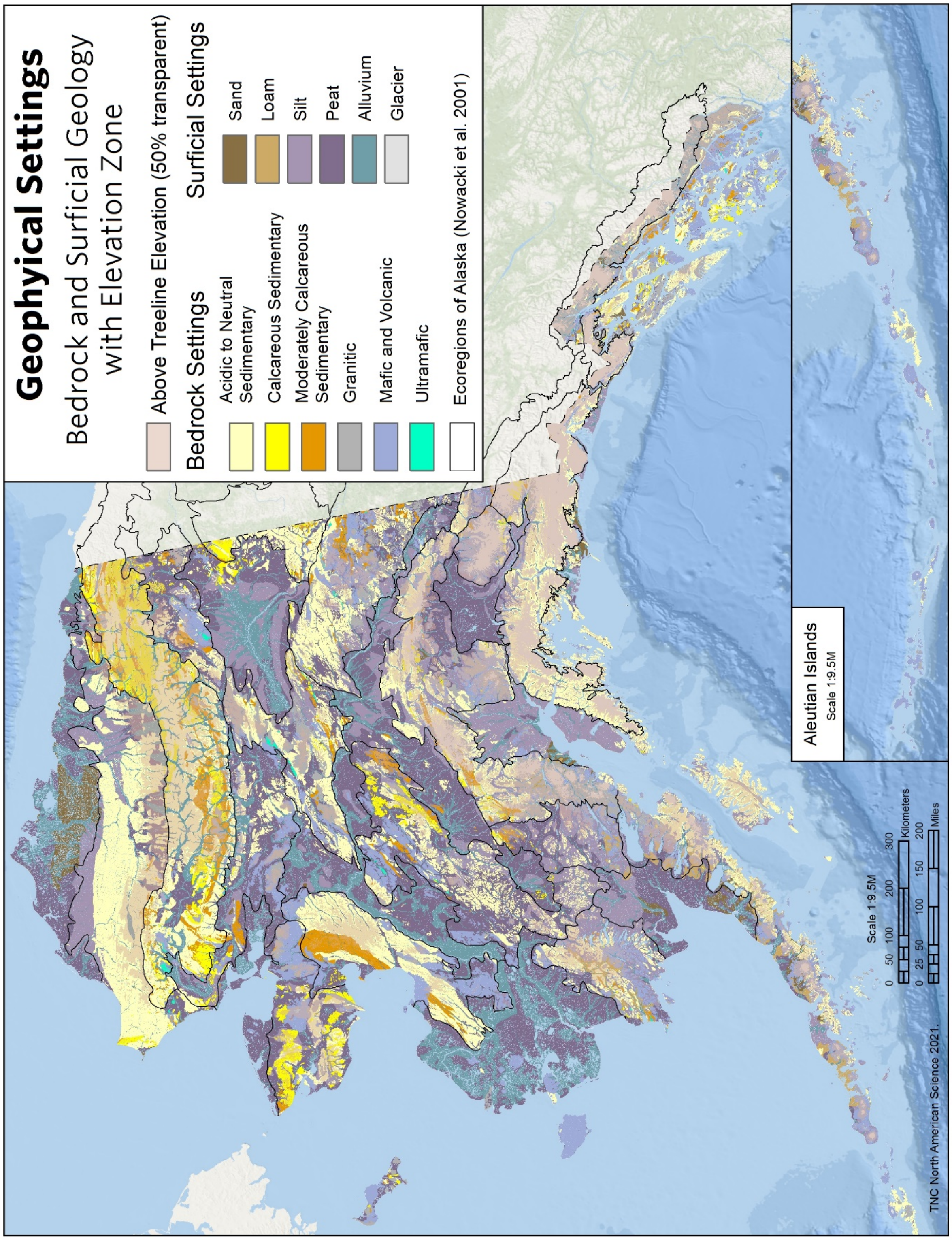


Table 2.3: Acres of each Geophysical Setting.

Elevation Zone	Acres (land)	% of Land	Geology
Below Treeline	73,157,199	21	Peat
	57,790,348	17	Acidic to Neutral Sedimentary
	41,612,553	12	Silt, Silty Loam
	38,261,922	11	Alluvium
	25,963,647	7	Mafic and Volcanic
	12,011,274	3	Granitic
	6,422,265	2	Moderately Calcareous Sedimentary
	6,361,375	2	Calcareous Sedimentary
	3,874,267	1	Sand
	2,408,994	1	Loam, Sandy Loam
	329,846	0	Ultramafic
Above Treeline	28,887,148	8	Acidic to Neutral Sedimentary
	9,683,930	3	Mafic and Volcanic
	7,580,087	2	Granitic
	6,083,963	2	Calcareous Sedimentary
	4,020,407	1	Moderately Calcareous Sedimentary
	2,507,020	1	Peat
	2,030,110	1	Silt, Silty Loam
	1,896,799	1	Alluvium
	337,584	0	Loam, Sandy Loam
	70,310	0	Ultramafic
	6,678	0	Sand
Other	15,462,476	4	Glaciated
	346,760,203	100	

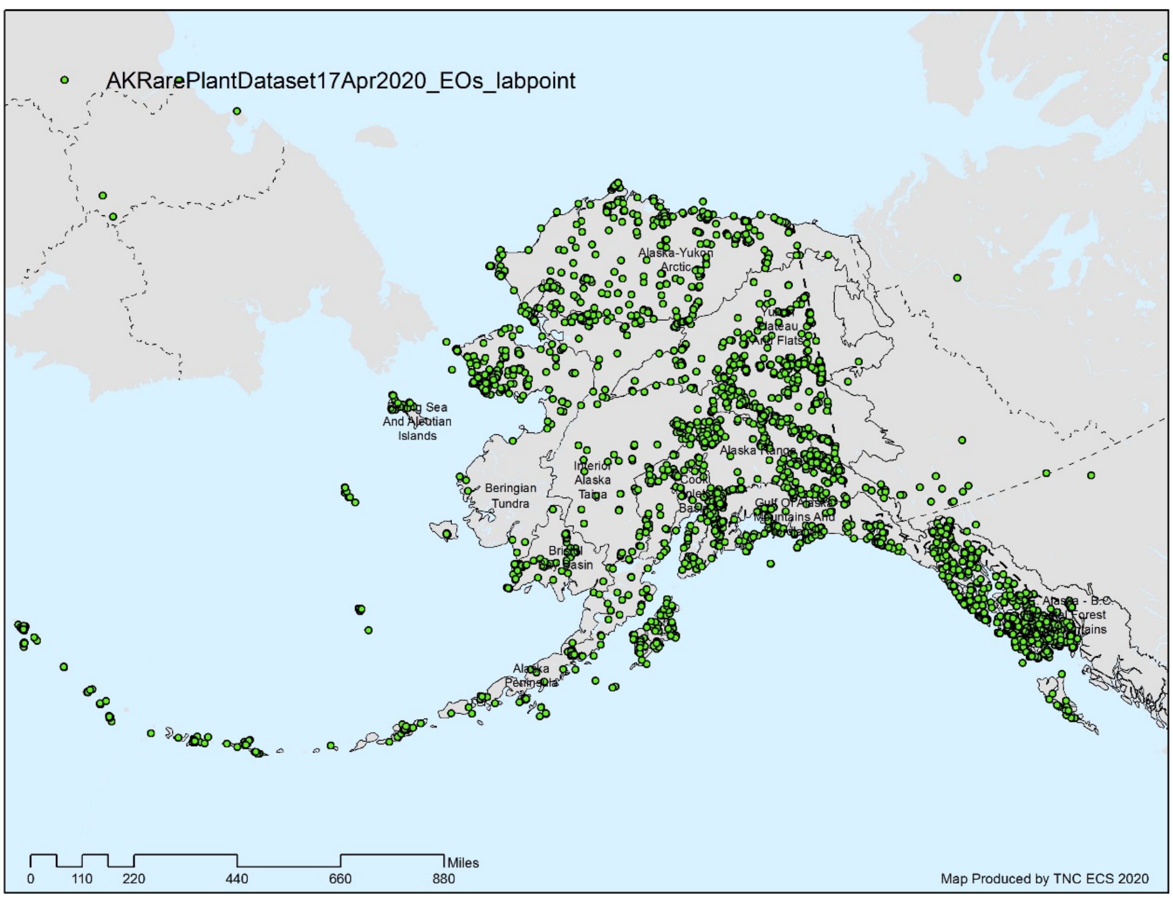
Figure 2.7: Geophysical Settings. The geophysical settings are a combination of Bedrock and Surficial Geology Setting with the Above and Below Treeline Elevation Zones.



Geophysical Settings and their Current Biota
The land's setting influences the type and diversity of natural communities and species occurring on a site. To assess the associations between the current biota and each setting we overlaid While we do not know exactly how the communities will rearrange, evidence from other climate zones suggests that the geophysical settings will continue to support distinct flora and fauna even under different climatic regimes. For example, around the globe, and under many climates, limestone areas favor distinct alkaline-tolerant flora, as well as fine-filter targets like cave-adapted species. These differ from the drought and fire-adapted species more common in sand (Kruckeberg 2004, Anderson and Ferree 2010, Beier and Brost 2010).

The Alaska Center for Conservation Science provided us with two excellent resources. First, a report and dataset describing ecosystems of conservation concern across the state (Boggs et al. 2019) and a dataset showing the occurrences of rare plant species across the state (Figure 2.8). By overlaying this information on the geophysical settings map we could confirm and test the distinctiveness of each setting.

Figure 2.8: Plant Element Occurences. Distribution of rare plant species across the state. Data from Alaska Center for Conservation Science and used with permission.



We found that each geological setting hosted 4-48 plant species that were concentrated in that over 66% of all known occurrences were found on that soil or geology. Additionally, many rare ecosystem types were identified within a specific setting (Table 2.4). This gave us confidence that the geophysical settings had ecological meaning to the species and communities.

Table 2.4. The number of rare plant species found predominantly in each geological setting.

Bedrock or Soil	# Species	# EOs	Examples: Plants mostly found in this setting	
Alluvium	4	96	Cardamine microphylla	Chrysosplenium rosendahlii
Calcareous Sedimentary	19	348	Puccinellia arctica	Sidalcea hendersonii
Granitic	5	97	Boechera calderi	Cirsium edule
Mafic/Intermediate Granitic	33	926	Ligusticum calderi	Polystichum aleuticum
Moderately Calcareous Sed.	4	52	Saussurea triangulata	
Peat	55	748	Carex xerantica	Cicuta bulbifera
Sand	11	163	Koeleria asiatica	Mertensia drummondii
Sedimentary Mixed	48	1040	Podagrostis thurberiana	Podistera yukonensis
Silt, Silt Loam	38	635	Botrychium tunux	Botrychium yaaxudakeit
Ultramafic	3	22	Aspidotis densa	Botrychium robustum

Bedrock or Soil	Examples: Ecosystems defined by this setting
Alluvium	Artemisia alaskana – Dianthus repens Gravel Bar PA,
Calcareous Sedimentary	Beringian Alpine Limestone Dryas BpS, Calcareous Fen
Granitic	Granite Hotspring
Mafic/Intermediate Granitic	Papaver gorodkovii (Arctic Poppy) Volcanic Scree PA
Peat	Carex kelloggii-Sphagnum spp. sedge-moss bogs
Sand	Boreal Inland Dune BpS
Sedimentary Mixed	Unglaciated gypsum outcrops
Silt, Silt Loam	Picea sitchensis / Oplopanax horridus / Circaea alpina PA
Ultramafic	Serpentine biophysical setting

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CHAPTER 3

ESTIMATING SITE RESILIENCE

The physical characteristics of a site—its topography, soil characteristics, and the presence of wetlands—can buffer resident species from the direct effects of climate change. Plants and animals experience climate at such local scales that a landscape with topographic variation is experienced as a mix of microclimates: dry to wet, or cool to hot depending on slope position and aspect. Microclimates allow species to find pockets of suitable moisture and temperature even where the average background climate appears unsuitable. Intact sites with little fragmentation and a large variety of microclimates may enable species to persist longer under a changing climate, because individuals and populations can shift their locations locally to take advantage of the microclimate variation.

Sites with little fragmentation and many microclimates are hypothesized to have high **site resilience** because the presence of connected climatic variation allows species to persist and the site to retain diversity and ecological functions longer than sites that are fragmented and flat. In this section, we describe the concepts, methods, and data used to estimate the relative resilience of any given site. The two factors important to the estimate—**landscape diversity** and **local connectedness**—are discussed separately, because the tools for assessing and measuring them are distinctly different.

Section 1: Landscape Diversity

Our first climate change resilience factor - landscape diversity - addresses variation in topography and wetlands as indicator of microclimate variation.

Projections of future climate patterns indicate that North America is already experiencing increased temperatures, drought and fire, and these trends are likely to continue (Garfin et al. 2018 National Climate Assessment, Kasischke and Turetsky 2006, Boulanger *et al.* 2014). While climate projections should inform our conservation strategies, it's important to remember that climate data is based on regional averages. However, changes in global and regional climate interact with other factors, such as topography and landform to modify local microclimate conditions in patterns that are much more predictable at local scales. Understanding and mapping these persistent indicators of local climatic variation is the focus of this section.

Landscape-based climatic variation is substantial, on par with, and often greater than expected climatic changes for a region. These variations can be measured in even a gently rolling landscape such as Northern England, where temperature loggers placed across gradients of slope, aspect and elevation have revealed site differences in monthly maximum temperature measurements exceeding 34^0 F (Suggitt et al. 2011). In California's serpentine grasslands, microtopographic thermal climates showed a 34^0 F difference between maximum values at different slopes (Dobkin et al. 1987), and areas of high local landscape diversity were found to be important for long-term population persistence of butterfly species and their host plants under variable climatic conditions (Weiss et al. 1988). Vegetation, with its high moisture content, moderates the effect of topography on temperature variation, but even in heavily forested landscapes, variation in aspect and topography can create large differences in temperature. For instance, in the heavily forested Southern Blue Ridge Mountains scientists have measured a 25^0F difference between a hot south-facing slope and a cool sheltered ravine in mid-summer (P. McMillan, pers. comm., October 2010). In boreal regions like Alaska, Stralberg (2020) has highlighted the importance of "terrain-mediated" climate refugia particularly in coastal and mountain region. Some northern ecosystems, such as boreal peatlands, have high ecological inertia (resistance to external fluctuations) given their ability to retain high soil moisture and water table in the face for drought and provide more extensive buffering against climate change (Stralberg 2020).

The distribution of moisture in a landscape is also correlated with topography and aspect. Topography has been found to explain 40%-72% of soil moisture variation (Yeakley et al. 1998) in Appalachian forests. In grasslands, aspect alone can explain as much of 20% of the local differences in soil moisture (Bennie et al. 2006 & 2008). Studies of landscape-based climate variation continue to show how local climatic variation strongly influences species distribution patterns, suggesting that understanding microclimates is a key to understanding species persistence (Ashcroft et al. 2009, DeFrenne et al.2013, Dobrowski 2011, Pincebourde et al. 2016, Yeakley et al. 1998).

Topography redistributes temperature and precipitation so fully that in some landscapes no areas experience the "average" regional climate: basins are wetter, summits are dryer, south-facing slopes are hotter, and north-facing slopes are cooler. Coarse-scale models predicting the loss of all suitable habitats for plants in the Swiss Alps conversely predicted the persistence of suitable habitats for all species when they were rerun at local scales that captured topographic diversity (Randin et al. 2009).The term "microclimatic buffering" (Willis and Bhagwat 2009) has been coined for the situation where climate interacts with topography, moisture and aspect to create suitable climatic combinations for species in areas where coarse-scale climate models suggest unsuitable climate. In effect, microclimates "buffer" the resident species from the direct effects of regional climate change.

Figure 3.1: Examples of Topographic Microclimate variation. Examples of differences in moisture and temperature due to topographic variation in aspect, moisture accumulation, and slope.

By mapping a landscape's relevant variation in topography, aspect and moisture, we can incorporate proxies for microclimate variations into conservation planning. Specifically, the number and variety of topographically-derived microclimates present at a site—its **landscape diversity**—can be used to estimate the capacity of the site to maintain biological diversity over time (Anderson et al. 2014b).

In this section we describe our methods to build a spatial landform dataset at a resolution of 30m for our study area using topography, aspect, elevation, moisture and wetlands. We then describe our method to quantify landscape diversity at a relatively fine scale across the study area, and to estimate the number of species-relevant microclimates in 40 ha circle around every 30-m cell. The calculation of landscape diversity scores for each pixel included integrating the following inputs:

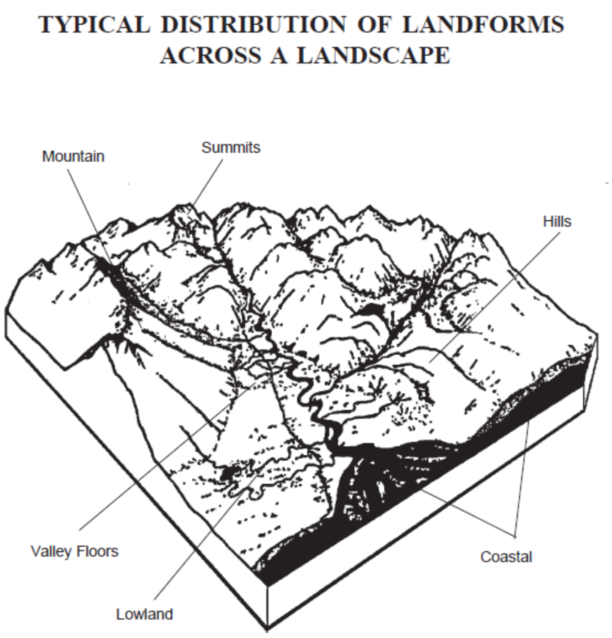
1. Landform Variety: the variety (count) of all landform types derived from topographic position, slope, aspect, and moisture
2. Elevation Range: additional weight where elevation range was greater than expected from the number of landforms
3. Wetland Density: additional weight to larger wetlands or dense wetland areas

Landforms

Landforms are natural features of the earth's surface created by topography - collectively the set of landforms comprises a region's terrain. A single landform can be described as a combination of topographic position, aspect, slope, and moisture (e.g., moist north-facing toeslope). The distribution of landforms in a landscape determines local vegetation patterns because these characteristics drive stable patterns of temperature and moisture, and correlate with exposure, nutrient availability, and soil depth (Barnes et al.1982, Forman 1995). Landform variation may create subtle biotic variation, for example in sand prairie species diversity, or distinct habitats such as a depression wetland, cove forest, or summit grassland.

The basic landform unit (a.k.a. ecological land unit, land facet, land segment, elementary landform, or relief unit) is the smallest homogeneous division of the land surface at a given scale. Because each unit is characterized by attributes such as elevation, slope, aspect, exposure, moisture, and topographic position, they can be used at a proxy for topographically-based micro climates, and the number and variety in an area can provide an estimate of the number of microclimates available to species. In Alaska, landforms have been described conceptually for mountains, hills, valley floor, lowland, coastal, and volcanic landform associations (USFS 1996), however they had not been mapped in GIS for the entire state.

Figure 3.2: Conceptual Diagram of Alaskan Landforms. From Landforms of the Alaska Region Classification Guide. USFS 1996.



To map landforms and quantify microclimates, we developed a GIS model that divides and classifies a continuous terrain surface into one of 19 landforms. Our methods are based on those of Fels and Matson (1997), and are described in detail elsewhere (Anderson 1999, Anderson et al. 2012).

We start with a 30-m digital elevation model. The Alaskan 30 meter per pixel resolution Digital Elevation Model (2020) was a newly created compilation of publicly-available elevation datasets published by the State of Alaska and the USGS which were aggregated by TNC into a single, statewide database. The Alaska Statewide Digital Mapping Initiative (SDMI) IfSAR-derived 5-meter per pixel digital elevation tiles were used to create the majority of the statewide 30 meter DEM, while the USGS 3D Elevation Program provided data for several islands which were not yet illuminated by the Alaska SDMI elevation program. Compiling 5tb of fine scale elevation data spread over 5,000 individual DEM tiles of differing resolutions required multiple mosaicking and resampling operations. The final statewide file was carefully reviewed for errors such as seamlines, blending artifacts and nodata issues. Areas in need of correction were remedied by hand using Esri's ArcGIS Pro Pixel Editing tools. As a final step before landform generation, we ran a standard 3x3 cell low-pass filter on the 30m which reduces the significance of anomalous cells and we filled sinks for the further terrain and hydrological modeling.

We derived estimates of slope, aspect, land position, and a moisture index for each 30m cell in the study area based on this statewide 30m DEM. Each of these derivatives are described below:

- Topographic Position Index: We evaluated the elevation differences between any cell and the surrounding cells within a search radius of 300m (10 cells) and scored it using a land topographic position index (TPI). For example, if the model cell was, on average, higher than the surrounding cells, then it was considered closer to the hill top (a more positive position value), and conversely, if the model cell was, on average, lower than the surrounding cells, then it was considered closer to the slope bottom (a more negative position value).
- Slope: Degree of slope was calculated as the difference in elevation between two neighboring cells, expressed in degrees.
- Aspect: Aspect was calculated using the GIS Aspect tool which fits a plane to the z-values of a 3 x 3 cell neighborhood around a center cell. The direction the plane faces is the aspect for the center cell.
- Moisture index: We calculated a moisture index following the topographic wetness index formula, also known as the compound topographic index (CTI). This wetness index is a steady state wetness index commonly used to quantify topographic control on hydrologic processes. It uses upstream flow accumulation and slope in the formula *Moisture index = ln [(flow accumulation + 1) / (slope + 1)]*. The resultant index was then smoothed using a 90m radius circular focal mean.

For slope, aspect, and land position, we defined thresholds that allowed us to partition values into different major landform zones (Figure 3.1) that corresponded with recognizable distinctions of landforms in the field. The primary divisions in the model were based on relative land position and slope (X and Y axis in Figure 3.1). Some slope classes were then further divided by aspect, and flats were further divided by the moisture index (Figures 3.1-3.3).

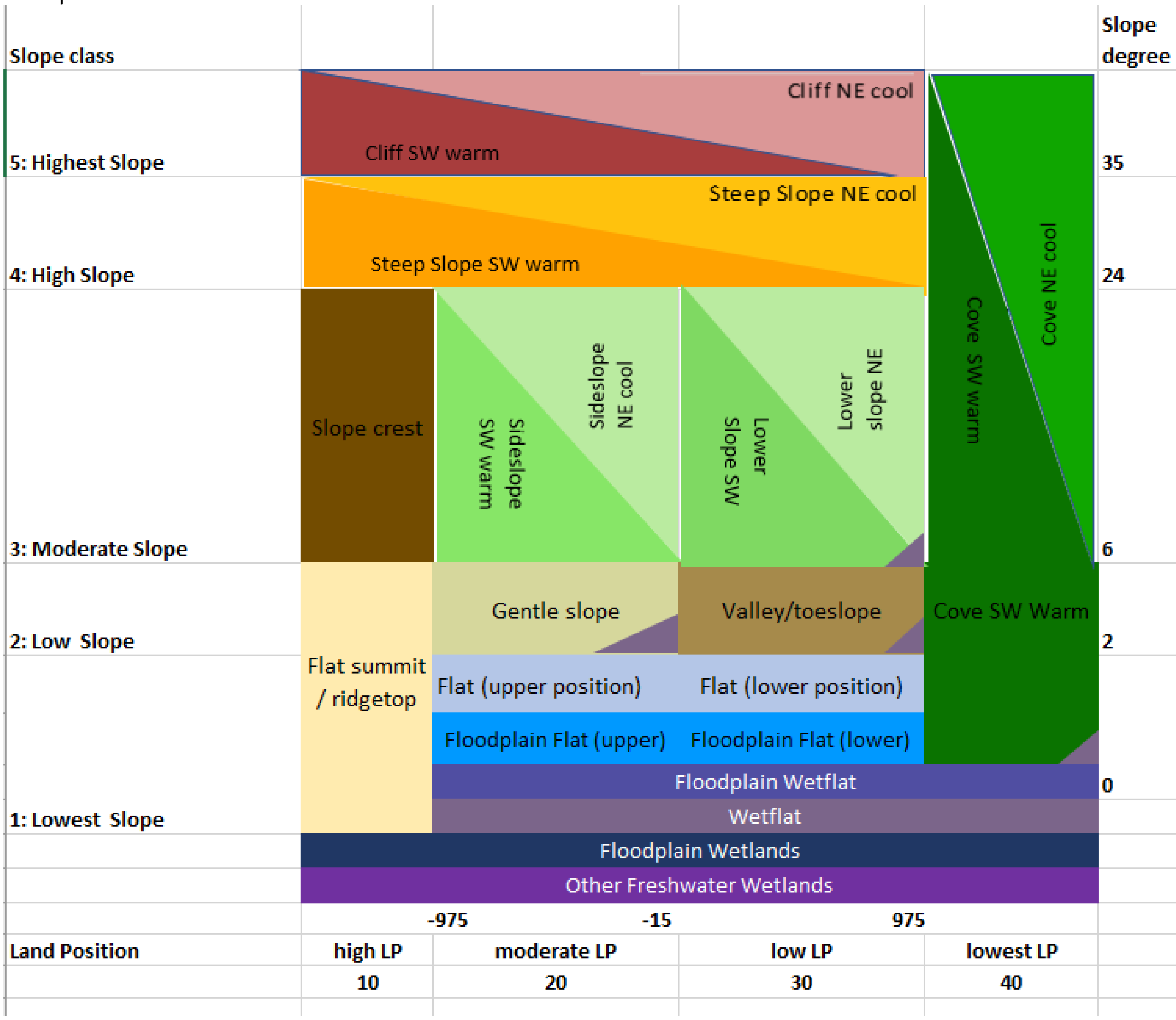
Combining specific classes of the above the slope, aspect, and land position index, allowed us to map the following 16 landforms (Figure 3.1):

·Cliffs (2 aspects)
·Steep slopes (2 aspects)
·Slope crests
·Side slopes: (upper land position, 2 aspects)
·Lower side slopes (lower land position, 2 aspects)
·Coves (2 aspects)
·Gentle slopes
·Valley/ toeslope
·Flat summit
·Flat, upper land position
·Flat, lower land position

High Moisture Accumulation Areas - Wetflats:
We applied the moisture index to further distinguish areas in landscape where we would expect higher soil moisture and overland upslope flow to accumulate based on the topography. Cliffs, Steep Slopes, Slope Crests, and Sideslopes were landforms in areas of extreme slope and/or higher land position and were not places we would expect moisture or overland flows to accumulate so they were not modified. However, for all other landforms, we modified their landform type to denote the influence of high moisture and overland accumulation as follows:

Lower land position and lower slope landforms were reclassified based on the moisture index into a new "wetflat" landform. This portion of the landscape was defined as areas that were >1 SD above the mean of the moisture index for the study area. Visual inspection against aerial photos confirmed that this threshold picked up wetter sections of coves and lower slopes, wet riparian areas, and wet basins often containing current wetlands or open water. To focus on the larger wetflat areas that we hypothesize are most likely to persist and smooth the results, we eliminated patches made up of only 1 and 2 cells to focus on wetflats >= .66 acres in size. These area of the "wettest or high accumulation" area that were falling on top of coves, lower position slopes, gentle slopes, valley toeslopes, and flats (upper and lower position) were then reclassed into the "wetflat" landform type.

Figure 3.3: The Underlying Slope and Land Position Model used to Map Landforms. Adapted from Fels and Matson 1997.



Wetlands:

Current wetlands were also added to the landforms to highlight areas where current emergent, forested, or tidal wetlands were mapped. Although the "wetflats" based on the moisture index provided information on where higher water accumulation was likely, we felt the actual confirmed emergent or forested wetland areas from the latest NLCD land cover dataset would provide additional validation to denote particularly wet areas where unique emergent or forested wetlands were validated. These areas might also include in some cases groundwater fed wetlands in areas that would be wet not due to overland flow based on topography (as our moisture index would pick up) but due to underground groundwater processes.

Emergent and forested wetlands were taken from the NLCD 2016 land cover product (Dewitz, 2019) which provided a recent and consistent interpretation of the extent of these wetlands at a 30m cell resolution. Tidal wetlands were taken from the Alaska Beringian Tidal Marsh Biophysical Setting - Area of Occupancy model from the Alaska

Ecosystems of Conservation Concern (Boggs et al. 2019). The landforms underneath these confirmed wetlands were reclassified into "wetland landforms" except if they fell on cliffs, steep slopes, or slope crests where we would not expect wetlands. This was done because NLCD wetland pixels occurring on these extremely high sloping or highest position landforms are often erroneously classified due to shading/reflectance issues in the source Landsat imagery used to develop the NLCD.

Floodplains

Floodplains were also integrated into the landforms from the Alaska Riverscape Area Project (Whited et al., 2013) which delineated larger floodplains for the state. The following landforms occurring in the floodplain were then tagged with a "floodplain" modifier: lower flat, upper flat, wet flat, and wetland (i.e., floodplain wetland). These landforms are likely subject to seasonal flooding and interact with the major rivers processes much more than other flat or wetland landforms so we would expect them to provide a unique habitat and microclimate value. Upland landforms that occasionally occurred in the floodplain were not distinguished from non-floodplain examples, as they were less likely to interaction with the river.

Water: Oceans, Rivers/streams, and Lakes/Ponds

To account for different types of waterbodies (e.g., rivers, lakes/ponds) in the landforms, we assigned 30-m water pixels to one of three classes: ocean, waterbody, and riverine. While the National Hydrography Dataset (NHD) for Alaska (USGS, 2020) does distinguish water types, the dataset was not available for the entire state. The National Land Cover Dataset (NLCD) 2016 (Dewitz, 2020) is available for the whole state but only has one water category, open water. We initially planned to use the NHD to assign water types to the NLCD open water pixels but there were many discrepancies in how water was mapped between the two datasets. For example, the NLCD might classify an area as water while the NHD identified the same area as land. Review of the underlying satellite imagery for areas with discrepancies did not show that any single dataset consistently and accurately captured what appeared to be water versus land. Consequently, developing a grid of water types was a challenging and multistep effort as summarized in the following paragraphs.

The first step was to develop a grid that most accurately represented ocean. We grouped the NLCD open water cells, converted the aggregated cells to polygons, manually selected the large ocean area polygons, and then converted those areas back to a 30-m grid, snapped to the NLCD to ensure alignment. As some of the NLCD ocean areas extended too far inland, we used the NHD coastline and riverine area polygons to create pixels where the ocean cells appeared to end. Where the NHD was incomplete, we used the Alaska Vegetation Wetland dataset (Flagstad et al. 2018) to identify these stops. We then re-grouped the ocean cells and repeated the process above of manually selecting large ocean areas.

Our second step was to fill in holes from the ocean cutoff process and identified missing ocean pixels using a combination of automatic and manual selection processes. To create the non-ocean water grid, henceforth the interior water grid, we merged the ocean grid on top of the NLCD open water pixels and removed the ocean cells. We aggregated the interior ocean pixels (four nearest-neighbor rule) and then calculated the area of NHD water types (i.e., riverine and waterbody) within each aggregated unit. We assigned a water type to the aggregated units based on the maximum area of type within each unit. We assigned a water type to interior water pixels based on the nearest type using the "Nibble" algorithm in ArcGIS. Depending on the spatial configuration of water pixels and NHD availability, the Nibble approach worked better in some areas while the maximum area-based approach worked better in other locations. We used the "Lookup" algorithm in ArcGIS to identify where the Nibble approach or the tabulate area approach was most appropriate to assign water types to the aggregated units. In locations where neither approach resulted in the correct assignment, we manually assigned water type. For parts of Alaska where the NHD dataset was unavailable, we used the NHD flowlines and the Alaska Vegetation Wetland dataset, but also had to do some manual corrections. While we had hundreds of test locations across all of Alaska's ecoregions to refine our methods to assign water types, there are likely errors in the type assignments as manual review of all water pixel assignments was beyond the scope of this project.

We integrated the DEM based landform map with the flooplain and water grids to create a single landform datalayer with 24 distinct units (Figure 3.4). Comparison with known places suggested that the landforms accurately represented the topographic and hydrologic characteristics of the landscape (Figure 3.5 -). This model became the basis of our microclimate model with each landform representing a distinct temperature-moisture combination.

Figure 3.4: Landforms. These landforms are used to characterize the region's topography and to calculate the landform variety metric (30m cell mapping resolution).

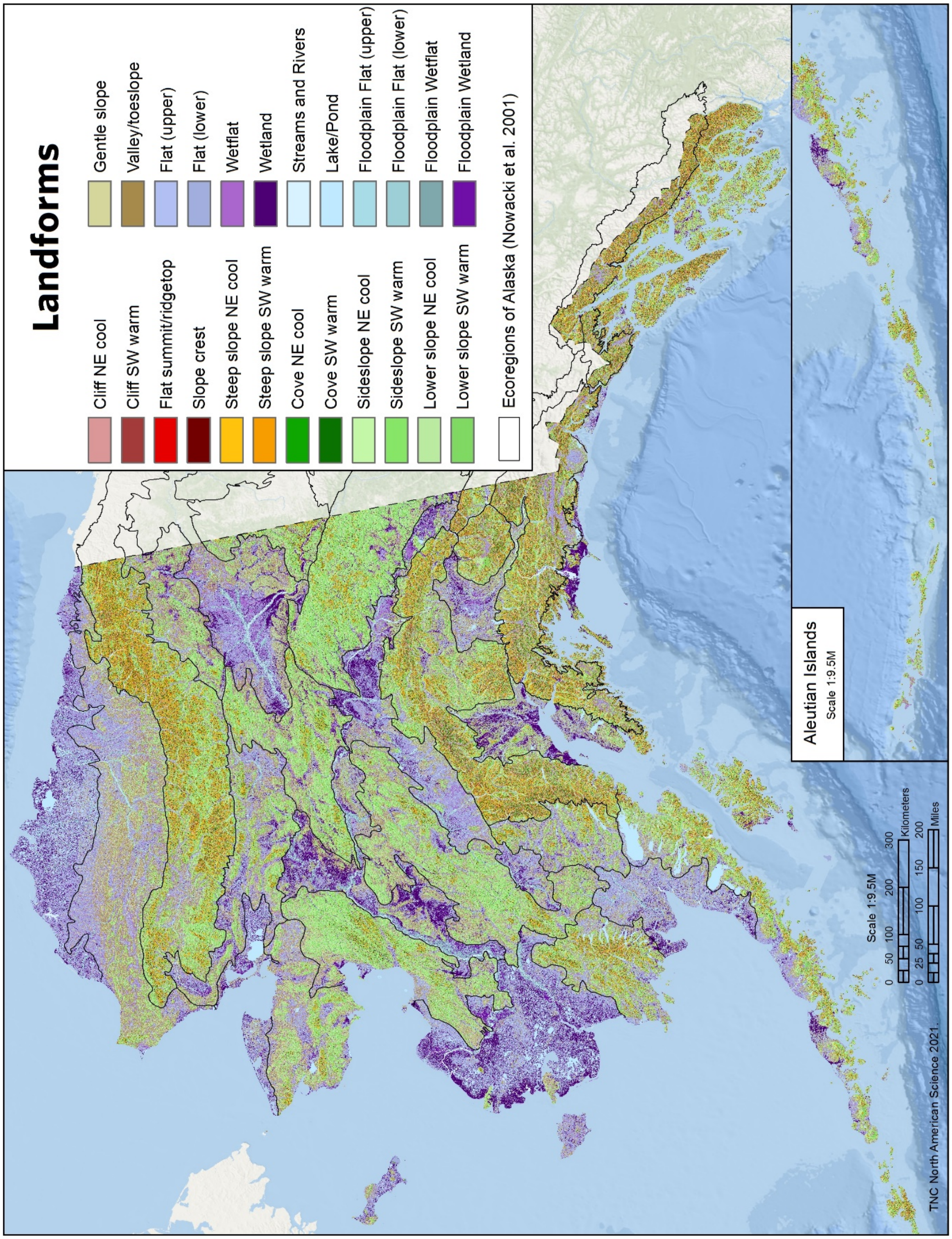
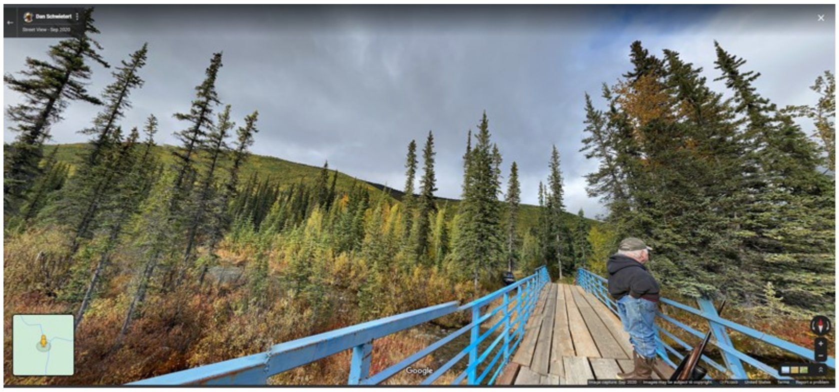
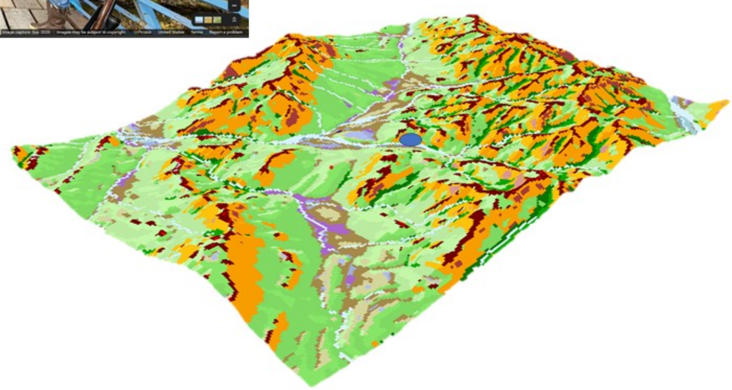
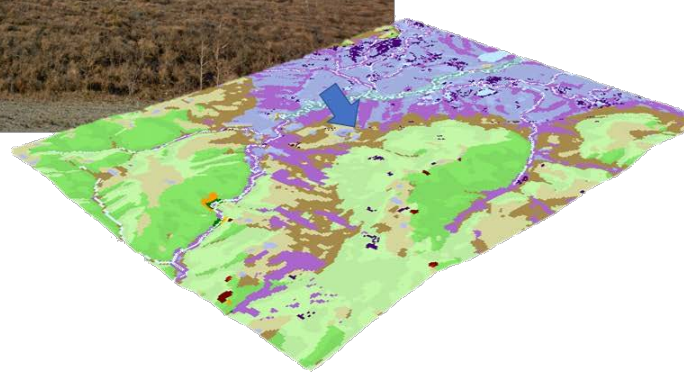


Figure 3.5: Landforms in Example sites

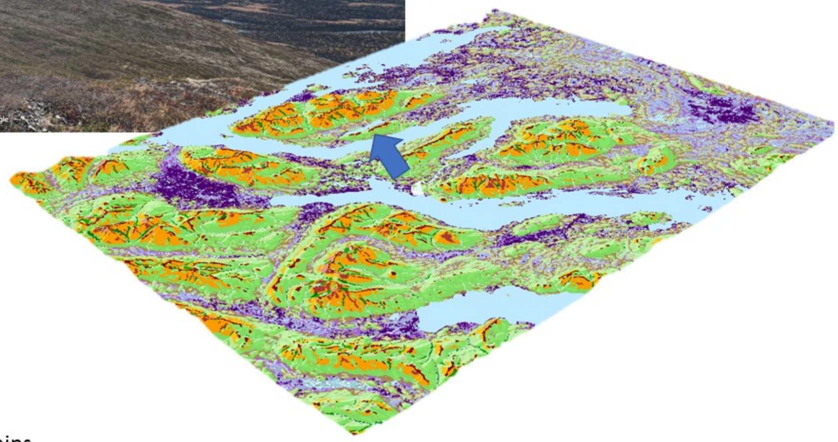




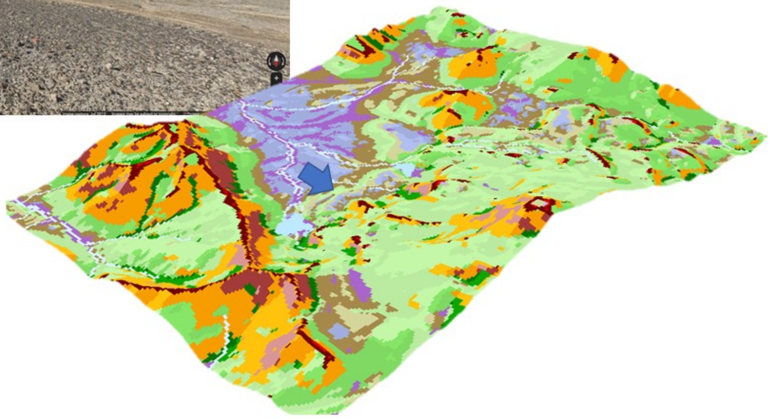
Ecoregion: Alaska Range
USGS 15 Minute Quad: Denali B-1-NE
Placenames: Stony Hill, Stony Dome



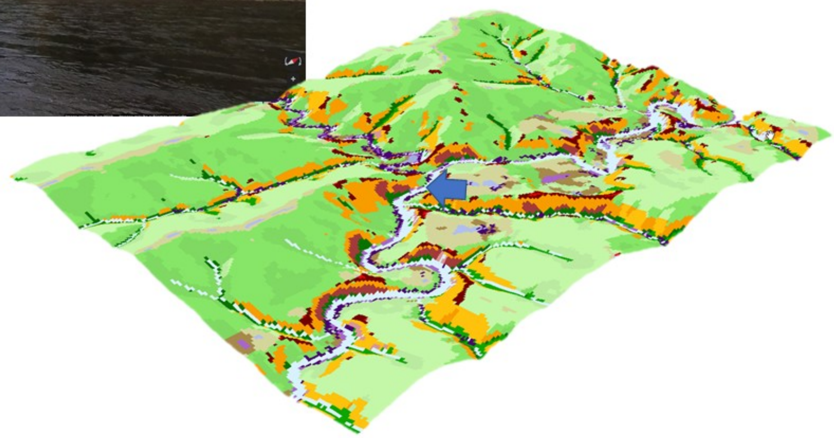
Ecoregion: Ray Mountains
USGS 15 Minute Quad: Bettles-B2
Placenames: Kanuti River



Ecoregion: Ahklun Mountains
USGS 15 Minute Quad: Dillingham B-8
Place Names: Alaknagik Lake, Frog Mountains



Ecoregion: Alaska Peninsula
USGS 15 Minute Quad: Mount Katmai B-4
Place Names: Buttress Range, Falling Mountain, Mount Cerberus



Ecoregion: Yukon-Tanana Uplands
15 Minute Quad: Eagle B-1
Placenames:

Landform Variety

To identify areas with the highest diversity of microclimates, we calculated the variety of landforms in a 40.4 ha (100-acre) circle surrounding every 30-m cell (Figure 3.5) using a focal variety analysis on the landform datalayer. This search area corresponds to roughly a 350-m radius around each focal cell and was chosen to conform to our resilience methods used throughout the lower 48 states and because this size provides the best discrepancy between cells (highest between-cell variance). The size is also a reasonable scale for a wide range of species, in that it suggests local population movements could access a 40 ha neighborhood.

Before running the focal variety analysis, we simplified the landform data layer slightly by combining two units into one unit where investigation suggested the microclimatic signature were similar or identical. This included: wetlands (floodplain, non-floodplain), flats (upper and lower) and inland water (rivers, lakes/ponds) reducing the number to 21. Finally, the smallest streams were combined into the “wetflat” landform because their scale and patterning were similar and most likely provide the same habitat. This reduced the total number of landforms being counted to 20.

The landform variety count was then transformed into standardized normalized score (Z score) where the mean is zero and standard deviation is 1 for the analysis area. A standard normal transformation (Z-score) is used throughout this project for combining datasets.

Figure 3.6: Conceptual Model for Landform and Landform Variety. Landforms are showing in different colors in this model. Landform variety is the count of the number of different landforms occurring within a 40ha (100 acre) circle in a moving window analysis**.**

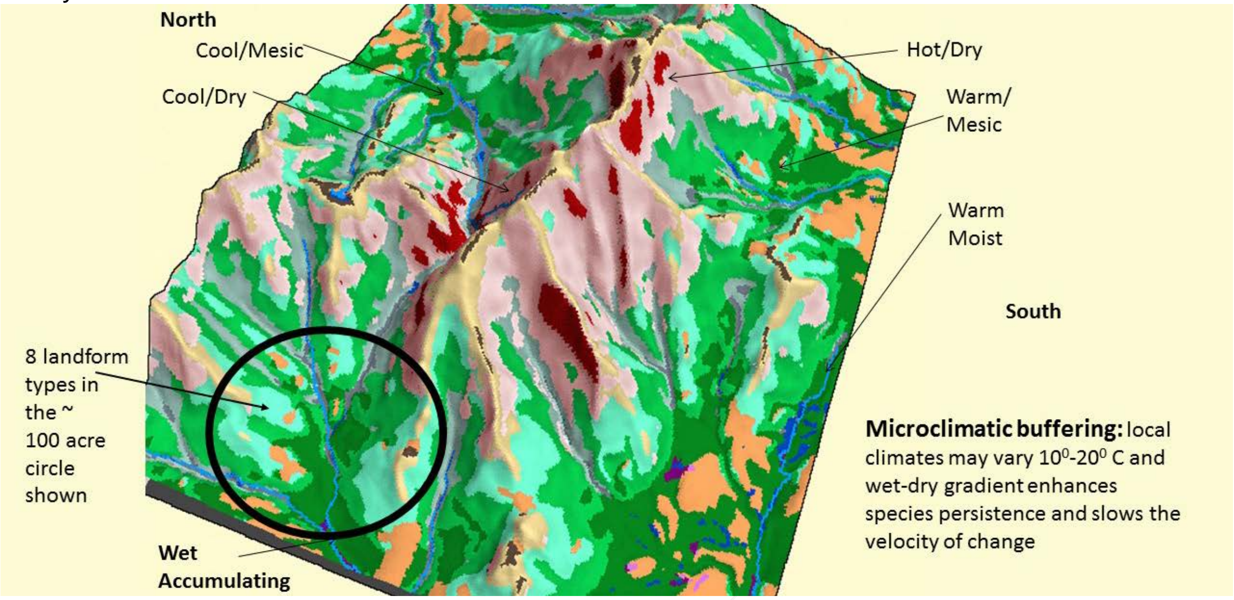
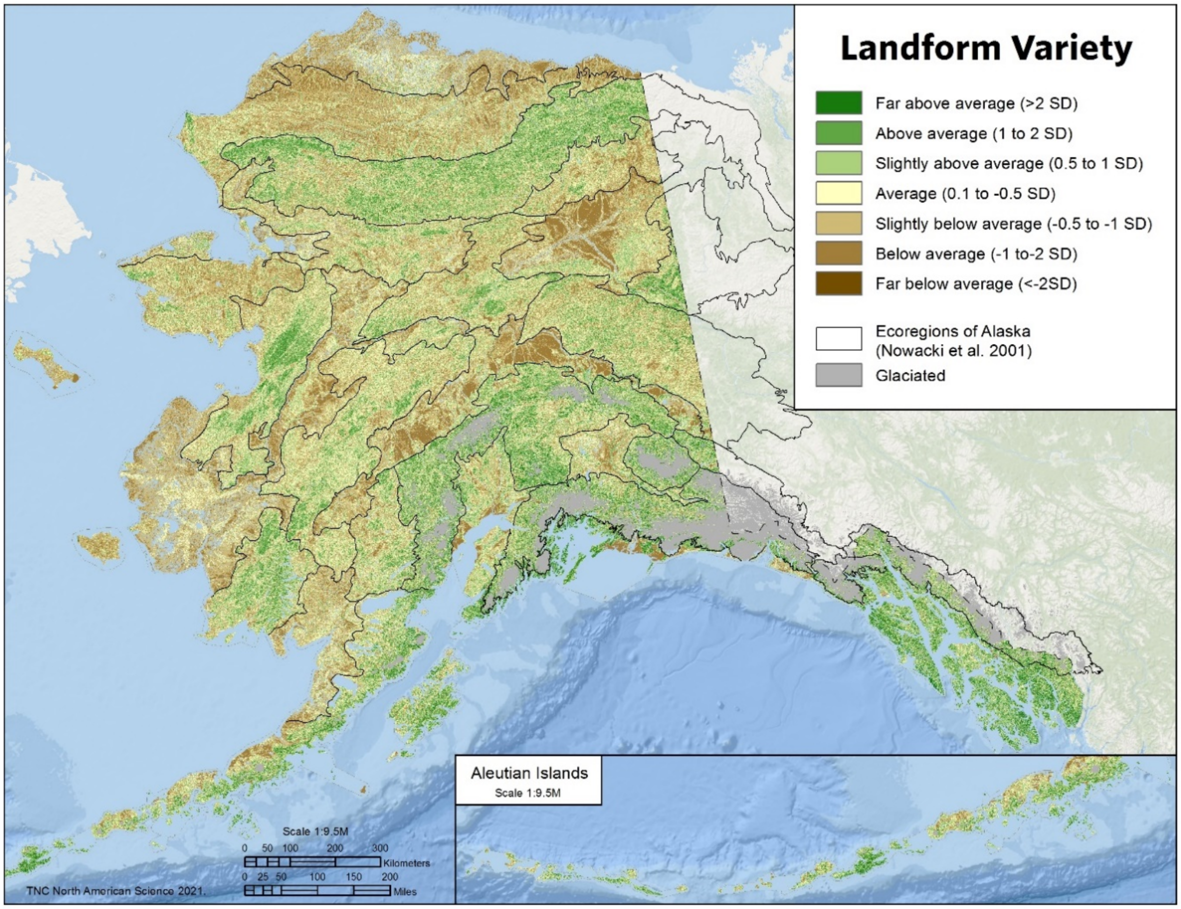


Figure 3.7: Landform Variety. The distribution of the counts of number of landforms in a 100-acre circle for the region. Areas with higher landform counts (more topographic variation within local neighborhood) appear in green, and lower counts appear brown.



Wetland Density

Large wetlands or wetland concentration areas play a unique role in sustaining site resilience. As the climate changes, persistent wetlands will become increasingly important because they retain soil moisture longer and preserve a mixture of organic and wetland soils. Further, wetland basins tend to have high evapotranspiration rates and moderate the local climate (Geiger et al. 2003). Protecting wetlands and riparian corridors has been suggested as one of the single best actions in promoting resilience and in sustaining biodiversity (Naiman et al. 1993, Fremier et al. 2015). We expect the current wetlands will continue to be important under variable climates even though the size and wetness of the areas are likely to change. Small and isolated wetlands are more vulnerable to shrinkage and disappearance than wetlands embedded in a landscape dense with other wetlands. We created a wetland density metric that allowed us to identify these larger wetland areas.

