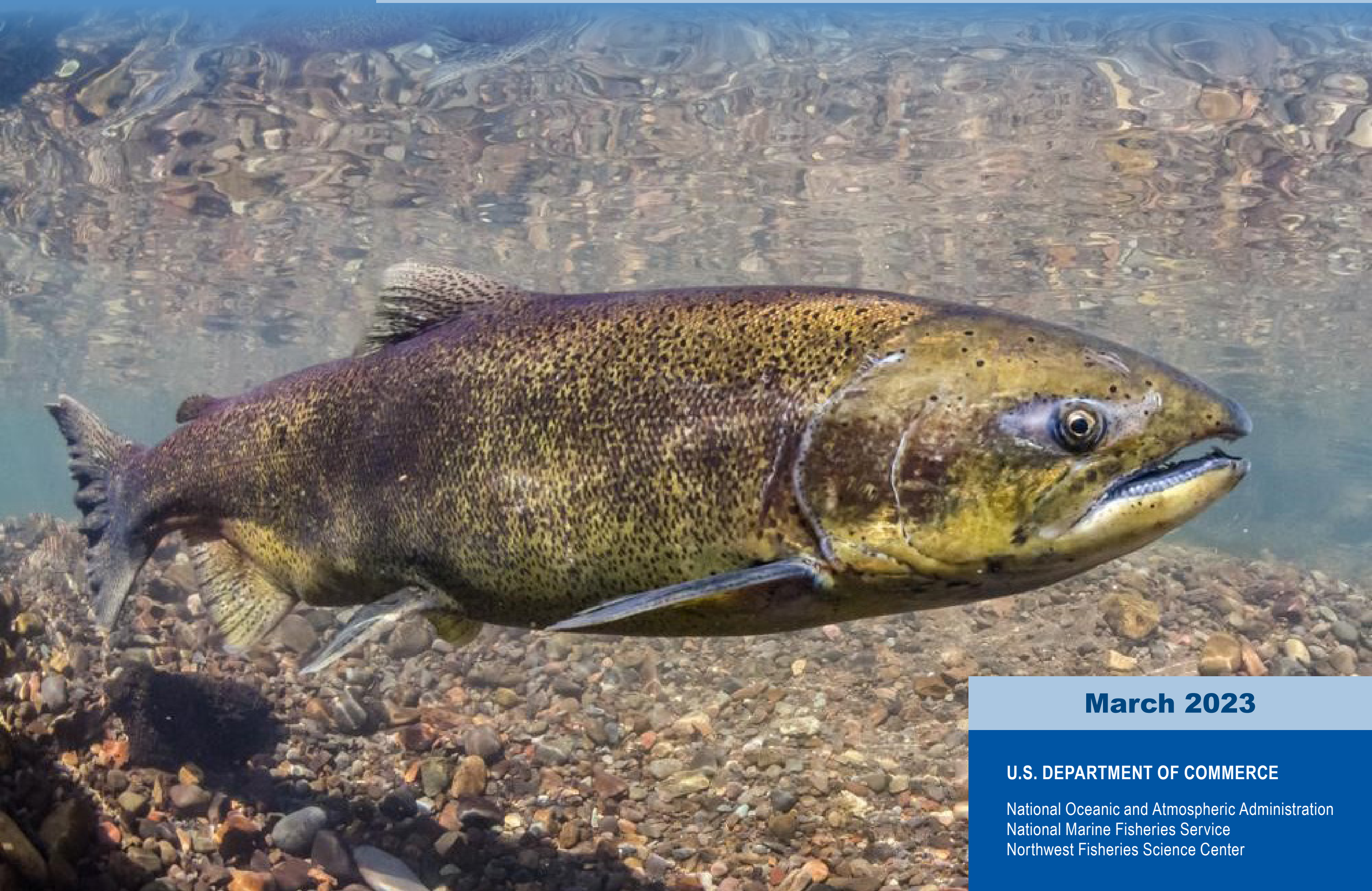
NOAA Technical Memorandum NMFS-NWFSC-181

https://doi.org/10.25923/nahb-s175

Interim Report of Data Supporting Phase 1 Reviews of Essential Fish Habitat for Pacific Coast Salmon



March 2023

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

NOAA Technical Memorandum Series NMFS-NWFSC

Cover image: Chinook salmon (*Oncorhynchus tshawytscha*) swimming in the McKenzie River, Oregon, September 2016. Photograph by M. Bond, NMFS/NWFSC.

Reference this document as follows:

Stefankiv, O., M. Bond, and P. Kiffney. 2023. Interim Report of Data Supporting Phase 1 Reviews of Essential Fish Habitat for Pacific Coast Salmon. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-181.

https://doi.org/10.25923/nahb-s175

Interim Report of Data Supporting Phase 1 Reviews of Essential Fish Habitat for Pacific Coast Salmon

Oleksandr Stefankiv, Morgan Bond, and Peter Kiffney

https://doi.org/10.25923/nahb-s175

March 2023

Fish Ecology Division
Northwest Fisheries Science Center
2725 Montlake Boulevard East
Seattle, Washington 98112

U.S. DEPARTMENT OF COMMERCE

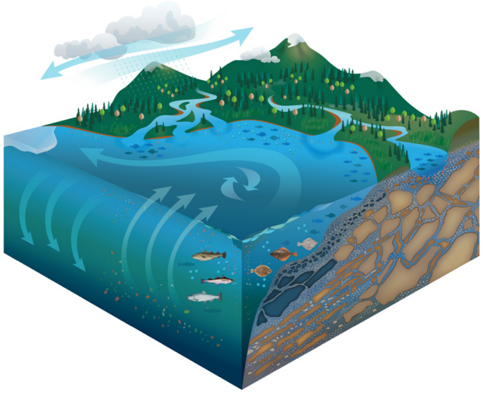
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

Contents

Figures

Tables

Plain Language Summary



In order to survive and thrive, fish and other marine species need access to clean, healthy habitats. From streams and tributaries to large rivers, lakes, and reservoirs—from estuaries to the coast and the open ocean—marine fish, shellfish, mammals, and birds depend on these habitats for every stage of their life cycles. Essential fish habitat, or EFH, refers to the water and substrate that fish require in order to successfully spawn, breed, feed, and grow to maturity.

In the United States, the Magnuson–Stevens Act governs marine fishery management. In addition to establishing and defining EFH, the act requires federal agencies to consult with NOAA Fisheries on all actions or proposals that a) are permitted, funded, or undertaken by the agency, and b) may negatively impact EFH.

Whenever NOAA Fisheries learns of an action by a federal or state agency that may adversely affect EFH, it is required to provide conservation recommendations on how to avoid, minimize, or otherwise offset the effects of the action. State agencies are not required to respond to these recommendations, though federal agencies must do so within 30 days.

This document focuses on the management of freshwater EFH for Pacific salmon and steelhead and presents new analysis of the riverine landscape that supports these species at the spatial scales necessary to make conservation decisions. Our objective was to create a database of the key spatial layers (hydrology, channel gradient, and confinement) necessary to estimate the capacity of available riverine habitats to support Pacific salmon and steelhead populations across the U.S. Pacific coast region. Other uses include identifying the potential for habitats above natural and artificial barriers, like dams, to support salmon or steelhead populations in the future.

Links used in this section:

- Essential fish habitat: https://www.fisheries.noaa.gov/national/habitat-conservation/essential-fish-habitat
- Thumbnail image: https://www.fisheries.noaa.gov/resource/document/essential-fish-habitat-ecosystem-approach
- Magnuson–Stevens Act: https://www.fisheries.noaa.gov/topic/laws-policies/magnuson-stevens-act
- Consult with NOAA Fisheries: https://www.fisheries.noaa.gov/national/habitat-conservation/consultations-essential-fish-habitat
- Pacific salmon and steelhead: https://www.fisheries.noaa.gov/species/pacific-salmon-and-steelhead

Abstract

The Magnuson–Stevens Fishery Conservation and Management Act of 1976 (MSA; amended 1996 and 2007) mandated the identification of essential fish habitat (EFH) for federally managed species and consideration of measures to conserve and enhance the habitat necessary for these species to carry out their life cycles.

The MSA also requires federal agencies to consult with the National Marine Fisheries Service (NOAA Fisheries) on all actions or proposed actions permitted, funded, or undertaken by the agency that may adversely affect EFH—such as EFH necessary for anadromous salmonids—which use both fresh- and saltwater habitats. Federal agencies do this by preparing and submitting EFH assessments to NOAA Fisheries.

One of the first steps of managing freshwater EFH for anadromous salmonids in a changing environment is to have a strong understanding of the riverine landscape and environmental conditions that support these species.

Currently, the designation of freshwater EFH for Pacific Coast salmon and steelhead is limited to a binary classification of occupied (either currently or historically) or unoccupied habitat at the 4th-field (HUC-8) level. At this broad scale of designation, many smaller hydrologic units (e.g., 5th- and 6th-field) that are inaccessible and have never been occupied by salmon are designated as EFH. However, new datasets provide an opportunity to improve both the spatial resolution and nuance of designation. Data are available to classify accessibility at the 6th field (HUC-12) for most species and regions. State and regional partners have been developing detailed barrier datasets, and the National Hydrography Dataset (NHDPlus V2) improves our understanding of stream characteristics important to salmon access and use (e.g., stream gradients).

Here we provide updated spatial data layers for stream channel gradient and confinement across the range of Pacific salmon and steelhead. These data can be used to build models to estimate riverine habitat capacity for different salmonid species and life stages. In the near future, the Pacific Fishery Management Council, NMFS West Coast Region, and NWFSC intend to begin a review of EFH under the Pacific Coast Salmon Fishery Management Plan. This project will inform and support that review with greater specificity in the designation of Pacific salmon and steelhead EFH.

Introduction

The Magnuson–Stevens Fisheries Conservation and Management Act (MSA) defines essential fish habitat (EFH) as “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity,” and requires fishery management councils (FMCs) to identify EFH for federally managed species of anadromous fish in the family Salmonidae. The Pacific Fishery Management Council defines EFH for Pacific coast salmon “as all streams, estuaries, marine waters, and other water bodies occupied or historically accessible to salmon in Washington, Oregon, Idaho, and California, except for certain man-made barriers that define the upstream extent of Pacific salmon access” (PFMC 2014).

The designation of freshwater EFH for Pacific Coast salmon is currently limited to a binary classification of occupied (either currently or historically) or unoccupied habitat at the 4th-field (HUC-8) level. At this broad scale of designation, many smaller hydrologic units (e.g., 5th- and 6th-field) that are inaccessible and have never been occupied by salmon are designated as EFH. However, new datasets provide an opportunity to improve both the spatial resolution and nuance of designation. Data are available to classify accessibility at the 6th field (HUC-12) for most species and regions. State and regional partners have been developing detailed barrier datasets, and the National Hydrography Dataset (NHDPlusV2[1]) improves our understanding of stream characteristics important to salmon access and use (e.g., stream gradients).

---

[1] https://www.epa.gov/waterdata/get-nhdplus-national-hydrography-dataset-plus-data

Objective

Our goal is to quantify reach-specific habitat attributes (e.g., stream gradients) across the Pacific salmon freshwater range (Figure 1) based on spatially explicit geomorphic data, and then apply species-specific habitat needs for spawning or rearing to map EFH for multiple species of Pacific salmon. In the near future, the Pacific Fishery Management Council, NMFS West Coast Region, and NWFSC intend to begin a review of EFH under the Pacific Coast Salmon Fishery Management Plan. This project will inform and support that review with greater specificity in the designation of salmon EFH.