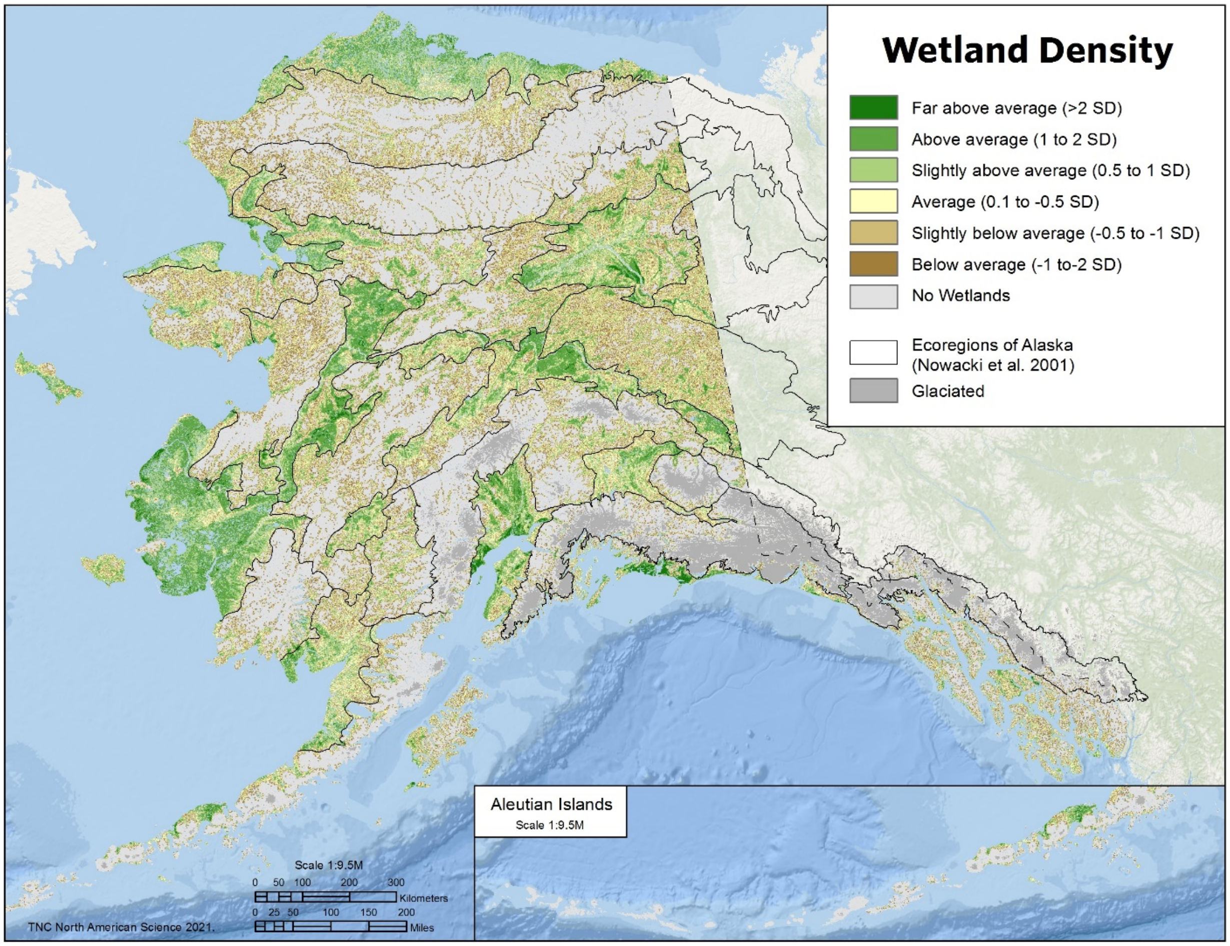
To analyze the distribution of current wetlands, we compiled a base dataset of mapped wetlands as described above in the landform section. We calculated a wetland density score for every 30-m cell using two scales, the percentage of wetlands within a 40.4 ha (100-acre) circle around the cell and within a 404 ha (1000-acre) circle around the cell. We included two scales to provide better discrimination between sites that might look identical at the 100-acre scale and include a larger zone of influence in which wetland microclimates and habitat values would be available to terrestrial ecosystems. Open water was excluded from the density calculation so that density was relative to the amount of land.

To integrate the two scales, we created Z scores for each scale (100 acres, 1000 acres) by transforming the density values to approximate a normal distribution using a Rank Transformation because the source values were non-normal (skewed low). Areas with a wetland density of zero were assigned a Z score of -3.5 SD (lowest number). We combined the standardized values from both search distances using the formula which gave twice the weight to values from the smaller (100-acre) circle, the same scale used in landform variety.

*Wetland Density = (2*100-acre wetland density + 1000-acre wetland density) / 3.*

The resulting wetland density index score was then Z scored a final time using the means and SD from that full analysis area as calculated using only cells which had a wetland density greater than zero. The results is a statewide map of wetland density (Figure 3.8).

Figure 3.8: Wetland Density. Weighted density of NLCD 2016 wetlands in 40- and 404-hectare circles around each central cell compared to the regional average. Areas with no wetlands were assigned to the lowest class.



Elevation Range

Our goal in the elevation range analysis was to identify areas had more elevation range than would be expected by their number of landforms. We were particularly interested in identifying long side slopes and low slopes that have been shown to offer climate relief to many species (Chen et al.2017). Using a 30-m Digital Elevation Model (Gesch et al. 2007) we calculated the total elevation range in a 40 ha (100-acre) circle surrounding each cell using a focal range analysis (the same search area as for the landform variety analysis). We converted the results to Z-score for the region using a Rank Transformation given the input values were non-normal (Figure 3.9).

Alaska's ecoregions vary drastically in their elevational range and landform patterns. To account for this, we stratified the state into 3 major groups of ecoregions looking at patterns in the mean elevation range in a 40 ha (100 acre) circle. Ecoregions were assigned to a "Mountain" group if they had an average of >100-m in elevation range, to a "Hills" group if they had on average 30-100-m of elevation, and to a "Lowlands" group if they had <30-m of elevation range within 40 ha. To identify areas of relatively higher elevation range within each stratification, we took a Z score using the mean and standard deviation of the area within a given group (Figure 3.10).

Figure 3.9: Statewide Elevation Range. Range of elevation within 40-hectare circles around each central cell compared to the regional average.

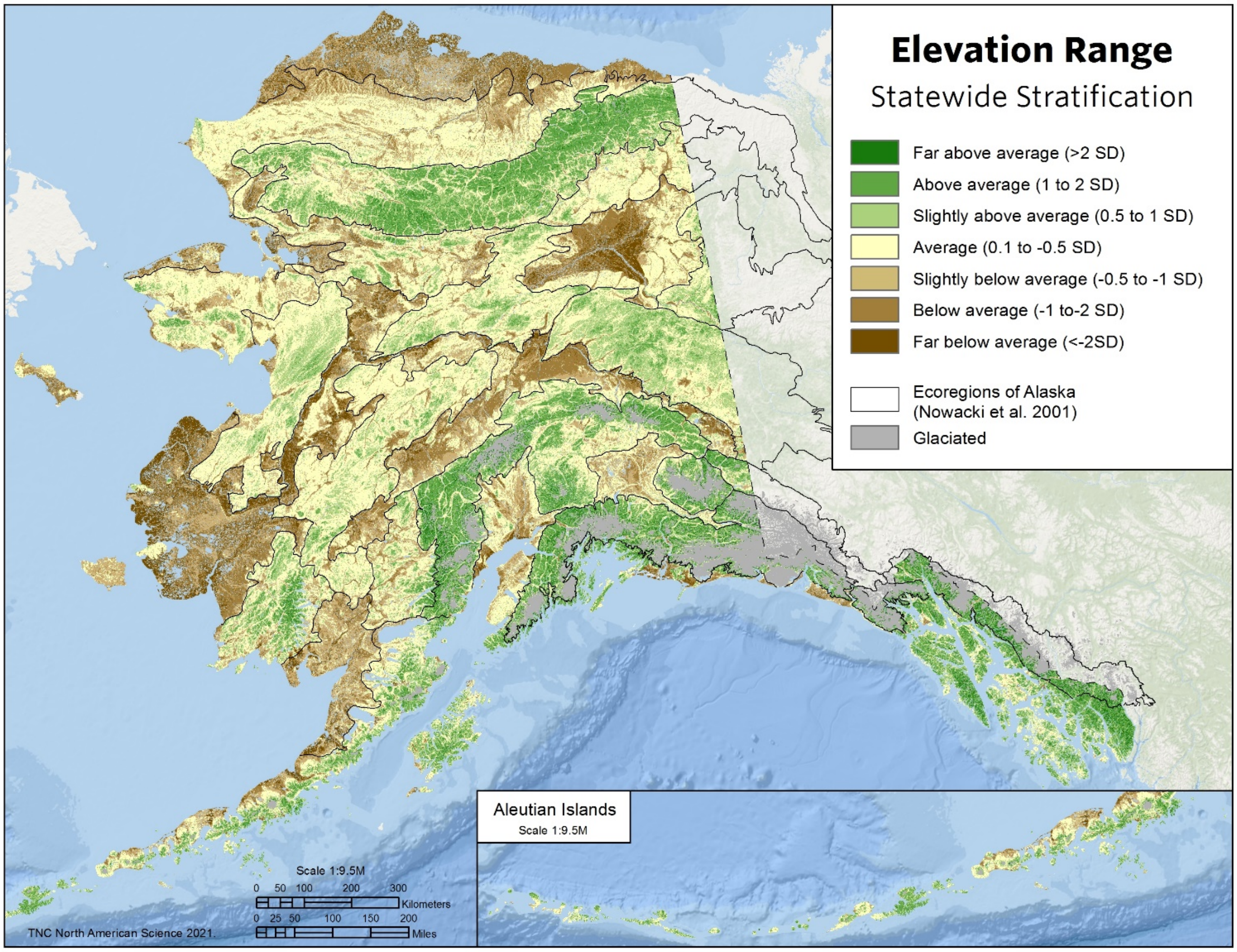
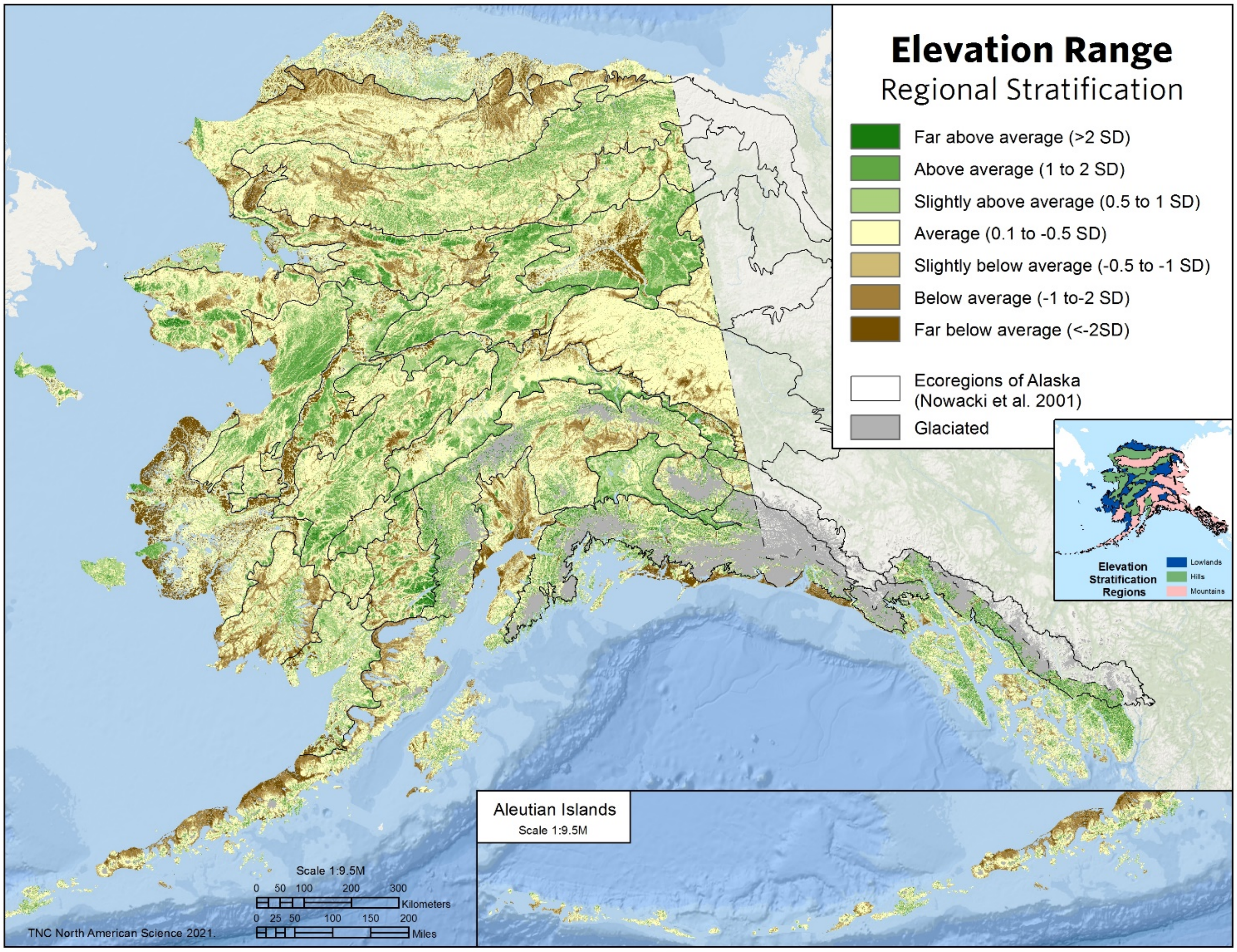


Figure 3.10: Regional Relative Elevation Range. Range of elevation within 40-hectare circles around each central cell compared to the average within the three elevation stratification regions.



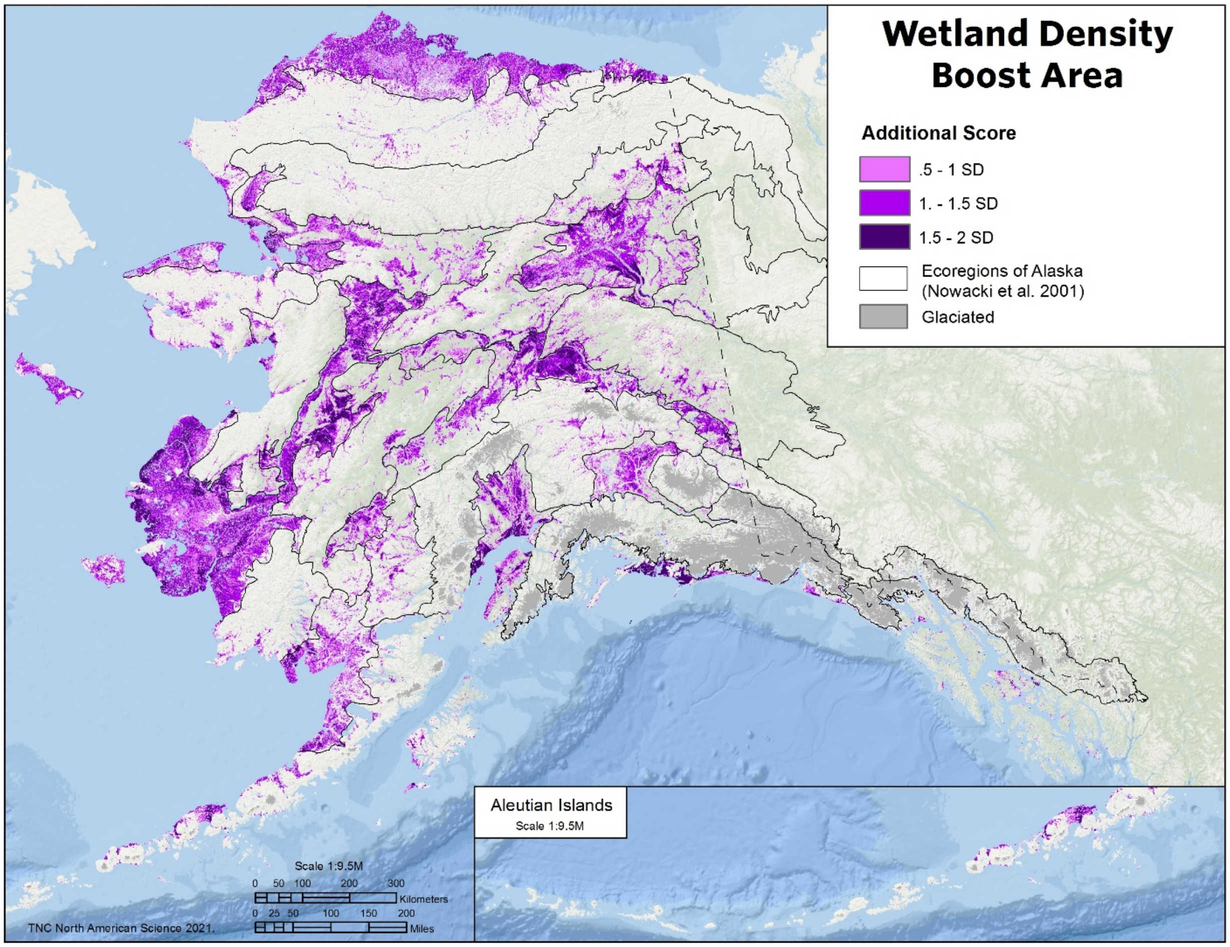
Landscape Diversity: Integrating Landforms, Wetlands and Elevation

To create a single landscape diversity metric that approximated the diversity of microclimates, we begin with landform variety as the base datalayer and then increased the score for each individual cell is the wetland density or elevation range were above average. To do this we created two additional indices:

<u>Wetland Density Bump</u>

We subtracted the landform variety score from the wetland density score such that a positive difference indicated the wetland density was greater than the landform variety relative to their respective means. We then identified areas where wetland density was both 1) above the mean (>0.5 SD) and 2) the difference between wetland density and landform variety was also above the mean (>0.5 SD) To these areas, we redistributed their original density Z values to be between 0.50 – 2 SD) giving a slight boost to the area (Figure 3.11).

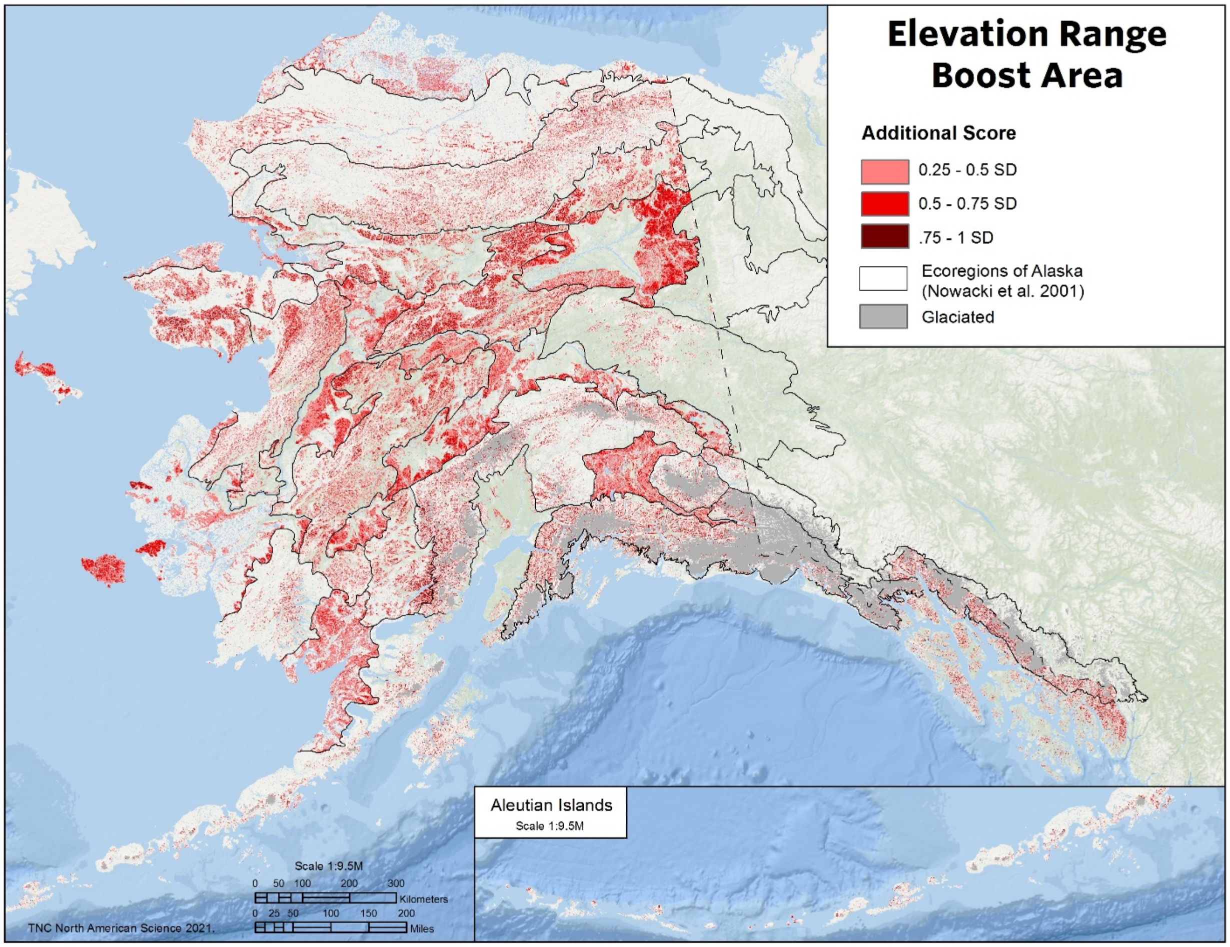
Figure 3.11: Wetland Density Boost Area.



Elevation Range Bump

We subtracted the landform variety Z score from the elevation range Z score such that a positive difference indicated the elevation range was greater than the landform variety relative to their respective means. We then identified areas where the elevation was both 1) above the mean (>0.5 SD) and 2) the difference between the elevation and landform variety score was also above the mean (>0.5 SD) To these areas, we gave a slight boost (0.25 – 1 SD) to the landscape diversity score by proportionally recalling their scores from their original 500-3500 SD to 250-1000 SD and adding them to the landscape diversity score (Figure 3.12).

Figure 3.12: Elevation Range Density Boost Area.



Base Landscape Diversity Score

To create the integrated map of landscape diversity, the base score of landform variety (Z score) was then increased if cells were identified by any of the boosting criteria for elevation range or wetland density (Figure 3.13). The magnitude of the boost varied depending on the cell characteristics described above. Boosts varied between:

1. Elevation Range boost: 0.25-1 SD
2. Wetland Density boost: 0.25-2 SD

The Landscape Diversity score was equal to landform variety score plus the sum of the boosts. This was then divided by the standard deviation of the analysis area to appropriately spread out the distribution and approximate standard normal units (Figure 3.14). When compared with satellite images, the resulting datalayer does a credible job of estimating microclimate diversity (3.15).

Figure 3.13: Combining Landform Variety, High Wetland Density, and/or High Elevation range. Base landform variety scores were increased in areas of high wetland density and/or high elevation range

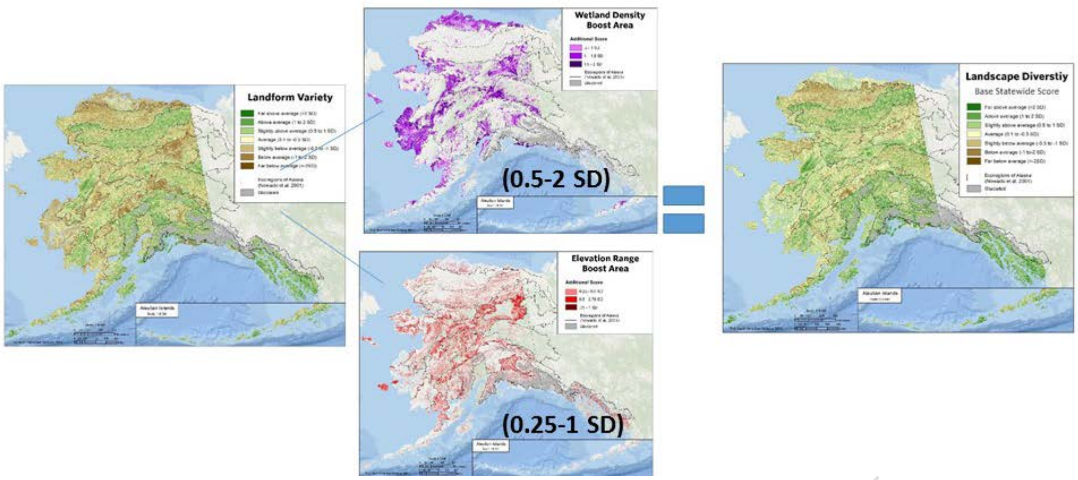


Figure 3.14 Alaska Statewide Landscape Diversity Score. Landscape diversity combined values of landform variety, elevation range, and wetland density influences. Values are relative within the whole analysis area.

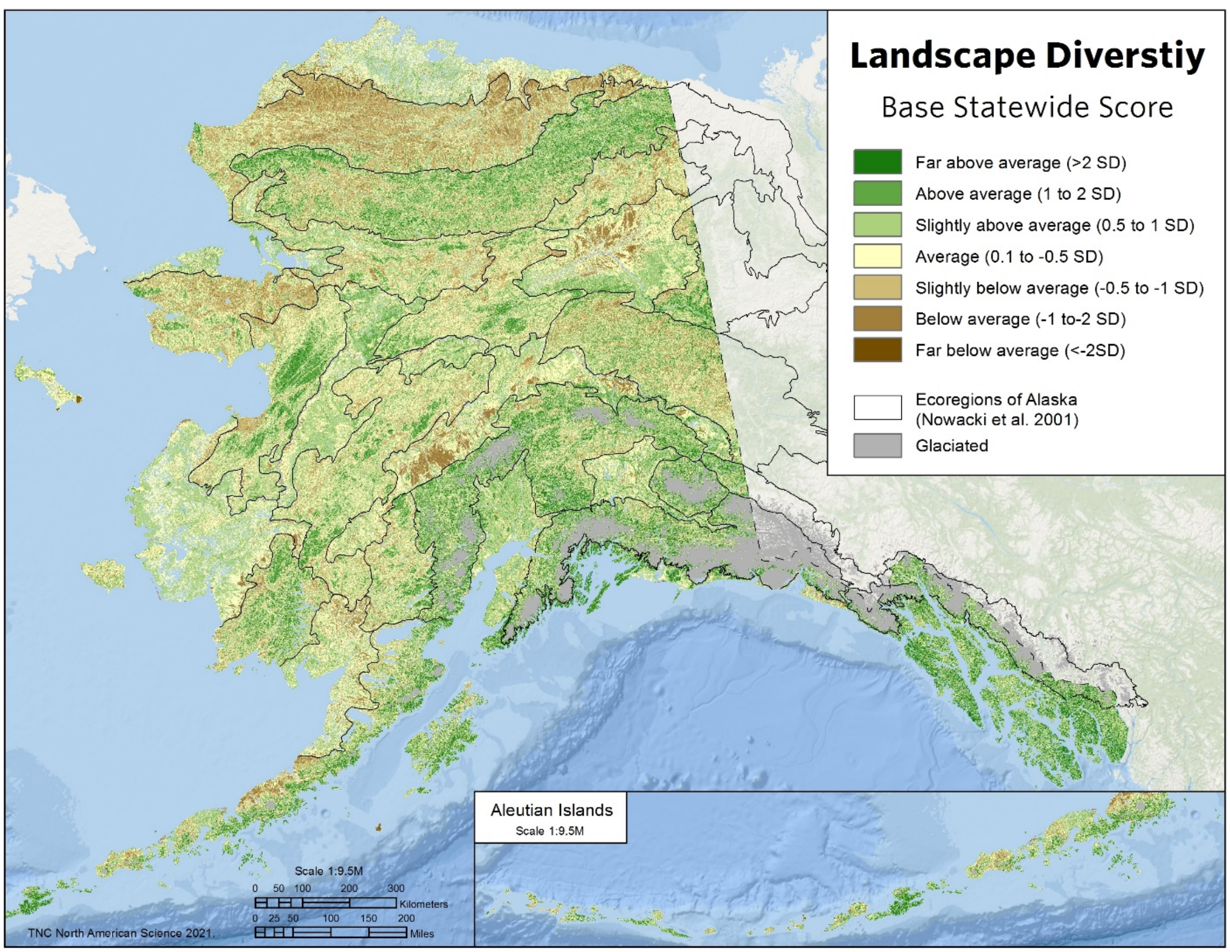
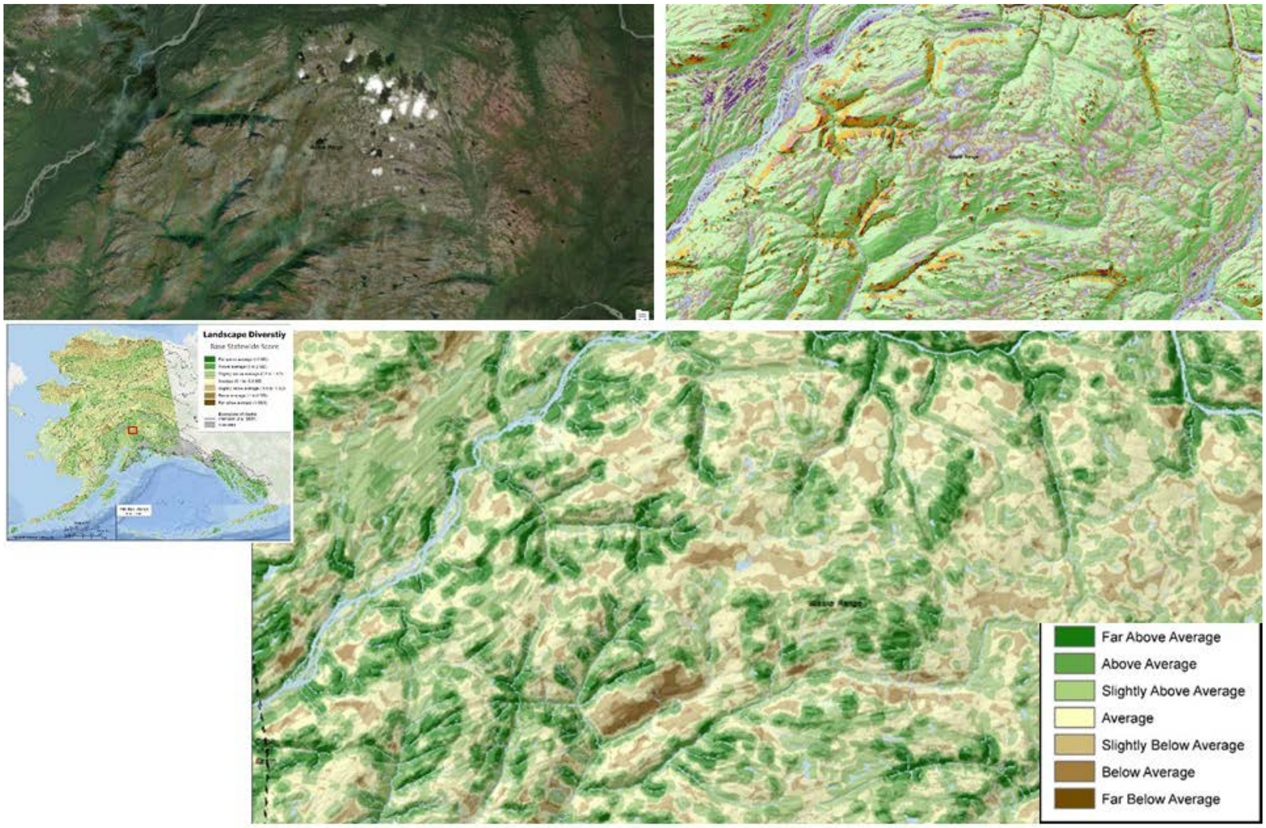


Figure 3.15 Example Landscape Diversity Score. Zoom in of the X area showing aerial photo, landforms, and landscape diversity.



Final Landscape Diversity Score

Ecoregion Stratification

The statewide Landscape Diversity map provided a measure for the entire study area, but this project also aimed to ensure we had a measure of site resilience relative to each ecoregion, and to settings within those ecoregions. For example, low elevation flat sedimentary areas that dominate the land area in one ecoregion may not have as high numbers of microclimates and landscape diversity as mountainous granitic areas of another ecoregion in Alaska, but are aim was identify those areas in both ecoregions that had relatively more landscape diversity.

To stratify the statewide values, we rescored the datalayer by ecoregion, or in ecoregions with more than one elevation zone into ecoregion plus elevation zone (e.g. Brooks Range above timberline, Brooks Range below timberline). We calculated a Z score for each, using the average score for the ecoregion or ecoregion-elevation zone combination.

Overrides
To the ecoregion-based landscape diversity score, we allowed an override to replace the cell score if the landscape diversity score was extremely high in any of two other key stratifications:

1) Statewide Low Elevation: >0.5 SD above average in the Z score of statewide lower elevation below treeline zone area
2) Geophysical Setting" >1SD above average in the setting within ecoregion.

The first override was important for highlighting state-wide outstanding areas within Alaska's vegetated region and corrected for the fact that some ecoregions had very high means. The second was a fine filter stratification to ensure at least the highest scoring representation of all geologic settings in each ecoregion. By including these stratifications, we ensured that the score truly represents the areas of highest landscape diversity relative to all of the soils, elevation zones and ecoregions.

Figure 3.16: Combining Stratifications and Overrides. Base landscape diversity was stratified by ecoregion and then overridden with highest scoring areas from the low elevation portion of Alaska and/or from the geologic setting stratification if those areas were higher than the original ecoregional score.

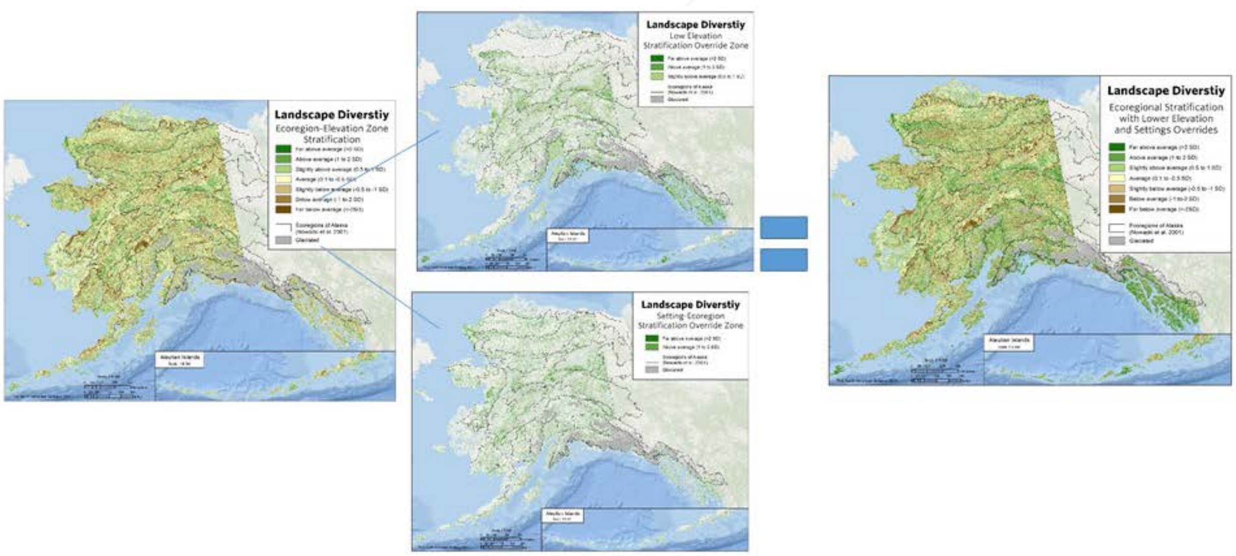
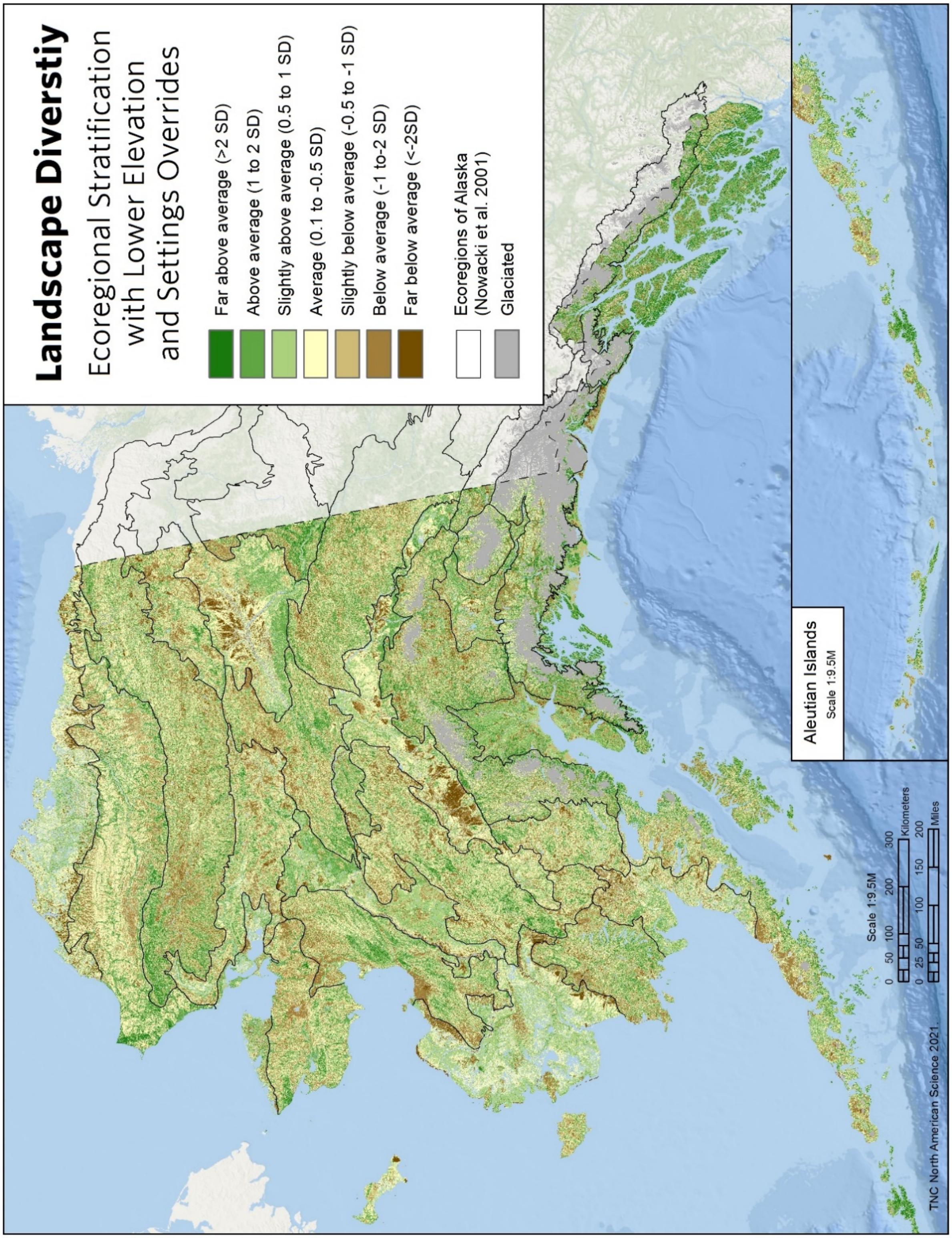


Figure 3.17: Landscape Diversity Score with All Stratifications. Values are relative to each ecoregion or ecoregion-elevation zone, with overrides to include the highest scoring areas for each geophysical setting or the highest in the state for low elevation.



Section 2: Landscape Permeability

Climate change is expected to alter seasonal temperature and precipitation patterns, and intensify disturbance cycles of fire, drought, and flood. Rapid periods of climate change in the Quaternary, when the landscape was comprised of continuous natural cover, resulted in many changes to species distributions but few extinctions (Botkin et al. 2007). Now, pervasive fragmentation across the U.S. disrupts ecological processes and impedes the ability of many species to adapt to change. Industrial agriculture, development, roads, and other barriers will likely impair the ability of species populations to move, and for nature to adjust to rapid change, leading to depleted environments and less diversity. Not surprisingly, the need to maintain **connectivity** has emerged as a point of agreement among scientists researching key strategies for helping biodiversity adapt to climate change (Heller and Zavaleta 2009, Krosby et al. 2010). In theory, maintaining a permeable landscape, when done in conjunction with protecting and restoring sufficient areas of high-quality resilient habitat, should facilitate the expected range shifts and community reorganization of species. Regional scale models suggest that the rate of natural migration for plants will not keep pace with the rate of climate change (Iverson et al. 1999; Iverson et al. 2004; Iverson and McKenzie 2013), highlighting the importance of microclimate buffers and refugia, and the need for species to be able to move locally to take advantage of them.

We prefer the terms '**permeability**' and **'connectedness'** over 'connectivity' because the latter is defined as the capacity of individual species to move between areas of habitat via corridors and linkage zones (Lindenmayer and Fischer 2006). Accordingly, analyses of connectivity entail identifying linkages between specific places, usually patches of good habitat or natural landscape blocks with respect to a species (Beier et al. 2011). In some studies, areas to connect have been defined by level of legal protection (e.g., Belote et al. 2016), which is particularly problematic in regions where there are few protected areas, but many large expanses of natural habitat in private ownership. Our emphasis on permeability reflects this goal of facilitating large-scale reorganization of species in response to climate change, which we suggest requires a more comprehensive and continuous analysis: all organisms, in all directions, over many years.

Landscape permeability is a measure of landscape structure: the hardness of barriers, the connectedness of natural cover and the arrangement of land uses. It is defined as *the degree to which regional landscapes, encompassing a variety of natural, semi-natural and developed land cover types, will sustain ecological processes and are conducive to the movement of many types of organisms* (definition modified from Meiklejohn et al. 2010). Accordingly, we developed methods that map permeability as a continuous surface, not as a set of discrete cores and linkages. Our aim was to create a surface that reveals the implications of the landscape structure with respect to the continuous flow of natural processes like dispersal, migration and recruitment.

We developed two analytical models to assess different aspects of permeability. The first, **local connectedness,** starts with a focal cell and estimates the resistance to flows outward from the cell in all directions. The second, **regional flow,** examines broad east-west and north-south flow patterns across the entire region. Both metrics estimate how flow becomes blocked, slowed, redirected, or channeled due to the spatial arrangement of human land uses and the remaining natural lands. The local connectedness metric was used in estimating the resilience of a site and the descriptions below refer to this metric. The larger scale, or regional flow analyses is a part of the Resilient and Connected Network analysis later in this report.

Local Connectedness

The **local connectedness** metric estimates the resistance/permeability surrounding a focal cell if movements were to flow outward in all directions from its center point. As a component of resilience, this metric estimates how easily species can access the microclimates within their local neighborhood based on the arrangement of roads, industrial agriculture, development and other human structures that create resistance to movement by creating barriers or increasing the risk of harm.

In the local connectedness model, the permeability of two adjacent cells increases with the similarity of those cells with respect to their land cover. If adjacent landscape elements are identical (e.g., forest to forest), then there is no disruption in flow. A contrasting element (e.g., forest to developed land) creates resistance and the connection is presumed to be less permeable. Organisms can and do move across different landscape elements, but the sharper the contrast is in structure, surface texture, exposure, or chemistry, the more likely it is that movement will be altered or slowed. The degree to which a cell alters the flow arriving from an adjacent cell is its **resistance**, and the corresponding land use is assigned a **resistance weight** based on its expected resistance.

<u>Creating a Resistance Grid</u>
Our analysis of resistance began with a step of sorting the landscape into three basic landscape elements and assignment of general resistance weights from 1-20:

1. <u>Natural lands</u> (resistance weight 1): Landscape elements where natural processes are unconstrained and unmodified by human intervention. Examples include grasslands, wetlands, and forests.
2. <u>Agricultural or modified lands</u> (resistance weights 5-7): Landscape elements where natural processes are modified by direct, sustained and intentional human intervention. Nutrients are often depleted and use by species may be constrained by management actions or chemical applications, fencing, and other barriers.
3. <u>Developed lands</u> (resistance weights 8-20): Landscape elements dominated by the direct conversion of physical habitat to buildings, roads, parking lots, or other infrastructure associated with human habitation and commerce. Vegetation is highly tended, manicured, or controlled.

Methods to quantify and objectively assign resistance weights have included similarity indices based on vegetation types or land cover classes (B. Compton personal communication 2009, Compton et al. 2007). Our weighting scheme was generalized with respect to vegetation types such that any natural land cover element adjacent to another natural land cover element was scored with a low resistance value assuming that dispersal and population movement requirements are less specific than those for breeding. In addition, our goal was to maintain the natural relationships and connections between all types of natural land and was not targeted towards a specific species (Hunter 2002, Ferrari and Ferrarini 2008, Forman and Godron 1986).

Previous work looking at statewide connecetivity in Alaska have used either the Land Condition Model (Trammell and Aisu, 2015) or the human modification for North America (Theobald, 2013). We adopted the methodology of the former developed by the Alaska Center for Conservation Science (Trammell and Aisu, 2015) because of its focus on Alaska specific landuse factors. After conversations the authors of the Landscape Condition Model and our steering committee, we decided to upgrade the resistance grid with newer data. Following the same methods, we were able incorporate the most up-to-date GIS datasets and reduce the grid cell size of the data. We assigned resistance weights by using similar weights to previous TNC Resilience projects (see methods for Eastern US, Great Lakes and Tallgrass Prairie, Great Plains, Lower Mississippi and Ozarks, Rocky Mountains and Desert Southwest, Pacific Northwest).

To create the revised resistance grid, we combined several datasets representing land cover, land use, roads, railroads and agriculture. The primary data source was the 30-m 2016 NLCD, which identifies each grid cell as belonging to one of 16 classes of land cover (Yang et al. 2019). We made several upgrades to the basic land cover data that substantially improved their performance as resistance grids, including:

1) Oil and gas development
2) Hydropower development
3) Roads and railroads
4) Logging
5) Current and Historic mining
6) Energy transportation – pipelines and powerlines

Oil and Gas Development

There are 7,873 active and inactive wells in Alaska concentrated around the Cook Inlet in the south and the North Slope. Oil and gas development leaves visible scars on the landscape in these areas with highly developed oil and gas infrastructure (Figure 3.18). Oil and gas development results in both direct and indirect effects on species movement. Roads and well pads fragment the landscape and the noise associated with pumping and daily vehicle traffic amplify the effect of fragmentation discouraging the movement native species and favoring invasive species (IPIECA 2010).

Figure 3.18: Oil and Gas Wells in Purdhoe Bay Alaska. Purdhoe Bay Alaska is a large oil field in Northern Alaska. In this aerial, you can see the roads, well pads, and other infrastructure built to support oil and gas development.

To incorporate oil and gas wells into the resistance grid we used a methodology we developed in the Central US and the Rocky Mountains and Desert Southwest study areas (Anderson et al 2018). First, we compiled oil and gas well data from Alaska Department of Natural Resources Division of Oil and Gas (Alaska DNR 2021).

We separated the wells into active and inactive wells based on the "current status" field. The following well classes were considered abandoned: 1) administratively abandoned, 2) permit cancelled, 3) permit expired, 4) plugged abandoned, and 5) suspended well. All other wells were considered active.

Based on steering committee' observations and discussion, we gave the highest density oil and gas areas (>16 wells per square mile) a resistance effect equal to that of medium-density development. We used a two-pronged approach to accomplish this where part of the score comes from the resistance weight, and part comes from the density and pattern of development. To estimate the resistance of the well pads themselves, we created a 540 x 540-meter well pad area around each well point. The 540 m square was chosen because in high density areas with over 16 wells per square mile, the squares form a continuous coverage. Well pads were given a resistance score of 9, equivalent to medium density development at high densities.

To account for the cumulative and indirect effects of dense oil and gas development not directly on the well pad (i.e., traffic and noise) we generated a point density grid based on the individual well points and using a kernel density function which is sensitive to small differences. We included both inactive wells and active wells in the density calculation, but inactive wells received 1/10 the weight of active wells. We converted the density grid to a resistance surface using a graduated weighting so cells with a higher density of points had higher resistance (Table 3.1).

Table 3.1 Well Density Resistance Weights.

Well Density	Resistance Weight
0 – 1 well per square mile	0
1-2 wells per square mile	0.2
2-4 wells per square mile	0.4
4-8 wells per square mile	0.6
8- 16 wells per square mile	0.8
16 wells per square mile	1.0

To create a single integrated layer, the direct well pad area was given a resistance score of a 9, while areas not on the pad but within a well density class were given the resistance weight of that class (Table 3.3.). The latter were added to the base score from land cover. For example, an area that was not on a well pad and had natural cover (resistance = 1) but was within an area of 4-8 wells per square mile (resistance = 0.6) got a resistance value of 1+0.6 = 1.6. An agricultural area that has 4-8 wells per square mile got a resistance score of 7 (agriculture) plus 0.6 (well density) = 7.6.

Hydropower development:

Hydropower is Alaska's largest source of renewable energy and supplies over 20% of the state's total energy. Hydroelectric plants have a physical development footprint on the ground of the project footprint and the associated transmission lines. We used a dataset of hydro-electric sites and transmission lines obtained from Alaska Industrial Development and Export Authority by the state TNC office. We examined transmission plants on aerial photos to determine that the average footprint size of 540 square meters used for the well pads would also work for transmission plants. These are industrial facilities, so they were given a high resistance of 10. Based on steering committee discussion transmission lines are create a moderate decrease in local connectedness, so we gave them a resistance of 3.

Mines:

Mines are a major industry is Alaska and mining has been important in Alaska's economy. Currently zinc, lead, copper, gold, silver, coal as well and construction materials are the primary commodities mined. These mines leave a scar on the natural landscape and have a large impact on local connectedness. For many of the largest of mines, these scars are 10,000s of acres. The Alaska Center for Conservation Science has digitized all the historic and current mining areas in Alaska (Alaska Center for Conservation Science. 2020). We included these mines as high-density development with a resistance of 20.

Waterbodies:
Waterbodies in Alaska are a common feature on the Alaska landscape. The size, shape, and connectedness varies with season and climate. In this largely natural landscape waterbodies are part of the matrix of the natural landscape, so they were given the same resistance as other natural features.

Roads and railroads:
The 2016 NLCD landcover data set (Yang et al. 2018) contains an embedded roads data set from the Bureau of Transportation Statistics that does not align with the newer and more accurate 2018 Tiger Road dataset (U.S. Census Bureau 2018). To correct this issue, we removed the older roads from the NLCD and replaced them with roads from the Alaska Department of Transportation. To do this, cells in the 2016 NLCD's "developed open space" class were shrunk by one pixel to remove linear road pixels but not the larger developed areas. Values for these cells were replaced with the majority value of the surrounding pixels. Next, the Alaska Department of Transportation roads (Alaska Department of Transportation 2020) were "burned in" on top of the 2016 NLCD replacing the older road data.