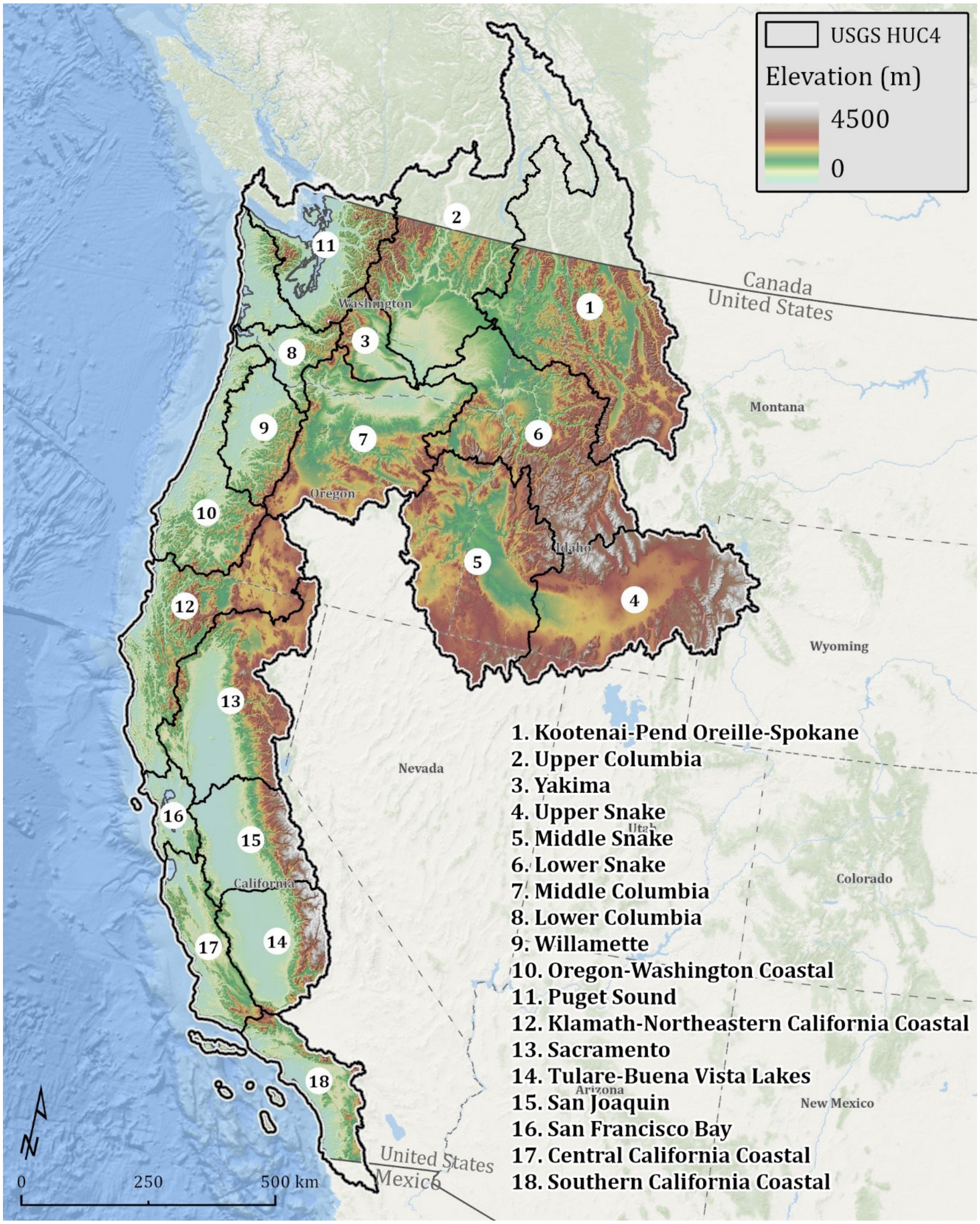


Figure 1. Subregional distribution of Pacific salmon and trout designated as freshwater EFH. Basin portions located on Canadian territory were excluded.

Approach

Our reassessment of essential fish habitat for U.S. West Coast salmon takes an intrinsic-potential approach modeled after previous intrinsic-potential models for Pacific Northwest salmonids (Cooney and Holzer 2006, Sheer et al. 2009, Busch et al. 2011). That is, we intended to estimate reach-specific habitat attributes derived primarily from geomorphic data and apply species-specific habitat needs for spawning or rearing to those spatially explicit habitat estimates across the range of designated freshwater EFH (Figure 1).

This project has three phases. Phase 1 is acquisition of spatial data for the historically anadromous portions of Water Regions 17 and 18. Phase 2 is the creation of habitat metrics from the sourced data. This report summarizes Phases 1 and 2.

If funded in the future, Phase 3 of this project would apply species-specific thresholds—such as stream gradient or water temperature threshold to define upstream distribution—to the data, to estimate usable and unusable habitat.

Accomplishments

Phase 1: Data Collection

The spatial distribution of species and population productivity are two important characteristics of viable salmon populations. Habitat capacity, or the ability of a specific habitat type to support a particular life stage, is a critical metric in evaluating the productive potential of a habitat for supporting stream salmonids. Habitat capacity is determined by a variety of environmental and biological factors, including stream gradient, channel confinement, watershed size, and location. To assess the spatial extent and habitat capacity of Pacific salmon and steelhead distribution across the U.S. West Coast region, we used existing datasets for hydrography, topography, stream flow, migration barriers, and stream temperature to estimate geomorphic and habitat attributes for each reach.

- **Hydrography:** The National Hydrography Dataset (NHD) stream reaches form the backbone of our analysis. We used the 1:100,000-scale National Hydrography Plus Version 2 (NHDPlus V2) hydrography to attach all subsequent data and derive metrics. While higher-resolution NHDPlus High Resolution hydrography is available (1:24,000 scale), the National Water Model (see below), a necessary data layer for estimating bankfull width, is based on the NHDPlus V2 stream network. NHD reaches with no flow direction were excluded from further analysis. That is, we only selected reaches where the NHD attribute *FlowDir* was equal to *With Digitized*. This too was carried out because NWM does not estimate recurrence interval flows for reaches without a flow direction. Therefore, a small number of reaches that are typically small and often intermittent or ephemeral streams were excluded from our final network.
- **Topography:** The National Elevation Dataset (NED) Digital Elevation Model (DEM) allows stream channel gradient, drainage area, and valley floor width to be calculated.
- **Stream flow:** The recurrence interval flows for each NHD reach from the National Water Model (NWM) allow us to estimate bankfull width (BFW) for each reach. NWM recurrence interval flow data also allow for a coarse estimate of grain size.
- **Migration barriers:** Geospatial data of natural and anthropogenic barriers to fish movement vary in quality and extent, but the most recent data from Washington, Oregon, Idaho, and California are collected to create anadromous and non-anadromous extent classifications for each stream reach. (Note that some barriers have fish passage, and others without passage have some collection and transport in one or both directions; these are accounted for in the anadromous extent).
- **Midsummer temperature:** NorWeST stream temperature estimates of average August temperatures allow for delineation of a likely downstream extent.

Phase 2: Estimation of Habitat Metrics

Key habitat metrics that determine spatial extent and the intrinsic potential for a habitat to support stream salmonids include:

- **Channel gradient:** An important indicator of salmon habitat availability as well as spawning and rearing range, determined by the difference in vertical distance over reach length (Cooney and Holzer 2006, Clarke et al. 2008). For instance, Chinook salmon have been found to spawn and rear in habitats with channel gradients up to 7%, while steelhead may be found in gradients up to 12% (Montgomery et al. 1999, Agrawal et al. 2005, WDFW 2019).
- **Channel confinement:** A key indicator of salmonid habitat quality, determined by ratio of valley floor width to bankfull channel width (Beechie et al. 2006). Reaches with a higher channel confinement ratio (>4) tend to have more complex channel forms with the potential for side-channel habitat important for rearing and spawning (Hall et al. 2007, Clarke et al. 2008). Bankfull channel width is largely a function of stream discharge, but can be estimated using drainage area (Leopold et al. 1964, Castro and Jackson 2001, Davies et al. 2007). In addition, Beechie et al. (2006) found that the potential for lateral channel migration, which affects salmonid habitat availability and quality, is influenced by a threshold of 15–20 meters in bankfull width, while variations in valley floor width impact the potential for salmonid habitat through processes that affect erosion, flow, and large woody debris inputs (McDowell 2001).
- **Reach classification:** The classification of reaches into anadromous and non-anadromous, and subsequently accessible and inaccessible, is an important metric in the identification of current and historical salmon habitat extent. Migration barrier datasets can be utilized in this classification, while reach channel gradients can help to confirm natural barriers, such as waterfalls, with gradients above 20% (Agrawal et al. 2005, Cooney and Holzer 2006).
- **Stream temperature:** A key indicator of downstream salmon habitat extent, as lower reaches with high midsummer temperatures can be harmful to salmon and steelhead (Cooney and Holzer 2006). For example, in the Shasta River (California), Stenhouse et al. (2012) found that stream temperature above 20.3°C is detrimental to coho salmon.

We were able to calculate channel gradient, bankfull channel width, valley floor width, and channel confinement across the U.S. West Coast region. While we collected stream migration barrier and summer water temperature data across the range of Pacific salmon and trout, classification of anadromous and non-anadromous extent and quantification of available habitat based on these attributes requires analysis that is beyond the scope of the current study.

Phase 3: Application of Species-Specific Habitat Needs for Spawning and Rearing (Future Step)

In this phase, after producing a migration barrier and stream temperature spatial layer, we will have the tools to estimate the intrinsic potential of freshwater habitats supporting Pacific salmon and steelhead across the U.S. West Coast region for the following species or ESUs: spring steelhead and Chinook, coho, and chum salmon (Puget Sound–Lower Columbia), and pink salmon (Puget Sound).

Methods: Data Collection and Estimation of Habitat Metrics

We collated and processed a suite of geospatial datasets to create more accurate maps of essential fish habitat (EFH) for U.S. West Coast Pacific salmon and trout (*Oncorhynchus* spp.). We generated key geomorphic attributes (i.e., gradient, bankfull and valley floor width, channel confinement) known to influence the distribution of Pacific salmon and trout utilizing the U.S. National Hydrography Dataset Plus (NHDPlus V2, 1:100,000 scale) hydrography layer as a stream network and the U.S. National Elevation Dataset (NED, 10-meter grid spacing) as a digital elevation model (DEM) for our analysis (Table 1). The processing was split by U.S. Geological Survey Hydrologic Unit Codes at the Level 4 scale and each dataset was projected to a common USA Contiguous Albers Equal Area Conic USGS version coordinate reference system (USGS 2018). We then segmented the stream network into 200-m reaches, and calculated gradient and confinement for each segment. We acquired and utilized simulated stream discharge data from the National Oceanic and Atmospheric Administration National Water Model (NWM), and upstream drainage area from the value-added attribute data (NHDPlus VAA) at an NHDPlus V2 reach level.

Table 1. Geospatial data used for the spatial analysis.

Input data layer	**Source**
Hydrography	National Hydrography Dataset Plus (NHDPlus V2), 1:100,000 scale. https://www.usgs.gov/core-science-systems/ngp/national-hydrography/nhdplus-high-resolution
National Elevation Dataset (NED)	U.S. Geological Survey (USGS) 10-m resolution Digital Elevation Model. https://lta.cr.usgs.gov/NED
Basin boundaries	U.S. Geological Survey (USGS) Level 4-scale Hydrological Unit Codes. https://water.usgs.gov/GIS/huc.html
Discharge	National Oceanic and Atmospheric Administration (NOAA) National Water Model (NWM). https://water.noaa.gov/about/nwm

Channel gradient was estimated by calculating the elevation difference between the start and end of a 200-m reach and dividing by the reach length. Due to the spatial misalignment of the NHDPlus flowline with the NED data, we utilized the lowest elevation value within 60-m radius of each reach endpoint (Hall et al. 2007, Beechie and Imaki 2014). Figures 2 and 3 provide examples of maps demonstrating the spatial variation in channel gradient at the river basin scale. Variation in stream length by channel gradient for major U.S. West Coast drainages can be seen in Table 2.