We assigned resistance based on the functional class of the road (Table 3.2).

Table 3.2: Resistance weight of roads.

Road Functional Class	**Resistance weight**
Interstate	20
Principal Arterial – Other	10
Minor Arterial	8
Major Collector	6
Minor Collector	4
Local	2

The main railroad in Alaska in the Alaska Railroad which stretches 470 miles from Seward to Fairbanks. Data on railroads were from the Alaska DNR (Alaska DNR 2020), and railroad tracks were given a resistance of 9.

Pipelines:
Pipelines have a moderate impact on local connectedness. In most places the pipelines are raised and studies have shown little effect on the migration routes of large mammals. In fact, roads with vehicle traffic pose a much bigger on connectedness, with impacts from collision and road noise (Coffin 2007). The pipeline dataset is from the Alaska DNR pipeline dataset (Alaska Department of Commerce, Community, and Economic Development 2020. The pipelines are anthropogenic structures, and we gave them a low to moderate resistance of a "3".

Industrial Forest:

Government policy and management of the National Forests have led to a significant decrease in logging since the 1970s. Most commercial logging in Alaska takes place in the southern coastal zone in the Tongass National Forest and Native corporation land (Resource Development Council 2020).

We used two timber datasets. The first is the USDA timber harvest dataset of timber harvests on Forest Service land (USDA Forest Service 2020). The second is industrial forest dataset is the 2012 Alaska Timber Task force (Alaska Department of Natural Resources – Division of Forestry 2012). The industrial forests got a small decrease in the resistance grid, similar to other study regions of a 1.5.

Table 3.3: Resistance scores. The land cover categories from the National Landcover Classification Database (NLCD) and supplementary data sources and the corresponding resistance scores assigned to each for assessing local connectedness in the study area.

Landscape feature	Land Cover Code (NLCD) – if applicate	Resistance Score	Source
Developed, Open Space	21	8	NLCD 2016
Developed, Low intensity	22	8	NLCD 2016
Developed, Medium Intensity	23	9	NLCD 2016
Developed, High Intensity	24	20	NLCD 2016
Barren Land, non-natural	31	10	NLCD 2016
Barren Land, natural	32	1	NLCD 2016
Deciduous Forest	41	1	NLCD 2016
Evergreen Forest	42	1	NLCD 2016
Mixed Forest	43	1	NLCD 2016
Shrub/Scrub	52	1	NLCD 2016
Grassland/Herbaceous	71	1	NLCD 2016
Hay/Pasture	81	1	NLCD 2016
Cultivated Crops	82	7	NLCD 2016
Woody Wetlands	90	1	NLCD 2016
Emergent Herbaceous Wetlands	95	1	NLCD 2016
Mines		20	The Alaska Center for Conservation Science, historic and current mining areas in Alaska
'Roads - Interstate	20		Alaska Department of Transportation

Roads - Principal Arterial Roads	10	Alaska Department of Transportation
Roads - Minor Arterial Roads	8	Alaska Department of Transportation
Roads - Major Collector	6	Alaska Department of Transportation
Roads - Minor Collector	4	Alaska Department of Transportation
Roads - Local	2	Alaska Department of Transportation
Railroads	9	Alaska DNR
Oil and gas well pad	10	Alaska Department of Natural Resources Division of Oil and Gas
Hydropower development	3	Alaska Industrial Development and Export Authority
Pipelines	3	Alaska DNR pipeline dataset
Industrial Forest	1.5	USDA timber harvest dataset, Alaska Timber Task force

Mapping Local Connectedness

Connectedness refers to the connectivity of a focal cell to its ecological neighborhood when the cell is viewed as a source (Compton et al. 2007). The analysis estimates the extent to which ecological flows outward from a cell are impeded or facilitated by the surrounding landscape. In the connectedness model, the theoretical spread of a species or process outward from a focal cell is a function of the resistance values of the neighboring cells and their distance from a focal cell out to some maximum distance.

We mapped local connectedness based on a resistant kernel model developed by Brad Compton of the University of Massachusetts (Compton et al. 2007). The first step in running the model was to convert the 30-m landcover and roads data in to a "resistance" grid by coding each land cover class with the resistant weights described above (Table 3.3). Next, we assigned a maximum distance of 3 km to the model (the default value recommended by the software developer) to represent the distance where the influence on the focal cell is zero. We implemented the resistance kernel based model by running focal statistics, neighborhood weighted kernel with center cells having more weight and less weight as you get further from the center to a maximum of three km. The map of all focal cell scores creates a continuous wall-to-wall estimate of local connectedness (Figures 3.19 and 3.20).

Figure 3.19: Examples of Four Resistant Kernel Cells shown with the Land Cover and Roads Map. The focal cell is the central point of each kernel and the spread, or size, of the kernel reflects the amount of constraints. The score for the focal cell is based on the area round the cell (i.e., the constraints) and is shown here in a bluish-purple color. Kernel A is the most constrained and has the lowest connectedness score, while D is the least constrained and has the highest connectedness score.

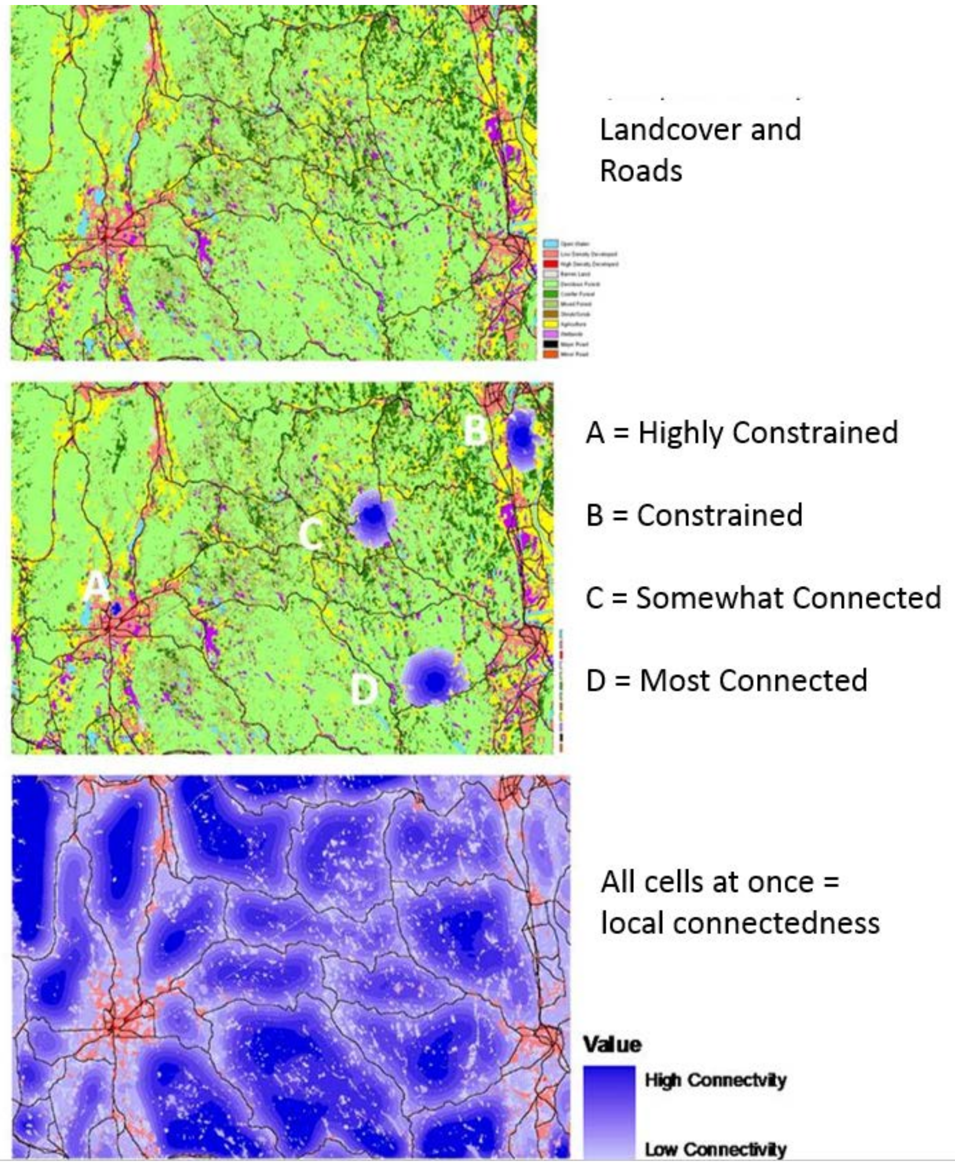
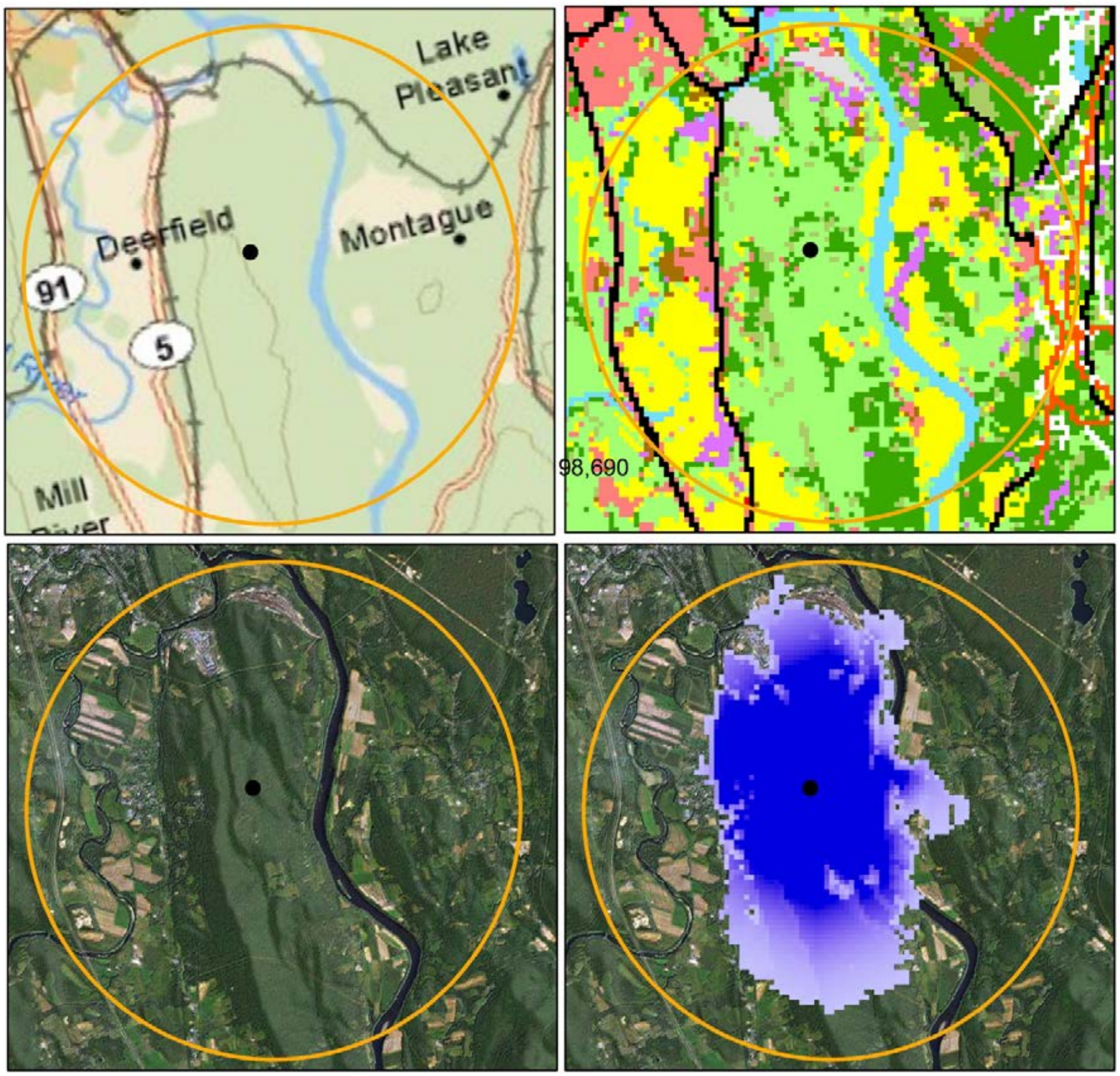
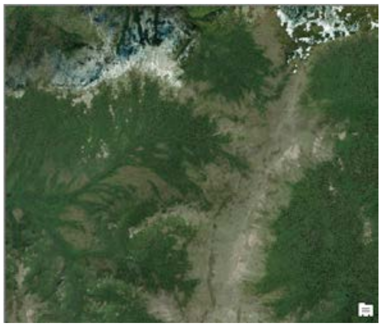


Figure 3.20: Detailed look at Kernel B in Figure 3.19. The top left image shows the topographic map. The top right image shows the land use grid details. The bottom left panel shows the aerial image with the 3-km circular resistant kernel distance outlined in orange. The bottom right box shows the kernel spread. Kernel B is constrained on the west by roads and railroads and on the east by water. The kernel can flow well through the natural landscape in the north and south direction.



The result was a grid of 30-m cells for the entire region where each cell was scored with a local connectivity value from 0 to 1. The actual scores had a mean of 0.94 and a standard deviation of 0.014 for the region. Sample areas within the study region were visually assessed to ensure that the results accurately reflect connectedness and to understand the distribution of values (Figure 3.21).

Figure 3.21: A Gallery of Satellite Images and their Corresponding Local Connectedness Scores. The resistant kernel (RK) scores and regional Z-scores are based on a roughly circular site positioned at the center of each image (not shown).



95 percent of Alaska has the highest Local Connectedness.

Slightly Above Average Local connectedness (LC = 1000) – Local Road

Average Local connectedness (LC = 0) – Timbered Land

Average Local connectedness (LC = -130) – A couple of roads

Slightly Below Average Local connectedness (LC = -1000) – Low density Oil and Gas and Rds

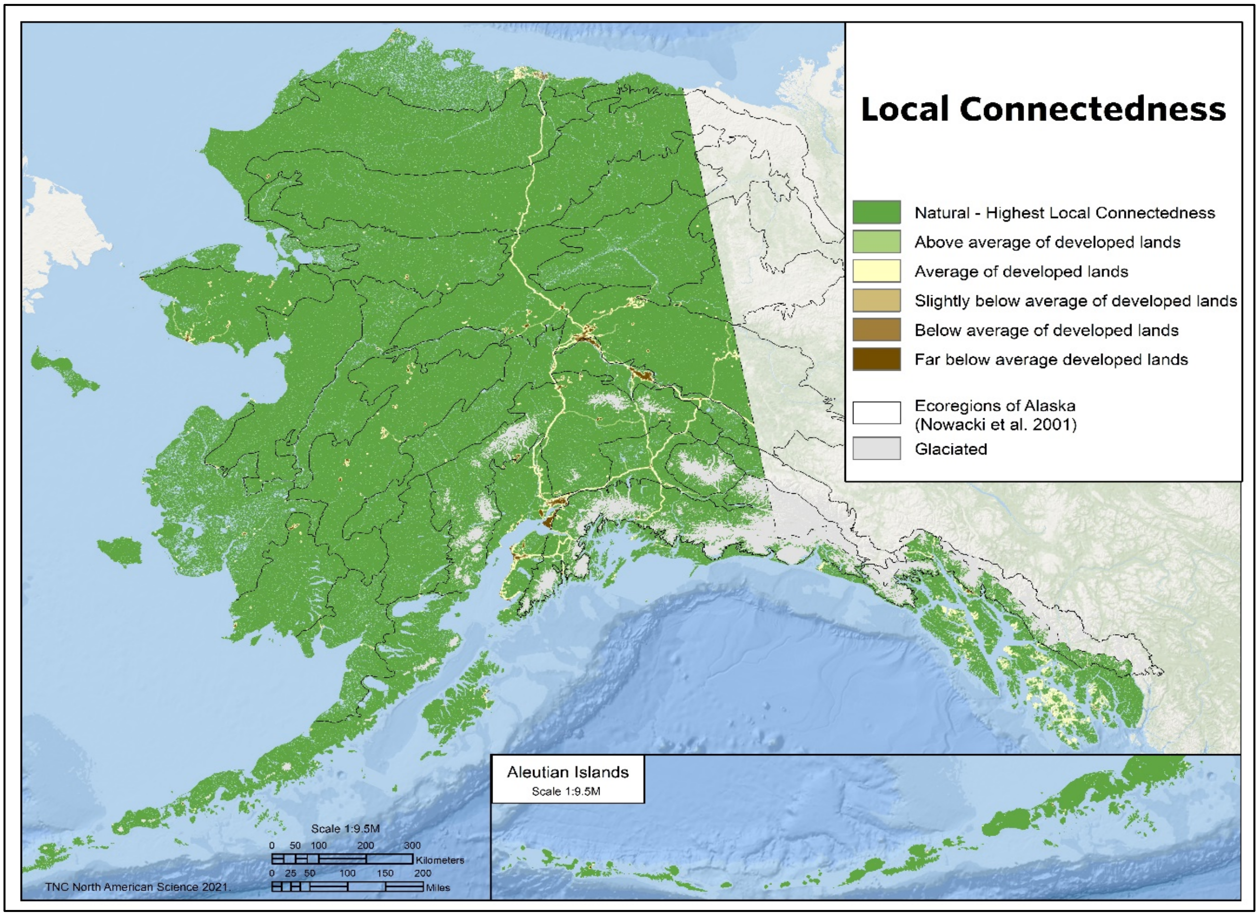
Far Below Average Local connectedness (LC = -2200) – Developed

Far Below Average Local connectedness (LC = -3500) – Current Mining

Transforming Local Connectedness Scores

Alaska is largely intact and thus the values in the Local Connectedness dataset are highly skewed towards the upper end with over 95% of the land not within 3-km of a fragmenting feature. To combine this dataset with others we transformed the scores so that all 95% were classes as "above average" (1.5 SD). Next we took the mean resistance score of 5% that have some development within 3-km and for the cells above the mean we distributed their resistant kernel value between 0 and 1.SD using an equal area method. Areas below the mean were distributed between 0 and -3500 by using an equal area method. This had the effect of preserving the dominant intact portion of the state while giving detail and weight to the areas fragmented by development, oil and gas, or other anthropogenic activities (3.22)

Figure 3.22: Local Connectedness. This map estimates the degree of connectedness of a cell with its surroundings within a 3-km radius with a custom ecoregional stratification.



Section 3: Resilience Scores

Creating a final resilience score involved the following four steps

1. Combine Landscape Diversity and Local Connectedness
2. Integrate Permafrost Persistence
3. Integrate Large Complex River Floodplains
4. Integrate Coastal Resilience

Each of these steps is briefly described below.

In the other study areas where we have mapped resilience, we sought to have the Landscape Diversity and Local Connectedness have equal weight in the final score. We aimed to do the same in Alaska, but because the local connectedness scores were so skewed towards natural, so we could not use a simple average of the two metrics. Instead, we used the landscape diversity value as our base score and use the following rules to increase or decrease the score based on local connectedness:

Local Connectedness	Adjustment
• >=1.5 SD. Completely intact natural area:	Add 0.25 SD
• 0 to 1.5 SD. Lightly modified landscape:	Increase between 0 and 0.25 SD
• 0.0 SD. Average of modified landscape:	Add 0
• -1.5 to 0.0 SD. Human altered landscape:	Decrease between 0 and 1.5 SD
• -3.5 to -1.5 SD. Highly developed landscape:	Resilience = Local Connectedness

This had the effect of letting the landscape diversity score determine the distribution of the resilience scores in 95% of the state, with the local connectedness score coming into play in and around the developed or industrial areas (Figure 3.23) Glaciated areas were not scored for resilience.

Figure 3.23: Combining Landscape Diversity and Local Connectedness. Combining Landscape Diversity and Local Connectedness yields an initial resilience score

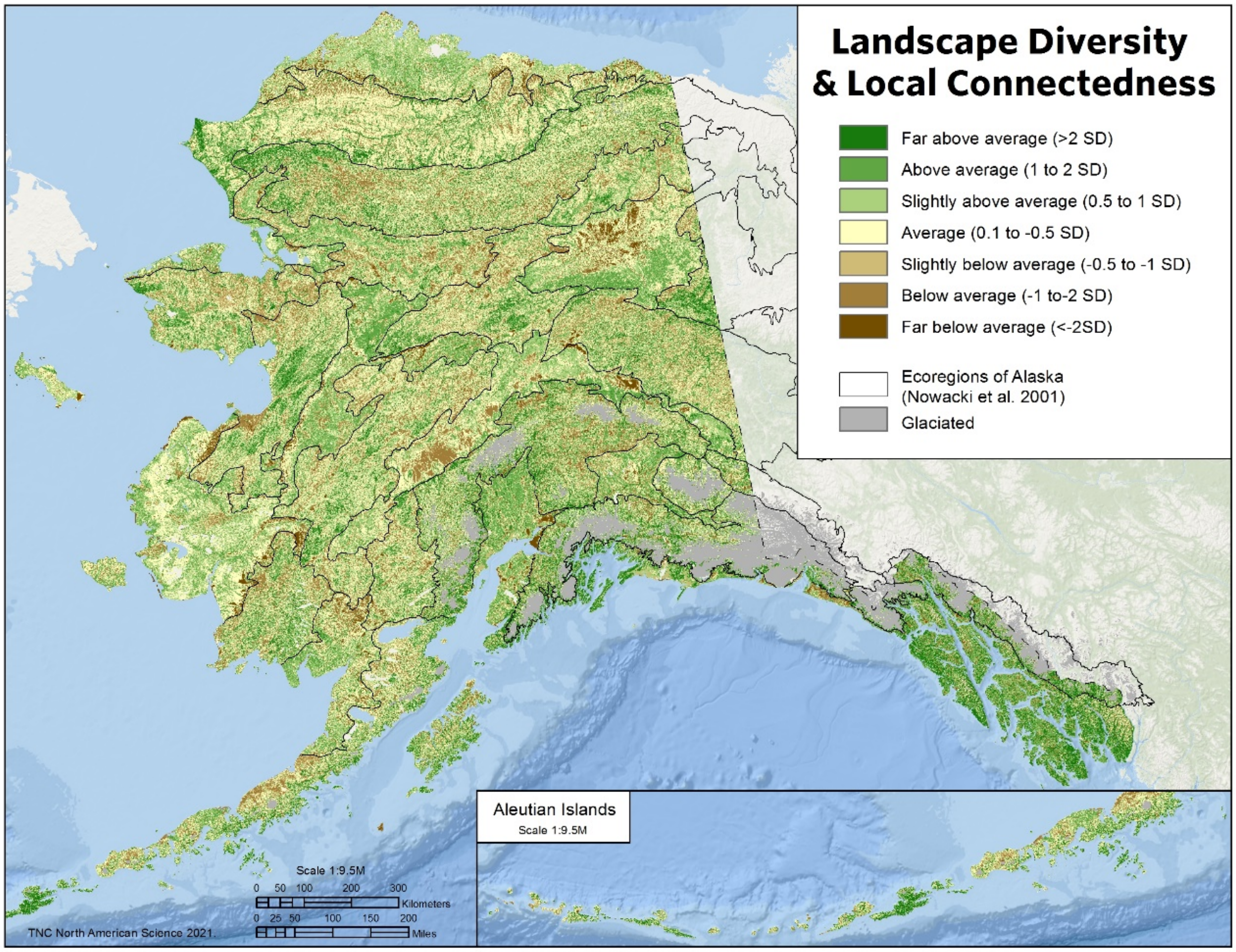


Figure 3.23 shows the relative resilience of the state based solely on micoclimates and connectedness. However, Alaska has several unique features that are expected to effect is resilience at a much larger scale: permafrost and large complex floodplain systems. We addressed these features at the scale of the whole state using the methods described below.

Permafrost

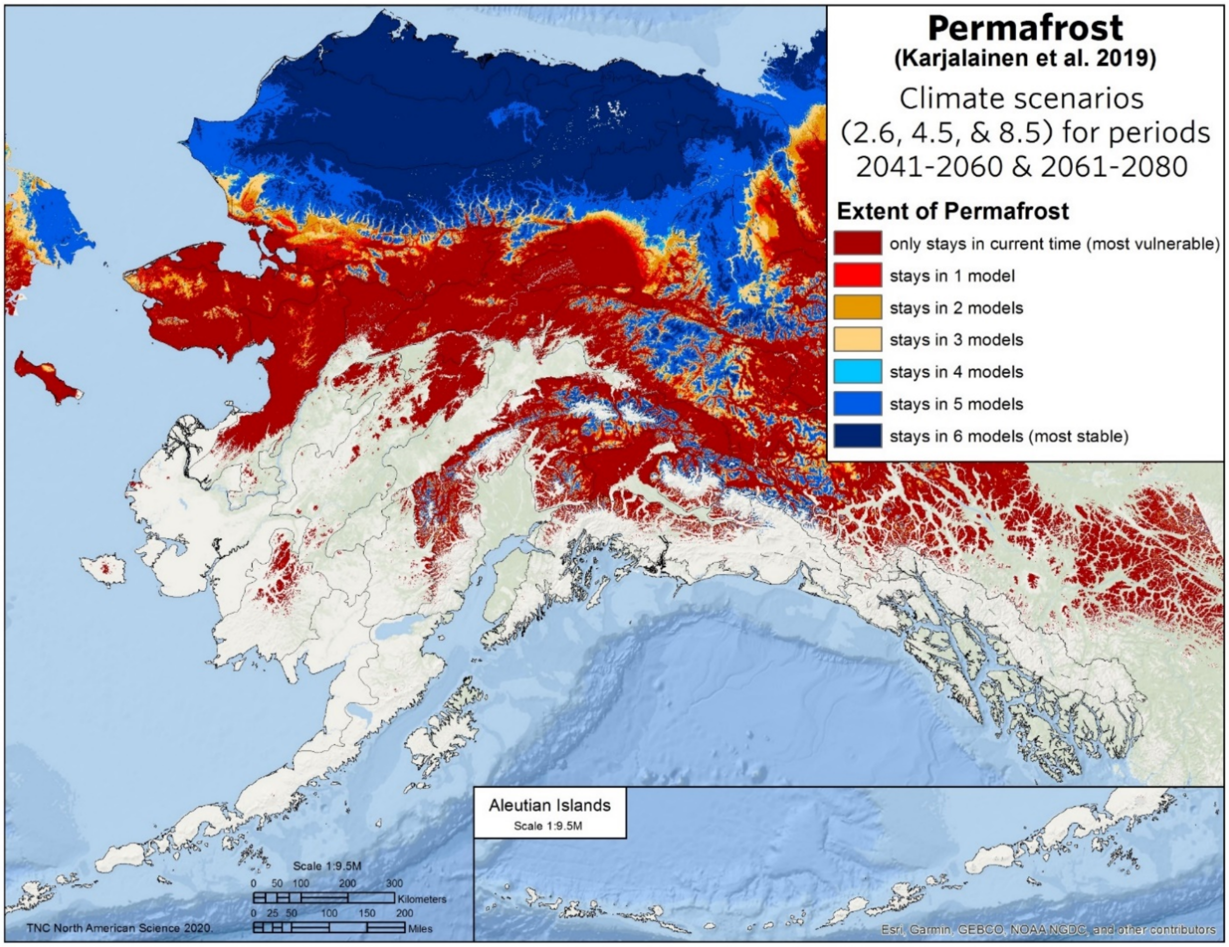
Permafrost is ground that remains frozen year after year. Made up of soil and rocks as well as frozen water, permafrost forms when the depth of winter freezing exceeds the depth of summer thawing. Permafrost is found to some extent beneath nearly 85 percent of Alaska (https://www.alaskacenters.gov/explore/attractions/permafrost). For example, in Fairbanks, Alaska, the soil is frozen just some 30 to 40 centimeters below the surface, while on the Alaskan Arctic Plain, permafrost is up to 650 meters thick.

Permafrost influences the extent and distribution of many ecological communities of Alaska (Boggs et al. 2019). For example, many of the grasses, flowers, and berries of the arctic tundra owe their existence to the presence of permafrost. With only a few inches of precipitation a year, arctic Alaska could be expected to be barren desert, but the little rainfall and snowmelt cannot percolate or drain off given subsurface permafrost. Instead, water collects at surface, providing moisture to nourish plants which in turn, insulate the permafrost beneath from thawing by sealing out the warm temperatures and sunlight of summer.

If the arctic continues to warm as quickly as climatologists are predict, an estimated 2.5 million square miles of permafrost, 40 percent of the world's total, could disappear by the end of the century (Karjalainen et al. 2019). When permafrost degrades (melts), waterlogged ground becomes soft and collapses triggering landslides and slumping with impacts on drainage, ground water, river runoffs, ecological systems, human infrastructure, and release of carbon that has been sequestered in the frozen soil, and human infrastructure.

Karjalainen et al. 2019 developed statistical models to predict ground temperature and the thickness of the seasonally thawed layer based on geospatial environmental data. These predictions were used to map permafrost extent at 30 arc-second resolution for 6 climate scenarios: 2041-2060 (Pathways 2.6, 4.5, 8.5) and 2061-2080 (Pathways 2.6, 4.5, 8.5). By overlaying the 6 scenario results and current permafrost extent, we determine which areas of Alaska are most likely to lose permafrost (Figure 3.24).

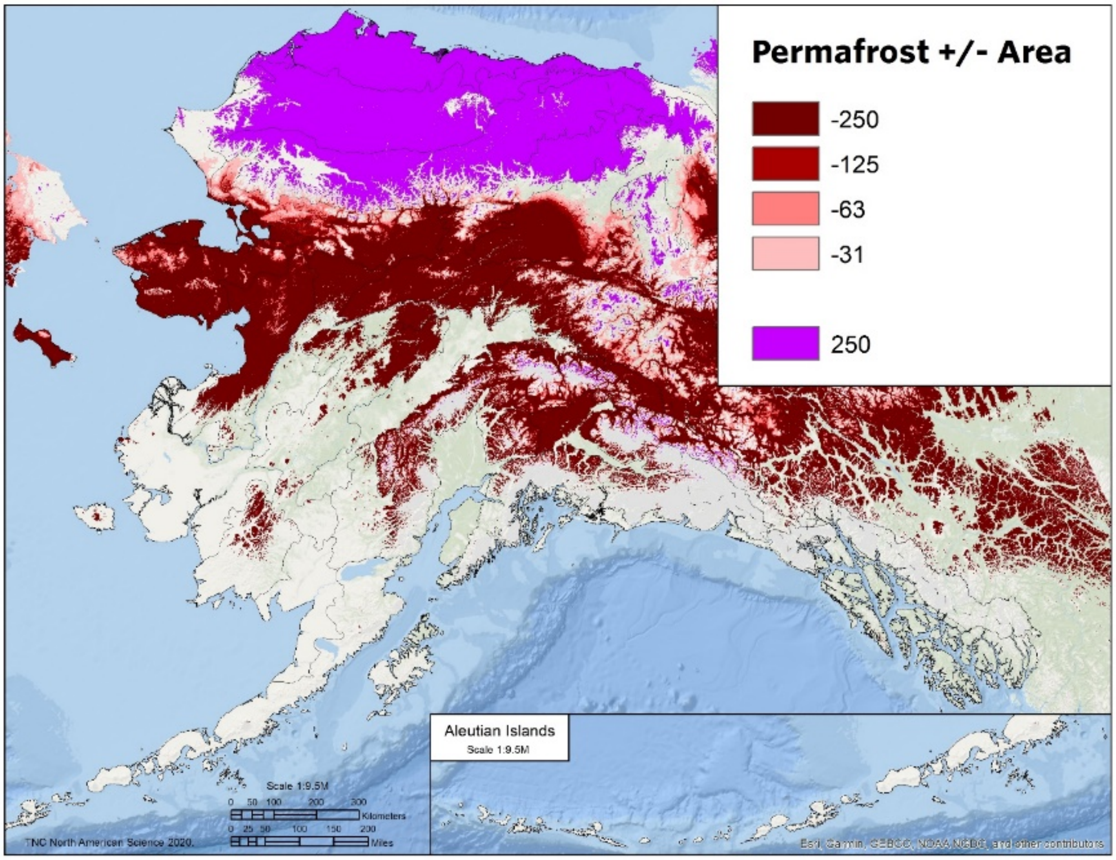
Figure 3.24: Permafrost Extent. Current and future projected extent of permafrost (Karjalainen et al. 2019)



Areas where permafrost is projected to disappear in many or most models would be areas of high landscape change and disturbance to the natural ecosystems. Our steering committee agreed after considerable discussion that these areas should get a small proportional decrease in their resilience score because they are unstable, while at the same time areas of permafrost refuge where permafrost is projected to be retained in all 6 models should have a small increase in resilience score. We implemented this adjustment to resilience score as follows

- Permafrost stays in all 6 models = increase +0.25 SD,
- Permafrost disappears in all 6 models = decrease - 0.25 SD,
- Permafrost disappears in 5 models = decrease -0.125 SD,
- Permafrost disappears in 4 models = decrease -0.063 SD,
- Permafrost disappears in 3 models = decrease -0.031 SD
- Permafrost disappears in 0, 1 or 2 models = no adjustment

Figure 3.25: Permafrost Resilience Score Adjustment. Areas where the score was increased (purple, 0.25 SD) to reflect stabiity or decreased (red, 0.03-0.25 SD) to effect likely transitions in permafrost. The remaining area is already permafrost free.



Large Complex River Floodplains

Floodplains provide a dynamic and critical habitat where terrestrial and aquatic processes interact to support water recharge, floodwater retention, nutrient cycling, sedimentation control, provide habitat for unique floodplain natural communities, and serve as migration corridors for many terrestrial species. In Alaska, where nutrients limit ecosystem productivity, the exchange of nutrients in floodplains from carnivores feeding on salmon also drives the entire larger ecosystem productivity (Shanley per com, 2021). Additionally, the value of these floodplains to juvenile salmon production and sustainability has been repeatedly documented (Whited et al. 2012, 2013), and highlighted how floodplain access and sinuosity can positively influence survival.

One landscape metric of floodplain structure, node-complexity, has been shown to have a very strong relationship to successful juvenile salmon production (Whited et al. 2012, 2013). This metric documents a "node" whenever a side-channel or tributary enters the main river channel and more "nodes/km" indicates a more complex channel arrangement per main river length. These highly complex channel arrangements are often found in low relief wide floodplains with many braided streams and intertwining side channels.

Floodplain patches mapped by Whited et al. 2013 had been attributed with node-complexity as part of a previous research project and the author (Diane Whited pers. comm 2020) recommended we use this variable to score and extract the most resilient and high biological value floodplains (Figure 3.26). This seemed fortuitous, as node complexity, being a physical metric likely to persist into the future, fit well with the concept of site resilience.

To apply it, we Z-scored the floodplains on the "node complexity" within three regions of Alaska which was a stratification we had developed in the elevation range analysis to group similar ecoregions into a set of lowland, hill, or mountainous ecoregions. The floodplain patches scoring >.5 SD above average within their stratification region were then extracted. The resilience score of these areas was then increased from between 0.5 SD to a maximum 1.5 SD, with the scores spread proportionally across the original Z score of the patches >0.5-3 SD above average (Figure 3.27).

Although small areas of floodplains were already emerging as above average resilient from our initial combination of landscape diversity and local connectedness, these were limited to small areas that had a high density of wetlands and/or floodplains in more narrow valleys where our landform variety picked up the valley wall and many local landform changes in that small distance. Many of the widest and largest floodplains in extensive flat unconfined valleys were scored average to below average because they lacked topographic variability or large areas of mapped wetlands. The node-complexity metric provided a way to account for the resilience of these sinous linear systems.

Figure 3.26: Floodplain Areas by Node-Complexity.

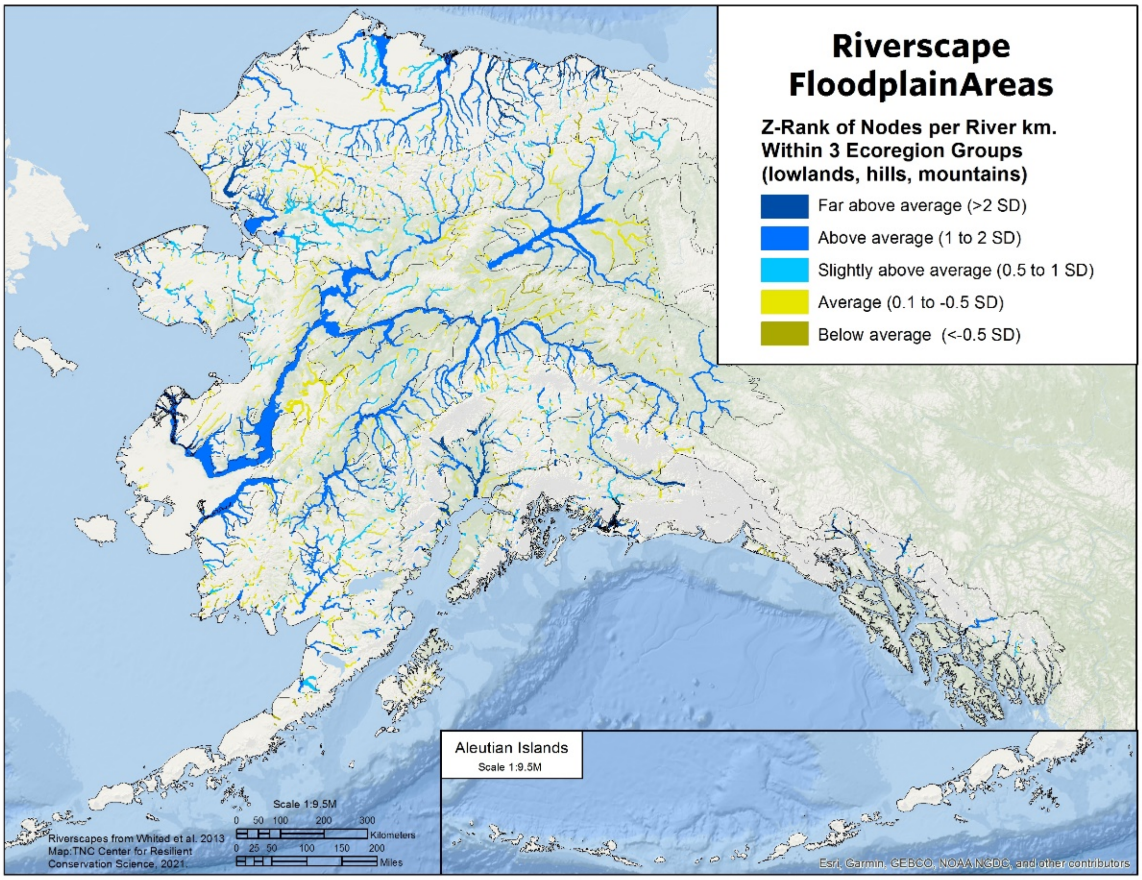
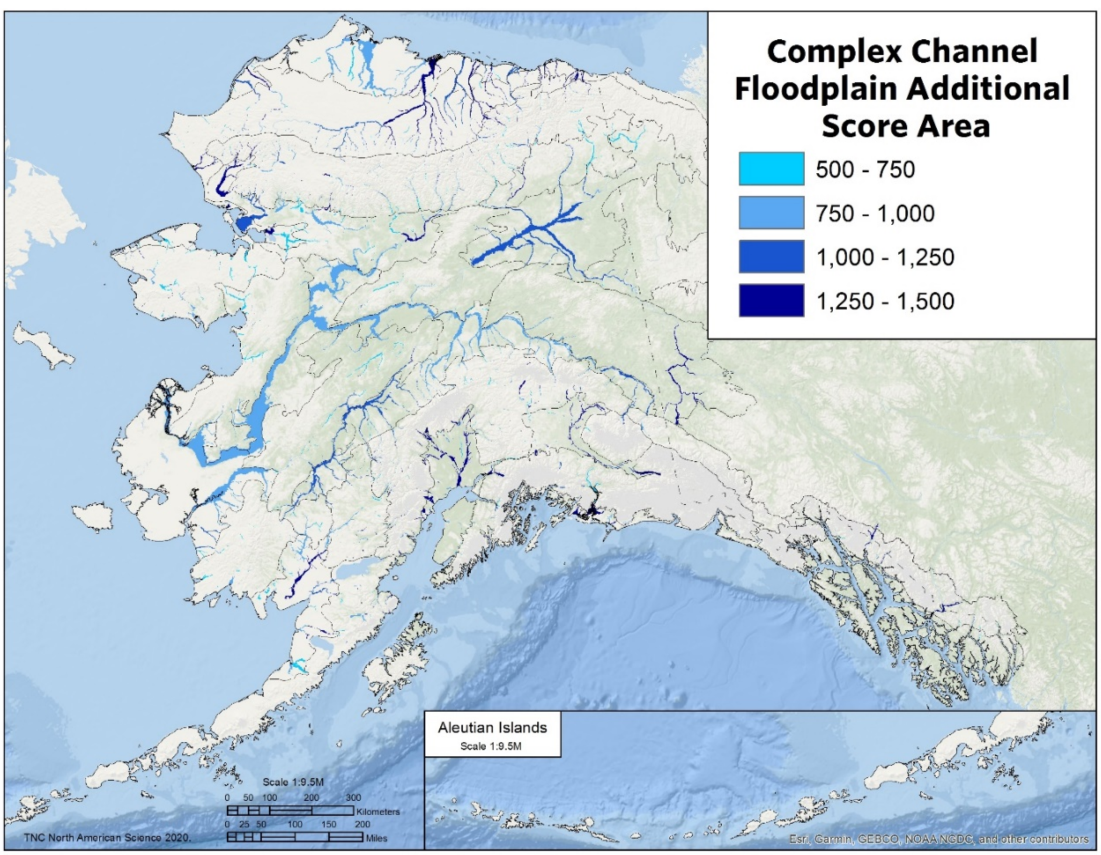
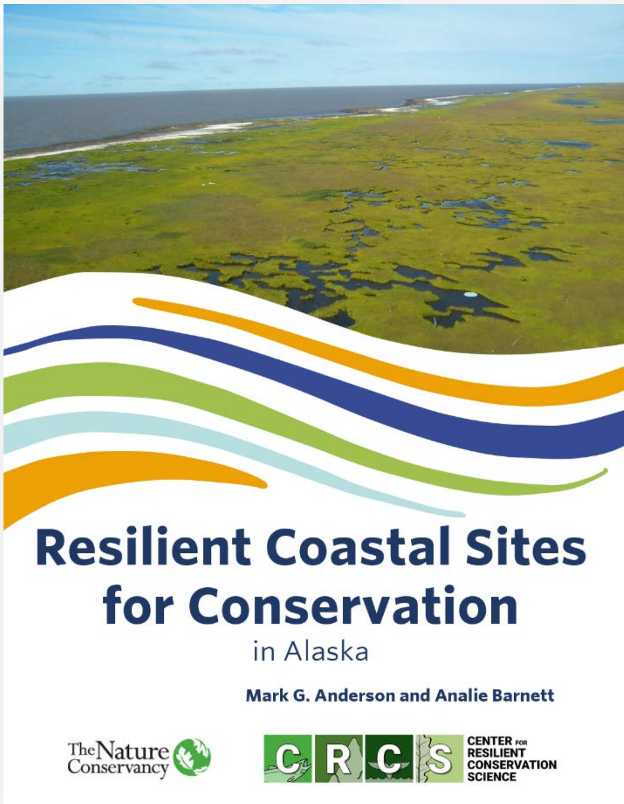


Figure 3.27: Floodplain Area Resilience Adjustment. This shows where the resilience score was increased due to the node complexity of the floodplain.



Coastal Resilience



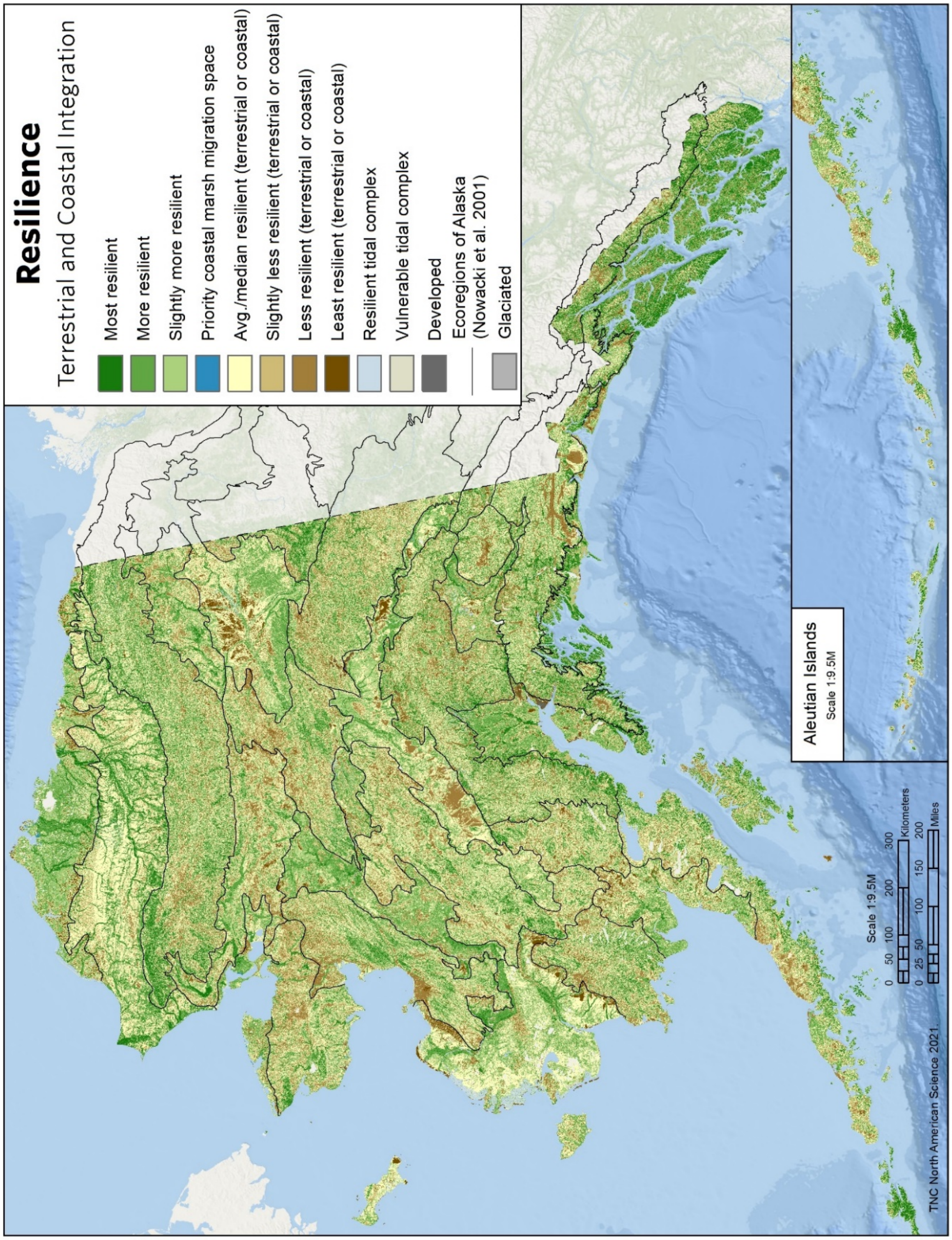
Read the report at:

nature.org/AKcoast

As part of this project, we performed a separate analysis on the resilience of coastal systems subject to sea level rise. The analysis looks at each tidal complex a determines if it has suitable adjacent area to migrate into and whether the processes are in place to likely facilitate that migration under various sea level rise scenarios. Of course, Alaska has unique challenges in that some shorelines are eroding while other are rising. We recommend interested user read the report for details (Anderson and Barnett 2022).

One of the products of the resilient coastal site analysis is a resilience score for every tidal complex as well as for its adjacent migration space. Migration space areas associated with an above average scoring tidal complex were incorporated into the final resilience map as an override on cells on the coast. These indicate areas important to conserve for coastal resilience (Figure 3.28).

Figure 3.28: Resilience Score with Adjustments for Unique Systems. The resilience score with adjustments for permafrost, large complex river floodplains, freshwater resilience values, and coastal resilience.



REGIONAL AND SUBREGIONAL RESULTS

CHAPTER 4

Results Overview

Based on our assumptions, concepts, and methods, 54% of the state of Alaska scores high for site resilience (Figure 4.1, Table 4.1). That is significantly more than the average for the conterminous US (34%) but in the same ballpark as some mountainous states like Colorado and Wyoming. The four Zoom-in maps (Figure 4.2-4.5) provide a closer look as each region of the state, and a link to a web-based map explorer is provided near the end of the chapter. As described in Chapter 1, site resilience is defined as "the capacity of a site to adapt to climate change while maintaining biological diversity and ecological function" (following Anderson et al. 2014b), suggesting that while many changes are certain to occur within the state due to the changing climate, there are many areas where species are likely to persist or where the change may be more gradual than expected from the rate of regional climate change

As with all the resilient site assessments, we use these ecoregions and geophysical settings as stratification factors. Therefore, scores across ecoregions and settings are not directly comparable.

Table 4.1: Regional Site Resilience. Acres and percent by resilience category.

Resilience Category	Acres	Percent
Far above average (> 2 SD)	28,412,817	7%
Above average (1 to 2 SD)	121,553,169	30%
Slightly above average (0.5 SD to 1 SD)	68,042,262	17%
Average (0.5 SD to -0.5 SD)	93,440,962	23%
Slightly below average (-0.5 SD to -1 SD)	48,733,954	12%
Below average (-1 SD to -2 SD)	26,130,547	7%
Far below average (<-2 SD	9,837,810	2%
Developed	2,167,342	1%
Water	2,611,420	1%
Grand Total	400,930,282	100%

Figure 4.1: Final Regional Site Resilience Map. Areas in green score above average and are estimated to be more resilient to climate change relative to comparable geophysical settings in the same ecoregion. Areas in brown are below average and are considered more vulnerable to climate change.