Channel confinement was estimated as the valley floor width divided by the bankfull channel width (Beechie et al. 2006, Hall et al. 2007, Clarke et al. 2008). To estimate bankfull width, we utilized hydraulic geometry relationships based on the discharge or upstream drainage area. We used models from Castro and Jackson (2001) that define varying bankfull discharge recurrence intervals for major EPA Level III ecoregions within the Pacific Northwest (Omernik and Griffith 2014). For the Pacific Maritime Mountain, West Interior Basin and Range, and Western Cordillera ecoregions, we utilized bankfull discharge equations with the 1.2, 1.5, and 1.4 recurrence intervals, respectively (Table 3). In reaches where bankfull discharge predictions were estimated to be zero, we used equations with drainage area only. For Mediterranean California and Warm Desert ecoregions, we utilized the model from Modrick and Georgakakos (2014) for Southern California, which also employs drainage area only.

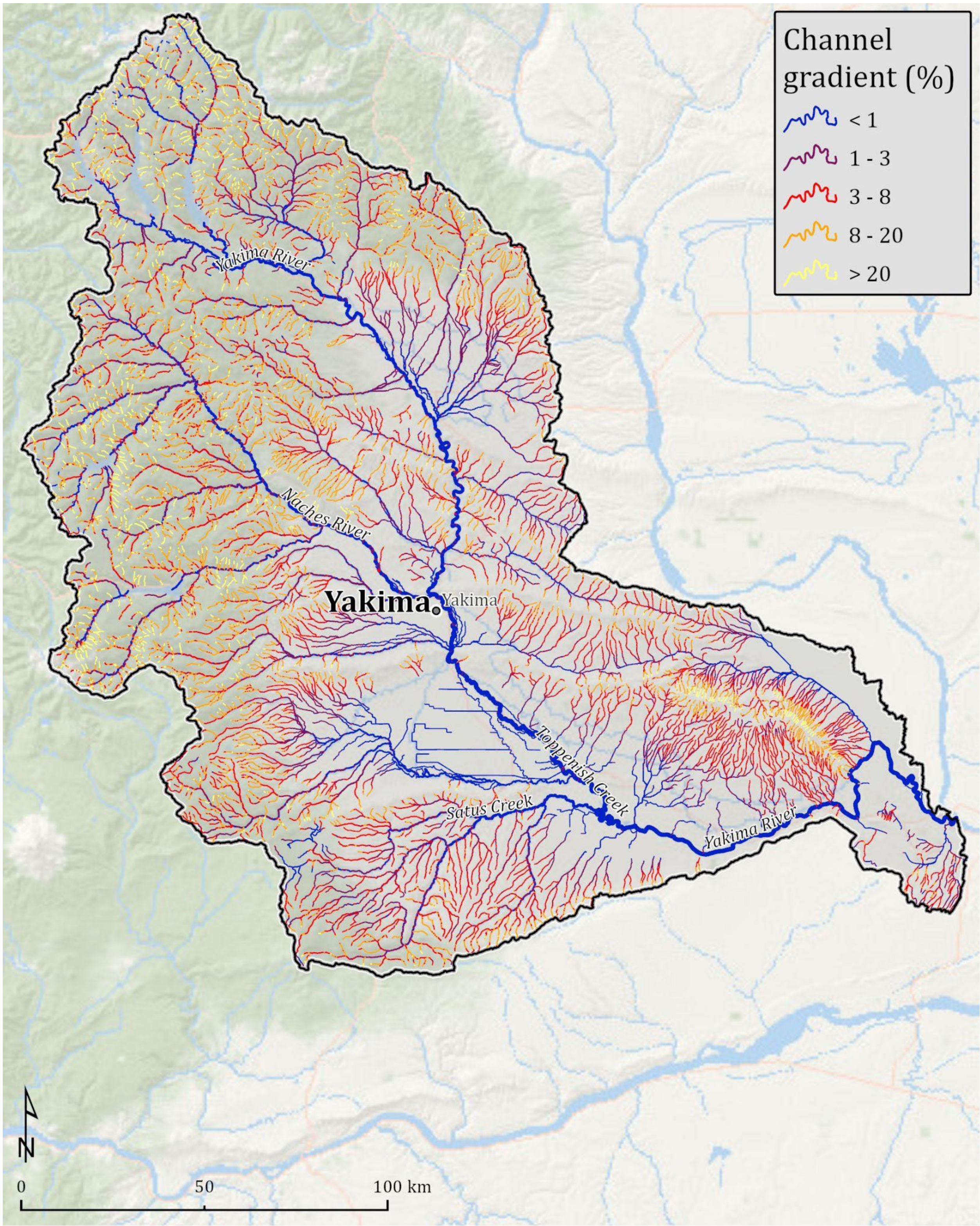


Figure 2. Spatial distribution of channel gradient (%) in the Yakima River (Washington) subregion.

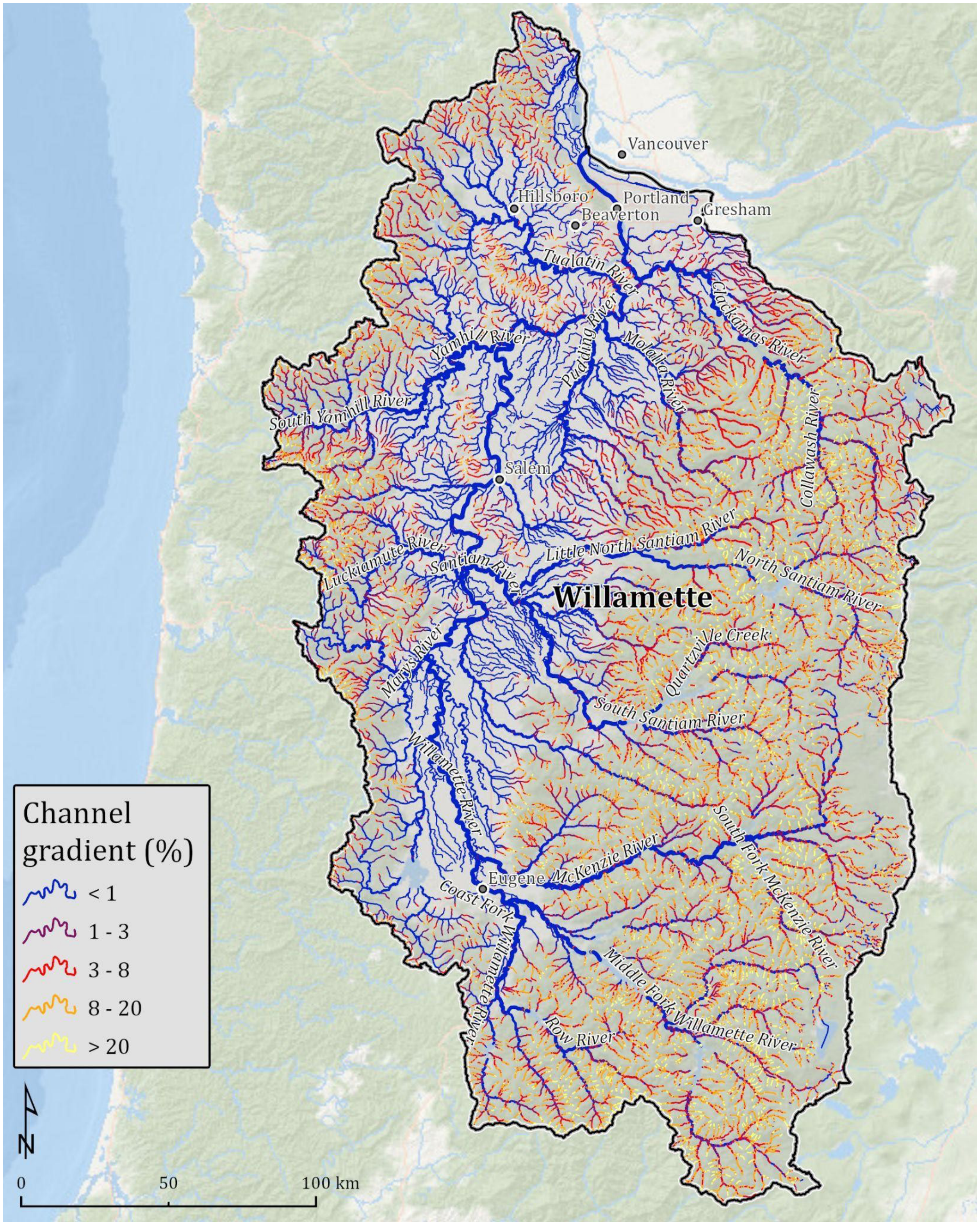


Figure 3. Spatial distribution of channel gradient (%) in the Willamette River (Oregon) subregion.

Table 2. The amount of stream length in each gradient and confinement class for major U.S. West Coast drainages.

Drainage	Channel gradient (%)	Length (km)	Confinement ratio	Length (km)
Central Valley California	<1	30,067	0–2	7,425
	1–3	19,991	2–4	14,346
	3–8	24,627	4–6	13,264
	8–20	18,867	6–10	17,316
	>20	7,877	>10	49,076
Coastal California	<1	19,990	0–2	10,068
	1–3	19,477	2–4	19,780
	3–8	23,546	4–6	17,915
	8–20	20,609	6–10	17,721
	>20	9,574	>10	27,712
Columbia River Basin	<1	79,655	0–2	19,035
	1–3	78,261	2–4	49,618
	3–8	102,217	4–6	38,311
	8–20	81,443	6–10	49,901
	>20	28,699	>10	213,409
Oregon and Washington Coast	<1	12,549	0–2	7,296
	1–3	8,607	2–4	11,522
	3–8	9,289	4–6	6,493
	8–20	7,498	6–10	6,493
	>20	2,183	>10	8,322
Puget Sound	<1	5,116	0–2	2,639
	1–3	3,379	2–4	4,613
	3–8	3,832	4–6	2,606
	8–20	3,764	6–10	3,017
	>20	3,508	>10	6,724

Table 3. Ecoregion groupings based on Castro and Jackson (2001). The relationships are reported in the following units: Q = bankfull discharge (ft^3/s in Castro and Jackson 2001, m^3/s in Modrick and Georgakakos 2014), A = drainage area (mi^2 in Castro and Jackson 2001, km^2 in Modrick and Georgakakos 2014), and w = bankfull width (ft in Castro and Jackson 2001, m in Modrick and Georgakakos 2014). Final bankfull widths were converted from feet to meters.

Locations	***n***	**Equation(s)**	***R*²**	**Source**
Mediterranean California and Warm Desert Streams	60	$w = 2.961A^{0.338}$	0.59	Modrick and Georgakakos (2014)
Central California Valley				
Mojave Basin and Range				
Southern California Mountains				
Southern California/Northern Baja Coast				
Pacific Maritime Mountain Streams	22	$w = 2.37Q^{0.50}$	0.76	Castro and Jackson (2001)
Coast Range		$w = 12.39A^{0.43}$	0.59	
North Cascades				
Puget Lowland				
Willamette Valley				
West Interior Basin and Range Streams	22	$w = 0.96Q^{0.60}$	0.87	Castro and Jackson (2001)
Central Basin and Range		$w = 3.27A^{0.51}$	0.83	
Columbia Plateau				
Northern Basin and Range				
Snake River Plain				
Western Cordillera Streams	32	$w = 3.50Q^{0.44}$	0.84	Castro and Jackson (2001)
Canadian Rockies		$w = 9.40A^{0.42}$	0.54	
Cascades				
Blue Mountains				
Eastern Cascades Slopes and Foothills				
Idaho Batholith				
Klamath Mountains/California High North Coast Range				
Middle Rockies				
Northern Rockies				
Sierra Nevada				

We estimated valley floor width using a transect length that intersects the valley wall at a specified height above the channel surface. For each 200-m reach, perpendicular transects were projected at 20-m intervals and elevation values were extracted using 10-m spacing along the transect. We utilized a filling depth of 5 m above the channel surface for the reaches with a bankfull width greater than or equal to 20 m, and a filling depth of 2 m for the reaches with a bankfull width less than 20 m (Beechie et al. 2006, Beechie and Imaki 2014). Transect length was at least 10 times the bankfull width of each reach. The minimum elevation within each transect was considered the channel surface, and the distance to the nearest elevation points above the filling depth (2 m or 5 m above the channel surface) on each side of the valley were calculated to derive valley floor width. The resulting widths were then averaged for each 200-m reach. Figures 4 and 5 provide examples of maps demonstrating the spatial variation in channel confinement ratio at the river basin scale. The variation in stream length by channel confinement ratio for major U.S. West Coast drainages can be seen in Table 2.