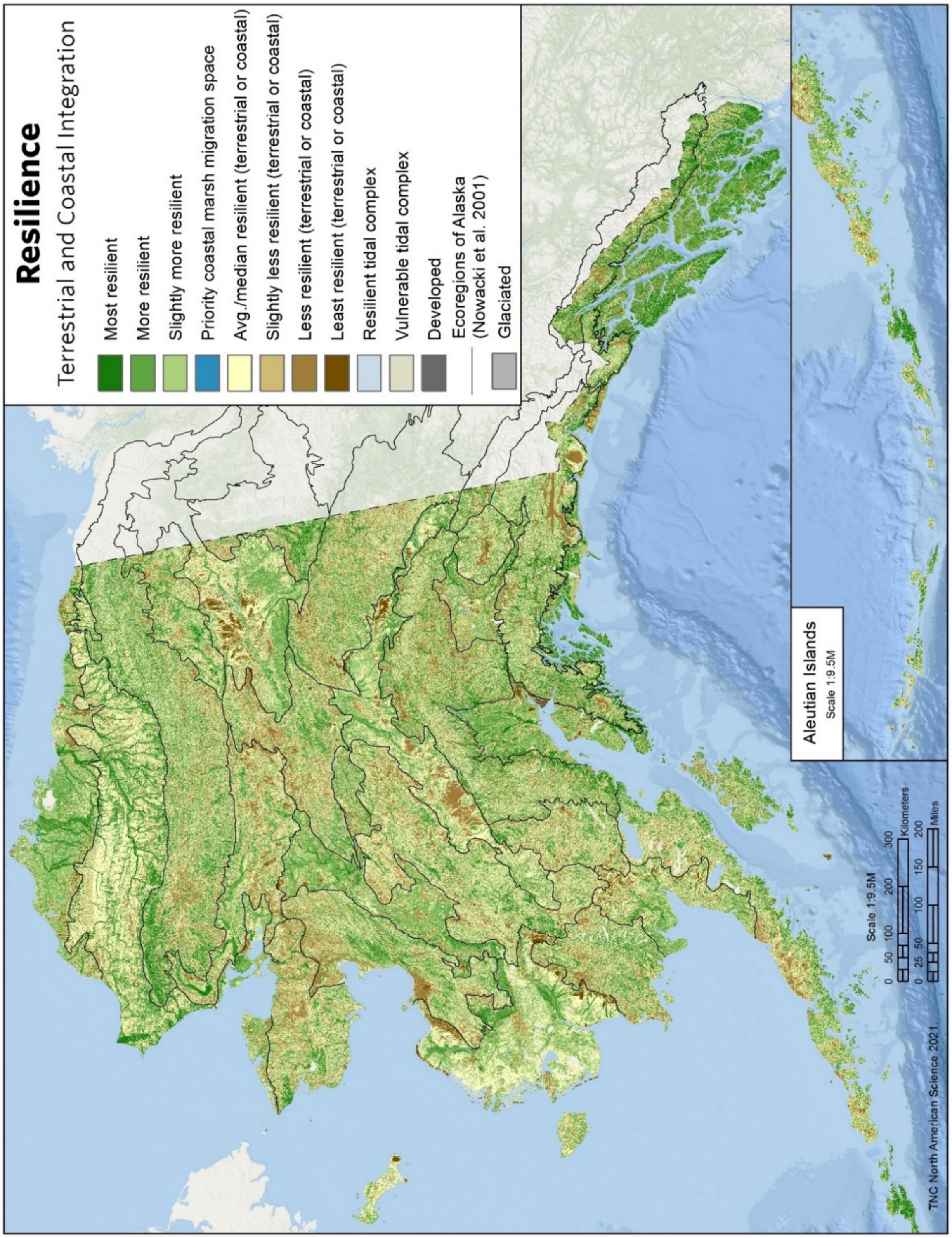


Figure 4.2: Zoom-in of Pacific Alaska Ecoregions: Final Regional Site Resilience Map.

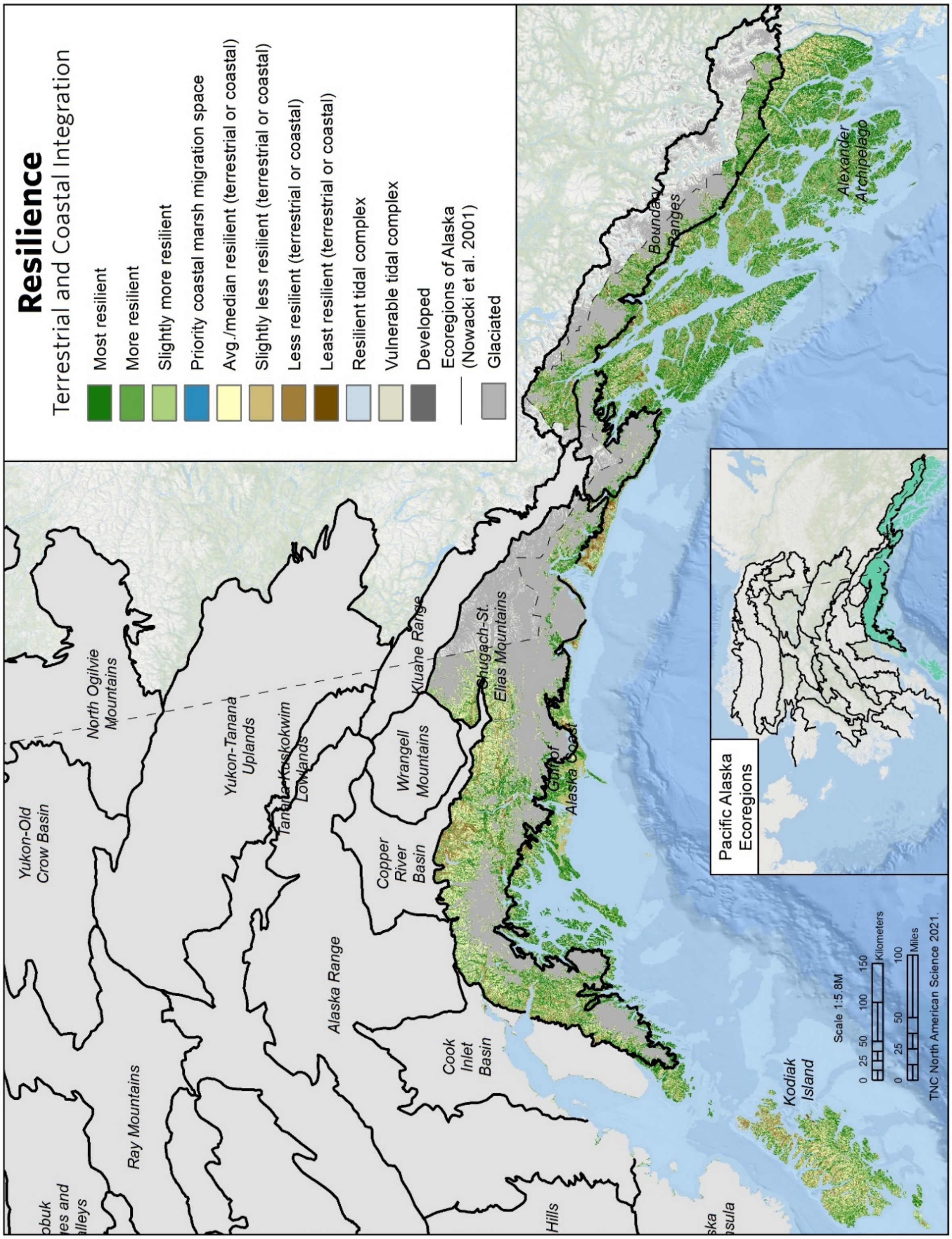


Figure 4.3: Zoom-in of Boreal Alaska Ecoregions: Final Regional Site Resilience Map.

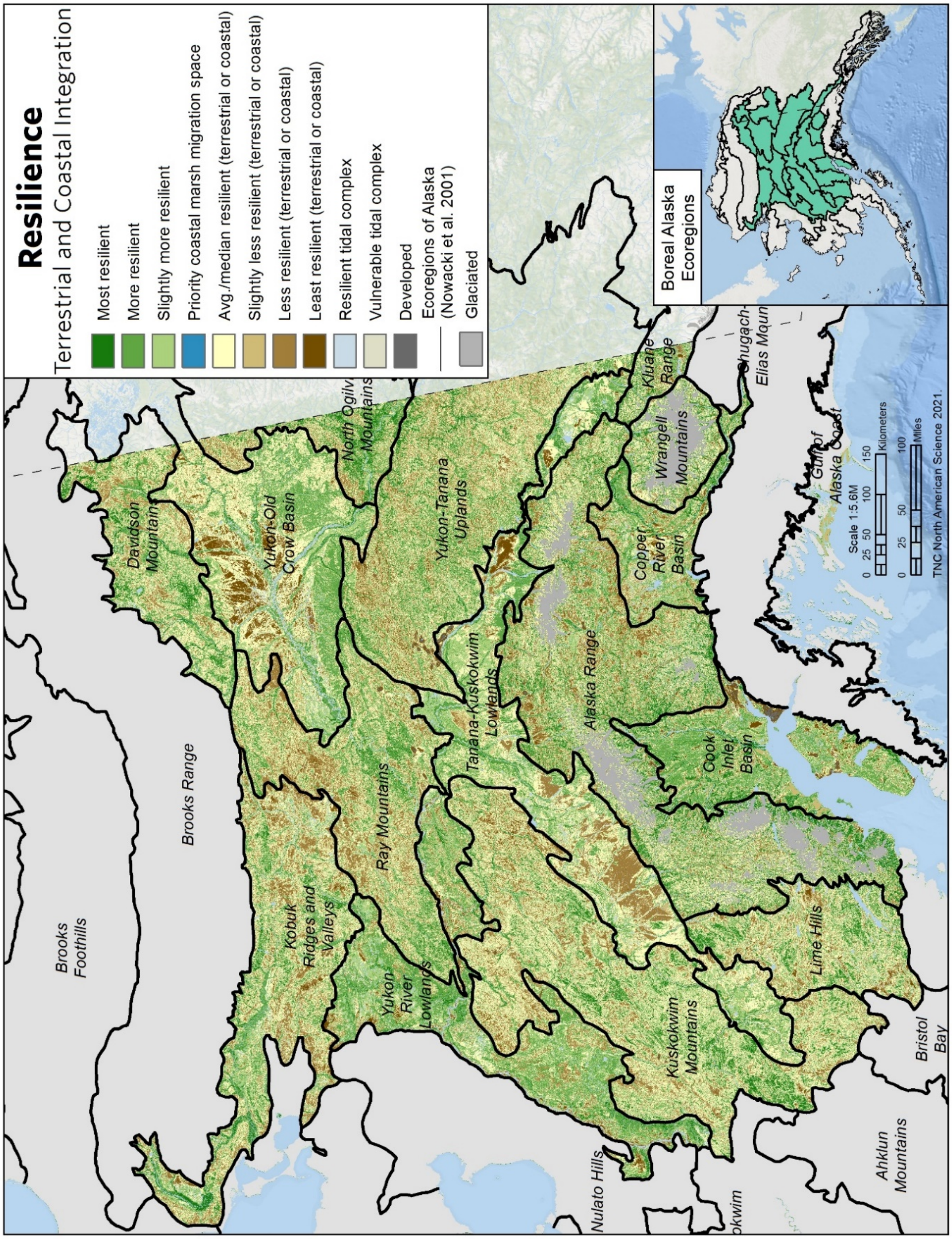


Figure 4.4: Zoom-in of Beringian Alaska Ecoregions: Final Regional Site Resilience Map

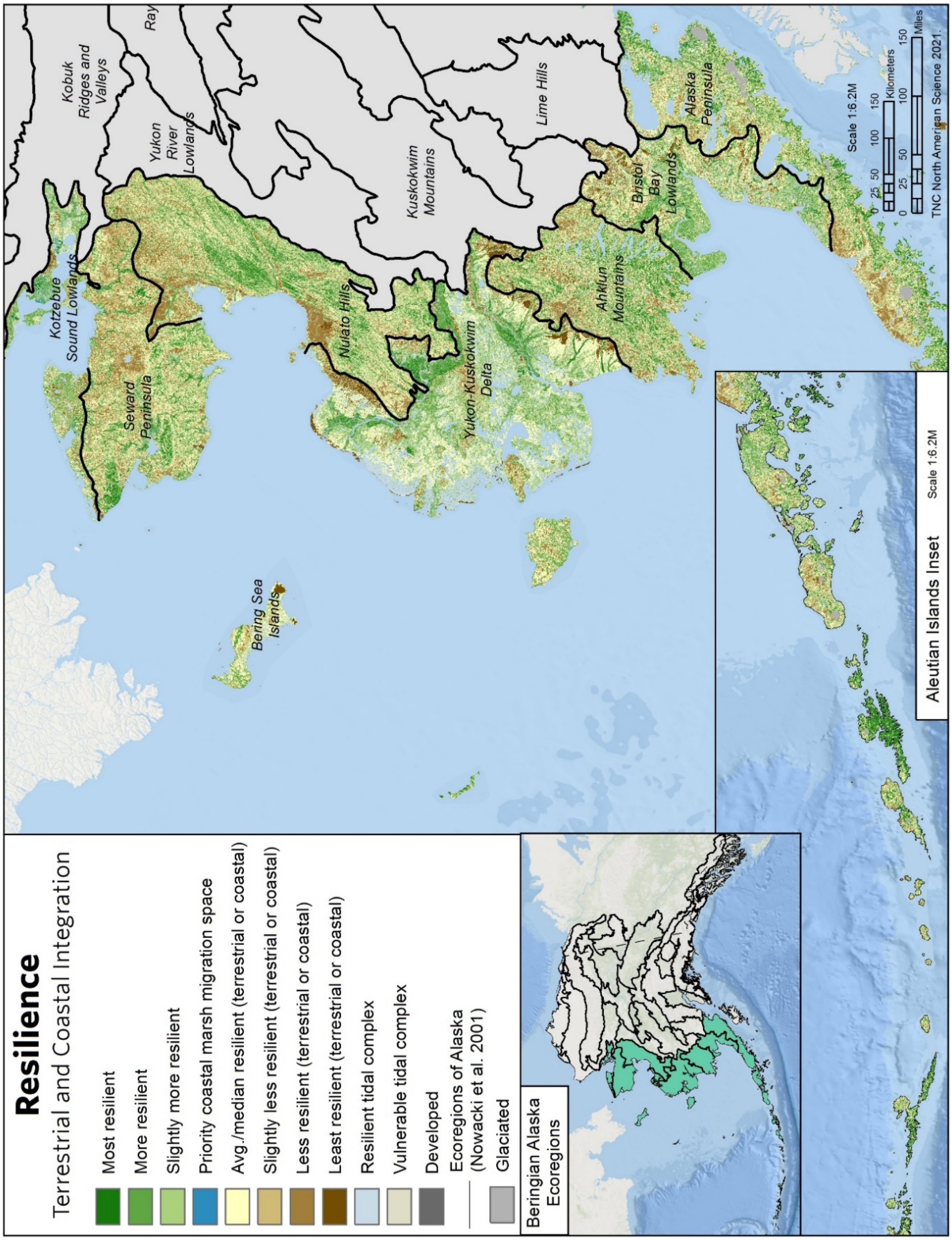
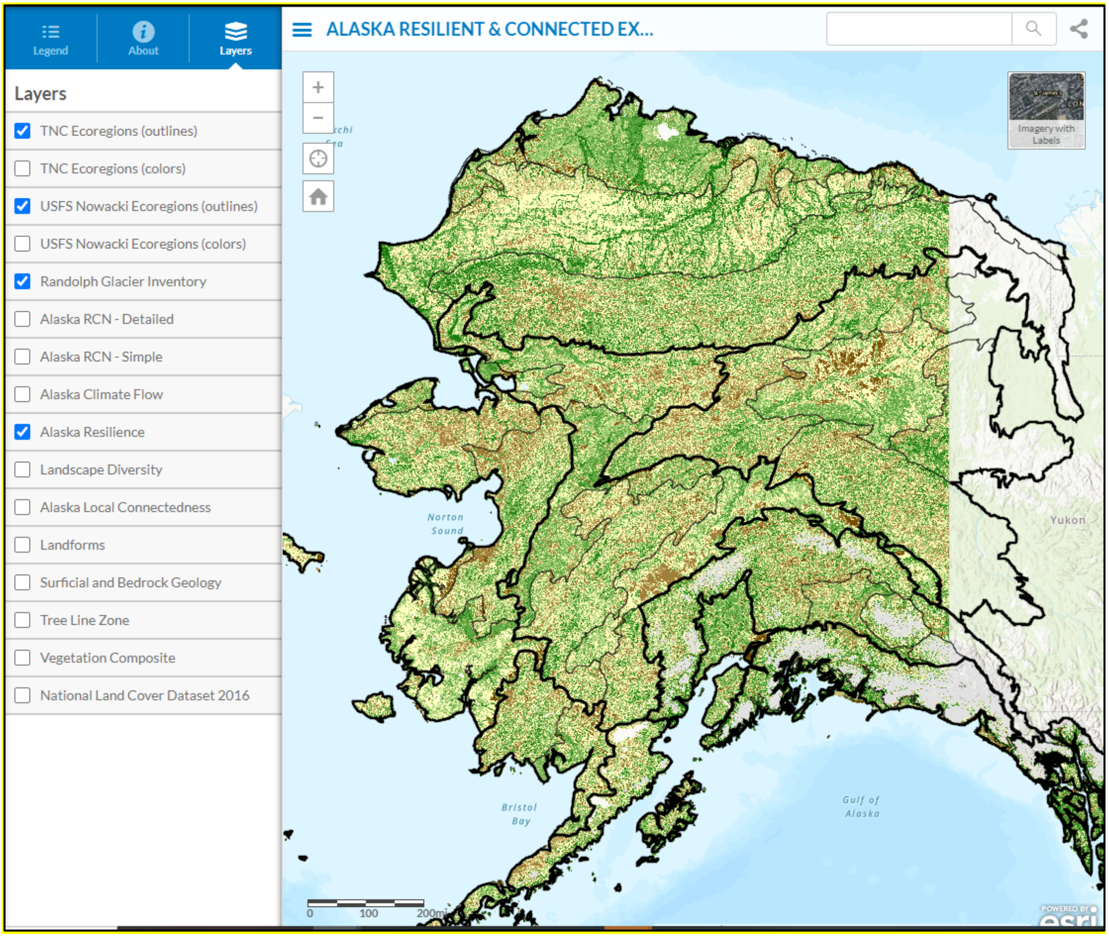


Figure 4.5: Zoom-in of Artic Alaska Ecoregions: Final Regional Site Resilience Map

Resilient and Connected Network Data Explorer

To exam the components in more detail, we created an "Alaska Resilient and Connected Network Data Explorer" (https://tnc.maps.arcgis.com/apps/PublicInformation/index.html?appid=f3d1938217614a9c876bff4f3365a6f3).

Figure 4.6. Alaska Resilient and Connected Data Explorer



Resilient Land Mapping Tool

The Alaska Resilience data will be added to the Resilient Land Mapping tool. The tool (http://maps.tnc.org/resilientland) allows non-profits, communities, and policy makers to view the resilience results and use basic analytic tools to understand the resilience patterns and assess specific areas.

CHAPTER

DISCUSSION 5

Resilience and Vulnerability

Our goal was to identify sites within each ecoregion, that have accessible, connected climate options benefiting many species under many possible climate scenarios, and not to predict species responses to a particular climate change scenario. The biota is not expected to be static. Over time, these sites will be exposed to shifts in climate patterns, which in turn are likely to promote changes in species composition and shifts in key functions and ecological processes. As these responses occur, we expect that these more complex and connected sites will sustain higher levels of biological diversity and ecological function.

Coarse-scale climate models were not used in this study, but they can provide useful estimates of the directional changes in temperature, and project future changes in precipitation and related variables like evaporative demand, albeit with high levels of uncertainty. These projections, however, are at a much coarser scale than the 30-m cells (1.2 square miles) used in this study. For example, mapped climate projection are often at 100-km grid cell (39 square miles) and we would expect to see a wide range of local moisture and temperature conditions within the cell due to the shape of the land, and characteristics of the soil and dominant vegetation (see full discussion in Chapter 3). These landscape and vegetation-based variations can be relatively uncoupled from regional averages in climate, and often much larger in variance. For example, ten bogs in Adirondack Park NY (a region of relatively low relief) were estimated to have an average of 128 growing season days based on PRISM 100-km climate models, but in-situ temperature loggers found them to be much cooler and more variable ranging from 20 growing season days to 130 with an average of 73 ± 33 (Langdon in prep).

Our focus was on mapping the most persistent drivers of the local variation, the landscape characteristics. Admittedly, we cannot predict the biotic responses of species nor the interactions between species, but by identifying and conserving sites with characteristics that increase options for species and communities to adapt, we can help set the stage for nature to remain resilient.

In this study, resilience to climate change and its converse, vulnerability to climate change, are relative concepts for which we do not have absolute thresholds. We defined a resilient site as one with more of the characteristics (microclimatic buffering and connectedness) that maintain species and functions than the average site in the ecoregion. We expect that these sites will support an array of specialist and generalist species, even as the species composition and ecological processes change. In contrast, a vulnerable site was defined as one where natural connectivity is disrupted and fragmented, and there are limited options for species to shift to a more suitable microsite as the regional climate changes.
Vulnerable sites may be quite important in terms of current biodiversity values, but they will likely need more management to retain those values. At a regional scale, vulnerable sites may be more likely than resilient sites to show a net loss of biological

diversity over time, as resident species are lost, and opportunistic species adapted to high levels of disturbances and anthropogenic degradation increase. Correlative evidence to support this was found in the Northeast where high-scoring resilient sites contained significantly more of the known biodiversity locations (including 75% of the ecoregional target species) and low-scoring vulnerable sites contained significantly less ($p < 0.0001$, Anderson et al. 2014a).

Climate change is expected to greatly exacerbate the degradation of vulnerable sites, through multiple mechanisms, including the dominance of generalist species described above. However, to the extent that a site retains natural forms of landcover, it will likely continue to perform many natural services, such as contributing to cleaner air, sequestering carbon, providing wildlife habitat and recreational opportunities, and filtering water. Vulnerable sites may have much value, but relative to other comparable sites they are places where the impact of climate change may be felt most severely, and where it may be most difficult to sustain the full suite of natural functions and species diversity that could occur on the site over time.

Our emphasis on enduring land characteristics that influence the distribution of the biota and their sustaining resources implies a long-term perspective. These tools are thus well-suited for informing choices on where to invest in land protection or implement restoration strategies. They can also help inform site-scale adaptation strategies where variation in a site's resilience factors suggest higher or lower vulnerability, which can be addressed through specific management tactics and monitoring plans. Further, the maps and assessments in this report allowed us to see the sites and landscapes we seek to protect through a new lens, expanding our focus from the many readily-apparent drivers of current species loss to envisioning how we can help nature adjust to a rapidly changing world - with a goal of sustaining a dynamic and diverse natural world capable of adapting to continued climate change.

We place a considerable emphasis on the role of microclimates in sustaining local biodiversity, the evidence for which is substantial and growing (Chapter 3). Understanding microclimates, topoclimates and climatic microrefugia is an active field of research, and some suggest it may revolutionize climate change biology (Hannah et al. 2014). Species populations use microclimates in multiple ways: to persist for a limited time under deteriorating climatic conditions (holdouts), to facilitate range shifts (stepping-stones) or to persist through a long period of unfavorable climates (microrefugia). Conservation strategies built around holdouts and stepping-stones make logical sense under a rapidly changing climate (Hannah et al. 2014), although microrefugia have clearly played a needed role in past climatic events (Rull 2009, Keppel and Wardell-Johnson 2015). From the perspective of sites, areas with high microclimate diversity may serve all these functions, but more studies quantifying the climatic differences among microclimates, and how species exploit these differences, would greatly improve our ability to predict site resilience.

Current research is also reinforcing the value of connectivity in facilitating adaptation and has strong historical evidence and widespread agreement among the scientific community (Chapter 3). Improving the local connectedness of a site is an achievable strategy in many places, and much more feasible than increasing topographic diversity at a meaningful scale. The final maps and datasets of local connectedness and landscape diversity may prove useful for conservationists investigating the independent influence of each of these factors on a site. For example, users of this analysis can identify places where increasing local connectivity could significantly improve the current resilience score or areas where the resilience score is more limited by the inherent low landscape diversity.

It is worth repeating that this study does not predict what the future will look like in terms of vegetation structure or species composition. The places identified will likely be important strongholds for diversity in the future because of their enduring geophysical characteristics, and they can provide the framework for a network of conservation lands aimed at sustaining diversity and ecological services. However, sustaining the natural diversity of this region will require many other actions, and elements of this work may help inform a variety of current conservation activities. For example, land managers seeking to prioritize areas for restoration could use the resilience and landscape diversity maps to determine what areas would be most likely to benefit from increased connectivity, or where these activities could favor potential grassland expansion into more topographically diverse areas.

With the help of our steering committee, we tried to make our analysis as transparent, consistent, and verifiable as possible. However, we necessarily approached site resilience as a relative concept because there are no known absolute thresholds. Due to our practice of presenting relative scores, a "high resilience" site in the more converted ecoregion may be less resilient and need more management than a site with an equivalent score in a very intact ecoregion. .

As with previous studies in other geographies we found a high correspondence between sites identified for climate resilience based on their geophysical characteristics and those selected for the high quality of their biodiversity features. This makes sense and was reassuring, but we recognize that there are still many uncertainties with respect to how any system will respond to climate. We have received extensive feedback on previous versions of this analysis in the lower 48 states, and most of it came from conservationists thoughtfully applying the results to places that they knew well. This ground testing has largely confirmed the patterns we were finding, but it also revealed important ecological variations that we had missed, or problems in the datasets. We expect that the relative role of site-based factors like those we have mapped here will vary geographically, especially in comparison to the inherent capacity of current ecosystems to persist as climate changes.

We tried our best to incorporate all the good suggestions from our steering committee into this latest study, but certainly there will still be discrepancies and areas for improvement. Our intention is to continue to work with our steering committee members to develop additional outreach products and examples that facilitate exploration of these rich data products, and we encourage feedback and suggestions from our peers on how we can continue to improve the approach and can correct specific problems

DATA SOURCES

This section lists spatial datasets and their source documentation. Other reference materials are listed in the Literature Cited section at the end of the report.

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CHAPTER
6

A RESILIENT AND CONNECTED NETWORK

In the second half of this report we describe our methods to map a resilient and connected network of sites that, if conserved, could sustain biological diversity and ecosystem services while allowing species to move and adapt to change.

In previous chapters, we describe how we mapped sites across the study area and identified the ones with the most microclimates and the highest local connectedness (i.e., the most resilient sites) with respect to ecoregion and setting. In the next four chapters we describe how we expanded on the site resilience analysis to look at connections between sites, and at the habitats, populations and communities that currently inhabit the sites. We use this information to construct a network.

We defined resilient sites as places more likely to maintain biological diversity and ecological function as the climate changes. These "biodiversity strongholds" are more variable in topography, and more locally connected by natural landcover, than other sites with similar soils/underlying bedrock. By identifying resilient sites across all types of bedrock and soil in a region, we hoped to create a blueprint for conserving ecosystem health over the long term, even as the specific character, species assemblages, and ecosystem structure at those sites changes over time. A map of resilient sites that represent the full range of geophysical settings can guide our investments in protection and management and increase the odds that plants and wildlife will be able to find sites that meet their requirements as conditions change.

By itself, conserving the resilient sites would go a long way towards sustaining the biological diversity of the study region, but it is not enough. If nature thrives in these sites, then the inhabitants (trees to salamanders) will produce offspring and these offspring will disperse to find new resilient sites to establish in, and over time the landscape will change. The objective of our network is to facilitate these dynamics, to ensure that plants and animals are thriving, to ensure that the landscape remains permeable to movement, and to ensure that dispersing species have a place to go.

This has happened before. In past eras of climate change, plants and animals shifted their distributions by colonizing and establishing in new territory, finding suitable microclimates that allowed them to persist and producing offspring to continue the process. The problem is that this takes time – generations - but the climate is changing faster than at any time in recorded history, and the landscape is fragmented by roads, intensive agriculture, dams, development, and other barriers to movement. The idea of conserving moving targets, and sustaining the capacity for adaptation in place, requires that we update our thinking about where to invest in land protection.

Sustaining biological diversity and ecological processes across the region is more likely if the resilient sites are embedded in a larger network of connected natural areas that allow for dispersal and movement between sites. In the next sections of this report, we examine the pattern of land use and barriers across the landscape, and we evaluate where dispersal and other movements are most likely. We recognize that the character of the landscape varies widely and that the options and character of movement corridors shift with different land use patterns and natural barriers. In our work to map connectivity across this landscape, we recognize both broad areas of unrestricted flow zones, and more constrained areas where small corridors play essential roles in supporting species movements. Our assessment method also gives additional weight to connections that are likely to traverse climate gradients, such as northward trajectories, and movements toward cooler riparian areas.

In our integration of the resilient sites with the patterns of landscape connectivity, we identify resilient sites that also play a role in supporting either broad flow patterns or high rates of flow through narrow corridors. In this process, we maintain a focus on representation of different geophysical settings, as connectivity is only an advantage if it provides access to necessary site conditions.

Our final step in designing a network is to integrate known strongholds for biodiversity – if we know a place supports important biodiversity elements now, that increases our confidence that it will support important biodiversity in the future. Further, the current biodiversity is the source of the future biodiversity, and the source of the dispersing species. We recognize that a site may be topographically diverse and in a relatively natural landscape but may still have lost species diversity due to some stressor, such as a reduction in natural processes like fire or grazing. At the scale with which we are conducting these analyses, we are not able to make site-by-site comparisons of current condition and diversity. However, we can incorporate known sites of biodiversity as mapped in other assessments like the TNC ecoregional plans or the State Wildlife Action Plans. Our intent in incorporating these datasets is to identify resilient sites more likely to have long term biodiversity value in part due to adaptation in place and in part as sources of dispersal and movement to other sites.

This work to integrate site resilience, landscape connectivity, and biodiversity is described in the following chapters:

1-5. Site Resilience: These chapters describe the concepts and metrics for estimating the relative resilience of a site and evaluate the status of protected lands in the region with respect to representation of geophysical settings and site resilience.

7. Landscape Permeability: This chapter describes our efforts to understand and map the permeability of the landscape and identify patterns of flow and connectivity across it. It begins with a review of the literature on species range shifts, highlighting key results and response patterns that guide our approach. The methods section describes our continuous ("wall-to-wall") method for quantifying and mapping the potential of areas across these landscapes to support species movement based on landcover in combination with anthropogenic and natural barriers. Next, we describe our methods for incorporating response to climate change (i.e., favoring movement pathways that follow climate gradients) into the connectivity models.

8. Biodiversity: This section describes our methods for prioritizing resilient areas that contain rare species, or have been identified as a priority by ecoregional, regional, or state conservation planning efforts.

9. Resilient and Connected Conservation Networks: This section integrates resilience, flow, and diversity to develop a connected network of sites that both represents the full suite of geophysical settings and has the configuration and connections necessary to support the continued rearrangement of species in response to change.

CHAPTER 7

LANDSCAPE PERMEABILITY

Maintaining a landscape that facilitates range shifts for terrestrial species

Objective and Background

Maintaining a connected landscape is the most widely cited strategy in the scientific literature for building climate change resilience (Heller & Zavaleta 2009). While it makes intuitive sense that species must have the ability to move in order to adjust to a changing climate, it is less clear how we design a network that facilitates change and adaptation over time while conserving the full range of biodiversity. The interplay between range shifts, local persistence, changing habitat suitability, and evolving populations are poorly understood despite a large amount of research on these topics.

The goal of this section is to describe the mechanisms by which climate change leads to species range shifts and understand how those shifts are influenced by the condition of the landscape through which species must move. The information is used to inform a spatially-explicit assessment of relative permeability across the Western U.S. and to develop conservation priorities and strategies aimed at maintaining a landscape that facilitates range shifts for terrestrial species.

Introduction

The history of the Earth has been characterized by dramatic shifts in climate leading to radical shifts in the range of species. At the dawn of the Eocene 55 million years ago, as global temperatures rose 5-6^0 C, cypress trees and alligators had moved as far as the high Arctic (Krosby et al. 2010). More recently, much of North America and Eurasia were repeatedly ice-covered during more than 2 million years of glacial cycles causing species to continually shift their ranges. While they did so at different rates and in different directions, all the species that currently occur in these areas expanded their ranges north to occupy their current ranges in the last 12,000 years. In all that change of the last glacial period, there were remarkably few known extinctions (Botkin et al. 2007).

We are now facing a period of even more rapid climate change where temperatures are changing at roughly ten times the average rate seen during recovery from historical ice ages. We assume many species will again respond by shifting their distributions to respond to changing conditions. Indeed, in response to present climate change, species' ranges are already shifting northward at rates of 10-20 km per decade and upslope at rates of 11 m per decade (Chen et al. 2011). However, our world is very different than it was 10,000 years ago. Human development has radically altered the landscape, causing fragmentation of natural land and creating obstacles to dispersal (Fischer & Lindenmayer 2007, Haddad et al. 2015).

How do conservationists ensure that the landscape remains permeable enough to allow such large-scale movements, particularly by species that disperse slowly or may be hindered by a variety of factors?

In this report, we address this question for terrestrial landscapes in the Alaska.

Climate Change and Range Shifts

Range Shifts

Species respond to changes in climatic conditions in several ways: 1*) individuals adapt* their behaviors or habitat niches while staying in the same location, perhaps choosing shadier nesting sites or spending more time in riparian areas or spending less time active in the day; 2) *populations evolve* new climate tolerances to adapt to changed conditions through natural selection. We often think of evolution as happening very slowly, but as was demonstrated by studies of the Galapagos Island finches (Weiner 1995, Visser 2008), they can do so rapidly in response to dramatic changes in climatic pattern. Furthermore, many species, from trees to corals, have genetic differences in their populations related to differences in climate experienced across the species range (Davis and Shaw 2001). Such genetic differences at the population level may facilitate rapid adaptation as a way of responding to climate changes.

The other way that species may respond to climate changes is that 3) *populations and species shift their distributions*. This can occur when climate change leads to previously unsuitable habitat becoming suitable for population persistence allowing colonization of new habitat patches outside of the current range of a species. It can also result from differential survival of individuals at the range edge leading to a more gradual redistribution, for instance individual propagules surviving preferentially in shadier or moister areas causing a local population to shift in elevation or to a more shaded aspect. It is likely that components of all three mechanisms occur for most species.

Range shifts may be essential for species with narrow climatic tolerances experiencing rapid and extreme climatic changes in their current ranges, or for species that depend on naturally patchy landscape features, such as amphibians that breed in isolated wetlands.

The term “range shift” refers to the permanent colonization and subsequent spread into a new geography by a species through dispersing juveniles, propagules, seeds, eggs, adults, or other life history stage. The pressure to disperse is driven by the number of source populations and the abundance of reproducing individuals within them. The probability of reaching the new habitat is partially a function of dispersal pressure and partially of the permeability of the landscape through which the species must disperse. Additionally, a successful colonization requires that enough propagules arrive, establish, and reproduce in a suitable new area to persist for more than one generation. Thus, range shifts are a population process that occurs over generations and are sensitive to variation in three factors: dispersal pressure and vagility, the permeability of the landscape, and the suitability of the receiving habitat for the species in question.

A range shift may be accompanied by permanent extirpation in some other parts of the range, with the resulting range retraction reflecting locally failed recruitment due to unsuitable habitat, barriers, or lack of dispersal pressure. If at the same time, new and climatically suitable areas remain remote from current distributions due to the loss and fragmentation of habitats, and beyond the dispersal capacity of many species, then the concern is that species with low adaptability or dispersal capacity will be caught by the dilemma of climate-forced range change and low likelihood of finding distant habitats to colonize, ultimately resulting in increased extinction rates (Walther et al. 2002). This has been found to be the case globally for some bumblebee species no longer found in the southern part of their historic ranges but not yet expanding their ranges northward (Kerr et al. 2015). Indeed, the modeled dispersal ability of a range of taxa including North American trees (Loarie et al. 2009 quoted in Iverson and McKenzie. 2013) and mammals (Schloss et al. 2012) suggests that many species are unlikely to be able to keep pace with predicted rates of shifts in the distribution of suitable climate.

To date, few examples of this extinction phenomenon have been documented and some evidence suggests that, at least in the short term, communities are tolerating climatic variation and/or incorporating new species without necessarily losing their current species (Roth et al. 2014). For example, alpine areas which are demonstrably sensitive to climate change (Walter 2016) and offer resident species little potential for upslope or northward movements, have yet to show any local extinctions apparently due to the abundance of local microclimates (Roth et al. 2014).

Dispersal and Dispersal Pressure

Whether species arrive in a new location that may be suitable for colonization depends on the population size and the build-up of dispersal pressure, their dispersal ability, and the proximity, relative abundance, and size of patches of suitable habitat (Primack & Miao, 2002). Research has shown that dispersal limitation is often more important than recruitment limitations for forest plant species (Honnay et al. 2002). Some animals are capable of long-distance dispersal in a single generation such as migratory birds and large mammals. Smaller mammals and herptiles are more likely to be restricted to shorter dispersal distances and therefore dependent on adjacent and proximal suitable habitats. However, smaller-bodied animals tend to reach sexual maturity earlier and often have higher fecundity. Assuming dispersing individuals can successfully establish in new habitat patches, these attributes allow the population to rapidly produce the next generation of dispersers for further expansion. Plants have evolved a host of mechanisms for dispersing their propagules: wind and water, hooks that hitchhike on feathers and fur, or seeds consumed by birds, ants, and small mammals. Bryophytes, ferns, and orchids have tiny wind-dispersed propagules that can effectively disperse over long distances and thus make up a greater proportion of the non-endemic flora in remote locations such as New Zealand (Meurk et al. 1995). Some species are particularly dependent on rare and inherently stochastic events for long-distance dispersal, whether by natural vectors, or inadvertently assisted by ubiquitous and constant human movement - in the mud of car tires or dust on freight trains or the cargo of ships (Higgins et al. 2003). Snails, for instance, are normally very short-distance dispersers, but can extend their ranges great distances when their larvae are caught in the tarsi of birds.

The greater the number of propagules, and the greater the number of vectors (in the case of chance long-distance dispersal), then the greater the likelihood of *some* successful dispersals leading to successful colonization (Rouget & Richardson 2003). High levels of dispersal pressure facilitate geographic spread regardless of biological traits, although the latter play a role in establishment and colonization (Pysek et al. 2009). Because the abundance of propagules is typically dependent upon the number, size, and demographic characteristics (such as density, age structure, and fecundity) of local source populations, these attributes are essential ingredients influencing successful dispersal and ultimate range shifts. Populations not producing surplus juveniles are unlikely to move, and thus, facilitating range shifts is directly tied to traditional conservation practices aimed at maintaining robust populations and source areas of breeding habitat with adequate resources for successful population growth.

Landscape Permeability: The Influence of the Medium through which the Organism is Dispersing

Successful dispersal and colonization is a numbers game, a question of enough dispersers beating the odds to get to new habitat, and thus for terrestrial dispersers a key factor in determining the likelihood of a range shift to an unoccupied territory is the nature of the intervening landscape. If the goal was simply to maintain genetic connectivity among populations, a few individuals occasionally reaching the new area might be enough, as even a few new genes can make a difference in an isolated population (Soule & Simberloff 1986). However, range shifts to places not yet occupied by the species are often dependent on many more successes, with sufficient individuals dispersing to initially establish a population, followed by continued arrivals of new dispersers over time to prevent stochastic extinction. Under these circumstances, the extent to which the intervening landscape facilitates or impedes successful dispersal can be critical in determining whether a range shift occurs.

The relationship between specific landscape characteristics (e.g., land use, land cover, elevation, or landform) and the likelihood of dispersal is often quantified on a species-specific or taxa-specific basis through the concept of *resistance*. Resistance refers to the degree to which specific landscape features facilitate or impede the movement of a species. It can be thought of as the willingness of an organism to cross the habitat type combined with the likelihood of surviving such a crossing.

The resistance of a landscape to successful dispersal may be due to anthropogenic changes in land use. Satellite images of the Atlantic Seaboard or California's Central Valley make it obvious that human land use changes have created "islands" of native habitat, similar to forests in the East now surrounded by development, or patches of grassland in the Midwest surrounded by intensive agriculture. It seems intuitive that species in these native habitat patches may have difficulty successfully crossing a landscape of development or agriculture or be reluctant to cross due to increased exposure to risk or higher mortality from predators or traffic collisions. Indeed, many studies have confirmed that movements among patches of habitat are influenced by, or dependent on, the characteristics of the intervening matrix (Ricketts 2001, Hokit et al. 1999, Haddad et al. 2015). For instance, Richard and Armstrong (2010) tracked radio-tagged forest passerines (*Petroica longipes*, in New Zealand) in a fragmented agricultural landscape and found that juveniles move preferentially through native forest, followed by plantation forest, then shrubland, then pasture, with a marked hesitancy to cross the latter. Observations such as these have given rise to a plethora of "landscape resistance" models that simulate species movement through a landscape based on the degree of resistance expected from different land use/land cover types relative to the preferred type. In these GIS models, resistance values are assigned to individual cells in a raster layer based on the cell's land cover type and the expected degree of resistance. Such a GIS resistance model, discussed later in this document, forms the basis of the continuous permeability models we used to model potential range shifts.

The resistance of a landscape to successful dispersal may also be ecological, i.e., a function of natural discontinuities in the landscape. The most obvious is dispersals of terrestrial species across ocean. The emergence of the Beringia Land Bridge during the

Ice Age allowed dispersal of species (including *Homo sapiens*) to the Americas. The emergence of the Panamanian Isthmus allowed North American species to expand their ranges to South America. Large-scale landscape features that are highly contrasting habitat with surrounding land, such as deserts surrounding mountains, can also create "sky islands." This phenomenon has led to marked diversification of species on the mountains of the Basin and Range country of America's West (McCormack et al. 2009). On a smaller scale, some species dependent on moist conditions such as prairie potholes or riparian areas likely find the surrounding dry prairie landscape resistant to dispersal. On the other hand, the pattern of high red maple genetic variation, even in northern parts of its range, suggests that the northern Appalachian Mountains were not a significant barrier in the most recent post-glacial climate warming. Rather, it is likely that the contemporary range of red maple is the result of a combination of frequent long-distance dispersal events, only minor topographic obstacles, and diffuse northern refugia near the ice sheet (Gugger et al. 2008). Of course, some features of the landscape may facilitate more frequent successful dispersals, both ecological, such as river valleys or long mountain ridges, and anthropogenic, such as roadside verges. For example, purple loosestrife dispersed north along ditches of the I-95 corridor (Stuckey 1980), and New England cottontail populations in Maine remain connected via roadside verges and power line right-of-ways.

Any feature that facilitates or impedes movement is likely to have different impacts on different species; however, long-term studies on the effect of anthropogenic fragmentation have shown remarkably consistent negative effects across many taxonomic groups. Haddad et al. (2015) synthesizing the results of fragmentation experiments spanning multiple biomes, multiple scales, five continents, and 35 years, demonstrated that habitat fragmentation reduces biodiversity by 13% to 75% and impairs key ecosystem functions. Across all studies, they found generally consistent decreases in the abundance of birds, mammals, insects and plants, and reduced species richness of arthropods, birds, butterflies and plants and this accumulated over time as a fragment became more ecologically isolated (i.e., there was marked resistance to species moving between fragments resulting in both local extinctions and immigration lags). This overall pattern emerged despite complex patterns of increases or declines in abundance of individual species with various proximate causes such as release from competition or predation, shifts in disturbance regimes, or alteration of abiotic factors. Haddad et al. (2015) conclude that although the effects of fragmentation are mediated by variation in traits across species (e.g., rarity, trophic level, dispersal mode, reproductive mode, movement behavior), this primarily helped to interpret variation around the overarching pattern of consistent reductions in richness and abundances across many species. If there is a positive side to these findings it is that the effects of fragmentation can be reversed by restoring the appropriate natural cover and adding a corridor which can produce up to 50% more movement (Gilber-Norton et al. 2005).

Establishment and Colonization

Successful range shifts are also reliant on the conditions found in the new unoccupied patches of suitable habitat available for colonization. In addition to the factors influencing the number of dispersers arriving as described in preceding paragraphs, whether species successfully colonize a new location depends on the breadth of their habitat tolerances, the rapidity with which they can reproduce, their success in competing with or escaping predation by native fauna or flora, and the amount of available habitat. In general, successful establishment is more likely for rapidly reproducing habitat generalists (including many of our "weedy" species) that can quickly establish and are more tolerant of spatial and temporal variation in the environment.

The more specific, uncommon, and distant the appropriate habitat is for any given species, the lower the frequency of chance dispersal into such habitats. It is easier to imagine that the arctic flora and fauna of dispersed mountaintops is a relic of a glacial period when such habitats were much more widespread than of long-distance dispersals since deglaciation. Furthermore, some specialist species have evolved lower dispersal abilities, thus stacking the odds against being stranded or landing in inhospitable habitat. The evolution of flightlessness in island-inhabiting birds is a familiar but not unique example. Likewise, although aerial ballooning is a common means of passive dispersal for many spiders, habitat specialist spiders in fragmented landscapes are much less likely to balloon (Bonte et al. 2003). Nevertheless, decades of inventory by botanists, have shown a remarkable consistency of flora on apparently isolated small-patch habitats like alkaline fens, shale slopes, serpentine outcrops, and limestone cliffs that, because of the discontinuousness of the underlying geology, are difficult to explain as remnants of once widespread populations.

The Evidence for Range Shifts in Response to Climate Change

For a range shift to be attributed to climate change it must occur when dispersing species gain access to suitable habitat that had previously been unavailable due to climatic conditions. This can happen directly through changes in mean temperature or short-term climate extremes that allow a population to expand northward, or through climate-mediated interactions with other species that remove competitive barriers. However, understanding and predicting climate-driven range shifts is complex, in part because species tolerances are not fixed. Davis and Shaw (2001) reviewed tree taxa shifts in latitude or elevation in response to changes in Quaternary climate and stressed the complexity of climate changes. Summer and winter temperature, seasonality, and the distribution and amount of precipitation, all changed in different ways that produced new combinations of climate, not simply geographic displacements of the same climate. Although range shifts clearly occur, they questioned the assumption that taxa disperse seed and establish in new regions more readily than they evolve a new range of climate tolerances, or even that the tolerance range for a species remains temporally stable given wide intraspecific variation.

The evidence is clear that rapid periods of climate change in the Quaternary saw many shifts in species distributions. As the climate cooled, the distribution of tree species such as red spruce in North America and Scots pine in Europe shifted south, and as the ice sheet receded, they moved north again 150 km/century (Davis & Shaw 2001). Considering that much of the northern third of the US was covered by ice miles thick for millennia multiple times, every species that now lives in this region had to arrive in the last 12,000 years by shifting their ranges northward. The fact that there were so few extinctions associated with all these massive displacements of species over broad areas of North America has been dubbed the Quaternary conundrum. A hypothesis put forward to explain this for North America is that the landscape remained highly connected by natural cover allowing species distributions to track the climate (Botkin et al. 2007). It may also be that the north-south trending mountain ranges and lack of major landscape impedances to northward movement facilitated these shifts, which is consistent with the assumed mechanism of differential extinction and colonization rates at northern versus southern range edges (Honnay et al. 2002). There is some evidence that northern Europe has been slower to recover its former species diversity in part because of the obstacles posed by east-west mountain ranges such as the Pyrenees and the Alps (Adams & Woodward 1989).

Evidence for contemporary range shifts in response to climate has now been documented for over 1000 species as populations shift their geographic distributions in one of four ways: 1) upslope toward higher elevations, 2) northward toward cooler latitudes, 3) downslope towards moist riparian areas, and 4) locally toward suitable microclimates. The evidence for upslope and northward movements is strong and consistent across many taxa groups and across several continents (Table 7.1, Walther 2002, Chen et al. 2011) and there are increasing indications of the other responses as well. As we review the evidence for these four responses, it is helpful to remember that a variety of ecological factors may create variation in a species response to climate: competitive release, habitat modification, or changes in amounts and patterns of precipitation, snow cover duration, water balance, or seasonality (Groffman et al. 2012). Any of these may cause range shifts to differ substantially from straightforward poleward or upslope movement largely driven by temperature (Garcia et al. 2014). These factors, coupled with relatively gradual rates of temperature change with latitude in the tropics, mean that detecting and predicting range shift patterns in the tropics will be much more difficult. In this paper we focus on temperate regions.

Table 7.1. Summary of elevational and latitudinal observed range shifts from 30 studies (modified from Chen et al. 2011). ORS = observed range shift, SE = standard error. "Margin" refers to whether the studies focused on changes in the upper leading margin or average distribution. The list of sources for Chen et al. 2011 are located at http://www.sciencemag.org/content/333/6045/1024/suppl/DC1

Observed Elevational Range Shifts

Taxa group	# of Species	Margin (Upper / Avg.)	Duration (yrs.)	Mean ORS (m)	Min ORS (m)	Max ORS (m)	SE of ORS (m)	Temp change (C)	# Studies
Invertebrate	554	U/A	20-42	37.7	7.4	108.6	12.3	0.62	5
Fish	15	U	25	32.7	32.7	32.7	12.7	0.65	1
Herptiles	30	A	10	65.3	65.3	65.3	24	0.24	1
Birds	326	A/U	11-25	-4.75	-19.3	7.6	9.3	0.795	4
Mammals	37	U/A	25-88	50	31	69	71.6	3.05	2
Plants	495	U/A	22-94	62.4	21	89	16.2	0.97	7

Observed Latitudinal Range Shifts

Taxa group	# of Species	Margin	Duration (yrs.)	Mean ORS (m)	Min ORS (m)	Max ORS (m)	SE of ORS (m)	Temp change (C)	# Studies
Invertebrate	332	U	8-25	59.1	7.9	104.2	15.9	0.6	3
Fish	15	U	25	47.2	47.2	47.2	15.4	0.65	1
Birds	361	U/A	12-31	24.2	3.6	46	19	0.49	4
Mammals	9	U	25	22.4	22.4	22.4	38.4	0.45	1
Algae	37	A	50	61.4	61.4	61.4	31.6	0.74	1

Upslope Movement: A recent meta-analysis of over 51 studies detected upslope elevational range shifts for five taxonomic groups with magnitudes ranging from 6.1 m to 11.0 m per decade and this was consistent with other studies (Chen et al. 2011, Parmesan & Yohe 2003, Lenoir et al. 2008). Upslope movement appears to be greatest among plants and herptiles, followed by mammals, invertebrates, and fish (Table 7.1). Responses by birds have been inconsistent (Tingley et al. 2012) although an eight-year monitoring study in Switzerland found significant upslope shifts in communities of birds (42 m), butterflies (38 m) and vascular plants (8 m), with rates of community changes decreasing with altitude in plants and butterflies (Roth et al. 2014). For immediate climate relief, moving upslope is more efficient than moving latitudinally. For example, in the tropics there is a 5.2°C to 6.5°C decrease in temperature per 1000 m elevation, nearly 1000 times as much as the latitudinal rate of decrease (Colwell et al. 2008). Although evidence for upslope movement seems overwhelming (Lenoir et al. 2010) and it may be the dominant way in which most species are accommodating climate change in the short term, there are obvious limitations to it as a long-term strategy for all species. First, it only works for species where upslope movement of suitable habitat is an option, which includes many plants, invertebrates, birds, and mammals, but not for those where a lowland physiographic setting is required for suitable habitat such as many wetland-associated species or plants that need deep, moist, nutrient-rich soils. Second, the extent of available upslope habitat is limited in many regions where the slopes are either so gentle or so distant that they offer little practical climate relief to most species, or the hills are so small that their summits are rapidly reached.