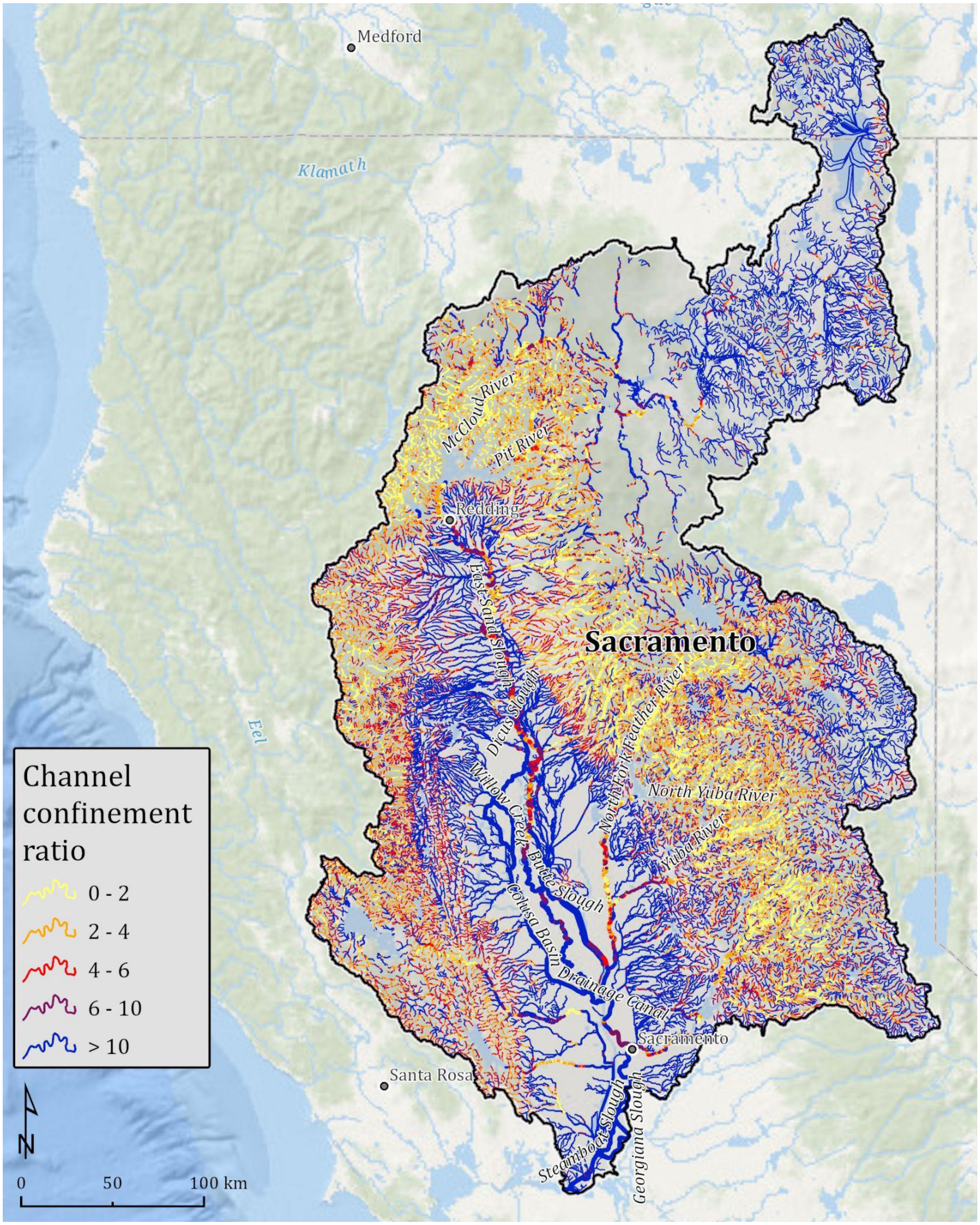


Figure 4. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Sacramento River (California) subregion.

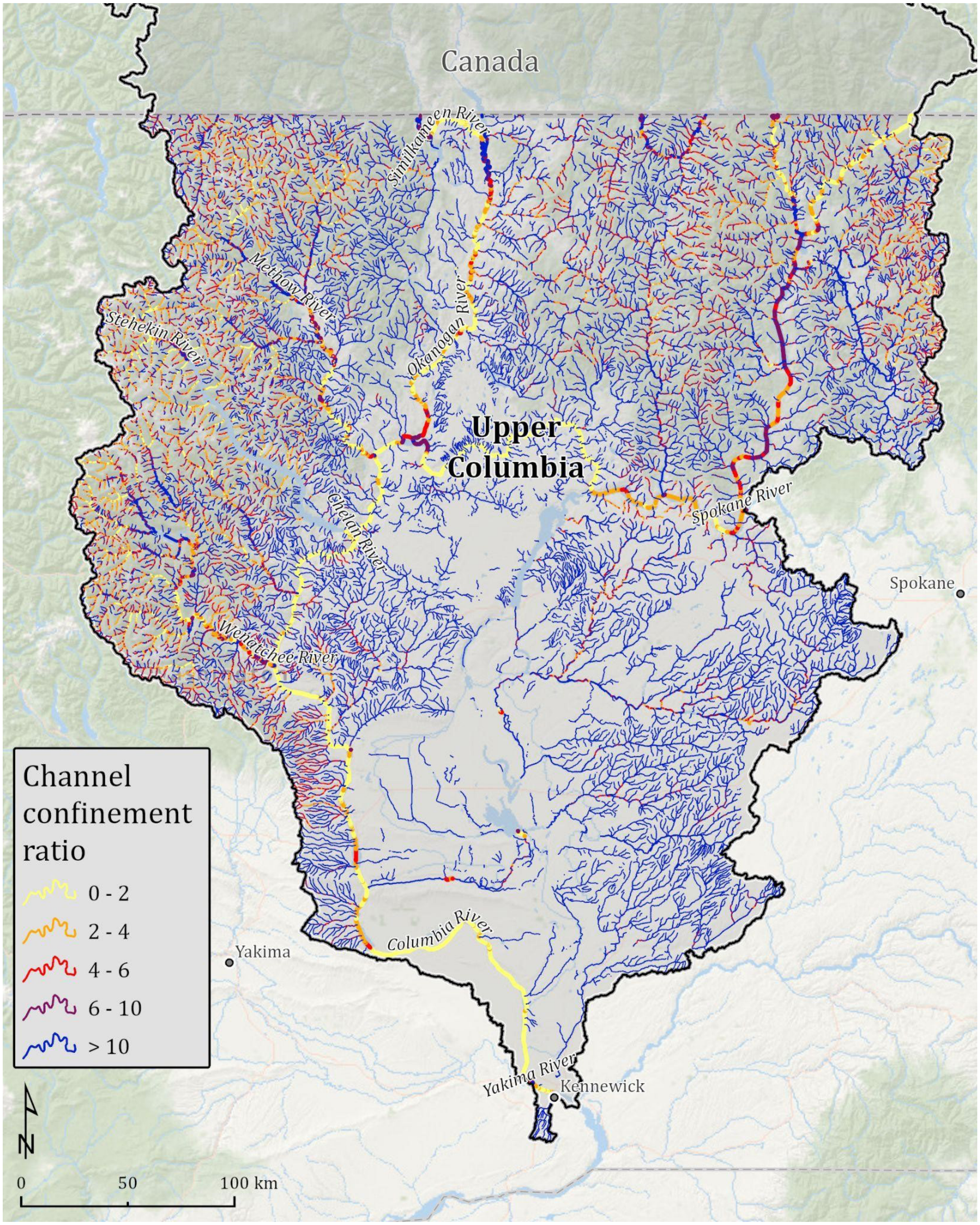


Figure 5. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Upper Columbia (Washington) subregion.

Implications and Recommendations

The geographic distribution of stream reaches with potential to support high-quality habitat for stream salmonids has bearing on the actual status of habitats and populations over broad spatial extents (Burnett et al. 2007, Busch et al. 2011). A broad-scale perspective is needed when designing, evaluating, and implementing freshwater habitat conservation measures for salmonids. This perspective includes both an accurate picture of the spatial extent of available freshwater habitat and the quality of this habitat in supporting salmon populations.

Quantifying the spatial distribution of important determinants of freshwater EFH, including channel gradient, for different species of Pacific salmon can be used to assess habitat suitability based on species-specific habitat accessibility and preferences (e.g., Lisi et al. 2013) at spatial scales (i.e., sub-basin to basin) important for making management decisions. For example, if a dam or culvert is considered for removal, knowing the extent and quality of available habitat above each barrier will help stakeholders make a decision.

Here we provide several important data layers necessary to improve our understanding of both the spatial extent and quality of habitat across the U.S. West Coast region for Pacific salmon and steelhead.

Two issues that arose during our data gathering and analysis were producing two key data layers to help us define spatial extent and intrinsic potential:

- **Migration barriers:** During the aggregation stage of our analysis, we discovered that in some of the barrier databases, numerous natural barriers contained an unknown status, which prohibited us from classifying our reaches into anadromous and inaccessible natural categories. Further investigation is necessary to review the status of natural barriers in order to increase confidence in the estimation of the natural salmonid range. In addition, the spatial alignment of barriers varies among the databases because many of them rely on higher-resolution hydrography (NHDPlus HR, 1:24,000 scale). As a result, more work is needed to adjust the barrier placement on our stream network (NHDPlus V2, 1:100,000 scale).
- **Stream temperature:** While the NorWeST stream temperature dataset (Isaak et al. 2017) is also based on the NHDPlus V2 stream network, numerous reaches in lower sections of the basins were removed to conform with the topology required for temperature modeling, including the adjustment of the basin network to a single outlet. Consequently, a large portion of our stream network does not contain stream temperature predictions, which severely limits its spatial extent. Additional work is needed to determine the optimal method for the estimation of stream temperature for excluded sections.

The spatial data layers that are products of this project are publicly available on the West Coast Salmon Attributes for Salmon Intrinsic Potential web page.[2]

---

[2] https://noaa.maps.arcgis.com/home/item.html?id=fadf2320d6d24df996de4b3b0c65776f

References

Agrawal, A., R. S. Schick, E. P. Bjorkstedt, R. G. Szerlong, M. N. Goslin, B. C. Spence, T. H. Williams, and K. M. Burnett. 2005. Predicting the potential for historical coho, Chinook and steelhead habitat in northern California. National Oceanic and Atmospheric Administration, Santa Cruz, California.

Beechie, T., and H. Imaki. 2014. Predicting natural channel patterns based on landscape and geomorphic controls in the Columbia River basin, USA: Predicting Channel Patterns in the Columbia Basin. Water Resources Research 50(1):39–57.

Beechie, T. J., M. Liermann, M. M. Pollock, S. Baker, and J. Davies. 2006. Channel pattern and river–floodplain dynamics in forested mountain river systems. Geomorphology 78(1):124–141.

Burnett, K. M., G. H. Reeves, D. J. Miller, S. Clarke, K. Vance-Borland, and K. Christiansen. 2007. Distribution of salmon-habitat potential relative to landscape characteristics and implications for conservation. Ecological Applications 17(1):66–80.

Busch, D. S., M. Sheer, K. Burnett, P. McElhany, and T. Cooney. 2011. Landscape-level model to predict spawning habitat for lower Columbia River fall Chinook Salmon (*Oncorhynchus tshawytscha*). River Research and Applications 29:297–312.

Castro, J. M., and P. L. Jackson. 2001. Bankfull Discharge Recurrence Intervals and Regional Hydraulic Geometry Relationships: Patterns in the Pacific Northwest, USA. Journal of the American Water Resources Association 37(5):1249–1262.

Clarke S., K. M. Burnett, and D. J. Miller. 2008. Modeling streams and hydrogeomorphic attributes in Oregon from digital and field data. Journal of the American Water Resources Association 44:459–477.

Cooney, T., and D. Holzer. 2006. Appendix C: Interior Columbia Basin Stream Type Chinook Salmon and Steelhead Populations: Habitat Intrinsic Potential Analysis. ICTRT Viability Criteria Review Draft. Northwest Fisheries Science Center, Seattle.

Davies, J. R., K. M. Lagueux, B. Sanderson, and T. J. Beechie. 2007. Modeling Stream Channel Characteristics from Drainage Enforced DEMs in Puget Sound, Washington, USA. Journal of the American Water Resources Association 43:414–426.

Hall, J. E., D. M. Holzer, and T. J. Beechie. 2007. Predicting River Floodplain and Lateral Channel Migration for Salmon Habitat Conservation. Journal of the American Water Resources Association 43(3):786–797.

Isaak, D. J., S. J. Wenger, E. E. Peterson, J. M. Ver Hoef, D. E. Nagel, C. H. Luce, S. W. Hostetler, J. B. Dunham, B. B. Roper, S. P. Wollrab, G. L. Chandler, D. L. Horan, and S. Parkes-Payne. 2017. The NorWeST summer stream temperature model and scenarios for the western U.S.: A crowd-sourced database and new geospatial tools foster a user community and predict broad climate warming of rivers and streams. Water Resources Research 53(11):9181–9205.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial Processes in Geomorphology. Dover Publications, Inc., New York.

Lisi, P. J., D. E. Schindler, K. T. Bentley, and G. R. Pess. 2013. Association between watershed attributes, water temperature, and salmon spawn timing in Alaska streams. Geomorphology 185:78–86.

McDowell, P. F. 2001. Spatial Variations in Channel Morphology at Segment and Reach Scales, Middle Fork John Day River, Northeastern Oregon. Pages 159–172 *in* J. M. Dorava, D. R. Montgomery, B. B. Palcsak, and F. A. Fitzpatrick, editors. Geomorphic Processes and Riverine Habitat, volume 4. American Geophysical Union, Washington, D.C.

Modrick, T. M., and K. P. Georgakakos. 2014. Regional bankfull geometry relationships for southern California mountain streams and hydrologic applications. Geomorphology 221:242–260.

Montgomery, D. R., E. M. Beamer, G. R. Pess, and T. P. Quinn. 1999. Channel Type and Salmonid Spawning Distribution and Abundance. Canadian Journal of Fisheries and Aquatic Sciences 56(3):377–387.

MSA (Magnuson–Stevens Fishery Conservation and Management Act of 1976). 2006. Magnuson–Stevens Fishery Conservation and Management Reauthorizaton Act of 2006. U.S. Code, volume 16, section 1851.

Omernik, J. M., and G. E. Griffith. 2014. Ecoregions of the Conterminous United States: Evolution of a Hierarchical Spatial Framework. Environmental Management 54(6):1249–1266.

PFMC (Pacific Fishery Management Council). 2014. Appendix A to the Pacific Coast Salmon Fishery Management Plan as Modified by Amendment 18 to the Pacific Coast Salmon Plan: Identification and Description of Essential Fish Habitat, Adverse Impacts, and Recommended Conservation Measures for Salmon. Pacific Fishery Management Council, Portland, Oregon. Available: www.pcouncil.org/documents/2019/08/salmon-efh-appendix-a.pdf/ (January 2023).

Sheer, M. B., D. S. Busch, E. Gilbert, J. M. Bayer, S. Lanigan, J. L. Schei, K. M. Burnett, and D. Miller. 2009. Development and management of fish intrinsic potential data and methodologies: State of the IP 2008 summary report. Pacific Northwest Aquatic Monitoring Partnership Series 2009–004. Pacific Northwest Aquatic Monitoring Partnership, Tacoma, Washington.

Stenhouse, S. A., C. Bean, W. R. Chesney, and M. S. Pisano. 2012. Water temperature thresholds for coho salmon in a spring-fed river, Siskiyou County, California. California Fish and Game 98:19–37.

USGS (U.S. Geological Survey). 2018. Hydrologic Unit Watershed Boundary Dataset. Available: water.usgs.gov/GIS/huc.html (January 2023).

WDFW (Washington Department of Fish and Wildlife). 2019. Fish passage barrier and surface water diversion screening assessment and prioritization manual. Washington Department of Fish and Wildlife, Olympia, Washington.

Appendix A

A.1: Subregional Maps of Channel Gradients

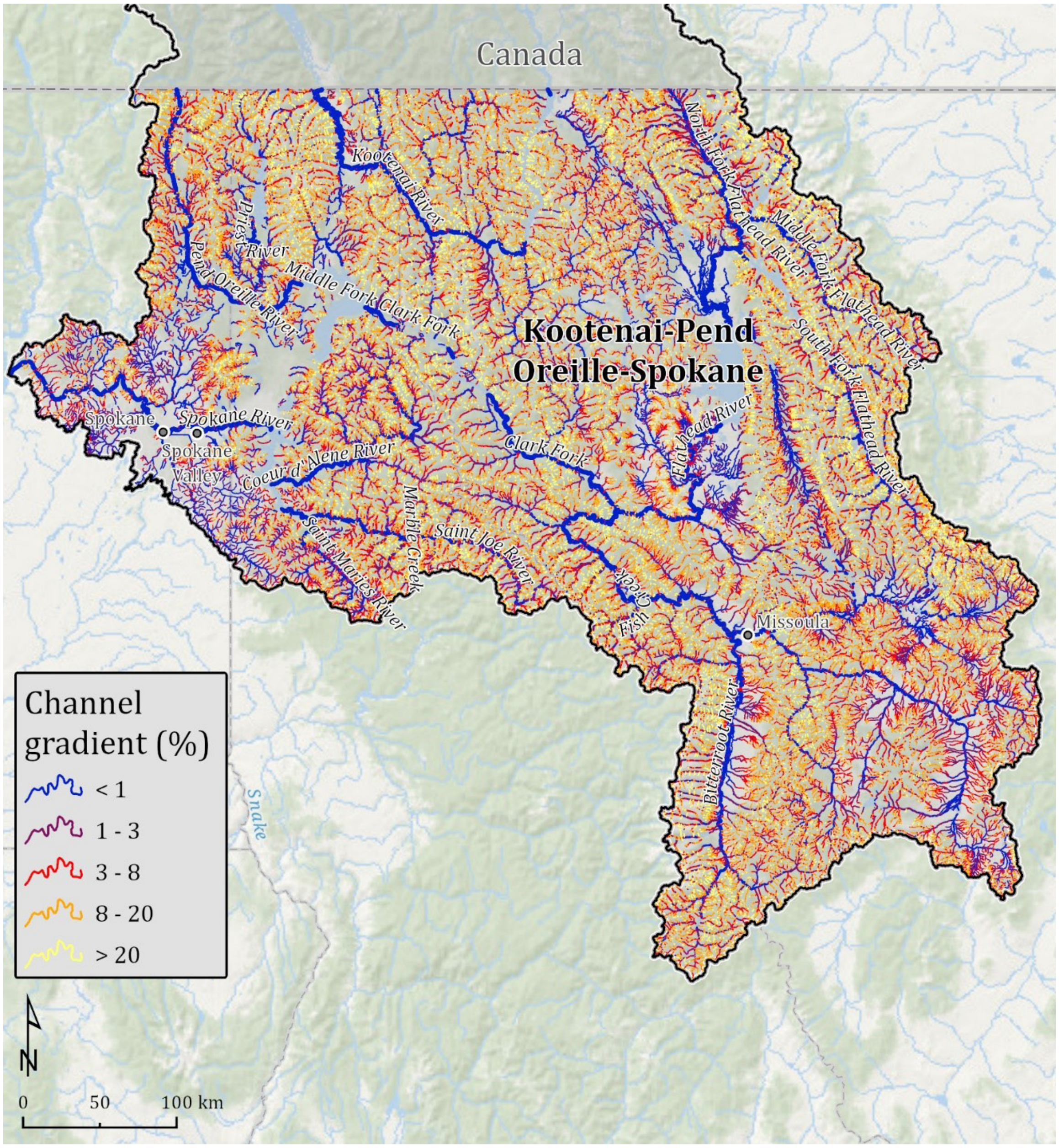


Figure A1. Spatial distribution of channel gradient (%) in the Kootenai–Pend Oreille–Spokane subregion.

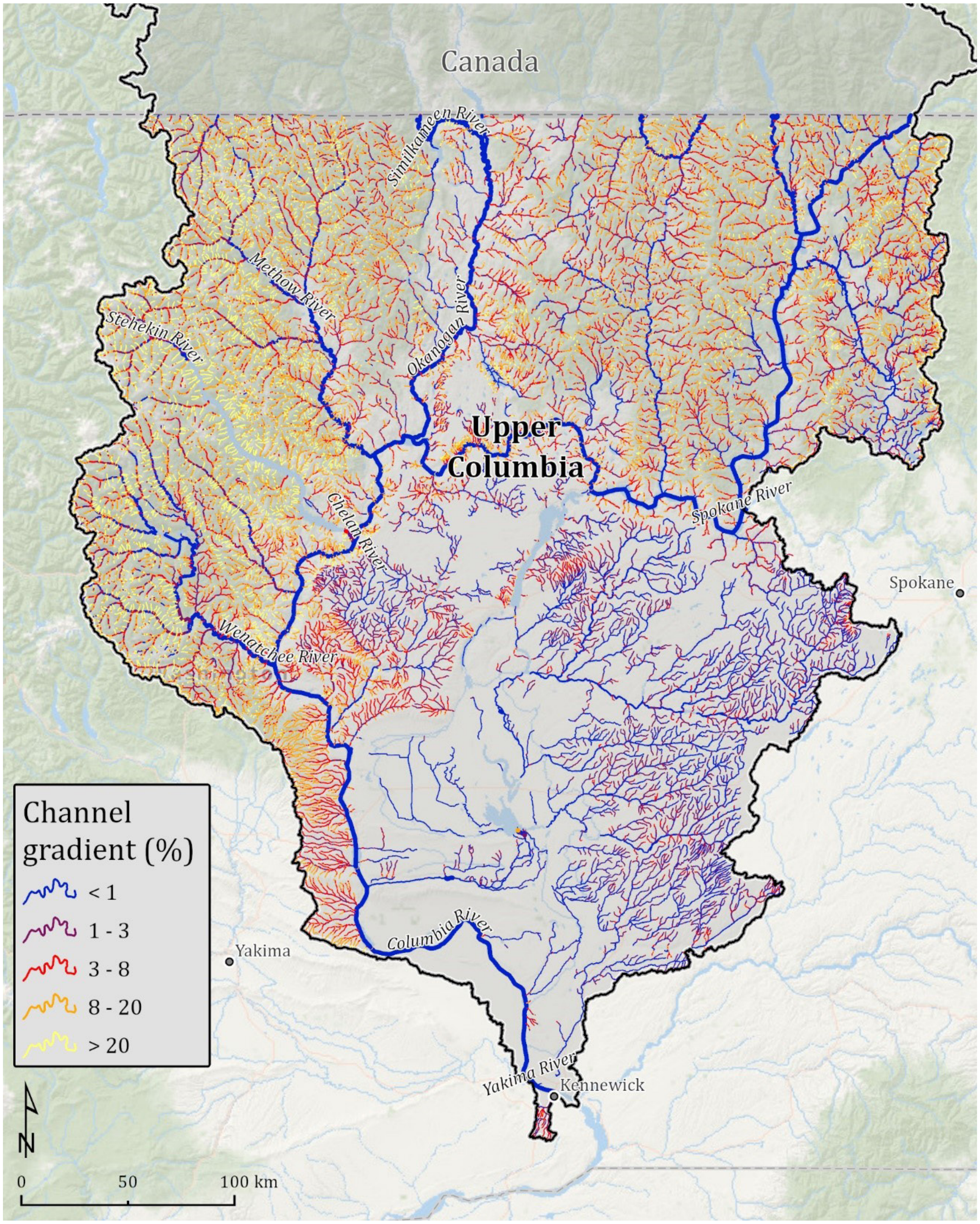


Figure A2. Spatial distribution of channel gradient (%) in the Upper Columbia subregion.