Northward Expansions: Northward movements are also well documented for 754 species across five taxa groups, and they appear to be ubiquitous across the northern hemisphere (Table 7.1, Chen et al. 2011). Studies have found latitudinal range shifts to range from 6.1 km to 16.9 km northward per decade (Chen et al. 2011, Parmesan & Yohe 2003, Lenoir et al. 2008). It is likely that latitudinal expansions will be the predominant long-term strategy of most species in response to climate change, and this is largely concordant with the evidence of historic range shifts in response to previous periods of rapid climatic change. Despite fears and reports that many species will lag behind, Chen et al. (2011) found that nearly as many studies of observed latitudinal changes fell above as below the expected rate suggesting that mean latitudinal shifts are not consistently lagging behind the climate.

Downslope Movements: Upslope and northward movements correlate with temperature change, but many species are more limited by moisture availability than temperature. Downslope regions collect moisture and feature microclimates that may be significantly cooler and more humid than immediately surrounding areas (Olsen et al. 2007). A recent study examining the response of eastern trees to climate change found changes in moisture availability had significantly stronger near-term impacts on vegetation dynamics than changes in temperature (Fei et al. 2018). Species seeking moisture tend to move downslope towards the water-collecting regions at the base of slopes or into moist riparian areas.

Species showing downslope shifts have been well documented (Archaux 2004, Popy et al. 2010). A survey of such range shift studies suggests that while roughly 65% of species have shifted their ranges upslope, 25% have shifted their ranges downslope, and 10% have not changed their mid-range positions (Lenoir et al. 2010). Similarly, a global review of the literature (Parmesan & Yohe 2003) suggests that about 20% of species have adjusted their ranges towards lower elevations. Long-term downhill shifts in the optimal elevations of plant species has been shown for California, apparently in response to decreased climatic water deficit (Crimmins et al. 2011). Our own spatially-explicit climate resilience analysis (Anderson et al. 2013) based on microclimates and connectedness identified many slope bases and riparian corridors as key landscape features because of the many climate options they provide, especially in relatively flat landscapes.

Moisture and temperature differences between riparian areas and their surrounding landscapes may be substantial, with riparian areas being 5-20^0 C cooler and 10-15% higher in soil moisture (Yeakley et al. 2008, Bennie et al. 2008). Thus, they are expected to provide microclimatic refugia from warming and drought for many species, particularly those that tolerate wet conditions (Seavy et al. 2009). Additionally, riparian areas naturally connect many landscape features, and this unique attribute make them logical and perhaps vital elements in any conservation network designed to maintain landscape resilience and facilitate range shifts. It is not surprising that the use of riverine corridors in a riparian connectivity network has been proposed as a strategy for maintaining climate resilience (Fremier et al. 2015). Although they comprise a minor proportion of the landscape, riparian areas are structurally diverse and more productive in plant and animal biomass than adjacent upland areas, suppling food, cover, and water for a large diversity of animals. Riparian areas sometimes serve as migration routes and connectors between habitats for a variety of wildlife (Manci 1989), particularly within highly modified landscapes (Hilty & Merenlender 2004).

Riparian areas that span climatic gradients might provide natural corridors that species could use to track shifting areas of climatic suitability and have been called riparian climate corridors (Krosby et al. 2014). In the Northeast; however, the temperature gradients *within* most riparian or floodplain corridors was found to be very small (Anderson et al. 2015), averaging 0.14^0 C on the Coastal Plain to a high of 1.3^0 C in the Central Appalachians. This suggests that although there is ample incentive for species to move into downslope or riparian areas, there may be less climatic reason to move directionally along the corridor.

The numerous studies documenting preferential use of naturally vegetated riparian zones by a wide range of species of terrestrial wildlife (e.g., Hilty & Merenlender 2004) do not necessarily demonstrate the use of such areas for long-distance dispersal. For example, a study of riparian zones as dispersal corridors for herptiles found that for many species dispersal along the riparian zone was likely impeded by species-specific habitat needs such as inundation patterns, appropriate adjacent upland habitats, or fishless pools (Burbrink et al. 1998). However, riparian habitat tends to include a higher density of wetlands in comparison to upland areas and thus on average will provide suitable breeding sites in closer proximity to one another, leading to an increased probability of successful dispersal of wetland fauna in riparian areas over time. Additionally, the rivers, themselves, clearly play a role in dispersal of fish and other aquatic species, and in the passive dispersal of plants in riparian zones whose propagules survive inundation (Jansson et al. 2005). Such dispersal is, of course, driven by the movement of the water downhill so could not be expected to contribute much if any to dispersal upslope or poleward in response to increasing temperatures, except on rivers that flow north.

Where intact riparian areas or bottomland floodplains occur in developed or converted landscapes it may be difficult to separate questions of the preferential use of riparian zones for movement from the use of strips of natural landscapes. In the Southeast Coastal Plain, for example, extensive, intact, large river floodplains contrast strikingly with the surrounding landscape providing both habitat and natural movement corridors. Radio-tracking studies have documented the use of these riparian areas for movement of large mammals in Georgia (Cook 2007) and it seems likely that many wildlife species would use a riparian corridor for dispersal if that is the only safe natural cover in the wider landscape (Fremier et al. 2015). Such corridors may allow multi-generational dispersal to occur between larger heterogeneous areas of protected habitat if the corridors include appropriate breeding habitat, and this may be particularly important for species with limited dispersal abilities. Further, it is postulated that ensuring riparian corridors right up to headwaters can provide critical over-the-ridge links for dispersal across watersheds (Olson & Burnett 2013). It is less clear in a landscape were the riparian areas occur within intact natural land cover whether upland terrestrial species would preferentially disperse along a river valley rather than along ridge lines or contour lines that have their preferred cover or food sources.

<u>Microclimates and Rates of Change:</u> The fourth and perhaps most common alternative for species is to find suitable habitat nearby, moving a small distance to take advantage of a local microclimate. Species experience climate at extremely local scales (cm to meters) and the available moisture and temperature in the near-ground "boundary layer" can differ greatly from the local average (Geiger et al. 2009). Thus, a topographically diverse landscape is experienced by its resident species as a heterogeneous mix of microclimates many of which might be suitable for persistence even where the average background climate appears unsuitable. Landscape-based climatic variation can be substantial, on par with or greater than the 1.5^{o}C warming expected for the future. Studies where climate data loggers are placed across gradients of slope, aspect and elevation have found maximum temperature differences over 20^{0} C (Surgett et al. 2010, Dobkin et al. 1987) and 15-20 % fractional soil moisture differences (Yeakley et al. 1998, Bennie et al. 2008). In Southern Appalachian watersheds, topography explains 40% to 72% of the variation in near-surface soil moisture (Yeakley et al. 1998). Even microscale patches of suitable climate may allow persistence of species over long time scales and serve as a source for recolonization or further dispersal. For example, Roth et al. (2012) found that although lowland plants in Switzerland were moving upslope, alpine plants were persisting in place, finding suitable habitat within a few meters due to the highly varied surface of the landscape. It is probable that both lowland and alpine plants were taking advantage of all suitable microclimates, and that the apparent difference in response was due to the difference in availability of upslope microclimates.

The examples above support the idea that stable refugia, effectively decoupled from the regional climate, may offer longer-term respite in a climatically variable regional landscape. Proximity to such refugia seems to have helped some species survive the last glaciers and then served as dispersal points for populations post glaciation (Provan & Bennett 2008). Besides the better studied refugia of southern and eastern Europe, it now appears there were also cryptic refugia in northern Europe in areas of sheltered topography with stable microclimates (Steward & Lister 2001). Mapping the distribution of microclimates has been the basis of a study by The Nature Conservancy to identify climate resilient sites (Anderson et al. 2014), and some of the areas identified as microclimate concentrations (e.g., the Piedmont-Coastal Plain Fall Line), correspond to areas where the ranges of plant species have expanded and contracted in historic periods of climate change (Weakley pers. com. 2015).

Some types of cool climate refuges occur at scales larger than the topographic microclimate, such as orogenic rain shadows, lake effects, cold air pooling, or maritime cooling. In the short term, ephemeral climate refuges that offer the coolest maximum temperatures when regional temperatures are relatively high may provide relief to transient species or even populations (Gollan et al. 2014). In eastern North America there is evidence of a refugium along the coast of Maine where the maritime influence allowed spruce to survive even when the relatively dry and warm climate of the hypsithermal prevented spruce survival inland (Schauffler & Jacobson 2002). These populations were likely the source of the rapid expansion and dominance of spruce through the rest of the state about 1000 years ago during a region-wide shift to cooler and moister conditions.

The localized movement of populations to utilize microclimates is so restricted that it probably does not qualify as a range shift unless accumulated small movements add up to a directional change (i.e., upslope). However, utilization of microclimates may explain how poor dispersers can track the changing climate within larger-scale range expansions. Chen et al. (2014) hypothesized that the real and apparent lags in species response to climate may reflect the topographic and microclimatic complexity of mountainous terrain, and they emphasized the need for finer-resolution analyses with additional topographic and geological detail if we are to understand the actual climates that species are tracking. Loarie et al. (2009) noted that owing to topographic effects, the velocity of temperature change varies spatially, and is lowest in mountainous areas, which may effectively shelter many species into the next century. Coarse-scale climate models are mapping something distinctly different from very local climates experienced by species on the ground, and this can lead to erroneous conclusions about extinction rates or the rates of dispersal needed to track climate change (Willis and Bhagwat 2009). This is good news because the rates of change in species distributions documented in recent decades as well as in the last post-glacial period do not come close to the estimated rate of range shift that would be necessary to keep up with predicted climate changes (e.g., 300-500 km/century as per Anderson and Shaw

2001, or one to two orders of magnitude faster as per Honnay et al. 2002). There are probably limits to the buffering effect of microclimates as the only precisely dated extinction of a tree species, *Picea critchfieldii*, during the Quaternary coincided with the exceptionally rapid warming during the transition from the Last Glacial maximum to the Holocene about 15,000 years ago. What is surprising, however, is that this example seems to be singular.

The evidence for contemporary range shifts provides support for the four types of responses discussed above, but the studies are unavoidably focused on cumulative short distance dispersals and leave many unanswered questions about long distance jumps to suitable habitat, or responses to broad-scale episodic extreme disturbances. It is likely that we simply do not understand enough about the actual dispersal of most species, particularly the low frequency but long-distance dispersals that could explain dispersal rates during the last post-glacial period (possibly aided by hurricanes or large migrating herbivores) being much higher than what is being observed or modeled currently. In plants especially, observed average seed dispersal distances cannot account for the rapid northward migration that occurred in many species (Reid's Paradox; Clark et al. 1998). In fact, Cain et al. (1998), modeling the seed dispersal curve for *Asarum canadense*, a woodland herb dispersed by ants, concluded that an empirically calibrated diffusion model would show that since glaciation *A. canadense* should only have traveled 10-11 km from its glacial refugia, but in fact it moved hundreds of kilometers during this time. They conclude that most woodland herbs and many other plant species have such limited dispersal capabilities that occasional extreme dispersal events and mechanisms are the only explanation for their documented migration. Griffin and Barret (2004) concurred after using a genetic analysis to study the range expansion of the woodland herb *Trillium grandiflorum*, finding that it likely survived in two refugia in the southeastern US during the last glaciation and that post-glacial recolonization of northern areas was characterized by long-distance dispersal beyond what the plant appears capable. Higgins et al. (2003) suggest that long-distance dispersal events in plants are usually caused by non-standard means of dispersal, that is, a plant seed adapted to wind dissemination may get lodged in the feathers of a bird and transported much farther than wind would take it. Although such infrequent long-distance dispersal events are likely to allow some species to move much further and faster than evidenced by their typical form of dispersal, it is important to recognize that for many taxa, especially specialist species, for such events to result in locating and establishing on a patch of uncommon habitat is highly improbable without animal or human intervention.

Habitat Fragmentation and Climate Change

Current species' responses to climate change may differ from historic responses because humans have modified the landscape, fragmenting habitats and disrupting natural movements. Fragmentation of the landscape has been shown to slow dispersal and hamper the successful colonization of new habitat by creating resistance to population movement through the intervening matrix. Above, we reviewed the 35-year synthesis by Haddad et al. (2014) of the world's largest and longest running fragmentation experiments, which clearly demonstrate a resistance to movement, and/or high mortality rates, for all major taxa groups when crossing contrasting or unfamiliar land cover. Further, colonization and radio-tagged movement studies reinforce these observations with respect to tree species (Honnay et al. 2002), forest passerines (Richard & Armstrong 2010), and many other taxa. Climate change does not appear to fundamentally alter the effects of fragmentation other than to intensify the need for species to move in response to directional changes in climate and to concentrate those movements on upslope or northward gradients, or downslope into local riparian areas. We assume that the responses to fragmentation are equally applicable to these features, and that even the dispersal of species to nearby suitable microclimates is facilitated by a connected landscape through which organisms can move easily.

Implications for Conservation

This review of the mechanisms for range shifts in response to climate change highlights several points. Range shifts are a well-documented species response to past episodes of climate change and there is abundant evidence that they are already occurring in response to current climate change. The latter are detectable as expansions upslope and northward, as downslope movement into riparian areas, or as very local movements to take advantage of proximate microclimates. The magnitude and pattern of the current response is likely to differ from historic responses because humans have modified the landscape, fragmenting habitats and disrupting natural movements. These modifications create resistance that may prevent species from colonizing new habitat, instead creating range constrictions.

The conservation implications of this review guide the work presented in the rest of this report. Some of the findings reinforce well-known conservation design principles while others call for new mapping and integration methods to identify the spatial implications of climate-driven range shifts. These are organized below as ten key points with the first three focused on facilitating dispersal, and the next seven on facilitating dispersal under climate change. When appropriate, we link the points directly to the resilience analysis (Anderson et al. 2016, 2018 a & b).

1. It all starts with dispersal pressure. It is essential that there are source areas for all species to produce enough propagules to ensure a high probability of successful dispersal. To function well as source areas, sites need to have the requisite size and optimal breeding conditions for that species. For many species, we believe sites that are above-average in local connectedness and landscape condition as defined by the resilience analysis (Anderson et al. 2016) are likely to correspond with source areas.

2. The quality of the landscape through which species disperse can impede the movement of species and there is strong and consistent evidence for this across all taxa. There is good justification for using resistance-based models to identify potentially important linkages and pinch points and solid evidence to support conservation efforts aimed at facilitating movement by maintaining or restoring suitable natural cover. This can often be accomplished through compatible land management over broad areas in conjunction with high natural cover in specific areas.

3. All species, especially habitat specialists, need sufficient suitable habitat to meet their specialized needs both now and in the future. This argues for the importance of the representation of all geophysical settings in a variety of climate zones as part of the resilient portfolio concept. For specialists, the uncertainties of occasional long-distance range expansions make the need for refugia even more important.

4. Upslope range shifts in response to climate are already widespread and are likely important for short-term reprieve, particularly in landscapes with low topographic relief. Mapping, prioritizing, and conserving connections to available upslope features are important when designing a local landscape for climate resilience.

5. Northward range extensions have been detected in over 500 species. Mapping permeability across north-south gradients should highlight areas for explicit conservation focus. This may include pinch-points that play a disproportionally important role in facilitating range shifts, diffuse areas that offer many options for movement, or low-flow areas that could be improved through restoration.

6. Downslope areas and riparian corridors are unique in that they offer cool, moist microclimates and also connect many features on the landscape. Wherever possible they should be used to connect resilient sites or already conserved land. Prioritizing downslope regions based on their degree of permeability and flow should identify areas that likely play an essential role in facilitating range shifts because they are cooler, wetter and more intact.

7. Microclimate refugia can play a role in promoting long-term persistence and slowing the velocity of climate change. In the short term, a species may find refuge by moving upslope or to another aspect of a hillside or valley or to a rock and soil type that holds more or less moisture. Such opportunities are more likely in areas with higher landscape diversity, as defined by an analysis of resilience.

8. Over the longer term, some geographies are likely to play an essential role as longer-term refugia. Some of these can be predicted based on microtopography or attributes that make their climates intrinsically more stable. Others may be harder to predict in advance, but this argues for ensuring a portfolio of conservation sites that includes geographic distribution, stratification by ecoregion, and geophysical representation.

9. Absolute contiguity of appropriate habitats may not be necessary and is in many cases impossible for most species, but proximity helps increase the odds of successful dispersal. The stepping stone concept makes sense. Even if we do not know and cannot model how occasional long-term dispersal events occur, the evidence shows that after glaciation many specialist species with poor dispersal prospects somehow relocated to pockets of suitable substrate and climate.

10. Given the apparent importance of infrequent long-distance dispersal in accounting for the pace of past range shifts, we should not discount the importance of sites that are distant and seemingly disconnected from additional habitat if they are robust source areas for multiple species, especially for uncommon habitat specialists. Integrating known sites with confirmed rare taxa or high-quality examples of unique communities should provide the best starting point for the latter.

Regional Flow: Mapping Landscape Permeability

The Nature Conservancy's analysis of site resilience sites addresses many of the recommendations summarized in the previous section, including recommendations to:

1) identify potential source habitat for species;
2) represent all geophysical settings in a variety of climate zones;
3) identify microclimate refugia in areas with higher landscape diversity;
4) ensure a portfolio of conservation sites includes representation and geographic distribution of all geophysical settings within ecoregions.

The resilience studies stop short, however, of identifying a connected network of sites that includes the linkages and confirmed biodiversity features needed to facilitate range shifts. This report is designed to address that issue. Specifically, we develop methods to map the permeability of the landscape in relation to anthropogenic uses and barriers, we examine where needed latitudinal or slope movements are likely to concentrate, and we locate sites with confirmed biodiversity elements such as rare species or exemplary communities. Finally, we integrate these components into a connected network designed to sustain diversity under climate change.

Introduction

The permeability of a landscape is a function of the resistance of its major elements and their spatial arrangement: the types and penetrability of barriers, the connectedness of natural cover, and the configuration of land uses. It is defined as the degree to which a landscape, encompassing a variety of natural, semi-natural, and developed land cover types, will sustain ecological processes and be conducive to the movement of many types of organisms (Meiklejohn et al. 2010). Consequently, our goal was to map landscape permeability as a continuous surface, not as a set of discrete cores and linkages as might be used to map an individual species' movement between areas of suitable habitat (Fischer & Lindenmayer 2006, Beier et al. 2011).

Several approaches have been developed to create a continuous model of landscape permeability: moving window (McRae in prep), centrality (Theobald et al. 2012), resistant kernel (Compton et al. 2007), and wall-to-wall (Clark in Anderson et al. 2012 and Pellatier et al. 2014). The wall-to-wall approach is particularly suitable for modeling potential range shifts because it allows for the creation of multidirectional and omnidirectional connectivity maps illustrating flow paths and variations in the ease of movement across large regions. The results provide a continuous view of connectivity across a study area at the full original resolution of the data and highlight pinch points, blockages, essential corridors and flow zones (Pelletier et al. 2014).

The mapping of permeability as a wall-to-wall surface has only recently become possible through the use of the software Circuitscape (McRae & Shah 2009), an innovative program that models species and population movements as if they were electric current flowing through a landscape of variable resistance. Circuit modeling is conceptually aligned with the concept of landscape permeability because it recognizes that movement through a landscape is affected by a variety of impediments, and it quantifies the degree and the directional outcomes of the compounding effects. One output is a "flow" map that shows the behavior of directional flows and highlights concentration areas and pinch-points. The results identify locally and regionally significant places where species range shifts are likely to be impeded by anthropogenic resistance, and that may warrant conservation.

"Flow" in an ecological sense refers to the gradual movement of plant and animal populations across the landscape over time. Populations expand when they produce a surplus of juveniles which disperse and colonize new habitat at a distance from their source point. Juvenile animals can walk, climb, fly, float, swim, glide, crawl or burrow their way to new locations, and plants have evolved a host of mechanisms for dispersing their propagules by taking advantage of many dispersal vectors such as wind, water, animals, and people. If the current habitat becomes unsuitable, but available suitable habitat exists nearby, a flow of dispersers helps ensure that the new habitat will be discovered and colonized.

Population responses to current climate change differ from historic responses because humans have modified the landscape, fragmenting habitats, and disrupting natural movements. Such modifications can create barriers that prevent species from colonizing new habitat, and may result in range constrictions in areas where range expansions were historically possible. Alternatively, the configuration of land uses can serve to channel population flow through a narrow corridor, increasing the importance of that corridor to maintaining flow. To detect and quantify these patterns within the study area we modeled how species populations will likely migrate and disperse through the anthropogenically modified landscape, and used the results to identify critical pinch points, blockages, or broad flow zones.

In a previous pilot study (Anderson et al.2016), we compared the results of regional scale flow modeling in Eastern North America against 58 smaller scale studies. The results can be found in the section titled called "Comparisons and Confirmation" and more completely in Appendix 1. We found that in spite of scale and methological differences between the studies, many showed similar results, particularly in modified landscapes where there were fewer available choices for movement through natural cover. Comparisons between the regional flow models and species based movement studies were the most similar, giving us confidence that species were likely to utilize the flow concentration areas. Results were least similar between studies that connected predeterminded habitat blocks, particularly when the connections between blocks did not follow the natural flow patters. This observation suggested that prioritizing habitat blocks that are located within the existing natural flow patterns might be the most effective way of maintining adaptive movement. We will come back to this point in the later section on integration of flow, diversity and resilience.

Initially we modeled flow based soleley on anthropogenic resistance which we refer to as 'regional flow." This model estimates population movement patterns based on the arrangment of human-modified barriers such as roads, development and energy infrastucture. Our next step was to incorporate the influence and response to climate change directly into the model. This is presented in the susequent section entiled "Climate Flow." Using evidence on how species are already responding to climate change, the climate flow model is a modified version of the regional flow model with more weight given to flow pathways that provided cooler temperatures (upslope and northward) or higher moisture (downslope, riparian).

Circuitscape Model

All modeling of landscape permeability and regional flow was done using Circuitscape (McRae & Shah 2009). Circuit modeling recognizes that movement through a landscape is affected by a variety of impediments (resistances) and quantifies the degree to which these impediments will affect movement and the directional outcomes of the compounding effects.

The Circuitscape program calculates the amount of "current" moving directionally across a landscape based on an input grid of cells with values indicating their degree of "resistance." One output of the program, a current map, shows the behavior of directional flows, analogous to electric current flowing across a surface with varying levels of resistance. Like water moving across an uneven watershed, the flow of current over the resistance surface results in patterns of high and low concentrations very similar to the streams, gullies, eddies, and braided channels associated with the overland flow of water. The program's ability to highlight flow concentration areas and pinch-points makes it particularly useful for identifying key linkages for permeability. Flow concentration areas are easily recognized in the Circuitscape output by their high current density.

In the Circuitscape program, the landscape is converted into a graph, with every cell in the landscape represented by a node (or a vertex) in the graph and connections between cells represented as edges in the graph with edge weights based on the average resistance of the two cells being connected (Shah & McRae 2008). The program performs a series of combinatorial and numerical operations to compute resistance-based connectivity metrics, calculating net passage probabilities for random walkers passing through nodes or across edges. Unlike a least cost path approach, Circuitscape incorporates effects of multiple pathways, which can be helpful in identifying critical linkages where alternative pathways do not exist (McRae & Beier 2007). More detail about the model, its parameterization, and potential applications in ecology, evolution, and conservation planning can be found in McRae and Beier (2007) and McRae and Shah (2009).

Anthropogenic Resistance Grid

In a Circuitscape analysis, the current flows across the landscape through a resistance grid, with lower resistance being more permeable and higher resistance less permeable. The base grid we used for anthropogenic resistance was land cover, but in theory resistance can be any factor that impedes movement (in later climate flow models we use slope and land position as well). When based on land cover, obstructions to species movement are assigned high resistance scores based on the degree to which they impede species population movements.

Our assumption was that the resistance between cells increases with their contrast to natural land. Elements that contrast strongly with natural land, such as high intensity development, were considered less permeable because of differences in structure, surface texture, chemistry, temperature, or exposure. In this model dispersing wildlife and plant propagules can cross any landscape elements, but the sharper the contrast (for example "forest" adjacent to "high-density development") the stronger the decrease in movement. Even if it is possible to cross developed land, a forest animal may prefer to avoid the risk inherent in crossing the more exposed habitat or a forest plant may fail to establish in the new environment.

Our three basic landscape elements were as follows:

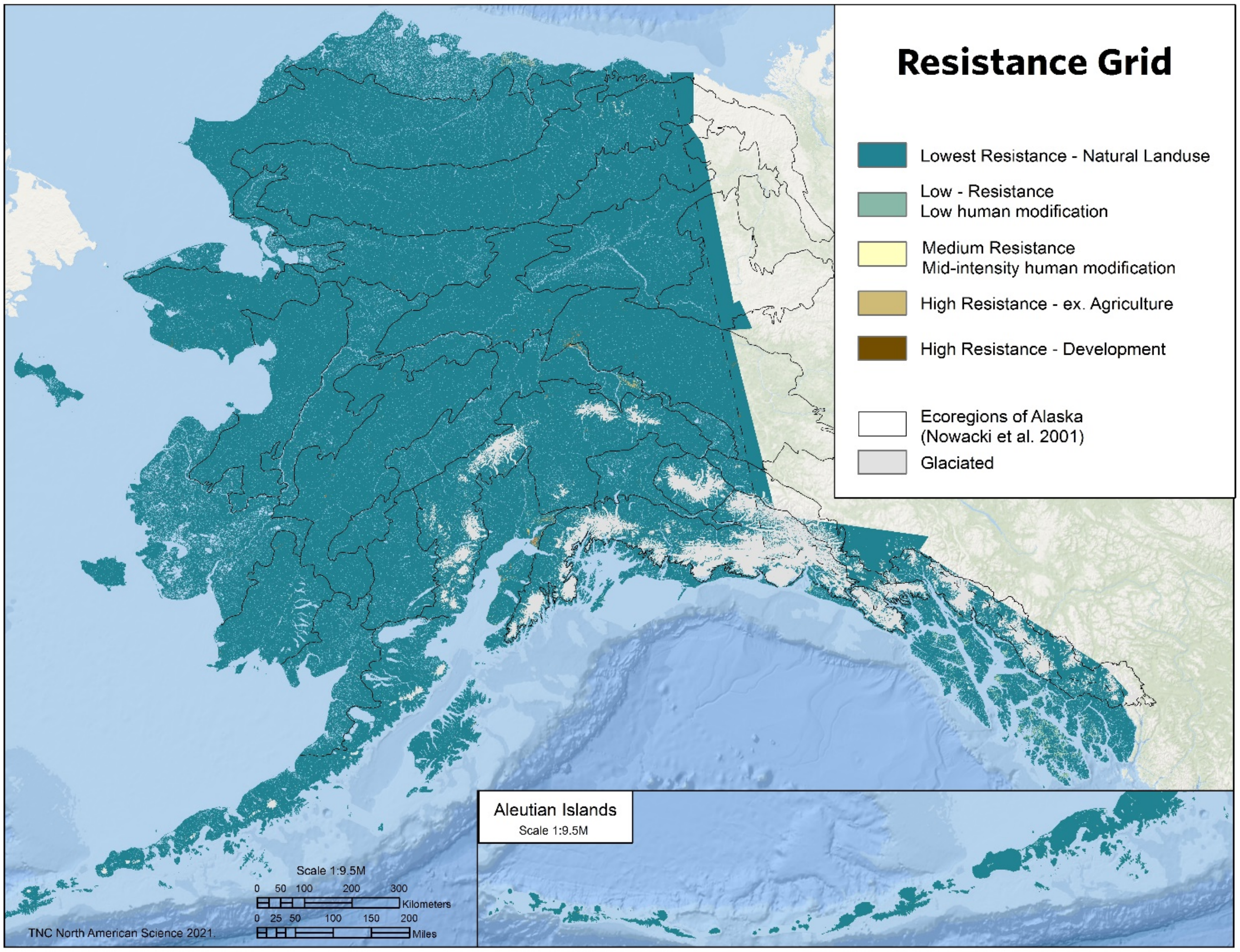
Natural lands: landscape elements where natural processes are unconstrained and unmodified by human intervention such as forest, wetlands, or natural grasslands. Human influences are common, but are mostly indirect, unintentional, and not the dominant process.

Agricultural or modified lands: landscape elements where natural processes are modified by direct, sustained, and intentional human intervention. This usually involves modifications to both the structure (e.g., clearing and mowing), and ecological processes (e.g., flood and fire suppression, predator regulation, nutrient enrichment).

Developed lands: landscape elements dominated by the direct conversion of physical habitat to buildings, roads, parking lots, oil and gas wells, solar arrays, or other infrastructure associated with human habitation and commerce. Natural processes are highly disrupted, channeled or suppressed. Vegetation is highly tended and controlled.

We used the same anthropogenic resistance grid that was created for local connectedness analysis with the exception of roads (See Chapter 3). Unpaved minor roads create little resistance for regional movement, so we removed them from the resistance grid, but kept the major roads and development which create barriers for regional connectedness (Figure 7.1).

Figure 7.1: Anthropogenic resistance grid used in the Circuitscape analysis. The figure shows the improved and integrated land cover map with each cell reclassified to its assigned resistance score.



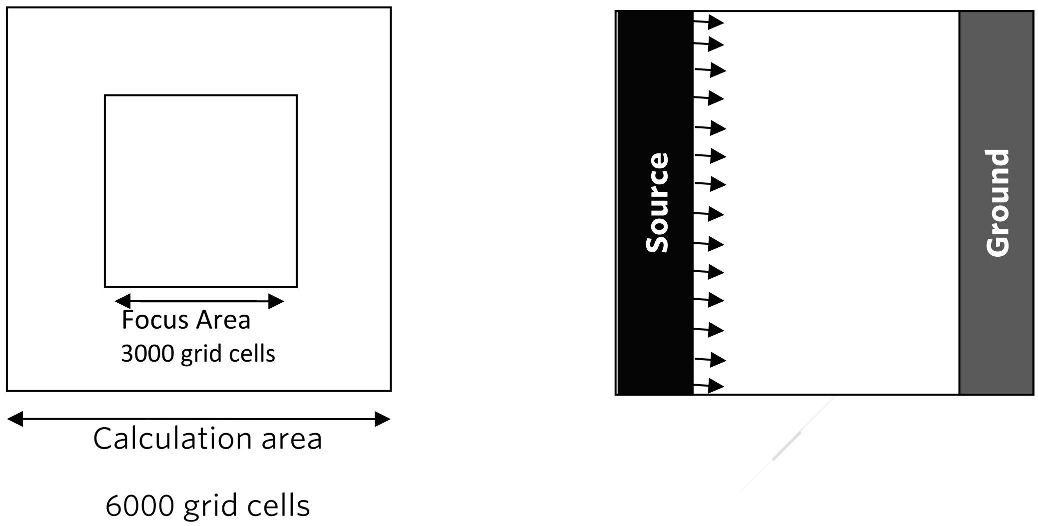
Mapping Regional Flow

Circuitscape was originally designed to measure point-to-point connectivity, calculating resistance-based connectivity metrics from one discrete patch to another. The point-to-point approach has been widely used in conservation planning to measure the connections between two patches of suitable breeding habitat as defined by the precise needs of a species (Beier et al. 2011). However, using a point-to-point approach can limit the utility of assessing connectivity over very large areas, or in evaluating the response of populations to climate change where there are so many habitat patches of interest that assessing connectivity among all possible combinations is prohibitive. Additionally, the point-to-point method is sensitive to the location of the starting points and may produce different results across the same landscape if different starting points are used. To overcome these conceptual and practical limitations, we used a minor adaptation of the Circuitscape model that allows for the "point free" creation of omnidirectional connectivity maps illustrating flow paths across large study areas. Our methods have been developed and refined over several years and were originally described in Anderson et al. (2013) and Pelletier et al. (2014).

Briefly, to obtain a multi-directional and wall-to-wall coverage of the region we ran the model in gridded landscape tiles where one whole side of the tile was assigned to be "source" and the other side to be "ground." Next, "current" was injected along the entire source side and allowed to flow across the landscape resistance surface towards the ground side. As the current flows it reveals the various flow pathways and highlights where flow gets blocked or concentrated. Because current seeks the path of least resistance from the source cells to any grid cell on the ground side, a run with the west edge as source and the east side as ground will not produce the same current map as a run with the east edge as source and west edge as ground. Runs were thus repeated in each of four directions: east to west, west to east, north to south, south to north, and summed across all directions. Lastly, we clipped out the central quarter of each tile (focus area in Figure 7.2) and joined it to the central regions of all the other tiles. This last step was done because testing had shown that the central quarter gave stable, repeatable, and consistent results regardless of the size of the calculation area. In contrast, the outer margins of the tile had considerable noise in the results created by the tile's exact boundaries. All calculations were performed using the latest version of Circuitscape in Julia with a cell size of 180 meters.

To run the analysis, we developed a systematic processing method and then used Python scripting to automate the process. First, the study area was divided into 15 tiles - calculation areas - comprised of 8000 cells by 8000 cells or roughly 2.07 million square kilometers. Each tile was intersected with the resistance map and the analysis was run as described above. All tiles with land cover information were included except for those that were 100% water (ocean).

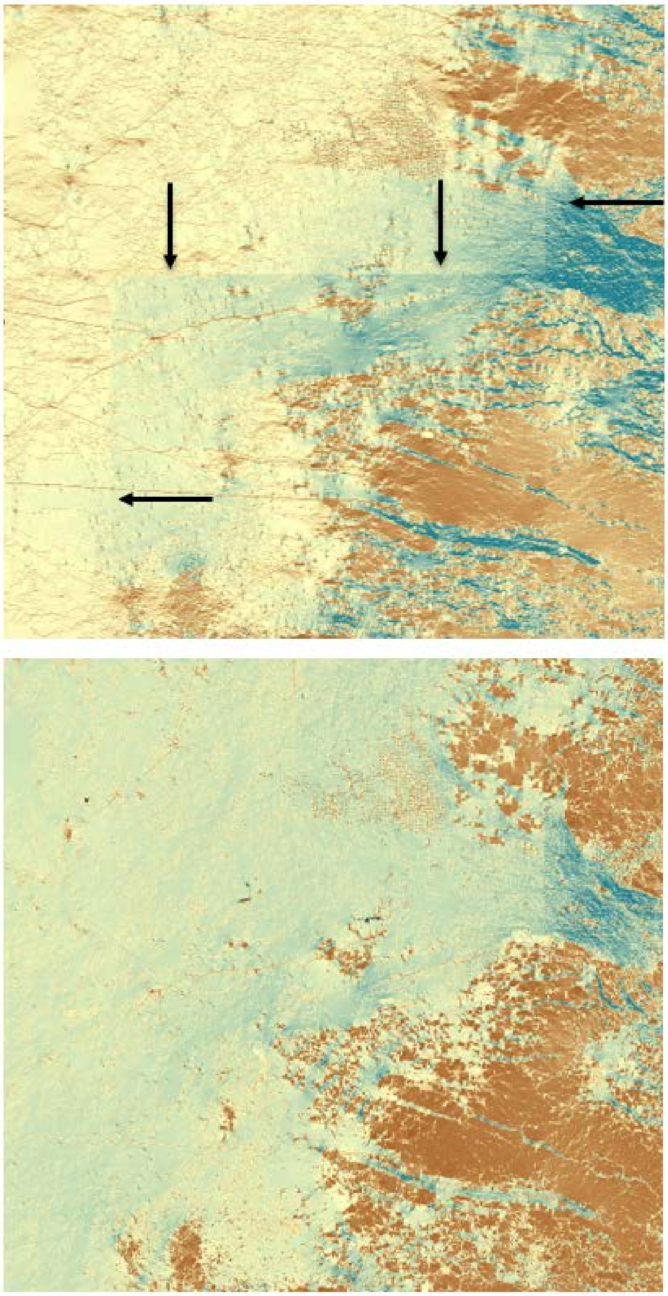
Figure 7.2: Diagram of tiles used in the Circuitscape analysis.
The image on the left shows the focus area in comparison to the calculation area. The image on the right shows how current is injected from every cell on the source (on the left) and can flow to any cell in the ground (right).



To inject current in the tile with coastal regions, where a proportion of the tile was filled by ocean or Great Lake, we used a method developed by Jeff Cardille of McGill University (personal communication, December 2015) to fill in the surface. We created a random raster with the same mean and standard deviation as the land resistance and replaced the large waterbodies with this random raster on the resistance grid. When current is injected along the "water" side of the tile it runs equally along the grid until it encounters a shoreline, allowing for equal current flow potential for coastal areas.

Lastly, the focus area was clipped out of each tile and joined together to create a single continuous coverage for the region. To standardize the scores across tiles, a cell of overlap was retained between all adjacent focus areas. Theoretically the scores within the overlap area should be the same between two adjacent tiles since they are the same area. To enforce this, the neighboring cell's score was adjusted so the overlapping areas had the same mean score as the starting tile, and this was repeated for all cells starting at the center and working outward in a starburst pattern. This created a more seamless surface than our previous method (Anderson et al. 2013) of using a standard normal transformation (Z-scores) to convert focus areas to the same scale and then joining the focus areas together (Figure 7.3). That method had minimized differences between areas that had very different mean scores such as a largely agricultural focal area adjacent to a largely natural focal area.

Figure 7.3: Edge mapping overlap. The figure on the top shows the artifacts of tiling on the middle bottom tile. The bottom figure shows the same tile with the edge artifacts smoothed out.



Regional Flow Results and Patterns

The map of wall-to-wall regional flow applied to the anthropogenic resistance grid highlights areas of highest flow in dark blue, areas of moderate flow in medium blue, and areas of blocked or low flow in brown (Figure 7.4 & 3.5). To symbolize the results in this very natural landscape, we used a similar method as we described for local connectedness (Chapter 3). When the score was above-average the classification were based on quantiles for the Rocky Mountain and Desert Southwest. When the score was below-average the values for the lowest two quantile breaks were based off the quantiles for a larger western area that included the Great Plains. This created a more accurate representation of the distribution of developed land.

A particularly useful feature of the wall-to-wall results is that they reveal spatial patterns in current flow that reflect how the human-modified landscape is configured (Figure 7.6). The results allow you to identify where population movements and potential range shifts may become concentrated or where they are well dispersed, and it is possbile to quantify the importance of an area by measuring how much flow passes through it and how concentrated that flow is. The four prevalent flow types found here each suggest a different conservation strategy:

- Diffuse flow: areas that are extremely intact and consequently facilitate high levels of dispersed flow that spreads out to follow many different and alternative pathways. A conservation aim might be to keep these areas intact and prevent the flow from becoming concentrated. This might be achievable through land management or broad-scale conservation easements.
- Concentrated flow: areas where large quantities of flow are concentrated through a narrow area. Because of their importance in maintaining flow across a larger network, these pinch points are good candidates for land conservation.
- Constrained flow: areas of low flow that are neither concentrated nor fully blocked but instead move across the landscape in a weak reticulated network. These areas present large conservation challanges. In some cases restoring a riparian network might end up concentrating the flow and creating a linkage that will be easier to maintain over time.
- Blocked/Low flow: areas where little flow gets through and is consequently deflected around these features. Some of these might be important restoration areas where restoring native vegetation or altering road infrastructure might reestablish a historic connection.

Alaska has very little human development. Most of the state is in average flow (yellow in figure 7.4, -0.5 to 0.5 sd). We classify this flow as diffuse flow. Flow gets higher as it accumulates around developed areas and glaciers (blue in 7.4, >0.5sd). This flow is classed as concentrated flow. Areas of low flow (brown in figure 7.4, <-0.5 sd) are areas of urban areas and agriculture. These areas area classed as blocked flow.

Figure 7.4: Results of the wall-to-wall Circuitscape model applied to the anthropogenic resistance grid. Brown indicates areas with low permeability. Medium blue indicates areas of moderate flow; often highly natural settings where species movements are diffuse. Dark blue indicates areas of concentrated flow where movements will accumulate or be channeled.

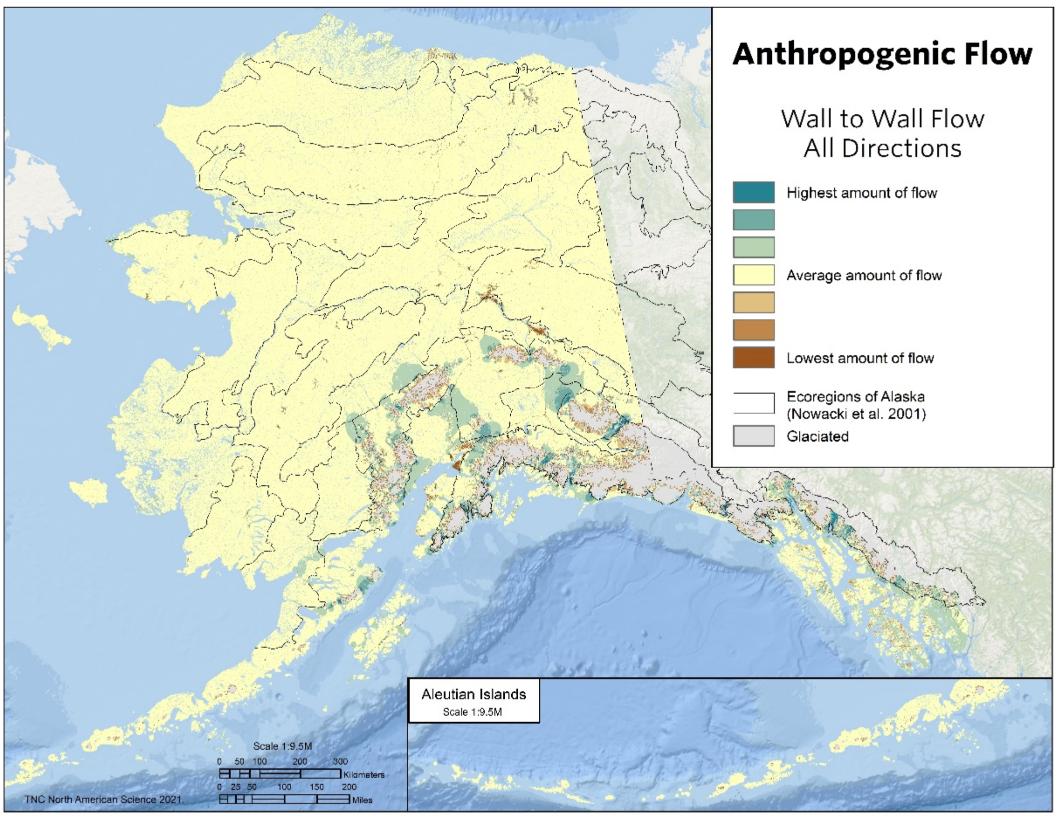
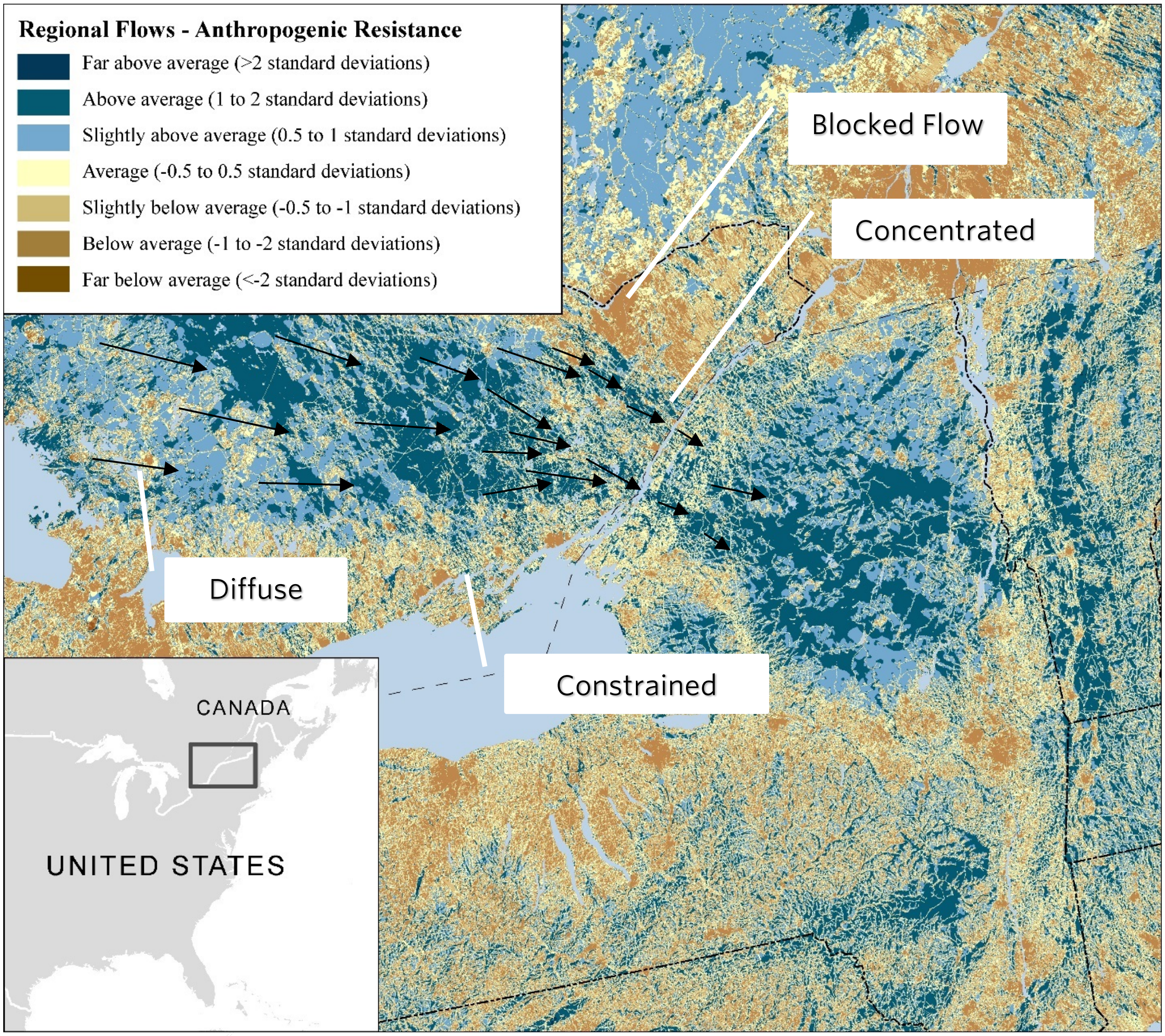


Figure 7.5: Flow types. This figure shows how the four flow types reflect the dynamics of a moving population over time. Location: St Lawrence Valley between the Algonquins and the Adirondaks.



Climate Flow

This section describes how we modified the regional flow model to specifically highlight connections that provide climate relief. Paleoecological studies show that movement was a near universal response to past changes in climate (Pardi and Smith 2012), but not every directional movement provides equivalent climate relief. Although all parts of the landscape are important in allowing and maintaining population movements, current evidence suggest that areas that offer cooler temperatures or higher moisture are particularly critical in providing local relief from a warming climate. Our goal was to evaluate how these features are arranged on the landscape and whether access to them is limited or prevented by fragmentation, or conversely enhanced by the contours of the topography. We refer to the regional flow analysis informed by features with strong climatic gradients: **climate flow**. In the previous section we defined "regional flow" as the gradual movement of populations tracking a set of changing conditions over time, and here we define the term "climate flow" to refer to specific directional movements in response to temperature and moisture changes.

A variety of approaches to incorporating climate gradients into connectivity models have been developed. The most straightforward are models that directly connect temperature gradients based on global or national climate data (see McGuire et al. 2016). The climate gradient approach is logical and promising but is currently hindered for our purposes by the coarse scale of the temperature models (typically 1 km or larger). The issue is that these models don't contain the fine-scale topography and microclimate relief that create the local climate environments experienced by most species. Here, we explore climate gradients at a finer scale, and in lieu of fine-scale climate data, we tie the models directly to local landscape features and observed evidence.

In response to climate change, populations are already moving at impressive rates: 3.6 ft. upslope per year and 1.1 miles northward per year in US metrics (Chen et al. 2011, Table 7.1). A recent study of eastern trees using US Forest Inventory data found many common species have shifted significantly in range just over the last 30 years: Paper birch (16 miles northward), Black Oak (13 miles northward), Red Oak (10 miles northward). Evidence for contemporary range shifts in response to climate has now been documented for over 1000 species, and can provide insight into the structure and direction of these movements. In response to temperature, the evidence for upslope and northward movements is strong and consistent across many taxa groups and across several continents. In response to moisture and precipitation changes there is rapildy growing evidence for the important role of downslope basins and riparian areas, as well as for eastward movements in some parts of the US. We summarized this evidence at the start of this chapter, and following the findings in the research litererature we focused our attention on four well documented responses of species movement to climate change:

Directional

1) **Upslope** toward higher elevations,
2) **Downslope** toward moist basins or riparian areas
3) **Northward** toward cooler latitudes,

Non-directional

4) **Locally** toward suitable microclimates.

In this section, we model the movement patterns expected from these responses and integrate them into the regional flow map. As with the regional flow map, we incorporate the arrangement and resistance of fragmentation and other human modifications into each model to explore the implications of such modifications on directional movements driven by climate change.

We integrate the directional factors into the flow map as a boost, and not as a fixed determinate of movement. Although the evidence shows that these factors are correlated with population expansions and range shifts, it is also clear that a variety of ecological factors may create variation in a species response to climate such as competitive release, habitat modification, or changes in amounts and patterns of precipitation, snow cover duration, water balance, or seasonality (Groffman et al. 2012). Our decision to give weight to these factors but not to override the other drivers acknowledges that many things might cause a range shift to differ substantially from straightforward poleward or upslope movement largely driven by temperature or moisture (Garcia et al. 2014) .

The wall-to-wall Circuitscape approach is well suited to exploring and mapping climate flow because it assumes that every cell in the region is a starting point for some species and the directional movement along elevation gradients could be conceived in terms of resistance, or latitudinal movement as source-ground flow. In the following sections we first look at 1) upslope movement primarily driven by temperature change, and 2) downslope movement primarily driven by moisture changes and 3) northward movement driven by regional temperature gradients. Finally, we integrate these factors into the regional flow model to create a map of climate flow.

Upslope Model: Local Temperature Relief

Chen et al.(2001) detected upslope elevational range shifts for plants, herptiles, mammals, and invertebrates with magnitudes ranging from 6.1 m to 11.0 m per decade. Upslope movement by birds has not been consistently detected, although Tingley et al. (2012) found significant upslope shifts in communities of birds. For immediate climate relief, moving upslope is more efficient than moving latitudinally in temperate regions because there is roughly a -1.7^{0} C (-3^{0} F) temperature change for every 1,000′ increase in elevation. That is equivalent to a 483 km (300-mile) change northward in latitude. Upslope movement has limitations as a long-term strategy because the extent of available habitat may be restricted or the habitat itself may be unsuitable for some species because it is dryer, more exposed or may have thinner soil. Still, the evidence for upslope movement seems overwhelming (Lenoir et al. 2010).