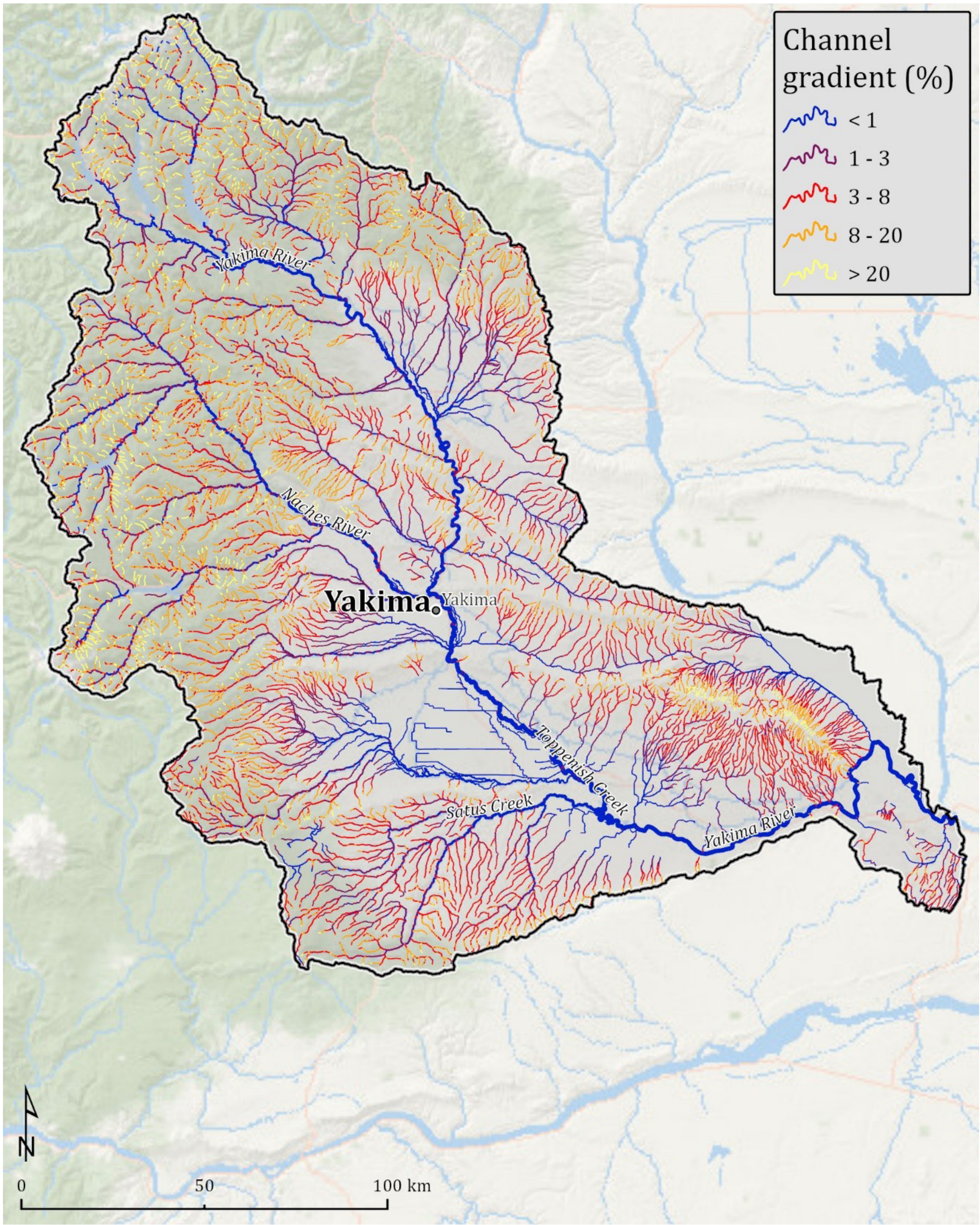


Figure A3. Spatial distribution of channel gradient (%) in the Yakima subregion.

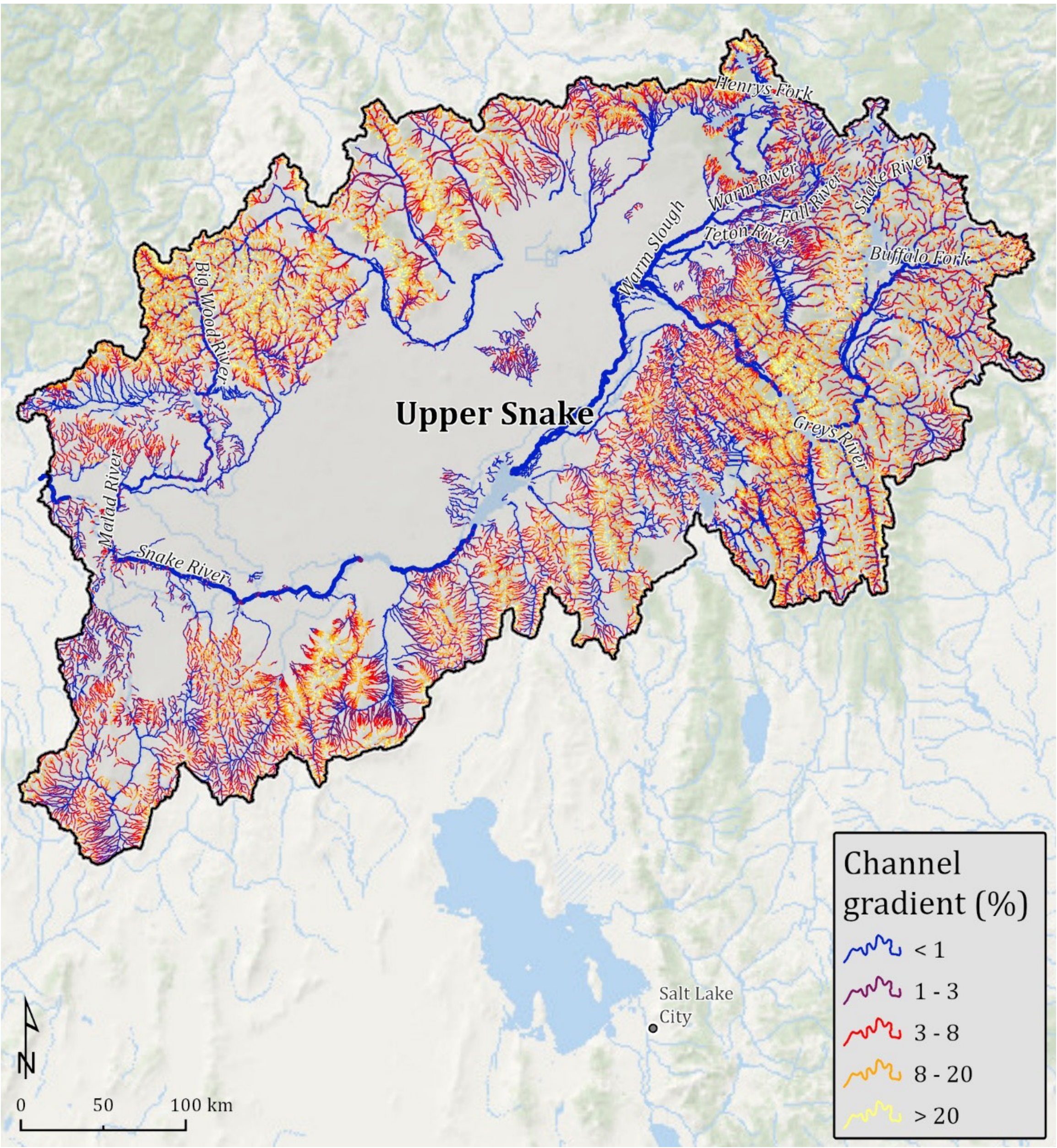


Figure A4. Spatial distribution of channel gradient (%) in the Upper Snake subregion.

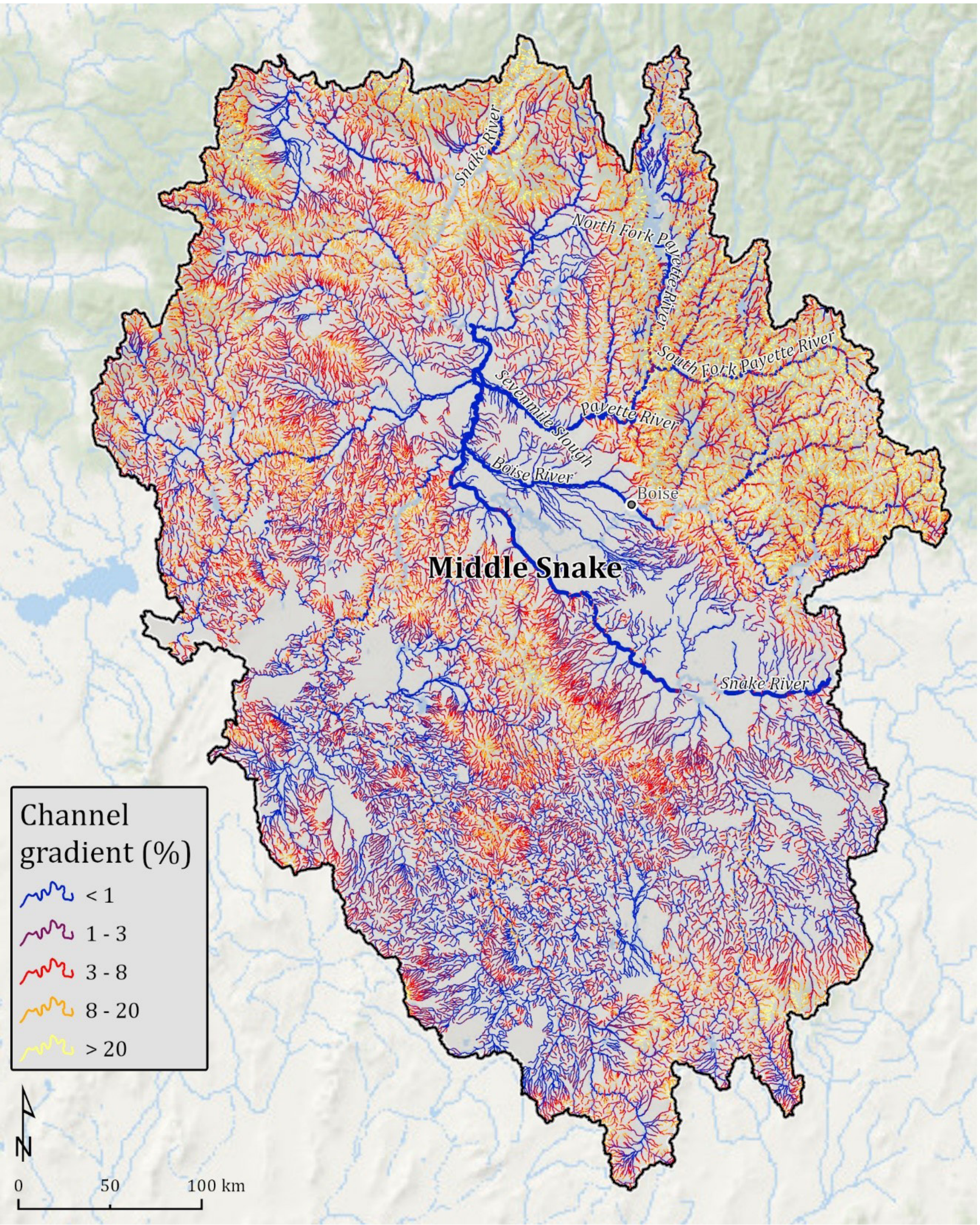


Figure A5. Spatial distribution of channel gradient (%) in the Middle Snake subregion.