To model upslope movement we created a 30-m continuous landform model based on each cell's relative land position and slope (Anderson 1999, Anderson et al. 2012). We converted this to a resistance grid by first isolating the relative land position value and assigning increased resistance to moving downslope and decreased resistance to moving upslope. Next, we modified the resistance score using the cell's slope value, to reflect the relative degree of effort versus gain in temperature differences (Table 7.2). For example, moving upward along a gentle slope is easy but provides little gain in temperature differences (moderate resistance), moving upward along a moderate slope provides larger gains in temperature differences for moderate effort (low resistance), moving upward along a steep slope is too difficult for most species despite the temperature gains (high resistance, Figures 7.6 and 7.7). Finally, the resistance on cooler aspects was reduced slightly with respect to warmer aspects (Table 7.2). We combined the land position and slope values into one resistance score.

Although mountainous areas may produce the largest amount of pure elevation change, species also experience temperature relief from slopes relative to their local landscape (e.g., a 10-m slope in a flat landscape may provide more relief to nearby species than a 10-m slope in an already mountainous landscape). To ensure that the model was upslope resistance grid was scaled to both local relief and larger regional relief we calculated both a regional resistance score and a local neighborhood resistance score around each cell and then integrated them. For regional relief we calculated the absolute amount of upslope resistance in a 3 km focal area around each cell and converted it to a Z-score using the mean and standard deviation for the whole region. For local relief, we used the same focal statistic algorithm to calculate the mean and standard deviations of upslope resistance for a 3 km radius around each cell and converted the flow to a Z score using only these local means and deviations. The regional and neighborhood resistance Z scores were combined by adding the two grids. We were aiming to give them equal weight, highlighting areas of both absolute upslope flow and neighborhood upslope flow, but the distributions of the two datasets were very different such that the local neighborhood resistance score overwhelmed the regional score. To correct for this, we gave twice the weight to the regional resistance grid. The results provide a single upslope resistance grid that was a weighted combination of regional and local resistance.

Table 7.2: Resistance scores applied to the landform model. Land position ranks (LP rank) were ordered so they decrease towards higher land positions. Slope (S-rank) were ordered so that they increase at the extremes of no slope (no temperature gain) and steep slopes (too difficult to transverse) and are lowest at moderate values.

Landform	code	Slope	Position	LP rank	S rank	Sum	Weight
Steep slope	3, 4	4 High	any	NA	9	18	9
Cliff	5, 6	5 Highest	any	NA	10	20	10
Flat summit/ Ridgetop	11	1flat	highest	1	7	8	4
Slope crest	13	3mod	highest	1	1	2	1
Gentle slope	22	2gentle	high	4	4	8	4
NE sideslope	23	3mod	high	4	1	5	2
SW sideslope	24	3mod	high	4	1	5	2.5
Lower Slope	25, 26	3mod	low	7	1	8	4
Valley/toeslope	32	2gentle	low	7	4	11	5.5
Dry flat	30	1flat	low	7	7	14	7
Wetland	31	1flat	low	7	7	14	7
Slopebottom flat	41	1flat	lowest	10	7	17	8.5
Slopebottom	42	2gentle	lowest	10	4	14	7
N-cove	43	3 mod	lowest	10	1	11	5
S-cove	44	3 mod	lowest	10	1	11	5.5
Floodplain	35,36,37,38	1flat	Low	7	7	14	7

Figure 7.6: Conceptual model: How a species population (black arrows) might move upslope and northward over five generations.

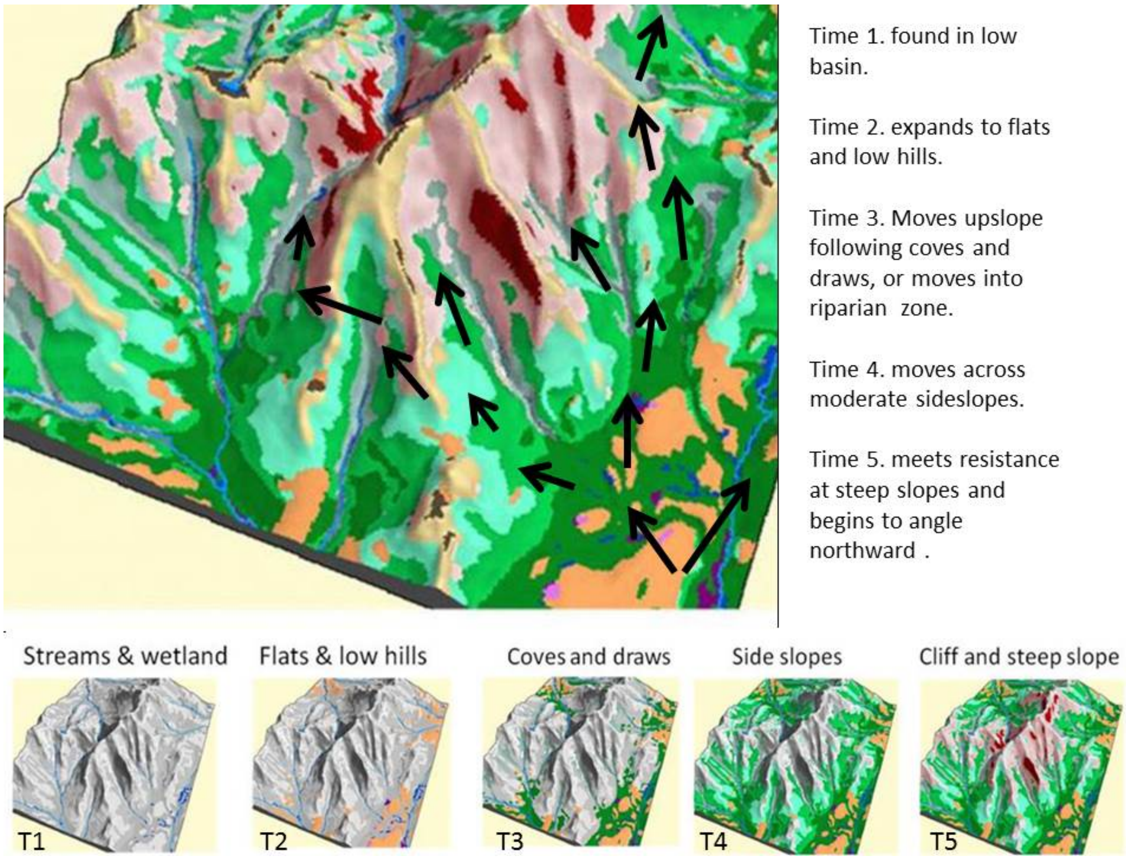
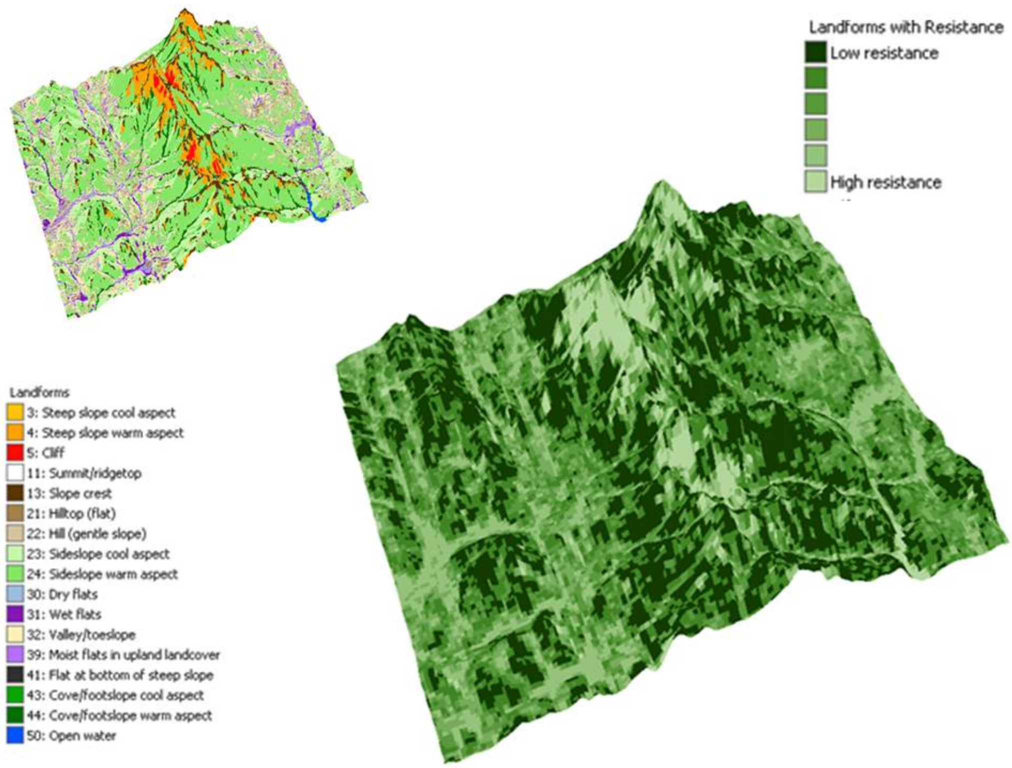


Figure 7.7: The resistance scores applied to the landform model. This picture shows a three-dimensional model of Mt Mansfield in Vermont. The left image shows the landform model. The second image shows the resistances where low resistance corresponds to areas with the most temperature gain for the least effort (moderately steep sideslopes). Flat valley bottom and steep slopes have higher resistance.



To incorporate anthropogenic resistance, we combined the upslope resistance grid with the anthropogenic resistance grid weighting the scores so that the final resistance score of each cell was 50% from the upslope resistance value and 50% from the anthropogenic resistance value. Glaciers present a major barrier to movement. We overrode the value of the combined resistance grid with a high resistance of 9 to all of the areas that have glaciers. In Circuitscape, we ran current through the combined upslope/anthropogenic resistance grid in all directions (as described previously for the regional flow model) to create an output of upslope current flow incorporating anthropogenic resistance (Figure 7.8).

The upslope model highlights areas with high potential for upslope range shifts are arranged locally and across the region (Figures 7.8 and 7.9). The realistic effect of the local scaling (Figure 7.9) is to create a much more distributed picture of where upslope movements may be available to species for local climate relief. This takes the emphasis off the mountains and highlights a wide range of moderate slopes that might play a large role in providing local climate relief (Figure 7.9).

Figure 7.8: The Upslope Model applied to the Study area.

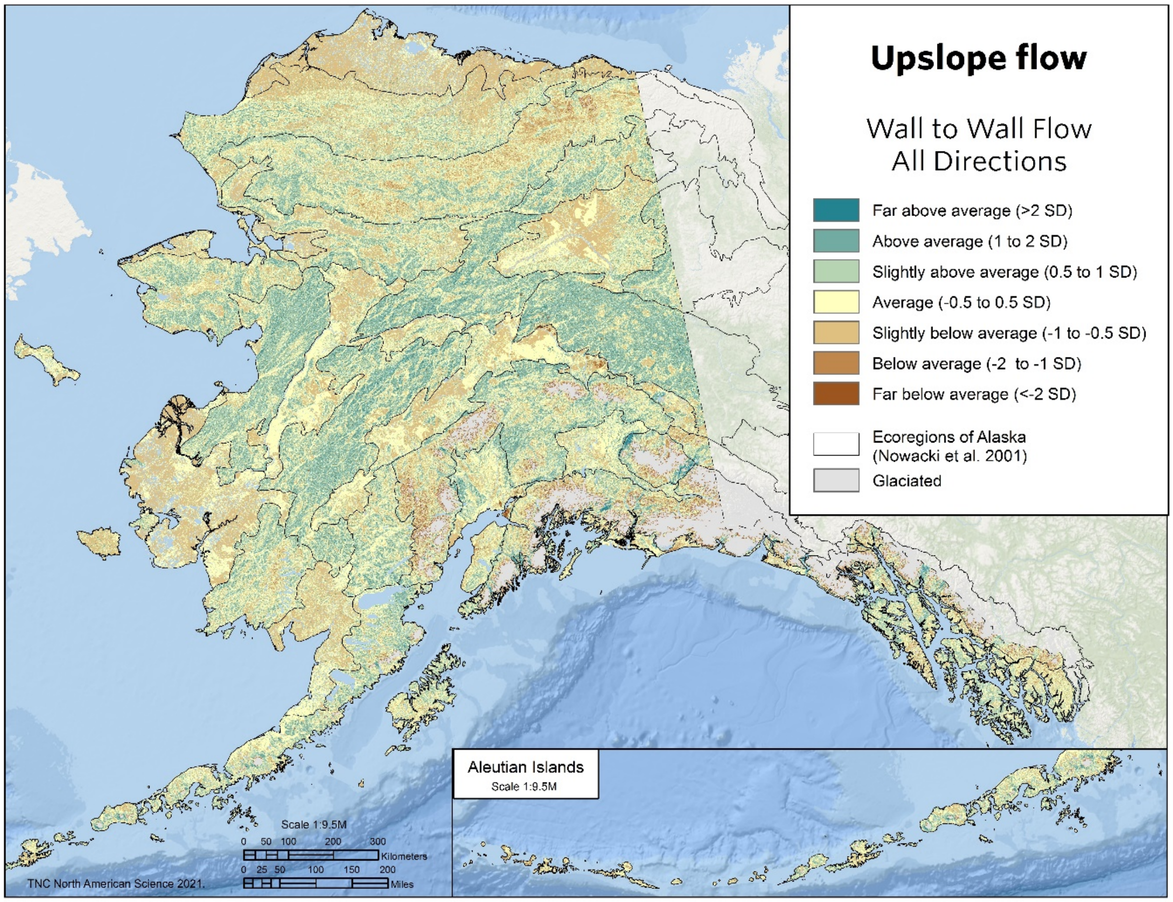


Figure 7.9: Zoom in of upslope model in Mertie Mountains located in the Yukon-Charley Rivers National Preserve. The map shows flow going upslope from the valleys to the uplifted mountain ranges.

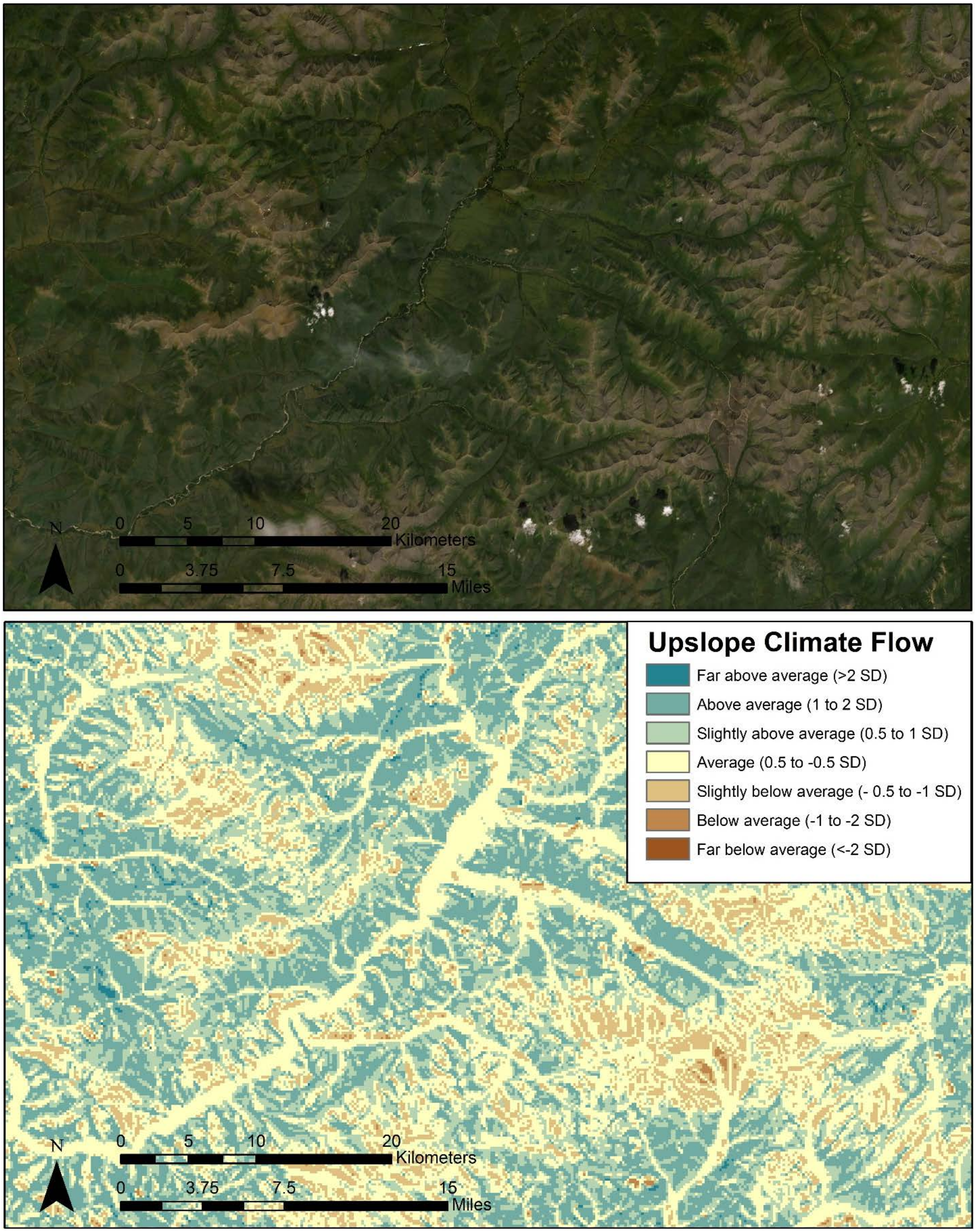
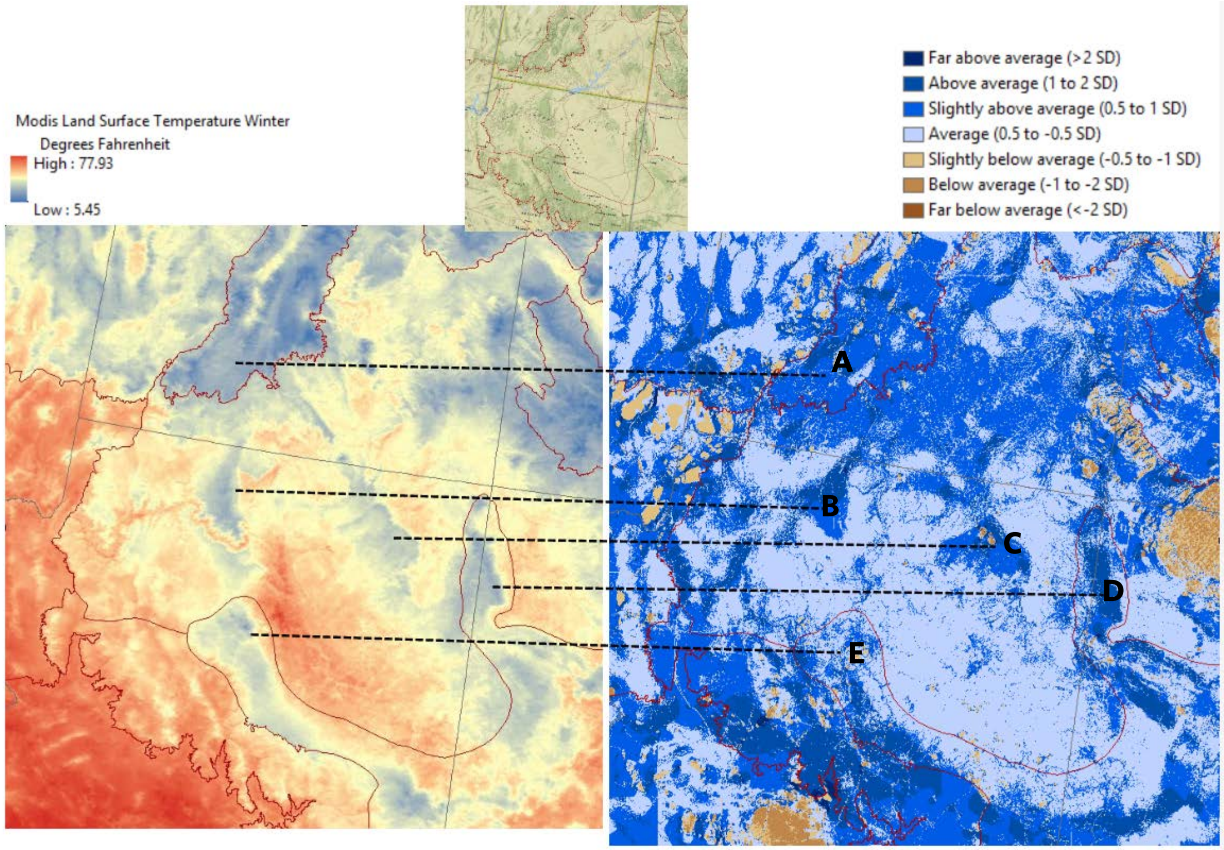


Figure 7.10: Comparison of upslope model with land surface temperature (LST). This figure shows the correspondence between the topography and surface temperature in fall for the Sandhills regions of the central US. The LST model is MODIS (MOD11A2.006) Terra Land Surface Temperature and Emissivity Winter mean at a 1km scale for September 2018. Although the scale of the LST model is coarse, local cool spots can be seen to correspond with the topography and the upslope model especially in: A) Sevier Plateau; B) Kaibab Plateau north of the Grand Canyon; C) Black Mesa; D) Ohuska Mountains; E) San Francisco Plateau and Peaks



Downslope Model: Access to Local Moisture

Introduction and Background

A recent study of eastern trees found changes in moisture availability had significantly stronger near-term impacts on vegetation dynamics than changes in temperature (Fei et al. 2018). Downslope areas collect water and feature microclimates that may be significantly moisture and cooler the surrounding landscape (Olsen et al. 2007).

As the climate becomes warmer and drier, species are expected to move downslope into cooler and moisture regions, and this pattern has been well documented (Archaux 2004, Popy et al. 2010). A survey of such range shift studies suggests that while roughly 65% of species have shifted their ranges upslope, 25% have shifted their ranges downslope, (Lenoir et al. 2010). Similarly, a global review of the literature suggests that about 20% of species have adjusted their ranges towards lower elevations (Parmesan & Yohe 2003). Long-term downhill shifts in the optimal elevations of plant species has been shown for California, apparently in response to decreased climatic water deficit (Crimmins et al. 2011). Our own spatially explicit climate resilience analysis (Anderson et al. 2013) which was based on microclimates and connectedness, identified many slope bases and riparian areas as critical parts of the landscape due to the presence of many microclimates.

Riparian areas, near where water collects, are usually a minor proportion of any landscape but they serve and outsize role in facilitating adaptations. Typically, they are structurally diverse and more productive than adjacent upland areas and have the unique characteristic of connecting many parts of the landscape. They serve as migration routes and connectors between habitats for a variety of wildlife, particularly within highly modified landscapes (Hilty & Merenlender 2004). In addition to their connectivity functions, riparian areas are important in mitigating nonpoint source pollution, removing excess nutrients and sediment from surface runoff and ground water. Riparian vegetation modifies the temperature conditions for aquatic plants and animals, stabilizes streambanks, mitigates flooding, and contributes to the health of adjacent freshwater habitats (Pusey & Arthington 2003).

In a previous study (Anderson et al.2013) we identified distinct riparian climate corridors (RCC) for the Eastern US and measuring a variety of characteristics about each RCC unit such as its size, length, intactness, temperature change. That work was inspired by Krosby et al. (2014) analysis for the Pacific Northwest where they identified potential riparian areas that spanned large temperature gradients, had high levels of canopy cover, were relatively wide, had low solar insolation, and low levels of human modification – characteristics expected to enhance their ability to facilitate climate-driven range shifts and provide microclimatic refugia from warming.

Here, we present a new approach that measures the potential contributions of downslope movement continuously across the whole landscape, rather than identifying individual corridors and summarizing their attributes. As with upslope movement, we evaluated where downslope movements were likely to concentrate or where they facilitate high current flow. This new approach emphasizes downslope and riparian areas as collectors of climate-driven movement from the surrounding landscape. It decreases the emphasis on directional movement within the riparian areas, although many of the resulting corridors traverse and connect large parts of the landscape and may facilitate movement for many species. We hypothesized that species could experience additional moisture, deeper soils, and local temperature relief by moving into these relatively lower areas.

Mapping Downslope Movement

To model downslope movement, we first identified areas that were down-gradient and lower in elevation than the surrounding landscape. We did this by creating a continuous 30-m dataset that assigned a relative elevation value to every cell by comparing its elevation to its neighbors within a 3 km neighborhood (the same radius used calculate upslope local flow and to calculate local connectedness in the resilience analysis). We used a focal statistic to calculate the mean and standard deviations of the elevations within a 3 km radius, and then calculated a Z-score for each cell based on the neighborhood mean and standard deviation. Values below the mean were lower than their neighborhood and values higher than the mean were higher in elevation than their neighborhood, and these values became the resistance values.

We used the Z-Scored relative elevation surface as a resistance grid in Circuitscape to force current to flow more easily into and throughout the downslope areas as they had less resistance. To give additional benefit to flow in moist areas, we integrated the landform model (described earlier in this section) into the resistance grid and further lowered the Z score within moister landforms. Areas of coves, pluvial moist flats, and wet flats were extracted from the landform dataset and their Z-Score was lowered. Alluvium settings were lowered to one quarter -0.25 standard deviations below average, wetland landforms were lowered to one half -0.5 standard deviations below average, and wetlands and wetflat landforms were lowered to -1.0 standard deviations below average if the elevation-based Z score was not already less than theses scores. This lessened the resistance slightly in moist and wet areas allowing current to flow more easily. The lowest part of the landscape and the area with the most moisture are the floodplains. Floodplain landforms were given the lowest resistance score of all, -3.5 sd. This moisture enhanced Z-scored resistance surface was used as the downslope resistance grid in further Circuitscape flow modeling.

We tested the model in Circuitscape by running current through it in all directions (as described for the regional flow model) to create an output of “current” flow based on the downslope and moisture-enhanced resistance surface. The output tracked downslope moisture patterns at a fine scale, but at this point did not account for any anthropogenic modifications of the landscape.

To create an integrated final downslope model that included human uses, we combined the downslope, moisture-enhanced resistance grid with the anthropogenic resistance grid to create a resistance surface that favored moving downslope but was sensitive to anthropogenic barriers. This was achieved with a 50/50 weighting of downslope resistance and anthropogenic resistance.

The Circuitscape analysis on the resultant resistance grid shows how the areas with high potential for downslope and moist range shifts are arranged locally and across the region, and how they intersect with anthropogenic resistance (Figures 7.11 -7.12).

The downslope model has very high flow accumulations in the valleys and streambeds, but we wanted to limit the extreme values in order to highlight the areas leading to these valleys and streambeds. To accomplish this, when Z-scoring the raw flow values we capped the z-score at 1.5 SD.

Figure 7.11: Downslope model. This map shows the results of the moisture-enhanced downslope model with anthropogenic resistance weighted at 50% and downslope flow weighted at 50%.

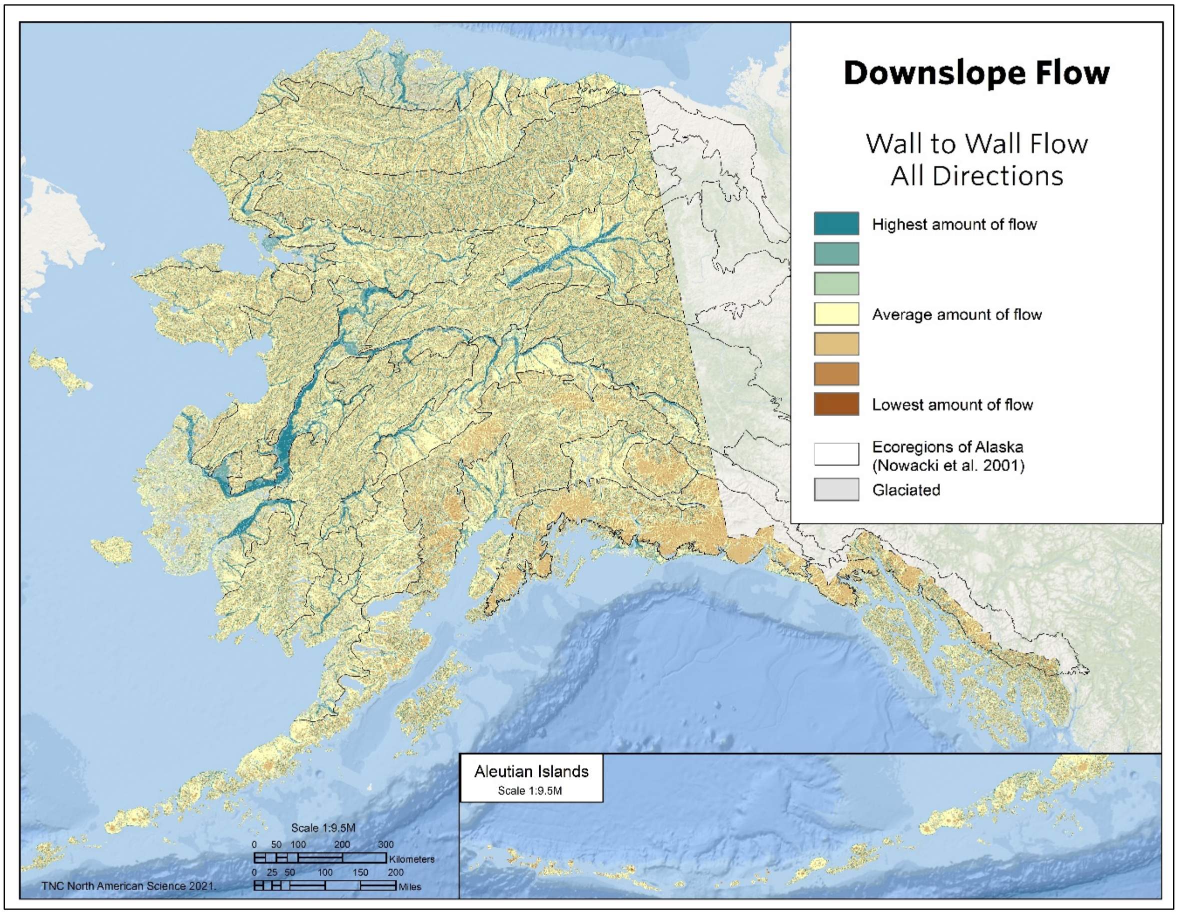
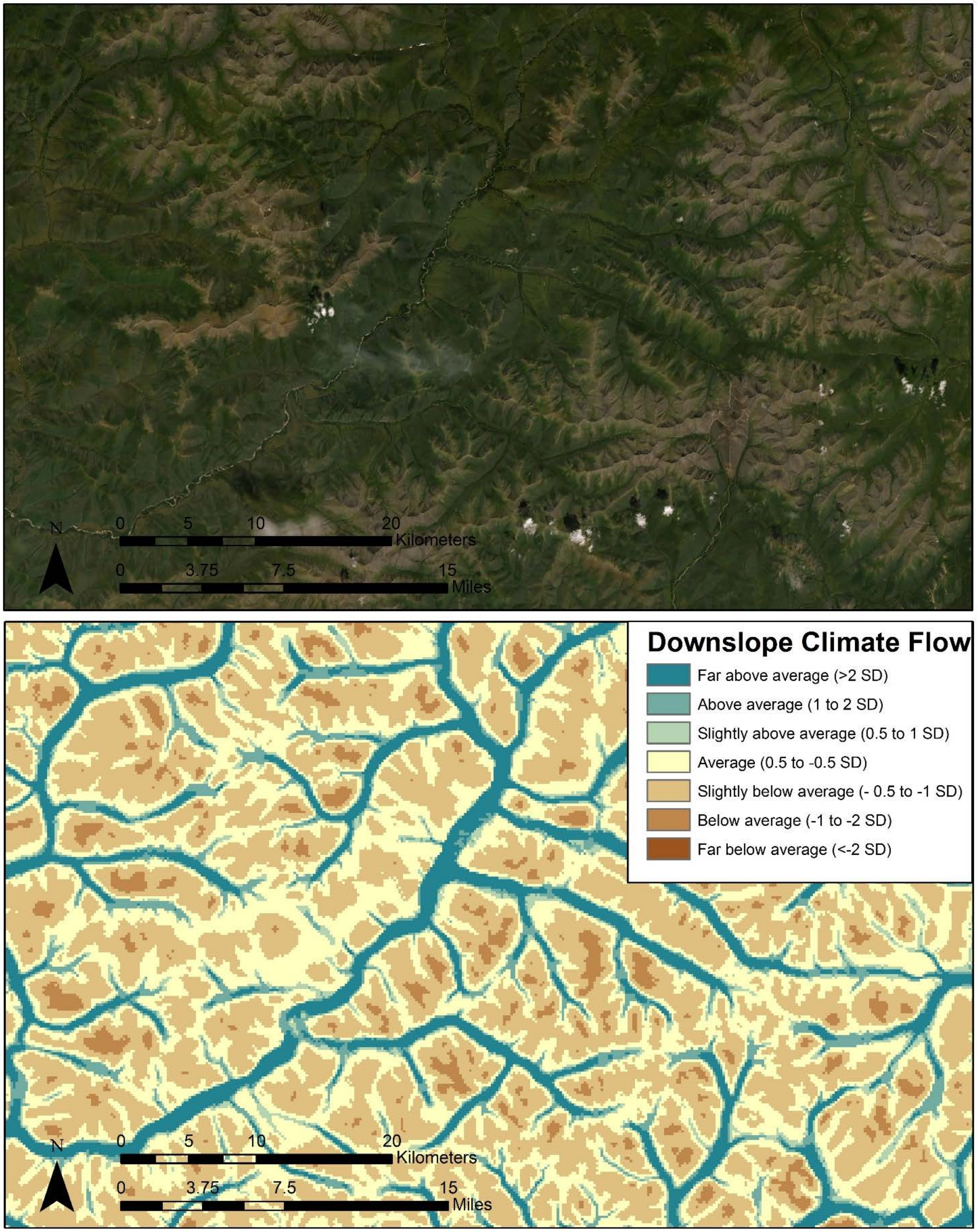


Figure 7.12: Zoom in of the Downslope Model. This map shows a zoom-in of the same area as 7.12 for Mertie Mountains located in the Yukon–Charley Rivers National Preserve. Downslope flow clearly tracks valley bottoms.



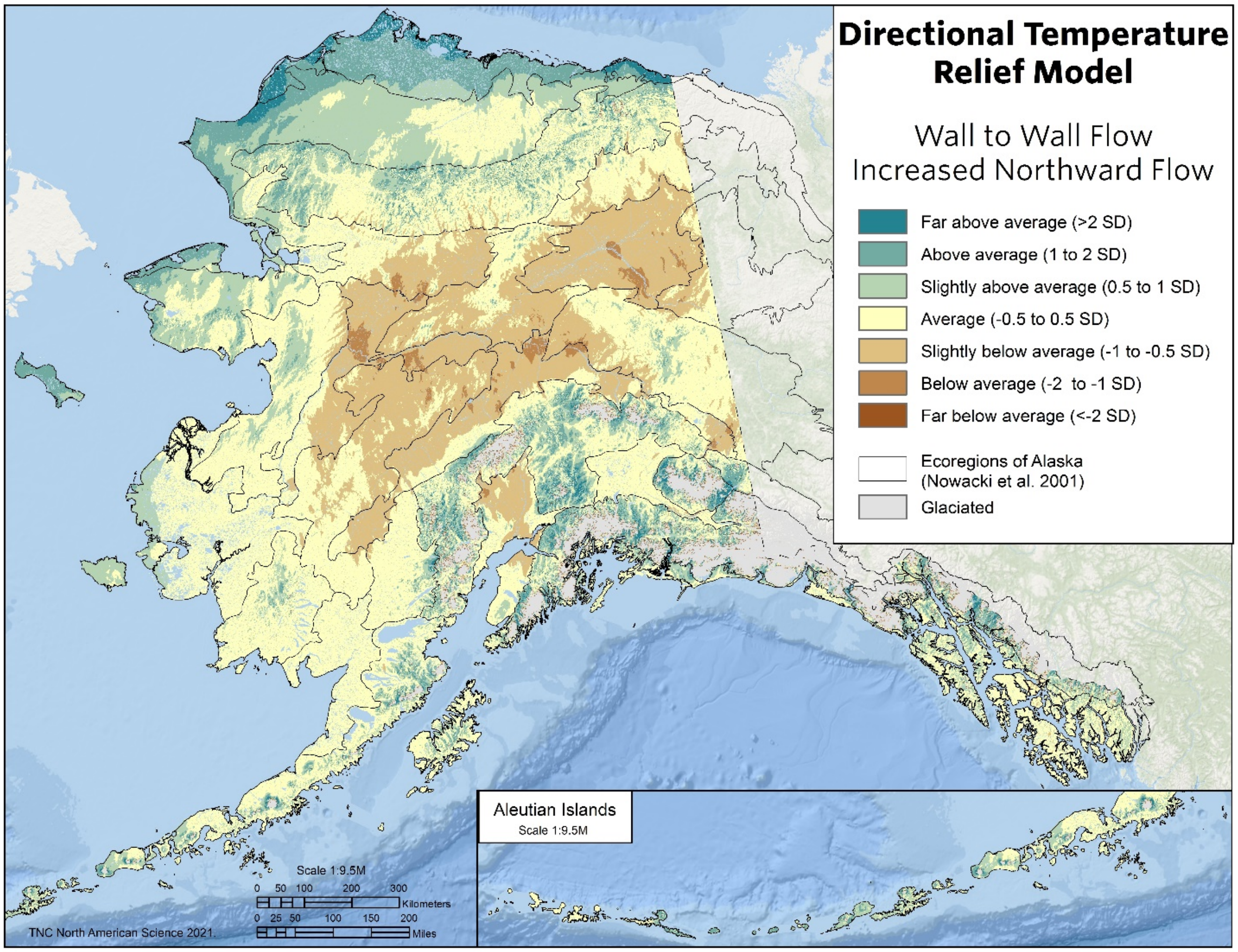
Directional Temperature Relief Model

Alaska's temperature does not follow a strict south to north gradient. In the summer, temperature varies geographically with coastal areas, the mountain ranges, and the far northern area being cooler, while the interior has the warmest mean monthly temperature. As species populations move and rearrange in a warming climate, we expect they will concentrate along climate gradients to cooler temperatures.

To model this geographic effect, we used summer mean temperature and distance to coast as the basis for resistance. For temperature, we used wall to wall PRISM data showing the mean temperature averaged for June, July, and August. To convert this to a resistance grid, a constant was added to the monthly temperature grid to make all the values positive (even in the summer, some areas of the mean monthly temperature are still freezing). This grid was used as resistances where the higher the temperature the higher the resistance. To reflect the cool coastal buffering, we calculated the distance of every cell from the coast and then binned the distances into 20 equal area bins. The amount and complexity of the coastline is such that binning the data into equal area bins results in more bins closer to the shorelines, giving more differentiation closer to the coast. The resistance for the temperature and distance to coast were transformed to Z scores and averaged to give both factors equal weight. Finally, we treated permanent glaciers as high resistance as snow and ice (though cold) can create resistance to movement due to exposure, wind chill and scarcity of food. We gave glaciers a resistance of 9.

Finally, we added latitudinal component into the climate flow model to simulate long-term climate relief for populations that expand or shift northward. We did this by modifying the four directional runs we used to develop the regional flow model (i.e., north to south, south to north, east to west, and west to east, see previous section for details) to emphasize the northward flows. We did this by combining the four individual runs so the north-south runs contributed 66% of the flow value and east-west runs contributed 33 % of the flow value (Figure 7.13).

Figure 7.13: Directional temperature relief model for Study Area. This map shows regional flow model with resistance based on temperature and distance from coast. The north-south movements are weighted 66% and east-west movements weighted 33%.



Final Climate Flow Model: Integration of Upslope, Downslope, and Directional Temperature Relief

For our final model, we weighted the regional flow model with the upslope, downslope and directional temperature relief models to simulate plant and animal populations moving through the natural landscape finding climate refuge both by moving up or down slopes and along climate gradients. The goal was to approximate a population expanding locally, first along upslope or riparian gradients, and then regionally along major temperature gradients.

We used the anthropogenic flow as the base map for climate flow. Areas of high anthropogenic flow (above average, >0.5 SD) such as areas around developed areas and through glacier passes were classified as concentrated flow, because flow concentrates in these areas. The majority of Alaska has diffuse flow (0.5 to -0.5 SD) where movement is unrestricted and can go in many directions.

Next, we added the areas of high climate flow along topopographic or geographically derived temperature gradients (upslope etc) to the anthropogenic flow map. We compared the flow scores for every cell. If the score from any one of the climate factors was above average (>0.5 SD) AND greater the anthropogenic flow score, we overroad the anthropogenic score with the climate factor score. If more than one climate flow model satisfied these criteria, the highest model value was used. This created integrated version of the two maps with the highest flow being intact natural areas with climatic gradients (Figure 7.15)

We categorized the climate flow as "diffuse flow (climate informed) if it added delineation to a diffuse flow area. If the climate flow was added in a concentrated flow area we categorized it as "concentrated flow (climate informed linkage)" (Figure 7.15 - 7.19).

Figure 7.15: Climate Flow model for Study Area. The results of a Circuitscape analysis applied to the regional flow grid and weighted for above-average upslope flow, downslope flow or directional temperature relief flow.

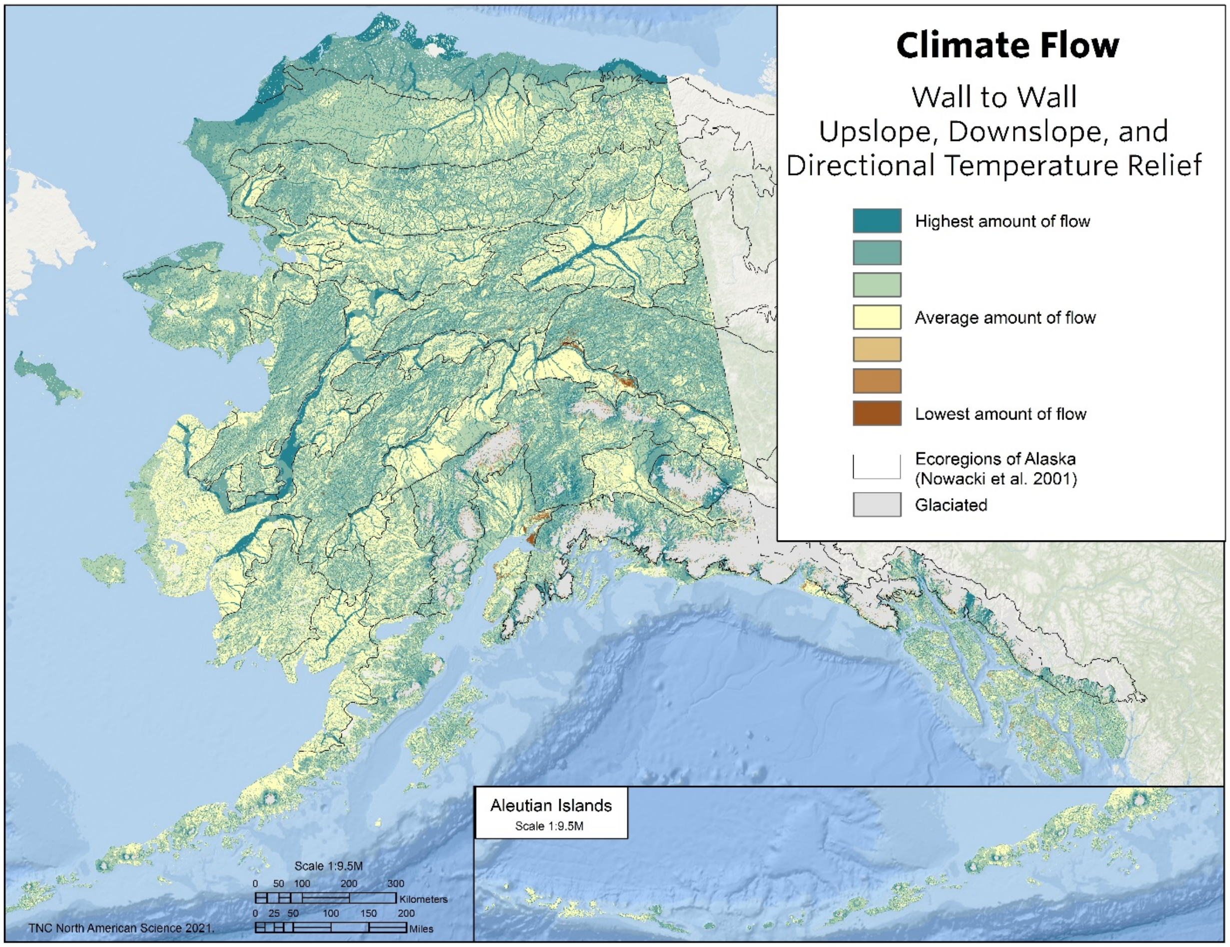


Figure 7.17: Comparision of results. These maps for Mertie Mountains located in the Yukon–Charley Rivers National Preserve compare the Circuitscape results for Regional Flow based on anthropogenic resistance only, with the enhanced versions that include upslope flow, downslope flow, directional temperature flow and the integrated Climate Flow.

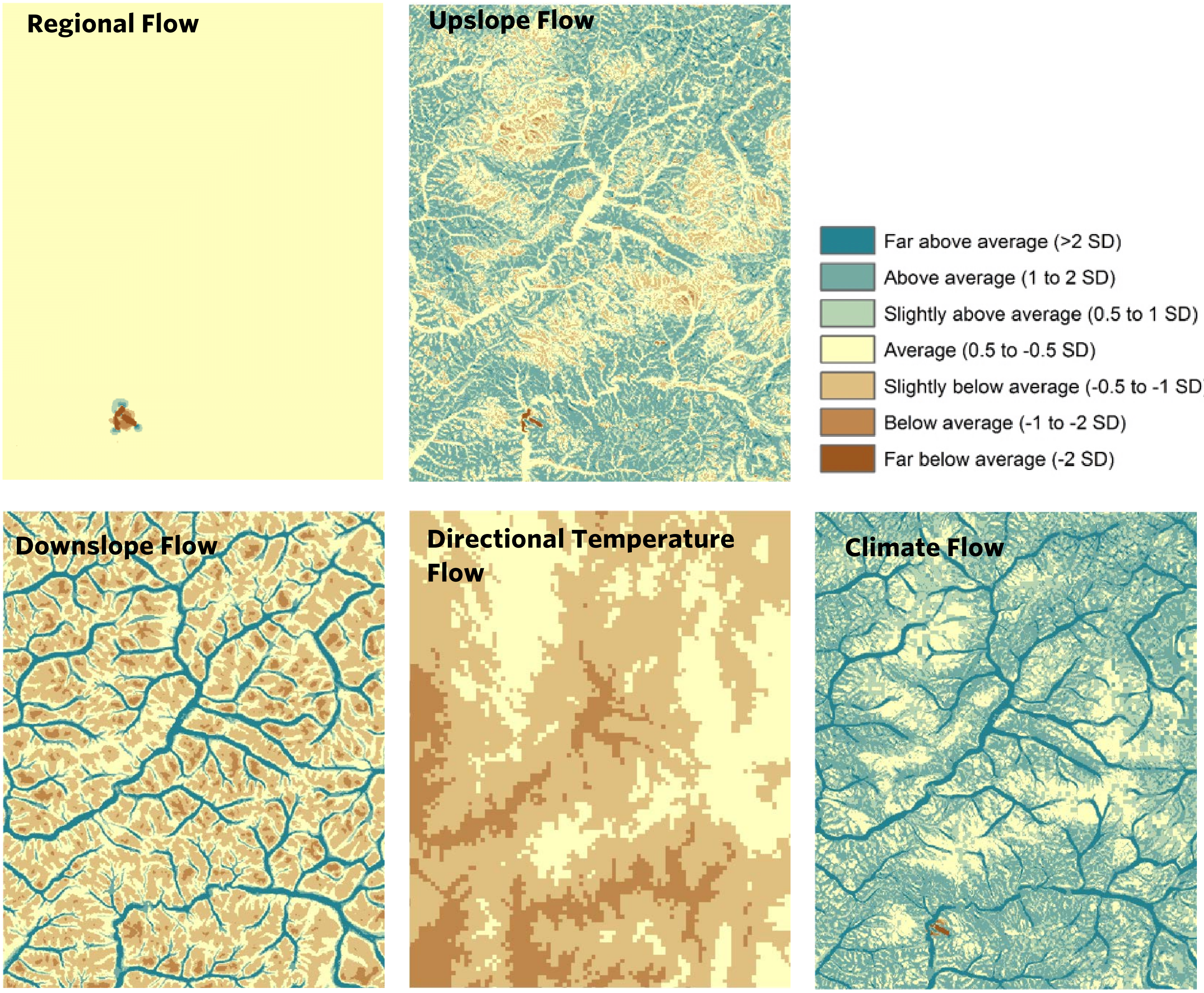


Figure 7.18. Classified Climate flow for Study Area. The results of classifying the climate flow map into 4 categories of flow density and spread.