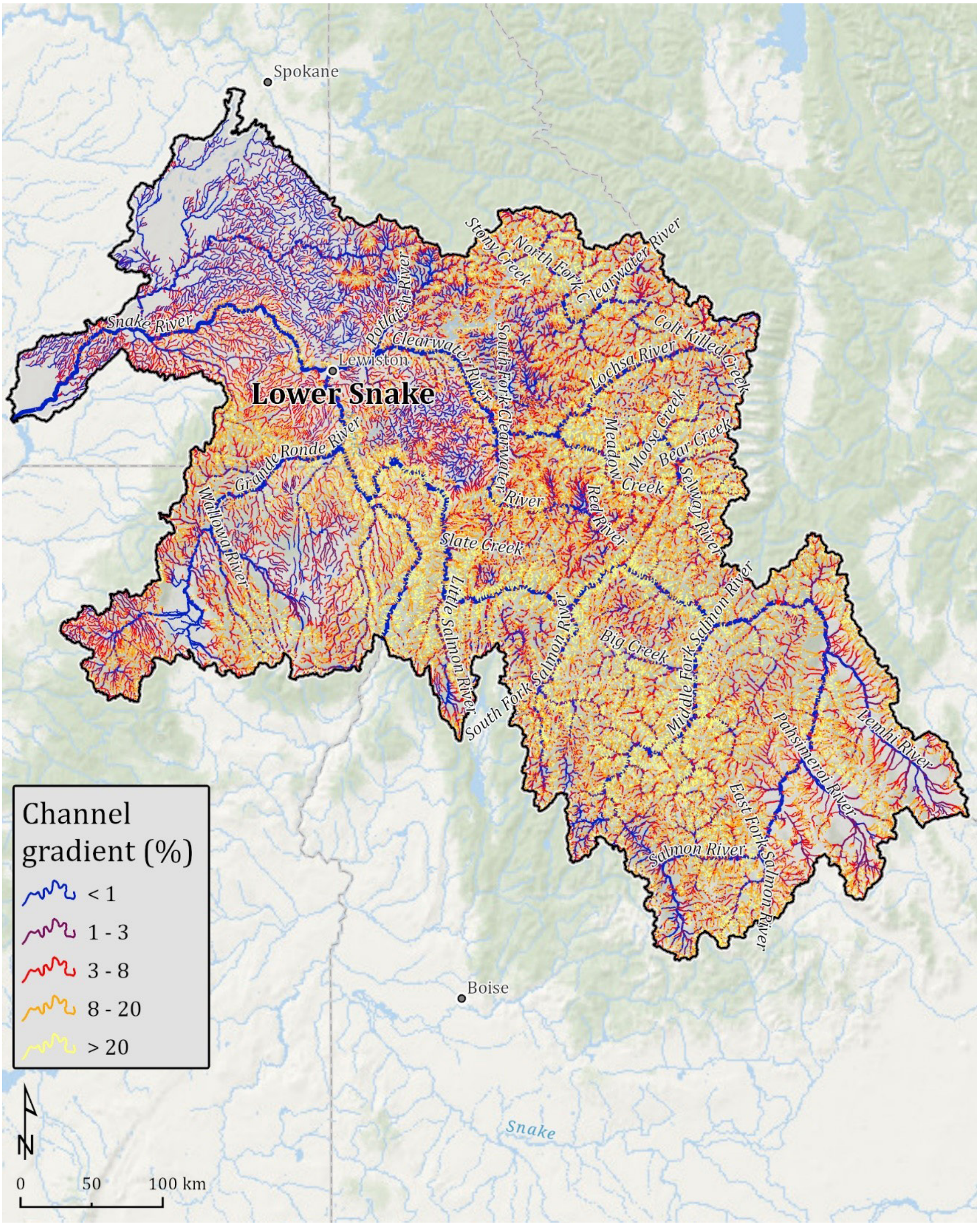


Figure A6. Spatial distribution of channel gradient (%) in the Lower Snake subregion.

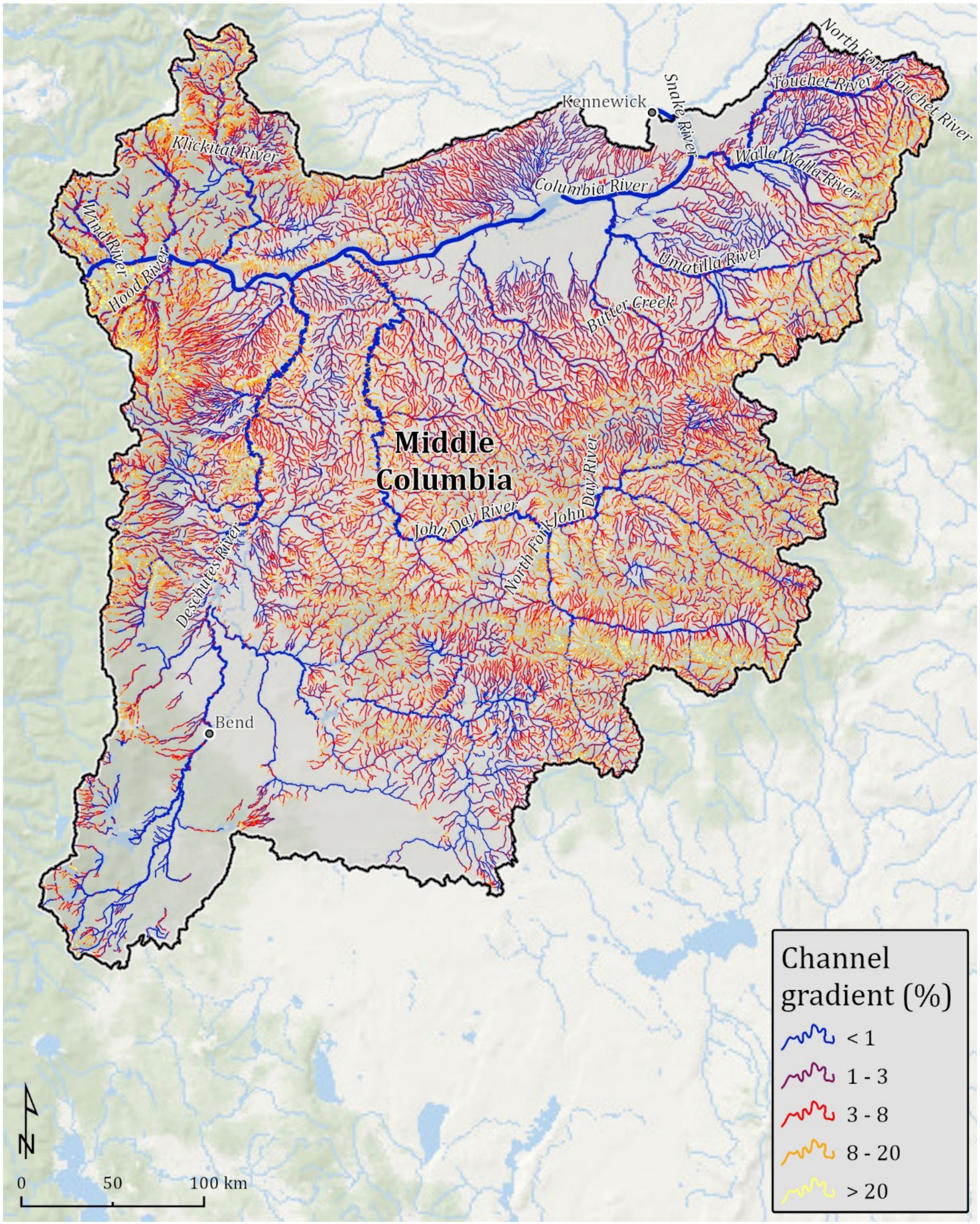


Figure A7. Spatial distribution of channel gradient (%) in the Middle Columbia subregion.

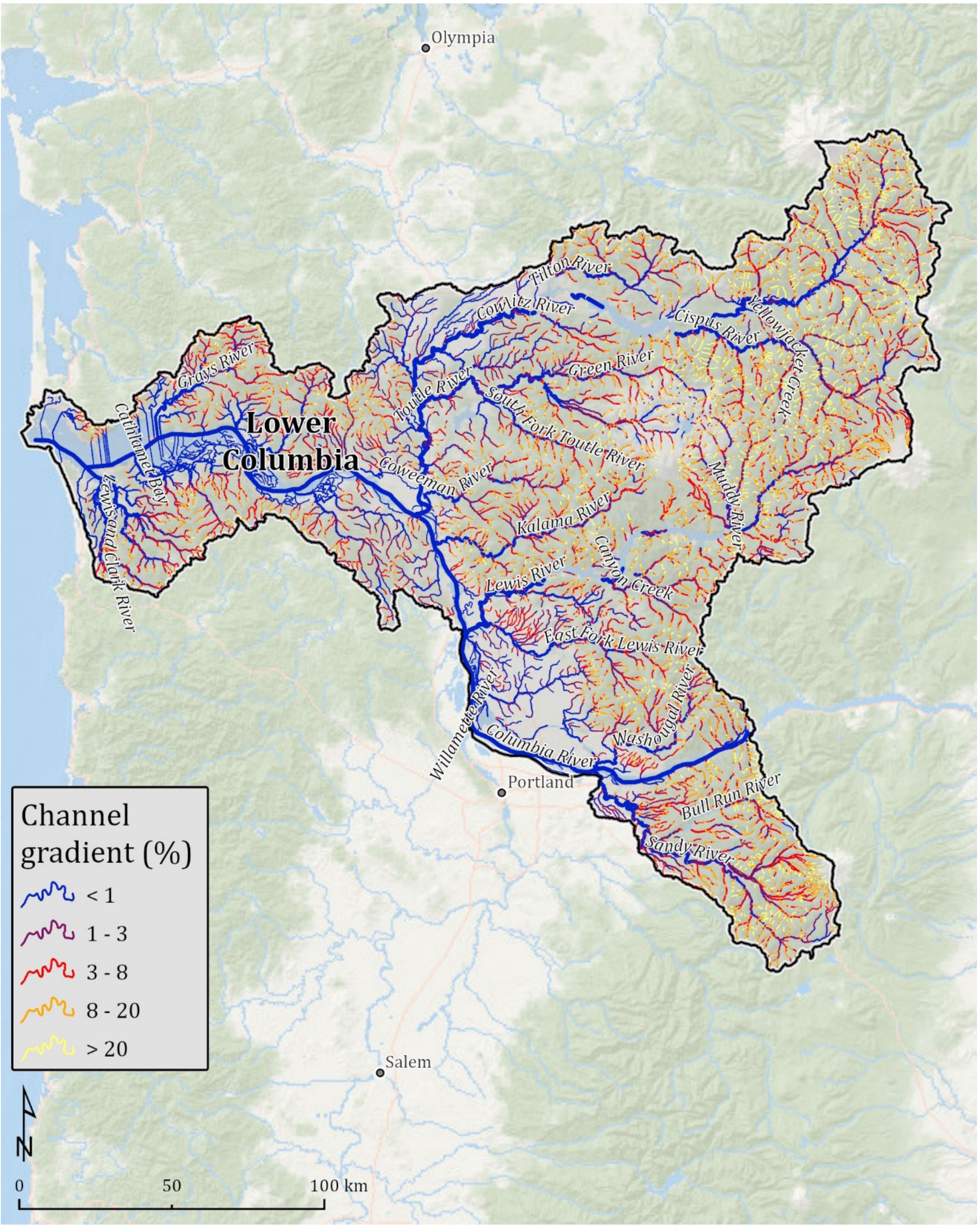


Figure A8. Spatial distribution of channel gradient (%) in the Lower Columbia subregion.