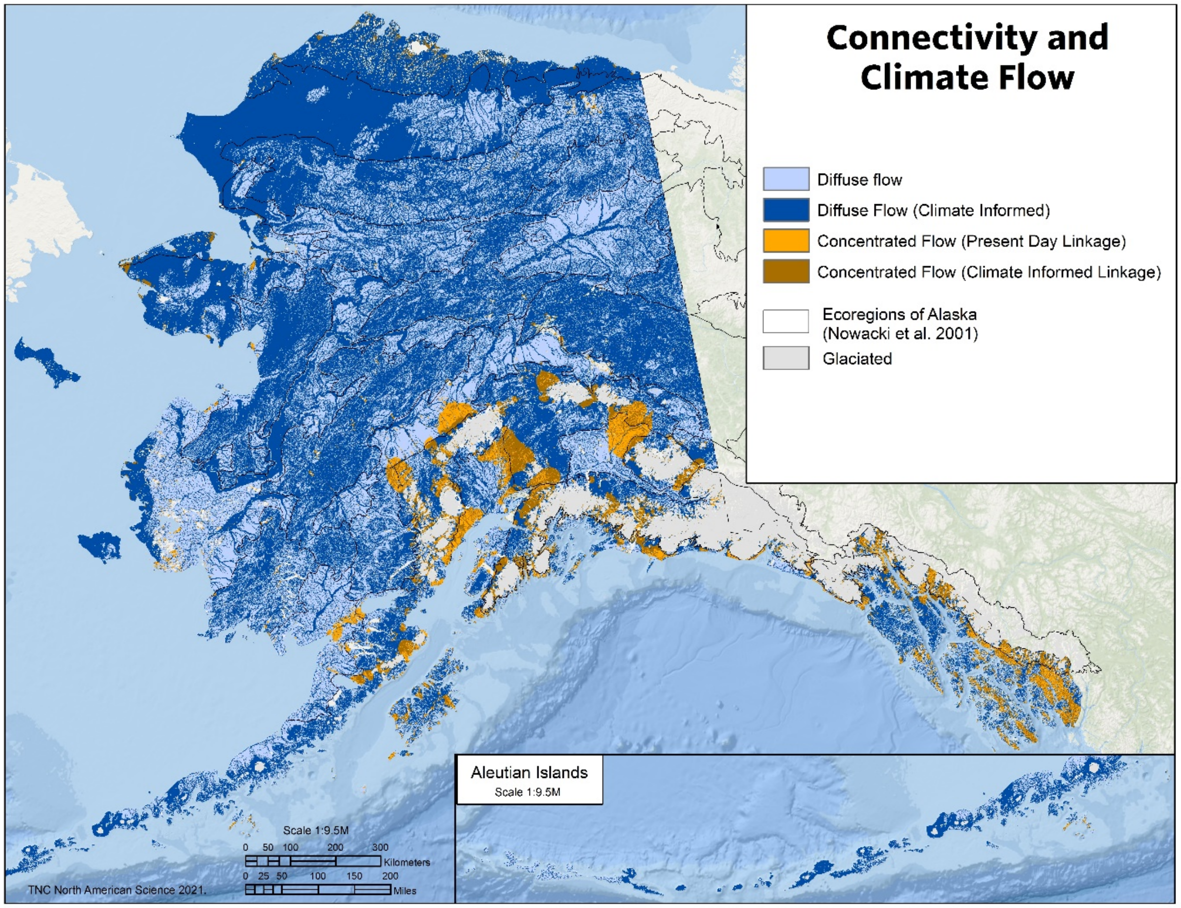
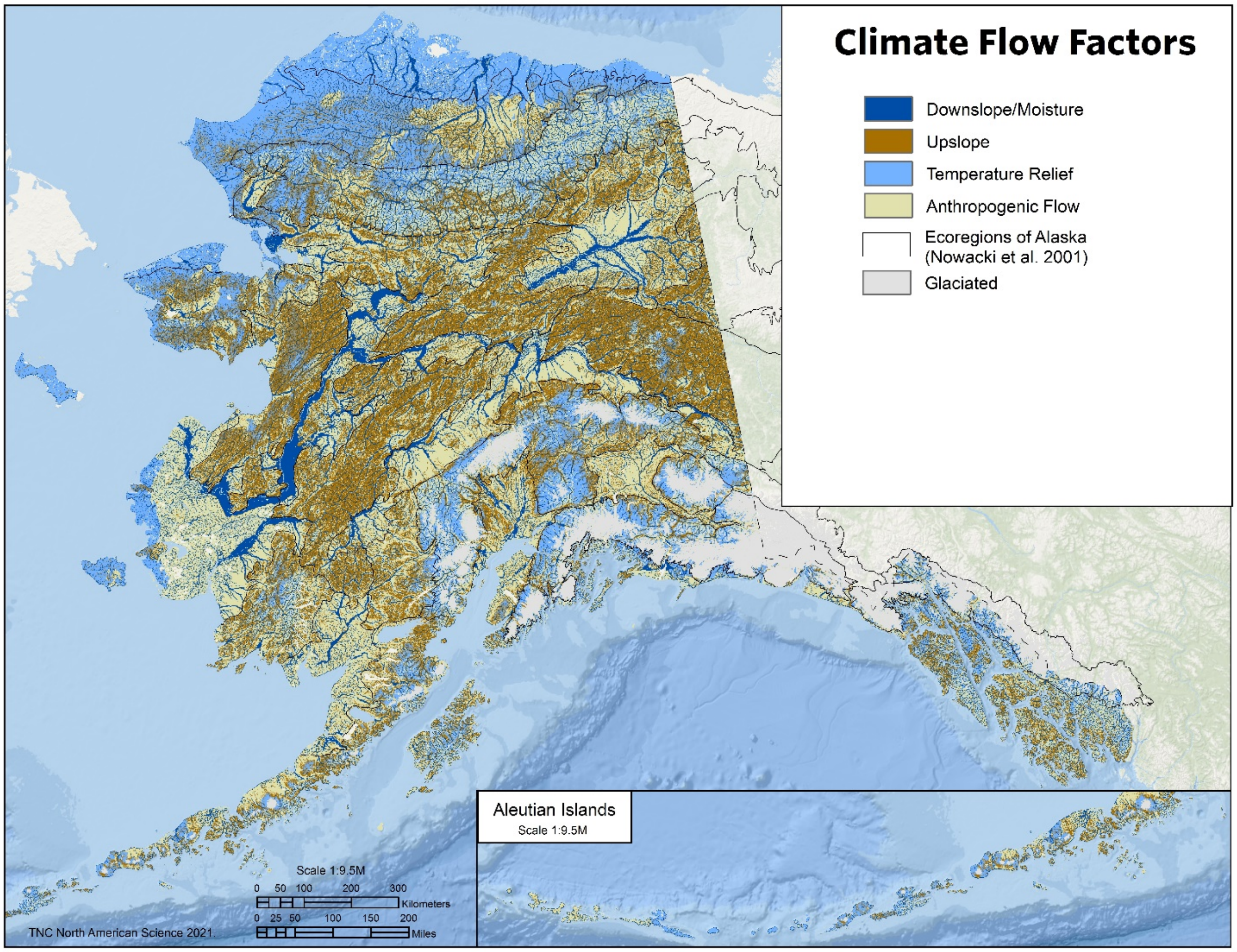


Figure 7.19. Climate Flow Factor. A map showing which climate flow factor contributes to the climate flow grid.



Access to Local Microclimates

We introduced this section with evidence for contemporary range shifts, and we suggested that population movement responses to climate change could be grouped into four main patterns: upslope toward higher elevations, northward toward cooler latitudes, downslope toward moist riparian areas, and locally toward suitable microclimates. The former three have been discussed previously and represent larger scale responses. The latter is a very small-scale response where a population shifts slightly over time to take advantage of a moist spot or cool microclimate and thus persist at a site.

Local microclimates may be the primary mechanism for species persistence under a changing climate for most organisms. Species experience climate at extremely local scales and the available moisture and temperature in the near-ground "boundary layer" can differ greatly from the local average (Geiger et al. 2009). Thus, a topographically diverse landscape is experienced by its resident species as a heterogeneous mix of microclimates, many of which might be suitable for persistence even where the average background climate appears unsuitable. Landscape-based climatic variation can be substantial, on par with or greater than a 1.5°C warming.

The focus of this report has been on mapping larger scale, between-site responses to climate change, and because mapping the distribution of microclimates is the basis of the climate resilient site analysis (Anderson et al. 2018a&b), we do not address it further here. However, microclimates are an important part of how species respond to climate change. Further, areas of high microclimate diversity are an important part of the upcoming chapter "Resilient and Connected Landscapes" because they are integrated into the resilient sites which form the base of the connected networks.

CHAPTER

8

BIODIVERSITY

Confirmed Areas for Biological Diversity

The central idea of a conserving-the-stage approach to conservation is that rather than trying to protect biodiversity one species at a time, the key is to conserve the geophysical "stages" that create diversity in the first place at local and regional scales (Hunter et al. 1988, Beier & Brost 2010, Lawler et al. 2014). Species ranges are not fixed, and the world has always experienced some measure of climate change. Thus, protecting the full spectrum of physical environments that provide habitat for distinct sets of species offers a way to conserve diversity under both current and future climates (Anderson & Ferree 2010). Toward that end, we performed a separate analysis of resilient sites (Chapters 1-5) and identified resilient examples of each distinct geophysical setting, but we did not consider the habitats, communities or species populations present at each location. In this chapter, we now integrate information on the biota with the physically based resilience map.

To identify a network of sites that could likely sustain biological diversity into the future, we wanted the network of climate resilience sites that contained the maximum amount of thriving biodiversity. To identify areas of high biodiversity value we compiled the results of a few intensive, multi-year studies that mapped the locations of exemplary habitats and rare species populations. For Alaska this included

- TNC/Audubon Ecoregional Plans
- Alaska Statewide Crucial Habitat Assessment Tool (CHAT)
- ACCS Ecosystems of Conservation Concern
- AKNHP Rare Plants
- High Complexity Floodplains
- High Species Richness Areas

The Nature Conservancy's Ecoregional Portfolios

From 1998 to 2006, The Nature Conservancy implemented a series of biodiversity assessments across each of the 81 terrestrial ecoregions in the U.S. The goal of each assessment was to identify a portfolio of sites that, if conserved, would collectively protect multiple viable examples of a set of focal conservation targets - species and communities characteristic of, or unique to, each ecoregion. Although the assessments were performed independently by ecoregion, the data are relatively consistent because the teams followed a similar methodology and applied a standard set of criteria (Groves et al. 2000, Anderson et al. 1999). Viability criteria were based on the size, condition, and landscape context of each biodiversity element occurrence (EO), and the results were reviewed by local experts familiar with the species and communities of the ecoregion. The assessments were performed and evaluated by teams of scientists from both TNC and other NGOs or agencies. Published versions are publicly available on TNC's Conservation Gateway along with many of the supporting datasets: http://www.conservationgateway.org/ConservationPlanning/SettingPriorities/EcoregionalReports/Pages/EastData.aspx

Unfortunately, although several ecoregional plans were launched for Alaska only one was completed and available: Southeast Alaska (Figure 8.1).

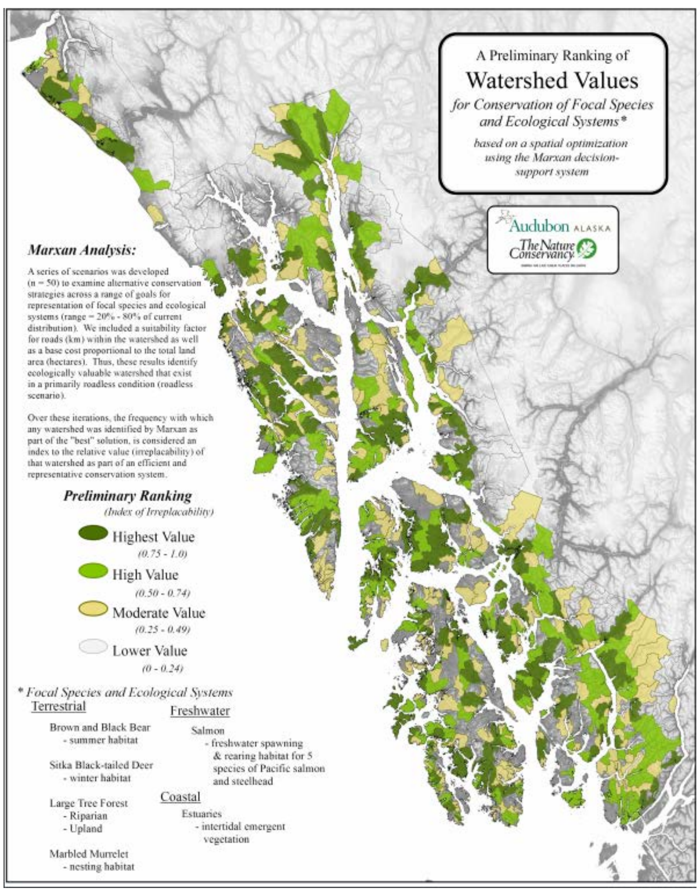


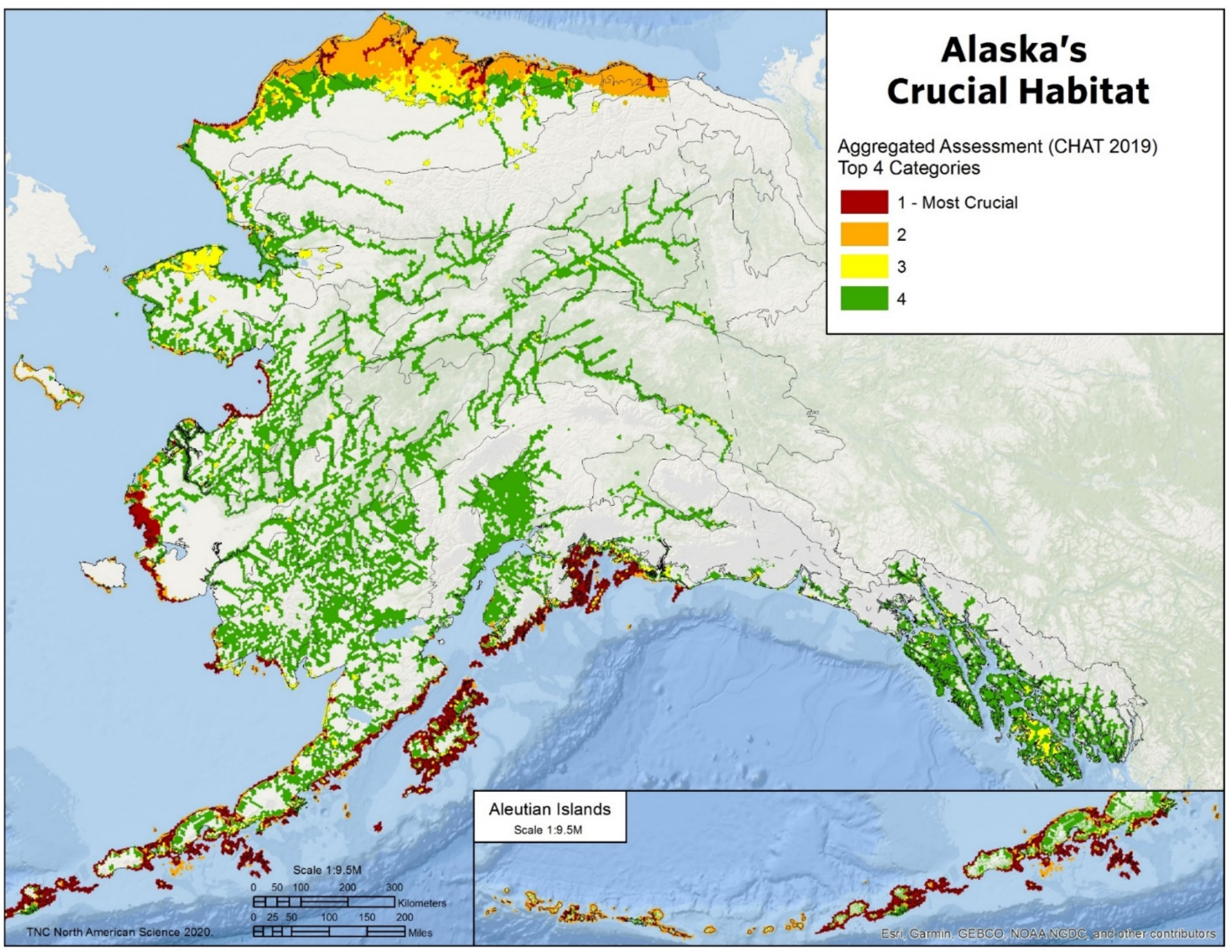
Figure: 8.1 Watershed Ranking. Figure 20. from Conservation Assessment and Resource Synthesis for The Coastal Forests and Mountains Ecoregion in the Tongass National Forest and Southeast Alaska. (TNC/Audubon John Schoen and David Albert, 2008.)

In Alaska the only ecoregional plan available was for Southeast Alaska. We obtained the Southeast Alaska Ecoregional Plan, A Conservation Assessment and Resource Synthesis for The Coastal Forests and Mountains Ecoregion in the Tongass National Forest and Southeast Alaska. (TNC/Audubon) John Schoen and David Albert, 2008. To identify areas of resilient confirmed biodiversity value, we included Tier 1-3 ranked watersheds with scores Highest, High, or Moderate.

CHAT: Crucial Habitat Assessment Tool

As a member of the Western Association of Fish and Wildlife agencies, the Alaska Department of Fish & Game (ADF&G) participated in development of the Crucial Habitat Assessment Tool (CHAT). This online GIS-mapping tool was designed to provide a coarse-scale view of important fish and wildlife areas to inform land use planning. The CHAT is displayed in a hexagon format at a resolution of 1 square mile per hexagon (Figure 8.2). The summary Crucial Habitat Rank metric for each hexagon reflects five habitat values: 1) terrestrial species of concern, comprised of threatened and endangered species, G1/G2, T1/T2, and others; 2) other species identified in Alaska's Comprehensive Wildlife Conservation Strategy; 3) aquatic species of concern based on the ADF&G Anadromous Waters Catalog; 4) species richness; and 5) an index of freshwater integrity based on the 2010 National Fish Habitat Partnership's (NFHP) assessment of human effects on fish habitat. This rank ranged from 1-6 with 1 being the most critical. With review from our steering committee, we selected hexagons with ranks 1-4 to represent those areas of highest biodiversity value.

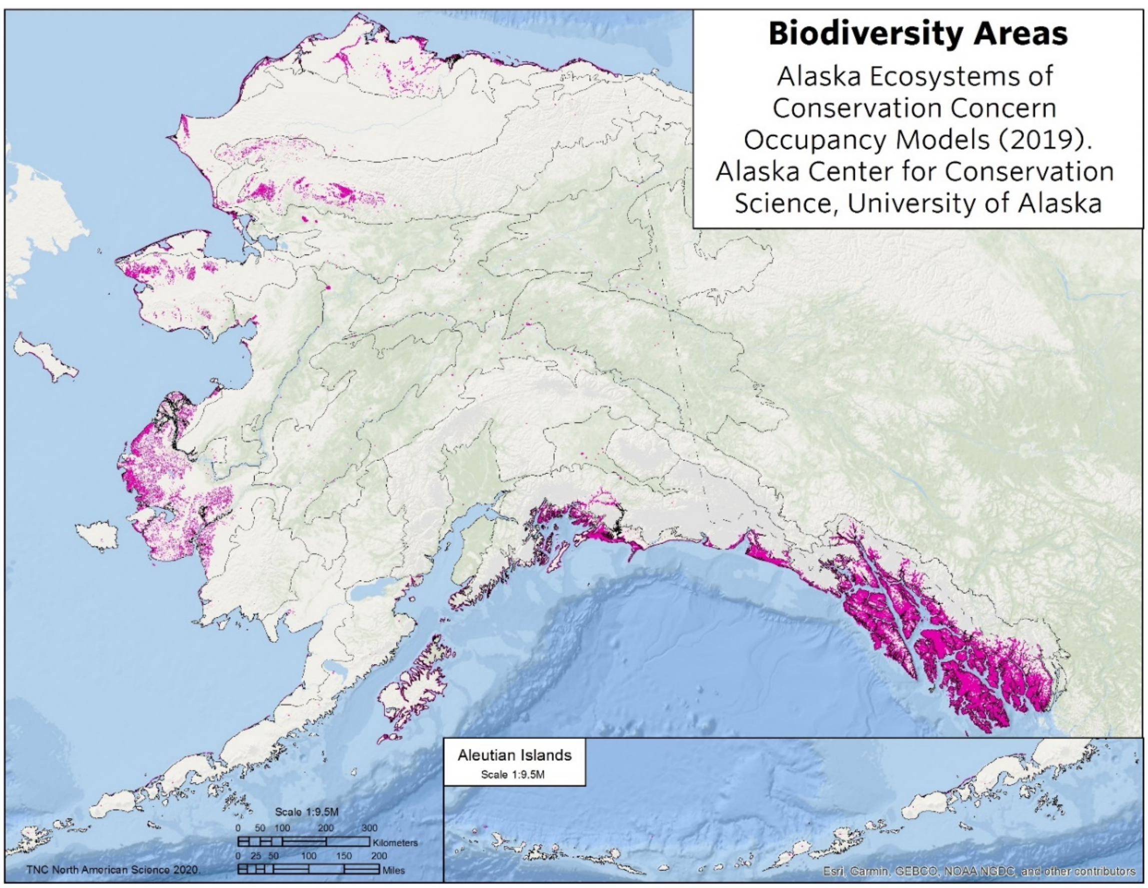
Figure: 8.2 Alaska Crucital Habitat Assessment Tool (CHAT). Highest ranking areas scored 1-4.



Ecosystems of Conservation Concern

Rare ecosystems support unique assemblages of specialized and/or diverse flora and fauna within a small geographic area or restricted range often represent vulnerable elements of biodiversity. Rare ecosystems often contribute disproportionately to regional biodiversity relative to their size, presenting a tremendous opportunity for conservation (Gaston 1994). Such geographically restricted ecosystems are also likely to face more severe consequences and have a higher probability of extirpation from threats relative to widespread ecosystems (Cole and Landres 1996; Wilson et al. 2016). Boggs et al 2019 provides the first formal recognition of Alaska's rare ecosystems and mapping of their current occupancy and distribution. Thirty-five ecosystems, representing different levels of ecological organization (plant associations and biophysical settings) and geographic scale were modeled (Figure 8.3). Detailed occupancy models were developed for 25 ecosystems where it was possible to map finer scale occupancy polygons using available spatial data. Nine ecosystems occupancy were mapped and distributed as 30m raster datasets. All available detailed occupancy models were merged together and used to represent areas of high biodiversity value.

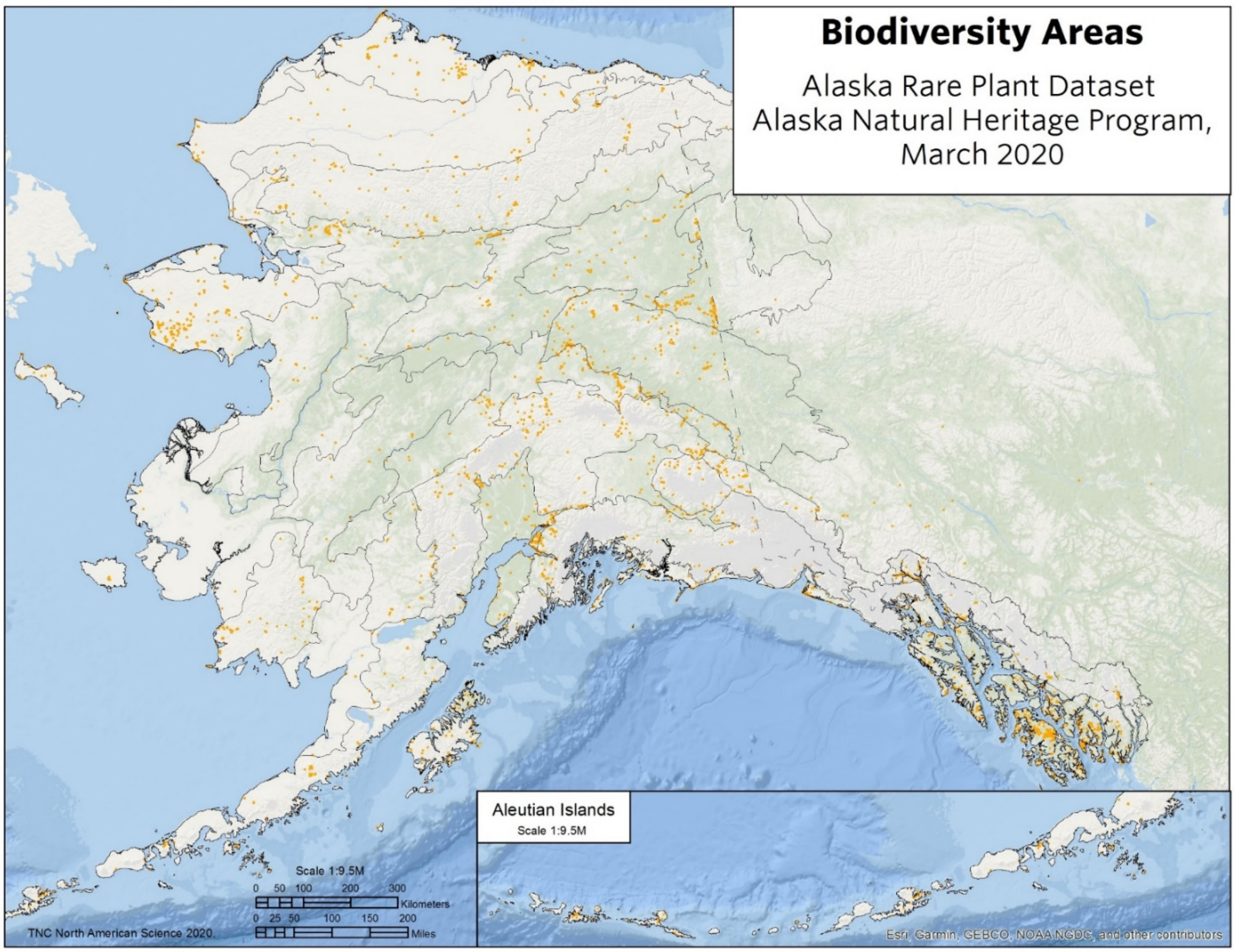
Figure: 8.3 Alaska Ecosystems of Conservation Concern. All occupancy models.



Rare Plant Inventory

Alaska Natural Heritage Program (AKNHP) is integrated within the Alaska Center for Conservation Science (ACCS). AKNHP collects, synthesizes, and validates information on Alaska's species of conservation concern and their habitats. Alaska Natural Heritage Program's provided a copy of the rare plant inventory as of March 2020 (AKNHP 2020, Fulkerson per comm.). Although many areas of Alaska remain unsurveyed, the team felt it was important to include all known rare plant examples wherever they have been documented to date. Each rare plant was mapped as a polygon with 1-km radius around the location of survey and included in our high value biodiversity area.

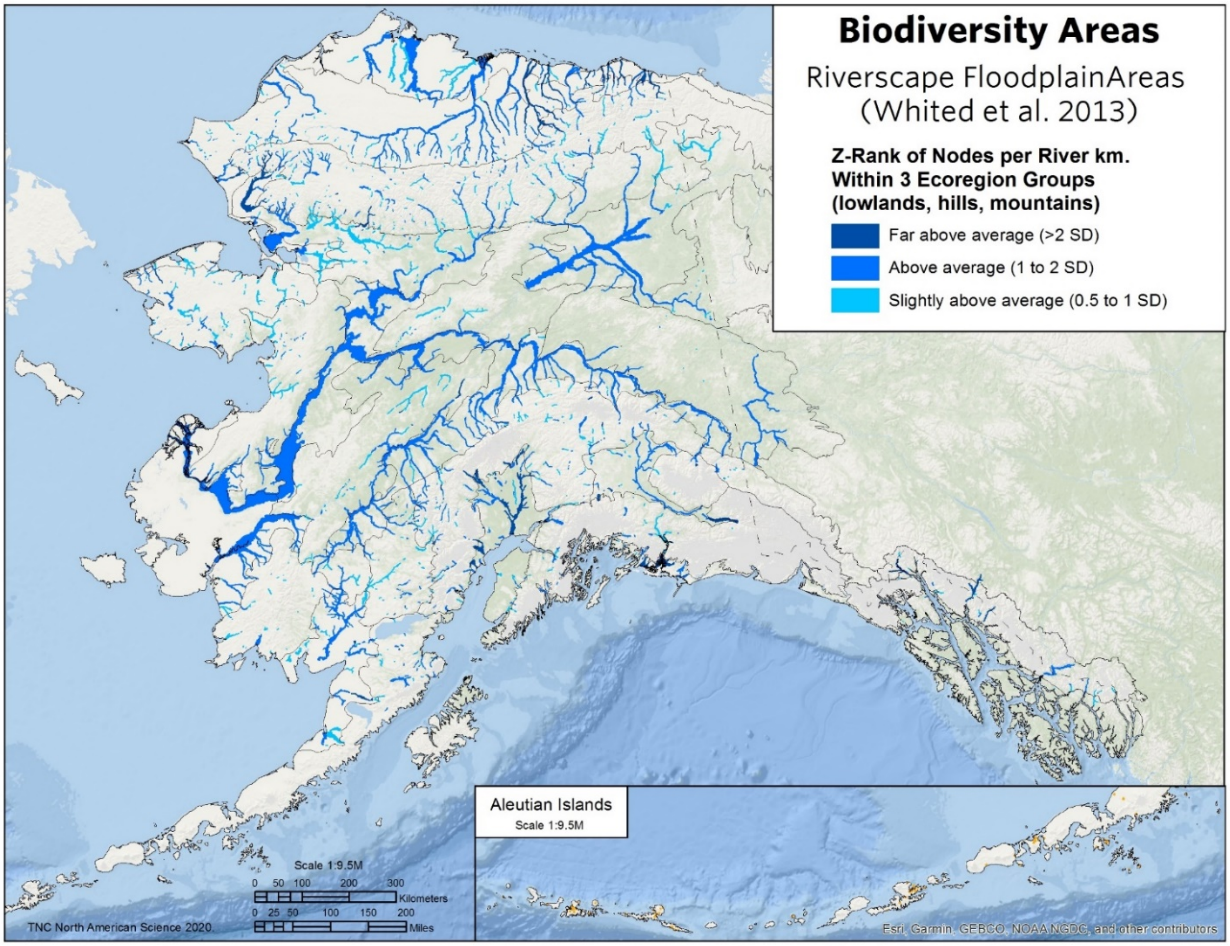
Figure: 8.4 Alaska Rare Plant Inventlry. All occurrences with 1km buffer.



High Complexity Floodplains

Floodplains support large and diverse populations of plants and animals and are critical areas where terrestrial and freshwater processes and species interact. Floodplains provide unique habitats which support natural flood storage and erosion control, facilitate groundwater recharge, water quality maintenance and are critical sources of energy and nutrients for organisms in adjacent and downstream terrestrial and aquatic ecosystems. In particular, the value of these floodplains to juvenile salmon production and sustainability has been repeatedly documented. The landscape metric of the floodplain, node-complexity, has a strong relationship to successful juvenile salmon production (Whited et al. 2012, 2013). This metric was available for large floodplains mapped in (Whited 2013) and recommended as the most useful metric to extract particularly high biological value floodplain patches (Whited per comm. 2020) The floodplain patches scoring >0.5 SD above average within their stratification region were extracted to represent the floodplains likely to provide the highest biodiversity value.

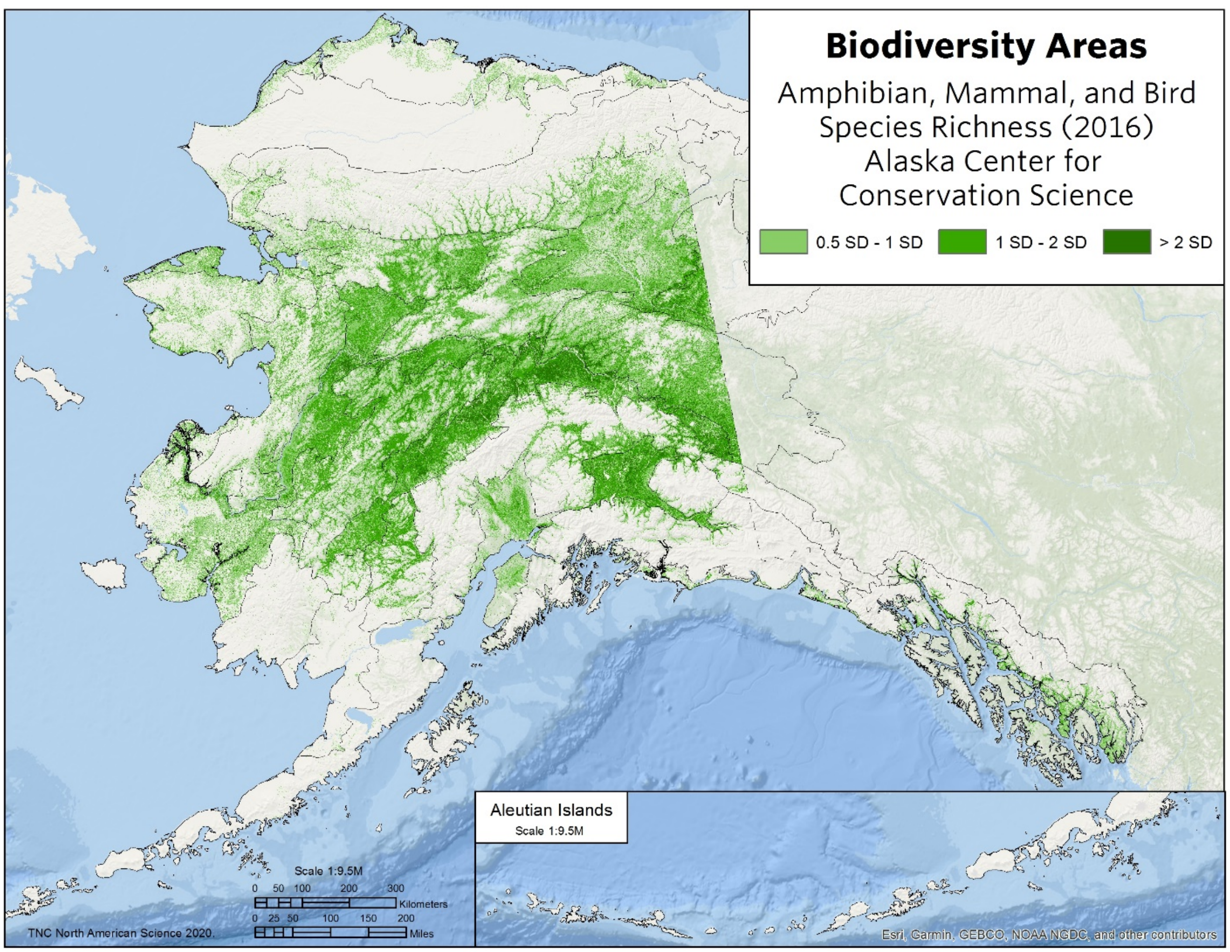
Figure: 8.5 Highest Biolgical Value Floodplains. Floodplains scoring above average in their region for channel complexity.



Vertebrate Richness

The Alaska Gap Analysis Project (AKGAP) is a statewide representative of the National Gap Analysis Program sponsored by the United States Geological Survey (USGS). One objectives of AKGAP project was to predict the distribution and map the range of all native terrestrial vertebrate species in Alaska. The Species Distribution Modeling Component of AKGAP was initiated in 2007 and completed in 2013. Each model was developed at a spatial scale of 60 m pixel across the state and distributed as a binary present/absent code. Individual species distribution maps were downloaded from http://akgap.uaa.alaska.edu/species-data and included amphibian, mammal, and bird species. We created a state-wide vertebrate richness map by summing the number of species that co-occured in the pixel (Figure 8.6). The richness map ranged from 0-127 with a mean of 50.2 and standard deviation of 25.6. Using this map, we extracted areas > .5 SD above the mean in species richness to use in our area of high biodiversity significance integration.

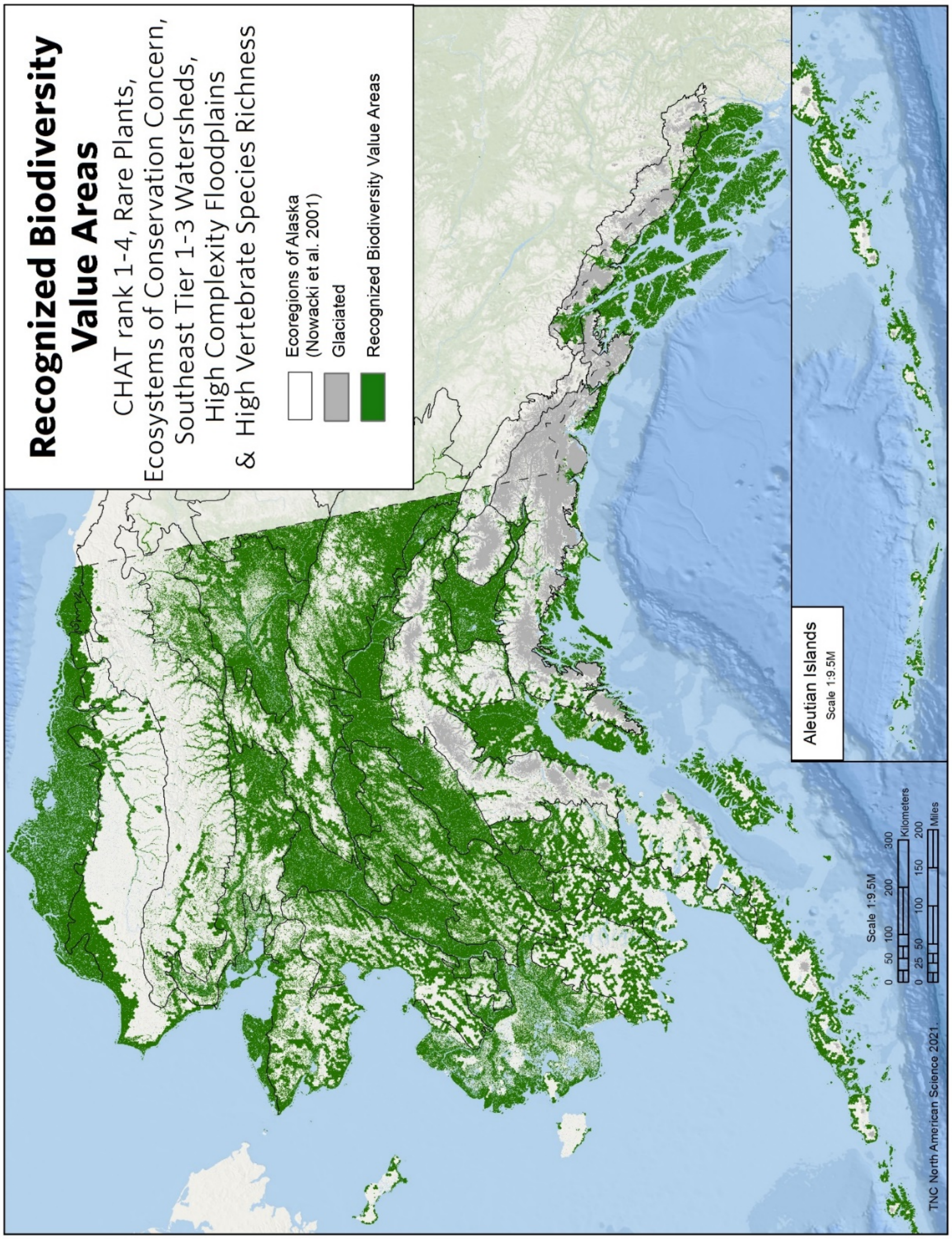
Figure: 8.6 High Vertebrate Species Richness. Areas scoring above average in their total number of predicted amphibian, mammal, and bird species.



Recognized Biodiversity Value

We integrated the separate data layers into a single map of recognized biodiversity value were each cell may be recognized by one to six sources

Figure 8.7. Biodiversity areas. Areas recognized for their biodiversity value in TNC portfolio, State Wildlife Action Plans and other sources



DATA SOURCES (other citations listed in Literature Cited)

Alaska Department of Fish & Game (ADF&G). 2014. CHAT: Crucial Habitat Assessment Tool. https://www.adfg.alaska.gov/index.cfm?adfg=chat.main

Alaska Gap Analysis Project (AKGAP) 2013. Vertebrate Species Distribution Models. http://akgap.uaa.alaska.edu/species-data.

Alaska Natural Heritage Program (AKNHP) is integrated within the Alaska Center for Conservation Science (ACCS).

Boggs, K., L. Flagstad, T. Boucher, A. Steer, P. Lema, B. Bernard, B. Heitz, T. Kuo, and M. Aisu. 2019. Alaska Ecosystems of Conservation Concern: Biophysical Settings and Plant Associations. Alaska Center for Conservation Science, University of Alaska Anchorage, Anchorage, Alaska. 301 pp.

Gaston 1994). Cole and Landres 1996; Wilson et al. 2016): SEE BOGGS 2019 ecosystems of conservation concern report

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Whited, D.C, J.S. Kimball, M.S. Lang, JA Standford. 2013. Estimation of juvenile salmon habitat in pacific rim rivers using multiscalar remote sensing and geospatial analysis. River Research and Applications V.29 135-148.

RESILIENT AND CONNECTED CONSERVATION NETWORK

CHAPTER 9

The goal of this section was to identify a network of resilient sites that if adequately managed or conserved would sustain the diversity of the region under a dynamically changing climate. Our approach to mapping such a network was to first combine the wall-to-wall resilience and flow datasets into a single coverage and then to overlay the confirmed diversity areas. We used this integrated coverage to identify a connected network of resilient sites which maximized resilience, diversity, and flow.

The resilient site analysis in the first five chapters highlights a relatively fixed portion (approx. 33-46%) of each of the region's geophysical settings based on the distribution of microclimates and degree of local connectedness. Our use of a statistical distribution to calculate the average resilience score for each geophysical setting and identify the places that score above-average guarantees perfect representation of each setting within each ecoregion.

In this section we prioritize among the resilient sites based on biodiversity and flow, to identify the places most essential for conserving and sustaining diversity under a changing climate.

One approach to prioritizing sites is to use a higher resilience score threshold. For example, selecting sites that score far-above-average for resilience (> 1 SD instead of > 0.5 SD, see Figure 5.11). That approach will identify the top scoring sites based solely on their resilience characteristics and will maintain perfect representation of the geophysical settings. An alternative approach, and the one that we used here, is to explicitly address the spatial configuration needed to produce an ecologically coherent network that allows for adaptation and change. Implementing the latter required that we study how the natural flow patterns are arranged across the region, where the rare species and exemplary natural communities are currently located, which riparian corridors naturally connect critical features, and where a stepping-stone pattern will have to be relied upon because there is no realistic way to functionally connect sites. By incorporating these characteristics into the network design, we hoped to strengthen its collective long-term ability to sustain diversity while allowing for range shifts and adaptation.

Go with the flow:

Our approach to creating a network differs from many other conservation network designs, in that we did not first identify sites and then try to connect them, instead we prioritized resilient sites that were aligned with natural flow patterns and contained high quality biodiversity. By ensuring that resilient source areas representing the region's diverse species and environments are situated in places that naturally intercept and transmit population movements, we hoped to ensure that the network will facilitate the adaptation and persistence of nature's diversity.

We prioritized the study area by integrating the three themes developed in previous sections of this report:

- **Site Resilience** criteria (Chapters 2-4) were based on microclimates and local connectedness applied to every geophysical setting within ecoregions and adjusted by macroscale processes like permafrost. These criteria ensured that the network was designed around representative areas of every environment where species could persist due to the site's connected climatic diversity.
- **Climate Flow** criteria (Chapter 7) were based on an analysis of circuit flow across a landscape of variable resistance as defined by the arrangement and resistance of land uses, weighted by key upslope, northward and riparian corridors. The idea was to use the natural flow patterns in designing the network by selecting resilient and biodiverse sites that reinforced or enhanced those patterns
- **Biodiversity** criteria (Chapter 8) were based on agency and NGO portfolios of critical sites for biodiversity. These criteria ensured that the network contained the full spectrum of current diversity features such as intact habitat, critical species populations, and rare or exemplary natural communities.

We did not set a numeric acreage goal for this prioritization, but we aimed to identify the portion of all the resilient areas that were the most connected and diverse, and by implication, the most critical to protect. In Alaska, resilient areas amounted to 46% of the region, and further prioritization reveals how site resilience is juxtaposed with the flow and diversity patterns.

The prioritization is not necessarily intended as an estimate of how much conservation is needed to sustain diversity over time but rather to provide a starting point for focusing conservation on the most critical network of sites and linkages. A good analogy is to think of the network as the landscape's skeleton and vital organs, critical but not necessarily enough to perform all the functions of nature that life depends on. If all the resilient areas were protected in totality (46%) it would encompass more than the network prioritized here and approach EO Wilson's Half Earth goal (Wilson 2016). A 50% goal is probably closer to the actual area that we need to be concerned about if we want to maintain all the natural benefits and services we derive from nature.

Site Prioritization: Resilience, Flow, and Diversity

Resilience and Climate Flow

The resilience analysis and flow analysis are both continuous and geographically comprehensive. To identify an ecologically coherent network, we first combined these two datasets in their categorical forms. This allowed us to study for example the above average resilience areas by the flow class (Figure 9.1). We could also study and map any of the 42 possible combinations of resilience and flow: eight levels of resilience scores and seven types of flow based on pattern and intensity.

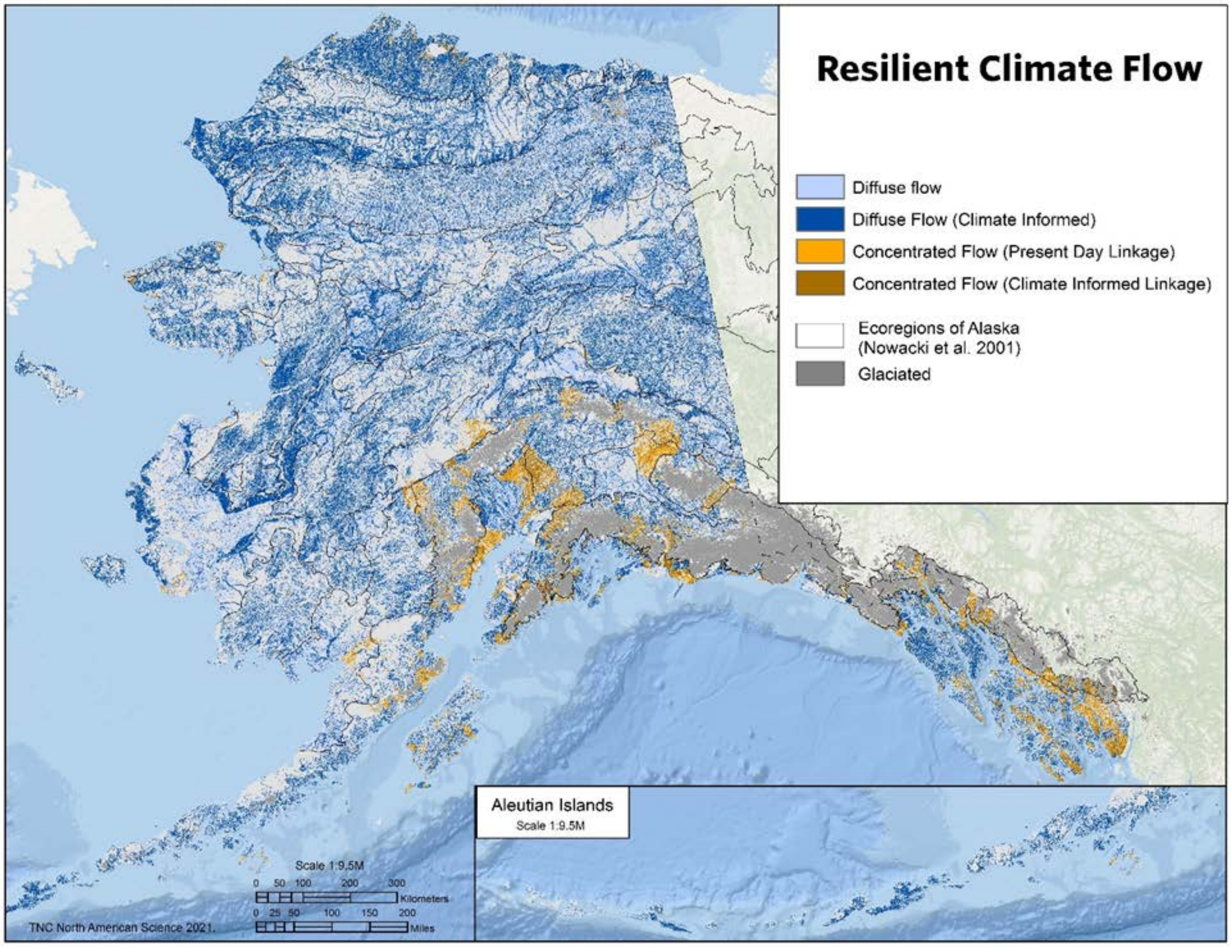
Using the categorical climate flow map (Figure 7.22), we selected places that met the criteria of above-average resilience and concentrated (high and low) or diffuse flow (high, medium, and medium-low), thus selecting the places that maximized geophysical representation, resilience, and flow. We included the medium-low diffuse flow in the network because it highlights potentially important areas of moderate upslope or downslope flow within the relatively intact landscape. Collectively the selected areas covered 38% of the region and delineated the structure, outline, and extent of the network.

Marsh Migration Space

Scientists from The Nature Conservancy evaluated every tidal habita in Alaska for their capacity to sustain biodiversity and natural services under increasing inundation from sea level rise. Each site received a relative resilience "score" based on the likelihood that its coastal habitats can and will migrate to adjacent lowlands, referred to as migration space, under six possible scenarios of sea level rise. Each site represents a spatially distinct complex of existing tidal habitats (salt marsh, brackish marsh, and tidal flats) that are likely to be inundated and altered by future sea level rise.

Resilient sites are those that scored greater than "Average," relative to their estuary type, because they have a higher likelihood of migrating to adjacent lowlands due to the size, quality, and accessibility of their migration space, and the intactness of key supporting ecological processes. However, as these marshes are likely to be inundated and altered by future sea level rise, instead of conserving the current marsh prioritized and evaluated the migration space (future marsh) of resilient marshes. We added the above average future marsh to the Resilient and Connected Network as "Resilient Coastal Migration Space".

Figure 9.1. Resilience and Climate Flow. This map shows the areas that met the criteria for above-average resilience by the various flow categories.



Biodiversity

The biodiversity criteria identified the resilient portions of sites that have been recognized for their conservation value by other independent studies described in detail in chapter 8 (Figure 9.2). These included:

- TNC/Audubon Ecoregional Plans
- Alaska Statewide Crucial Habitat Assessment Tool (CHAT)
- ACCS Ecosystems of Conservation Concern
- AKNHP Rare Plants
- High Complexity Floodplains
- High Species Richness Areas

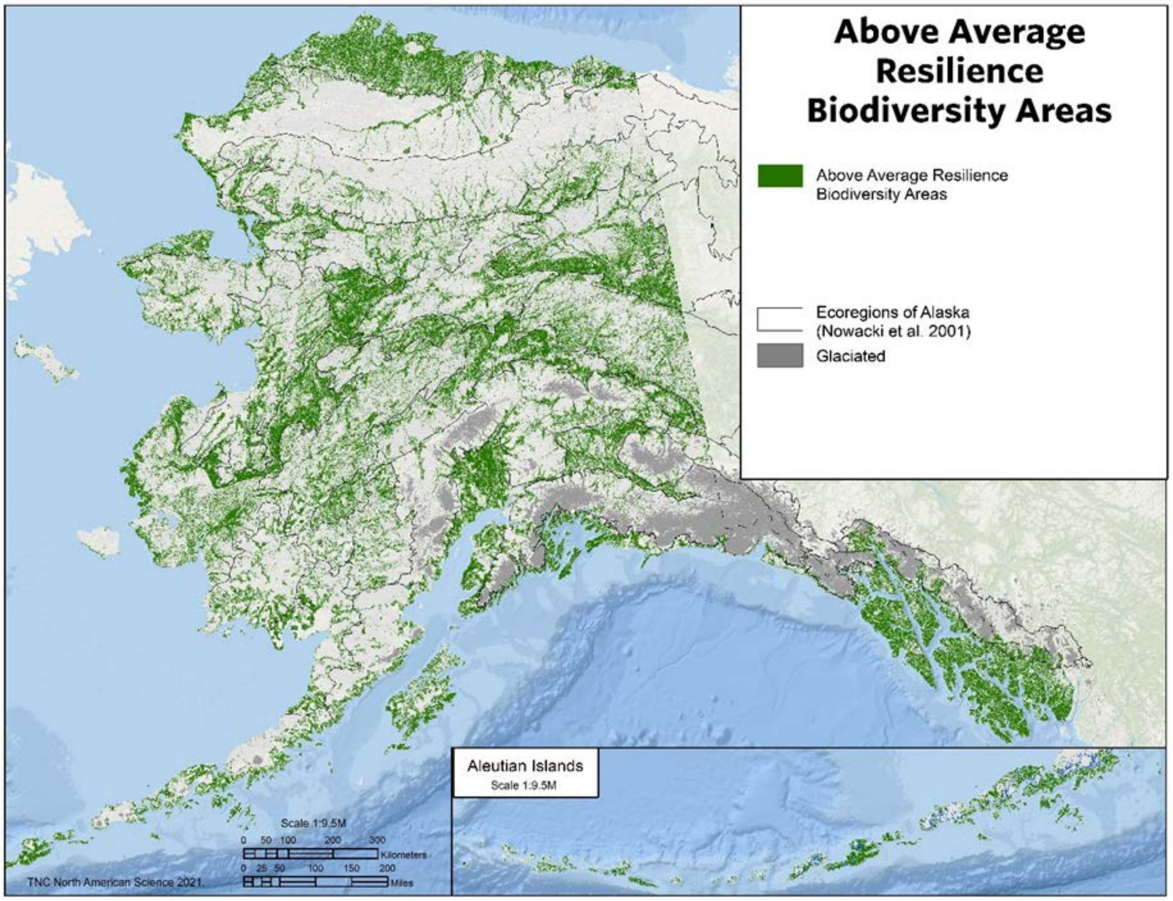
In total, the resilient biodiversity sites covered 29% of the study region, with almost all of them (97%) also overlapping with the flow network. The remaining 3% (1% of land area) were identified as resilient land with confirmed biodiversity.

The goal of the confirmed diversity criteria was to ensure that the prioritized resilient areas contained as many known rare species populations or high-quality natural community examples as possible. Unlike common species which are relatively easy to represent in a wide variety of configurations, rare species, because of their small populations, are difficult to pick up based on random chance. Building them into the prioritization ensured that we selected the sites where they are most likely to persist and that have the characteristics to support similar species as the composition changes.

The criteria also ensured that the network was capturing high-quality natural communities or thriving species populations. As the resilience analysis was based on enduring features alone, this was the first time in the analysis that biotic criteria on the structure and composition of the vegetated communities or size of the population was brought into the analysis. Although we expect the communities to rearrange and the species to move over time, this gives us confidence that the starting materials, the soils, topography, and existing vegetation, are in good condition.

We emphasize that although the recognized biodiversity sites give us high confidence in the current value of these places, other resilient areas, not recognized here, might well have high-quality natural communities or rare species on them. We simply have no information to confirm that, as they have not been recognized in any of the studies we compiled.

Figure 9.2: Recognized Biodiversity. This map shows the distribution of sites that 1) were identified for their biodiversity features in one of the sources listed above and 2) also met the criteria for above-average resilience.



Integration: Resilient and Connected Network (RCN)

Alaska's resilience is almosted unparalleled in the United States. The topographic diversity is relatively high, and the connectivity is exceptional. To account for this, we combined the two continuous datasets into a single data layer weighting climate flow twice as much as resilience.

Resilience+Flow Score = (1 *Resilience Score + 2*Climate Flow Score)/3)

To this we added a boost of one standard deviation to all areas with recognized biodiversity value.

Combined Network Score = (1*Resiience Score + 2 Climate Flow Score)/3) +1 SD (if Recognized Biodiversity Value)

If the Network score was above average (>=0.5 SD) than these areas were added to the Resilient and Connected Network, and categorized into the correct category. For instance, if the cell individually had high resilience, high diffuse climate flow, and recognized biodiversity value the area was added to the category called "Resilient, Diffuse (Climate Informed) with Confirmed Biodiversity."

This integration emphasized the connectivity patterns and created a relatively cohesive network which also encompassed most of the recognized biodiversity areas. However, we discovered during categorizastion that some areas with very high connectivity and biodiversity value were brought into the network even if their resilience score was only average (Figure 9.3, 9.4). This expanded the total area of the network by 9% bringing in virtually all the resilient areas (47%) plus sites with average resilience but high connectivity and diversity to reach a total of 56%.

In aggregate, the resilient and connected network covered 56% of Alaska (Figure 9.5-9.11). Just over a third of the network (67%) met all three criteria: resilience, flow, and diversity. Most of the remaining network had high flow and resilience (33%). The breakdown of the network compared to the total land area of the region was as follows:

Resilient and Connected Network

• Resilient, Diffuse Flow (Climate Informed), Recognized Biodiversity Value	46%
• Resilient, Diffuse Flow (Climate Informed)	21%
• Resilient, Diffuse Flow, Recognized Biodiversity	14%
• Resilient, Diffuse Flow	9%
• Resilient, Concentrated Flow (Climate Informed), Recognized Biodiversity	3%
• Resilient, Concentrated Flow (Climate Informed)	2%
• Resilient, Concentrated Flow, Recognized Biodiversity	2%
• Resilient, Concentrated Flow	1%
• Resilient Coastal Migration Space	<1%
• Resilient, Recognized Biodiversity	1%
Total (56% of area)	100%

The network is designed to represent resilient examples of all the characteristic environments of the region while maximizing the current biodiversity and climate flow contained within the network. By building the network around the natural flows that allow species populations to shift, and identifying representative resilient sites situated within those pathways, the network is specifically configured to sustain biological diversity while allowing nature to adapt and change.

Figure 9.3: Areas of Average Resilience, High flow, and Biodiversity.

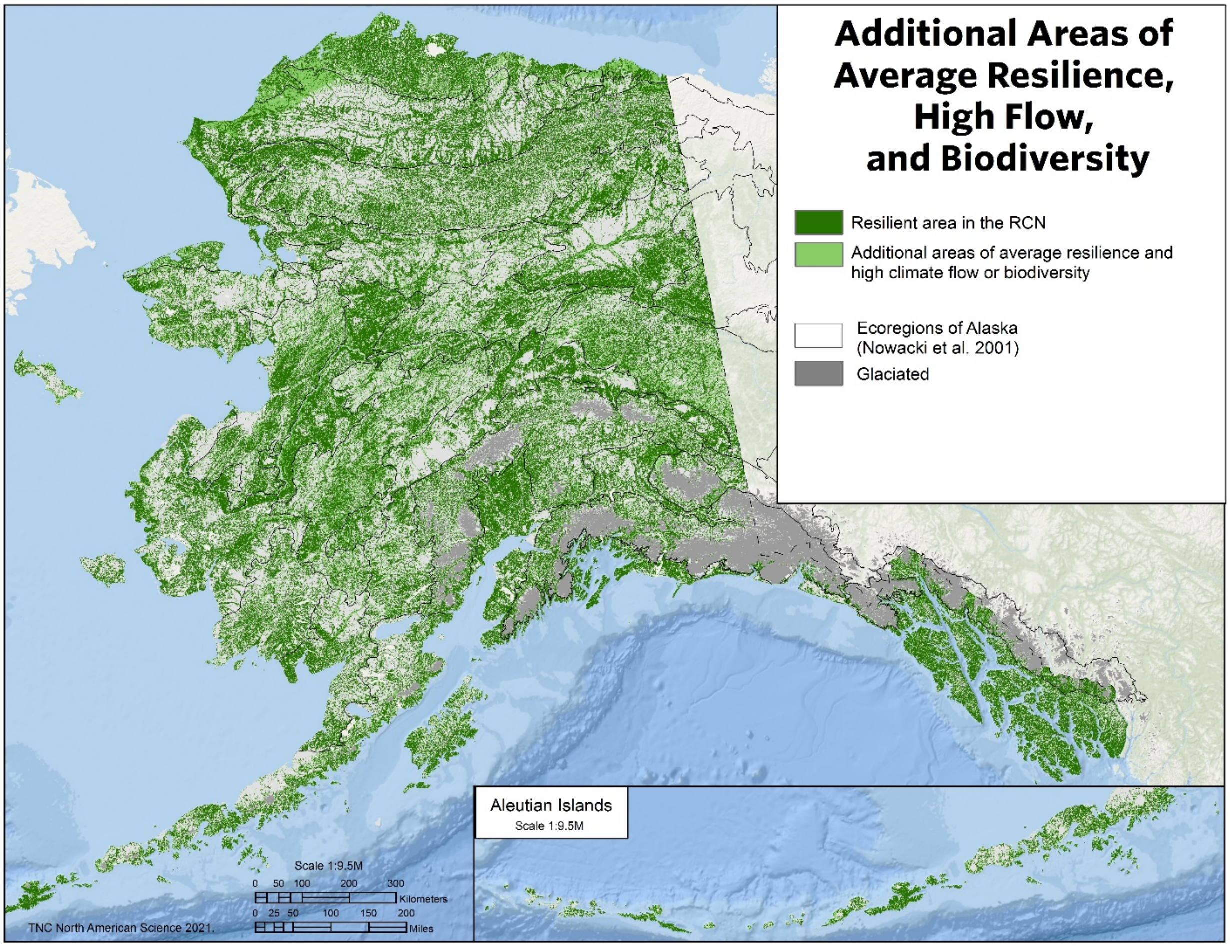


Figure 9.4: Zoom-in Area of Average Resilience, High flow, and Biodiversity. This map shows a zoom-in of the same area as 9.3 for Mertie Mountains located in the Yukon–Charley Rivers National Preserve. Areas in light green are the additions to the RCN with average resilience, high climate flow, or biodiversity. You can see in several spots that they help fill in and connect the network.

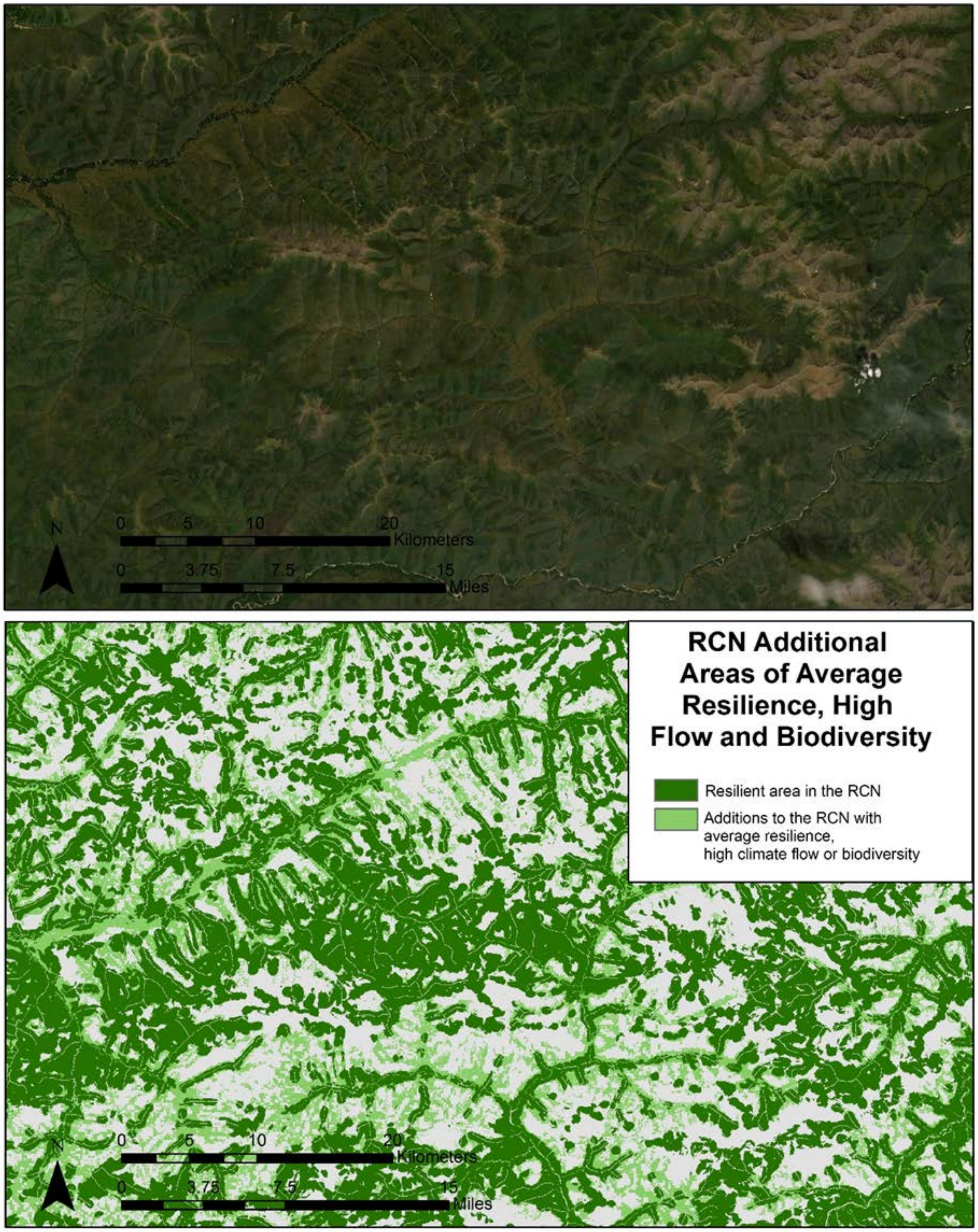


Figure 9.5: Resilient and Connected Network. This map shows the resilient areas that met criteria for confirmed biodiversity, climate flow or both. The network covers 67% of the Alaska.

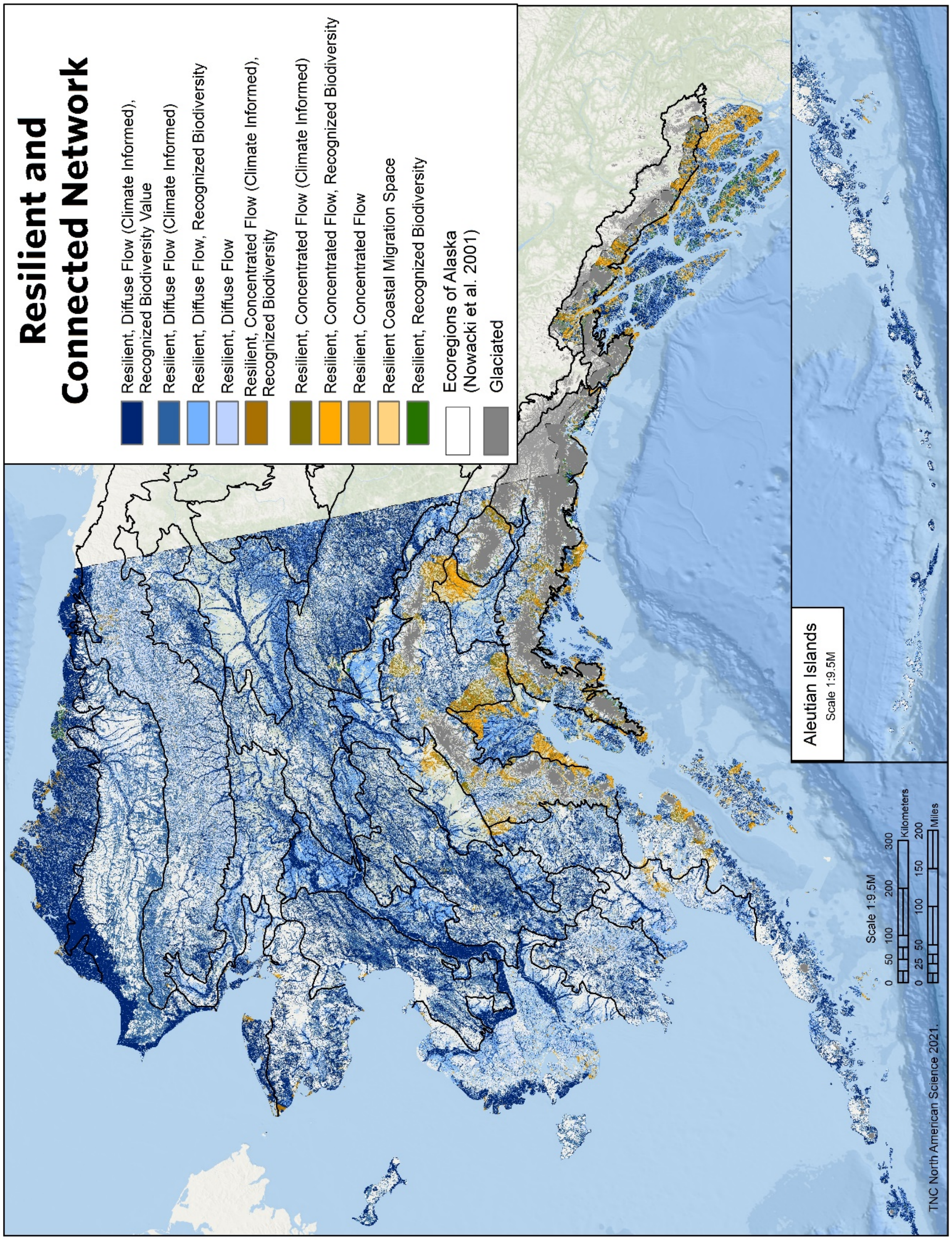


Figure 9.6: Resilient and Connected Network (Simple). This map shows the resilient areas that met criteria for confirmed biodiversity and flow (in green). Areas that are resilient with diffuse flow are in blue and resilient areas with concentrated flow are orange.

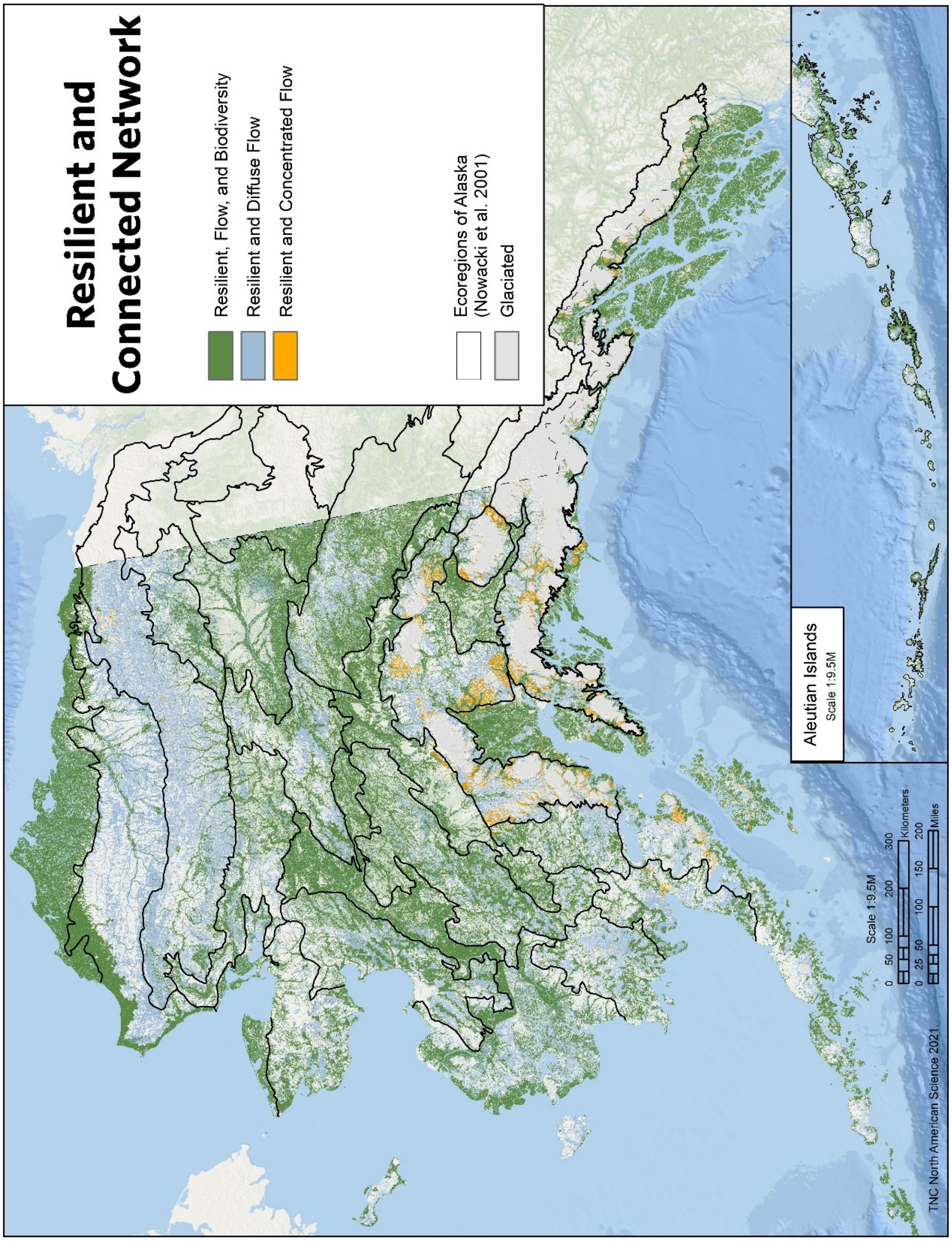


Figure 9.7: Resilient and Connected Network Zoom-in. This map is s detailed look (same area as 9.4) at resilient areas that met criteria for confirmed biodiversity, climate flow or both. The small area of resilient concentrated flow and resilient biodiversity is an area of an abandoned mine that lowers the flow.

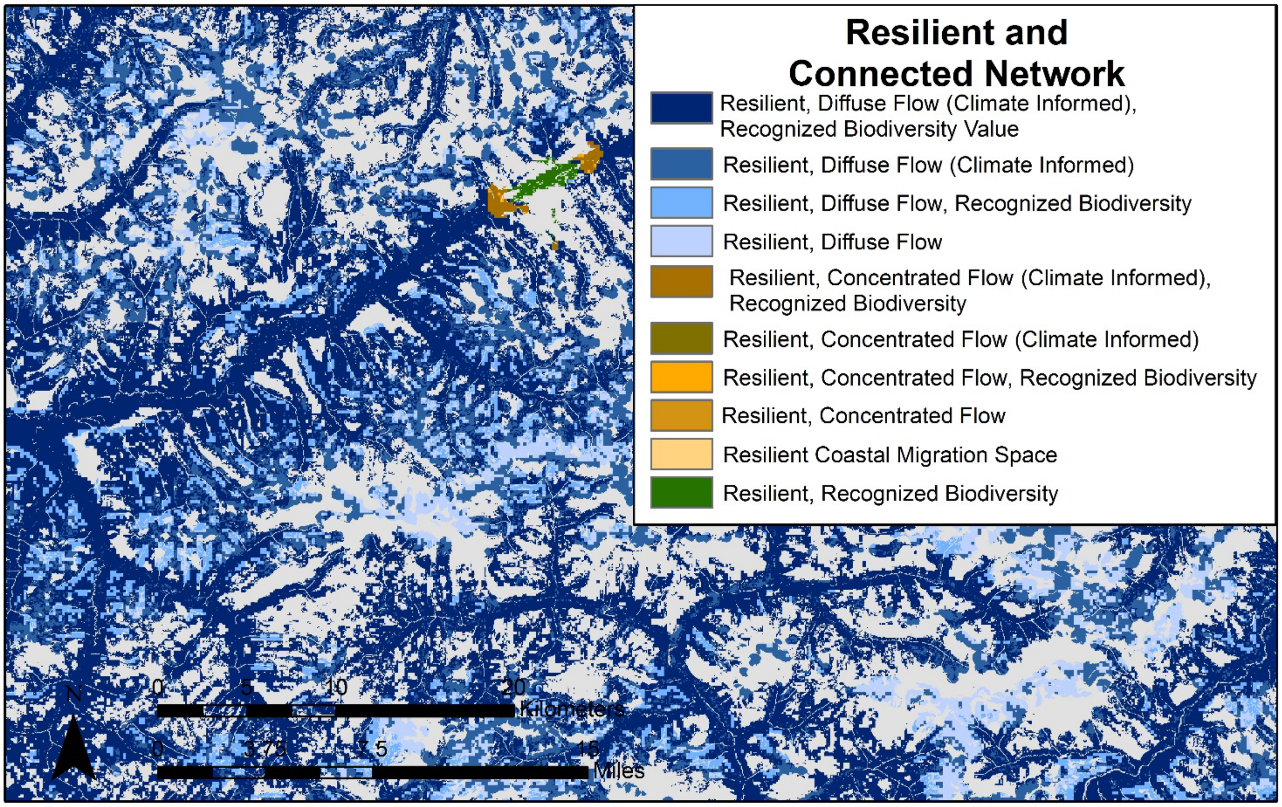


Figure 9.8: Resilient and Connected Network Zoom-in. This map shows the resilient areas that met criteria for confirmed biodiversity, climate flow or both. The network covers 67% of the Alaska.

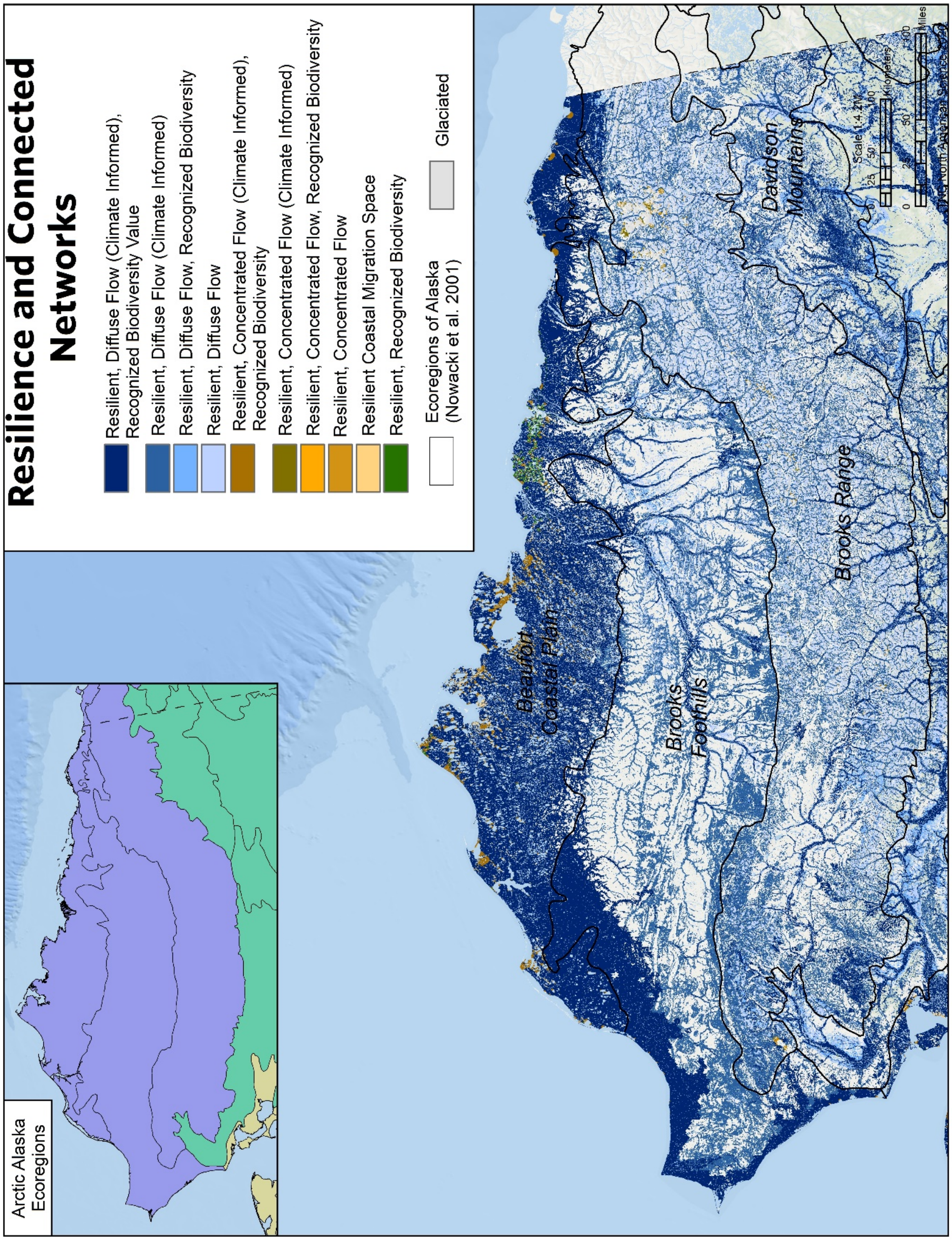


Figure 9.9: Resilient and Connected Network Zoom-in. This map shows the resilient areas that met criteria for confirmed biodiversity, climate flow or both. The network covers 56% of the Alaska.

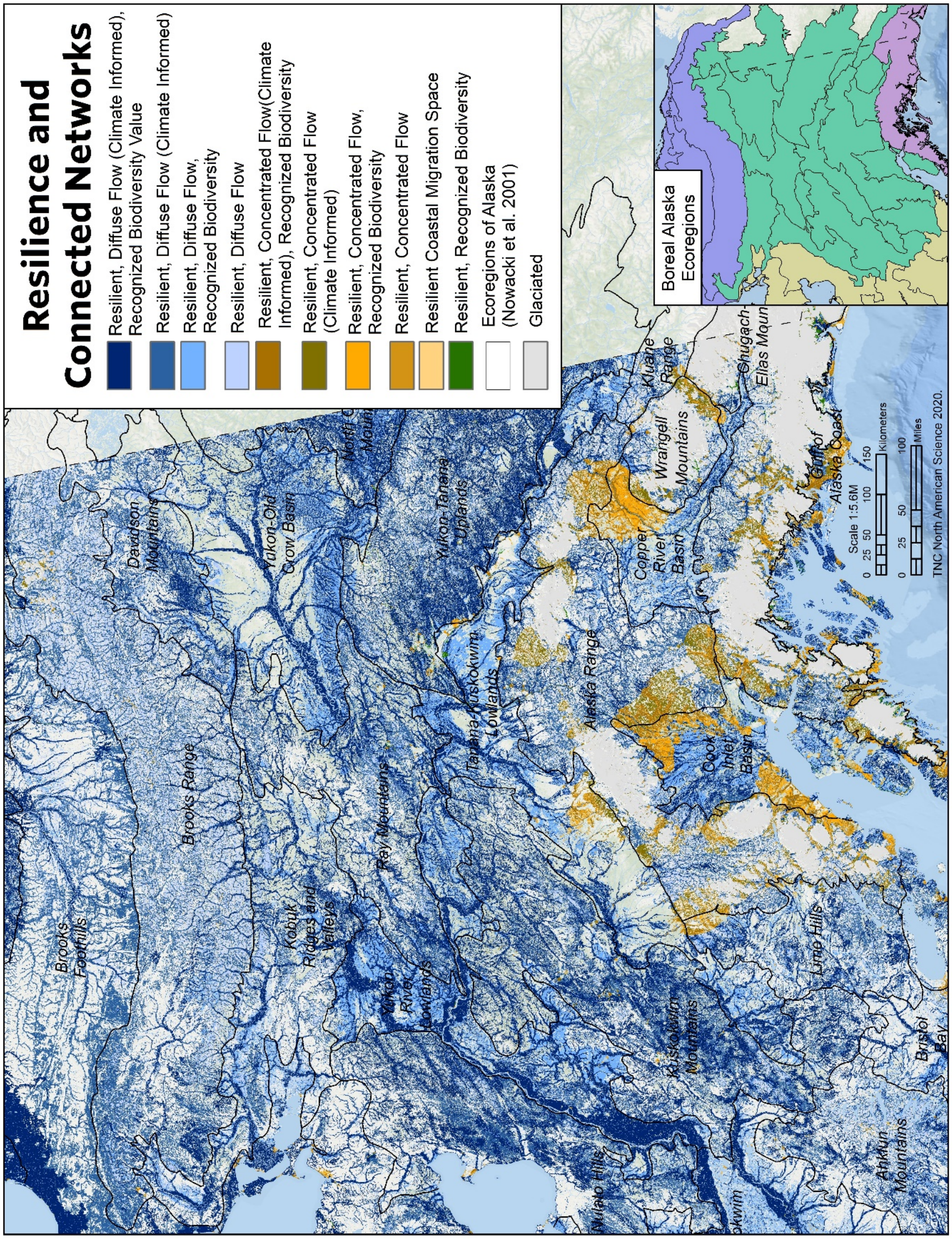


Figure 9.10: Resilient and Connected Network Zoom-in. This map shows the resilient areas that met criteria for confirmed biodiversity, climate flow or both. The network covers 67% of the Alaska.

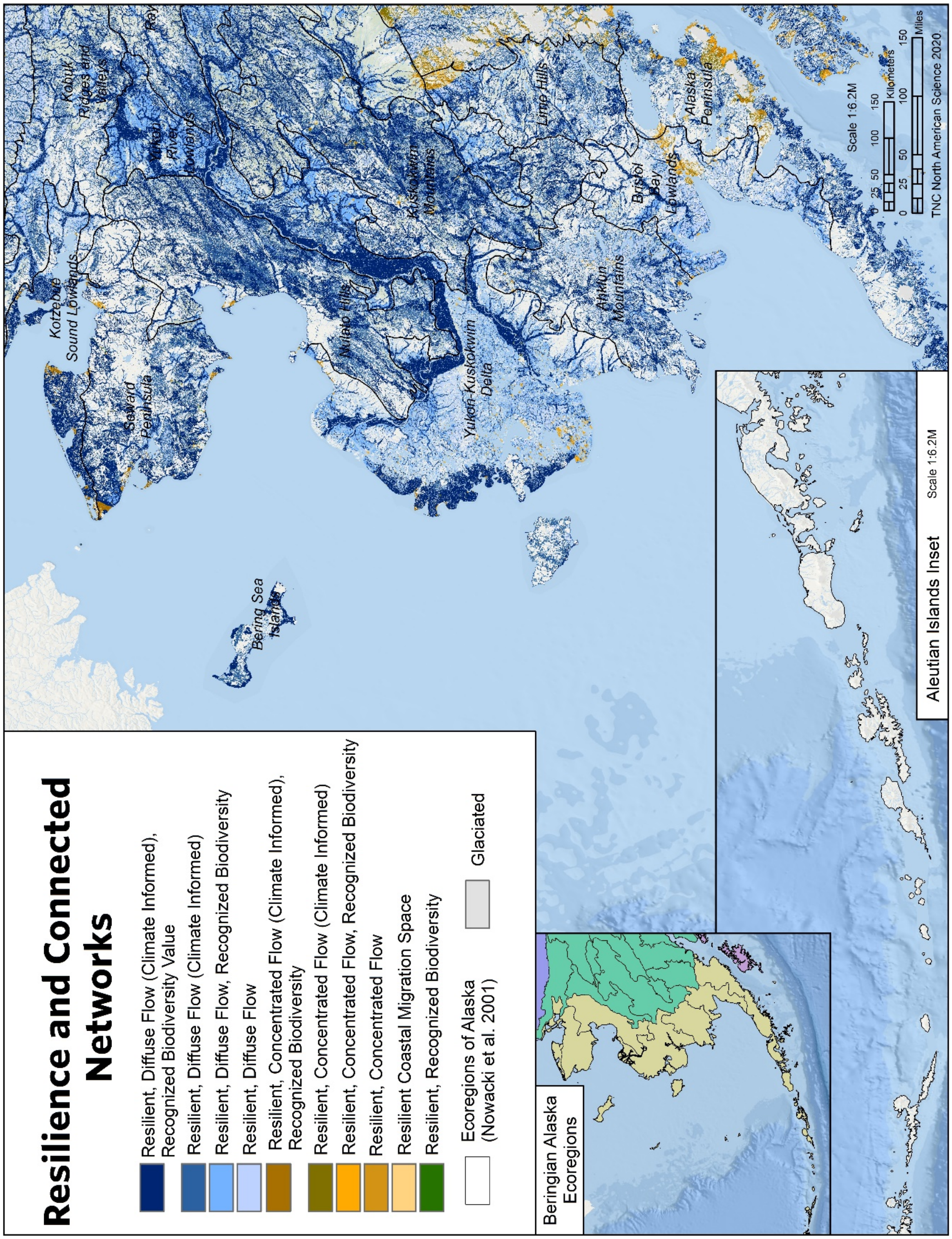
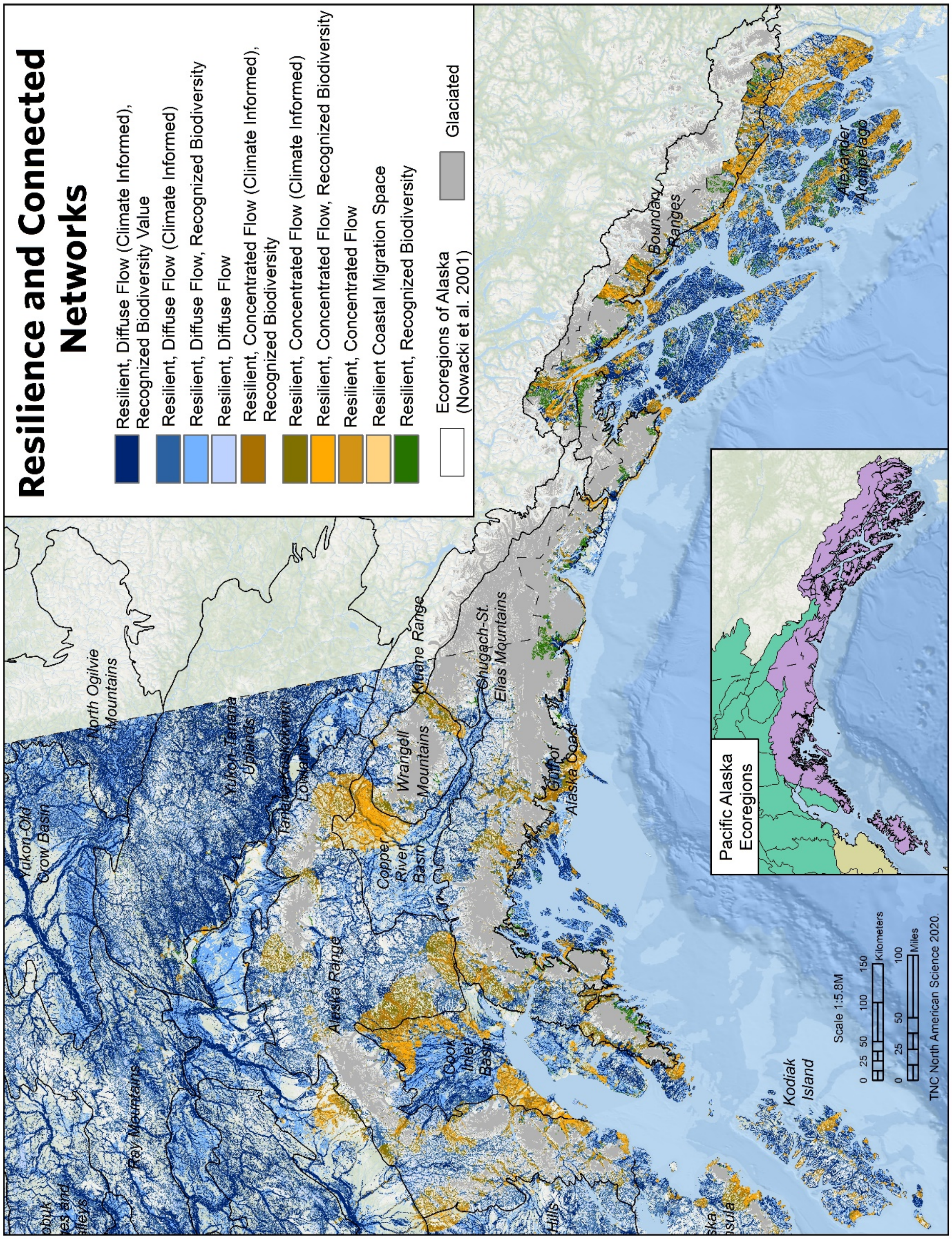


Figure 9.11: Resilient and Connected Network Zoom-in. This map shows the resilient areas that met criteria for confirmed biodiversity, climate flow or both. The network covers 67% of the Alaska.



Secured Lands and the Resilient and Connected Network

We compiled information on tracts of secured conservation land defined as "*land that is permanently secured against conversion to development*" (Figure 9.12). The process to compile and classify secured land is described in Chapter 1. Briefly, the definition was developed by an international group of scientists to differentiate "secured land" from the International Union for Conservation of Nature (IUCN) term "protected areas" which refers to land with a formal government designation of conservation value (Dudley 2008). Thus, this dataset includes tracts of land with no formal designation but with permanent protection and substantial conservation value, such as reserves held by The Nature Conservancy. Each parcel was classified to one of three GAP status values:

GAP 1 Intent: *Nature conservation with only natural processes*
Areas having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events can proceed without interference or are mimicked through management.

GAP 2 Intent: *Nature conservation with extensive management where needed*.
Areas having permanent protection from conversion of natural land cover and a management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance.

GAP 3 Intent: *Multiple uses, typically, resource extraction, recreation and conservation*
Areas having permanent protection from conversion of natural land cover for most of the area, but subject to extractive uses of either a broad, low-intensity type (e.g., logging) or localized intense type (e.g., mining).

Most of the network (67%) is secured against conversion to development, with 29% being protected for nature (Table 9.1, Figure 9.13). Securement ranges from 55% to 67% across RCN categories. (Table 9.2). This region has the highest amount of secured network in the U.S. suggesting that effective management of the secured public and private lands will be a critical tool for conservation of the network.

Table 9.1: Land securement across the Resilient and Connected Network.

Resilient and Connected Network	Acres	% Secured	% GAP 1	% GAP 2	% GAP 3
Climate Corridor	1,143,568	35%	0%	0%	35%
Climate Corridor with Confirmed Diversity	1,488,276	54%	9%	15%	29%
Climate Flow Zone	48,660,063	47%	0%	0%	47%
Climate Flow Zone with Confirmed Diversity	102,423,640	75%	23%	21%	31%
Resilient Confirmed Diversity	38,460,991	63%	15%	17%	31%
Resilient Secured	8,954,670	100%	0%	0%	100%
Not in the Network	201,131,207	67%	15%	14%	38%
Resilient Only	16,877,041	0%	0%	0%	0%
Average or Vulnerable	178,147,856	42%	5%	6%	30%
Developed	2,162,757	13%	0%	2%	11%
Water	2,611,420	-	-	-	-
Grand Total	400,930,282	52%	10%	10%	33%

Table 9.2. Land Securement by each RCN category

Resilient and Connected Network	% Secured	% GAP 1	% GAP 2	% GAP 3
Resilient, Diffuse Flow (Climate Informed), Recognized Biodiversity Value	55%	23%	10%	22%
Resilient, Diffuse Flow (Climate Informed)	65%	33%	12%	20%
Resilient, Diffuse Flow, Recognized Biodiversity	57%	35%	11%	11%
Resilient, Diffuse Flow	66%	46%	9%	11%
Resilient, Concentrated Flow (Climate Informed), Recognized Biodiversity	66%	25%	25%	16%
Resilient, Concentrated Flow (Climate Informed)	55%	31%	19%	5%
Resilient, Concentrated Flow, Recognized Biodiversity	66%	28%	29%	9%
Resilient, Concentrated Flow	63%	35%	22%	6%
Resilient Coastal Migration Space	67%	10%	7%	50%
Resilient, Recognized Biodiversity	67%	24%	20%	23%

Figure 9.12: Secured lands. This map shows the secured lands in the region by Gap status.

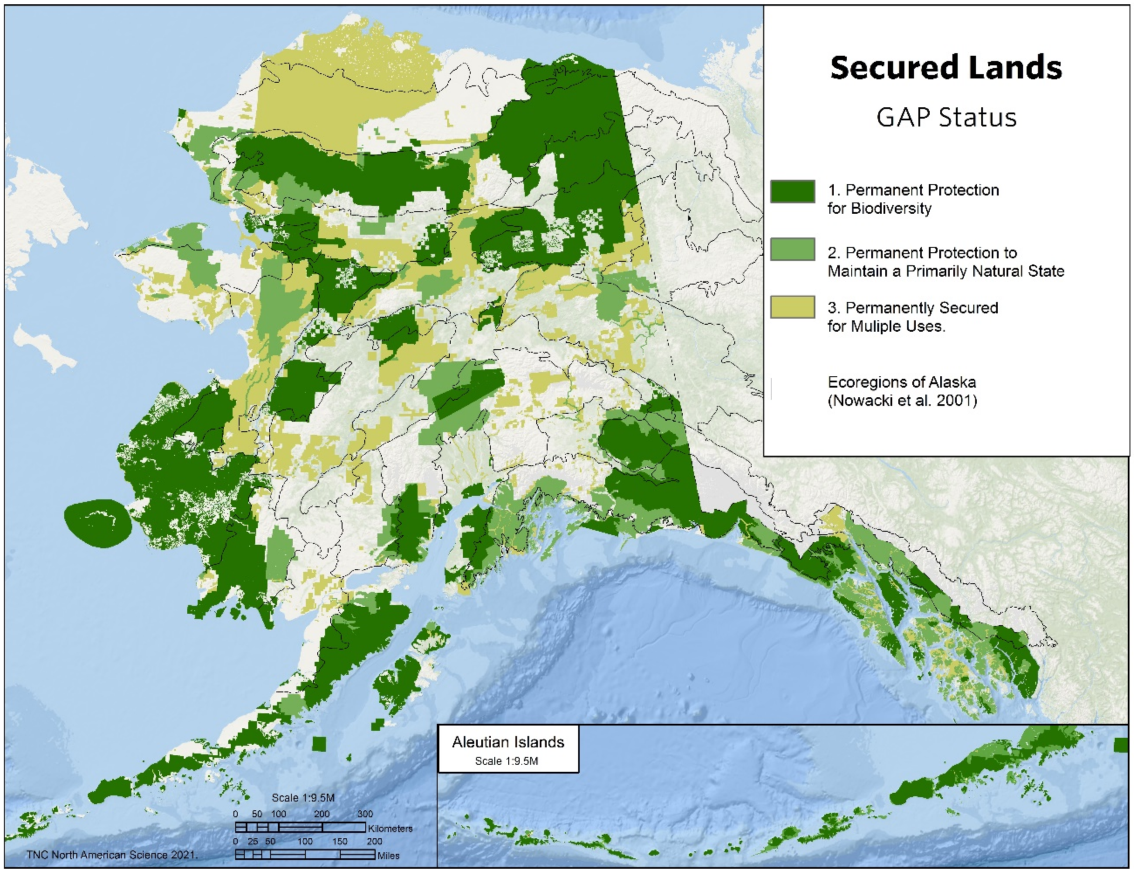
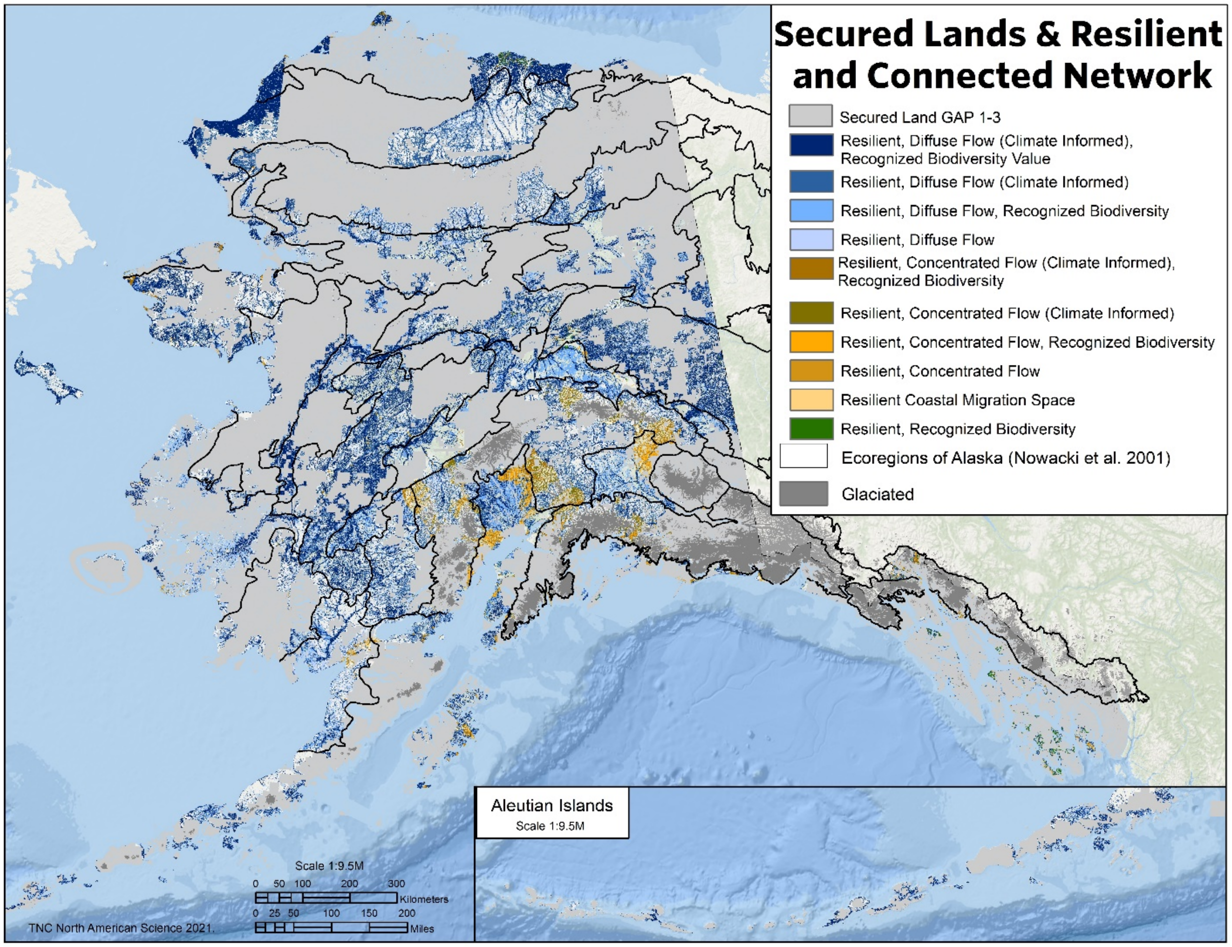


Figure 9.13: Secured land with the Resilient and Connected Network . The map shows the secured lands in gray on top of the resilient and connected network. In sum the network is 60% secured by conservation land in Gap 1-3 status and 40% is unsecured.



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