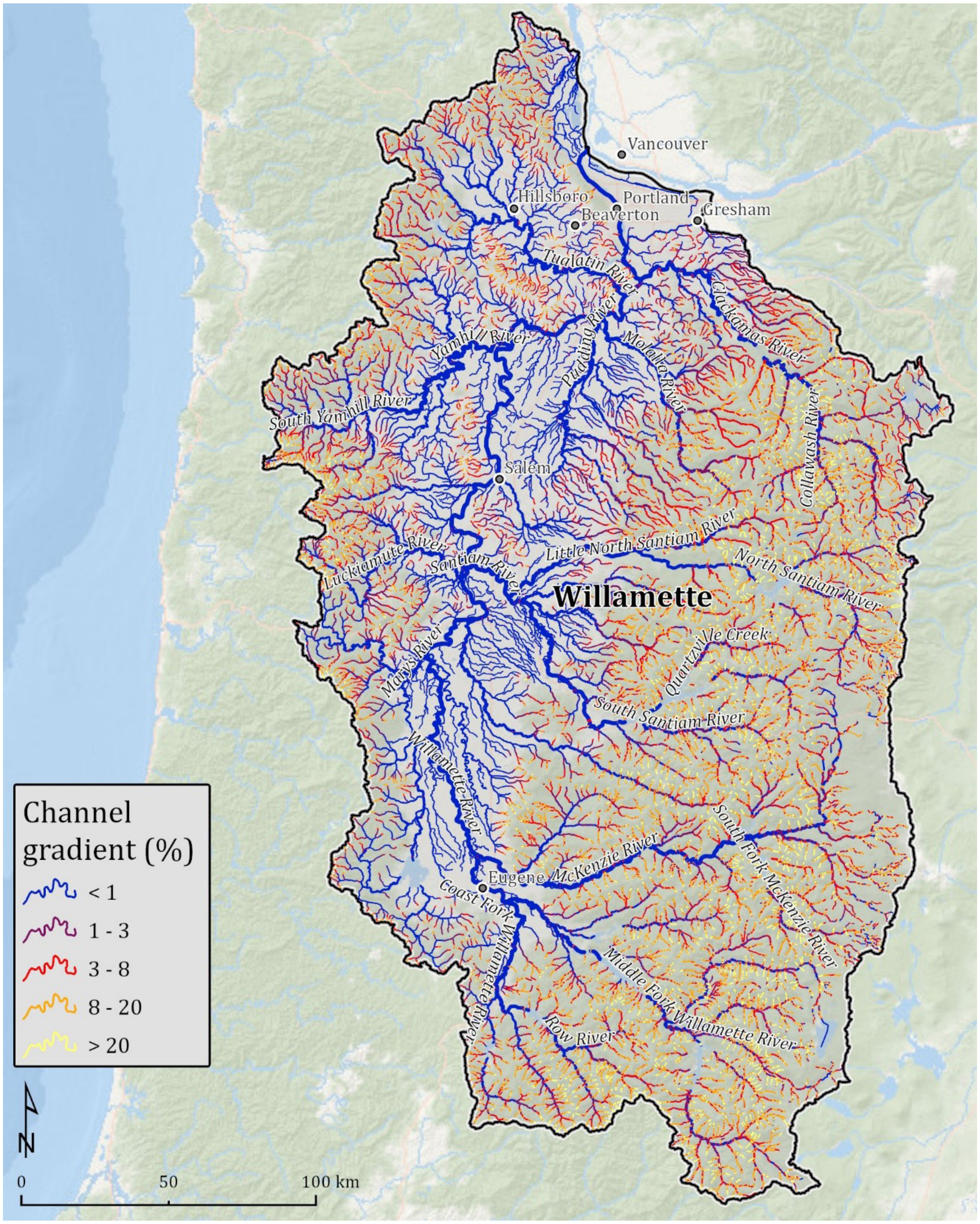


Figure A9. Spatial distribution of channel gradient (%) in the Willamette subregion.

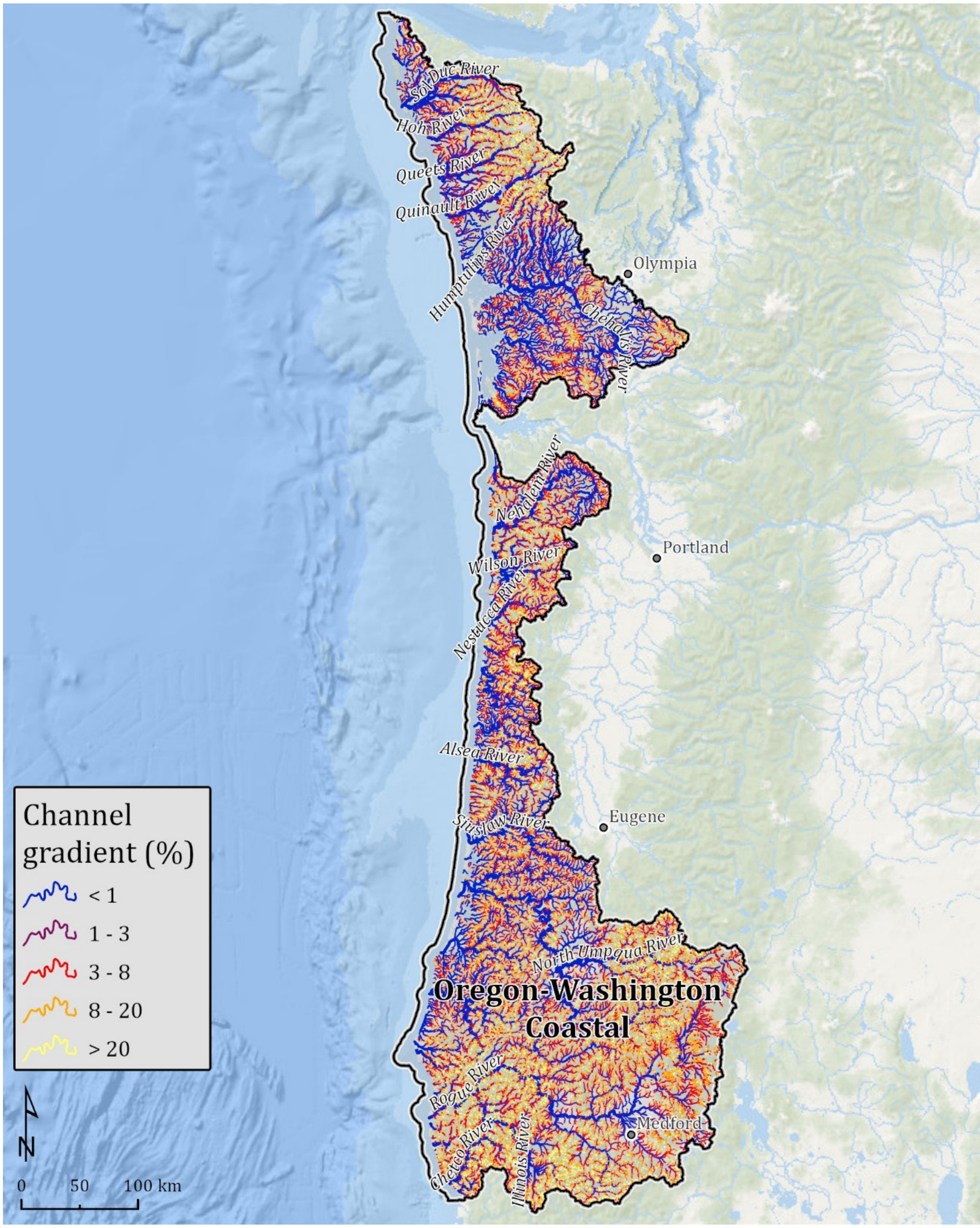


Figure A10. Spatial distribution of channel gradient (%) in the Oregon–Washington Coast subregion.

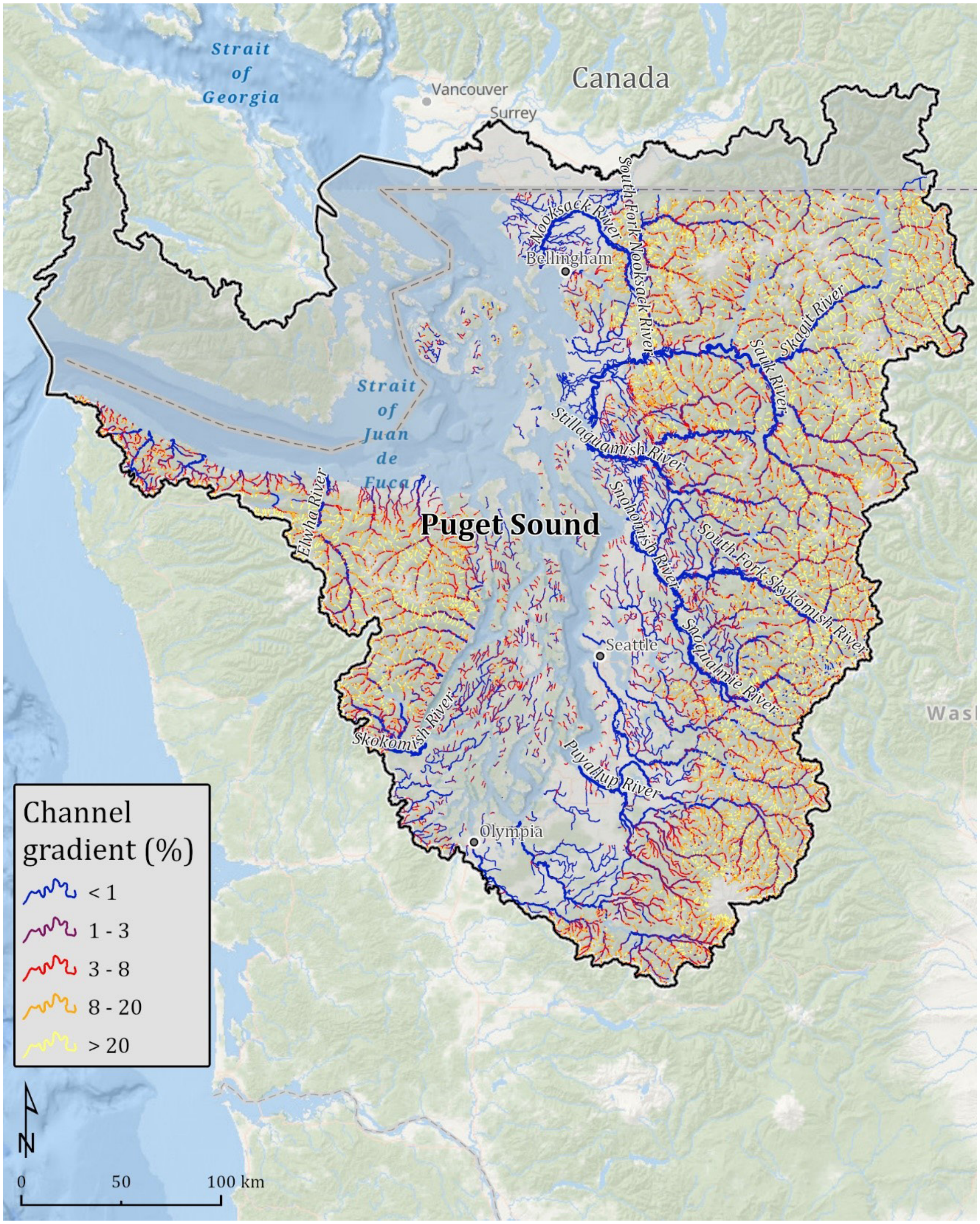


Figure A11. Spatial distribution of channel gradient (%) in the Puget Sound subregion.

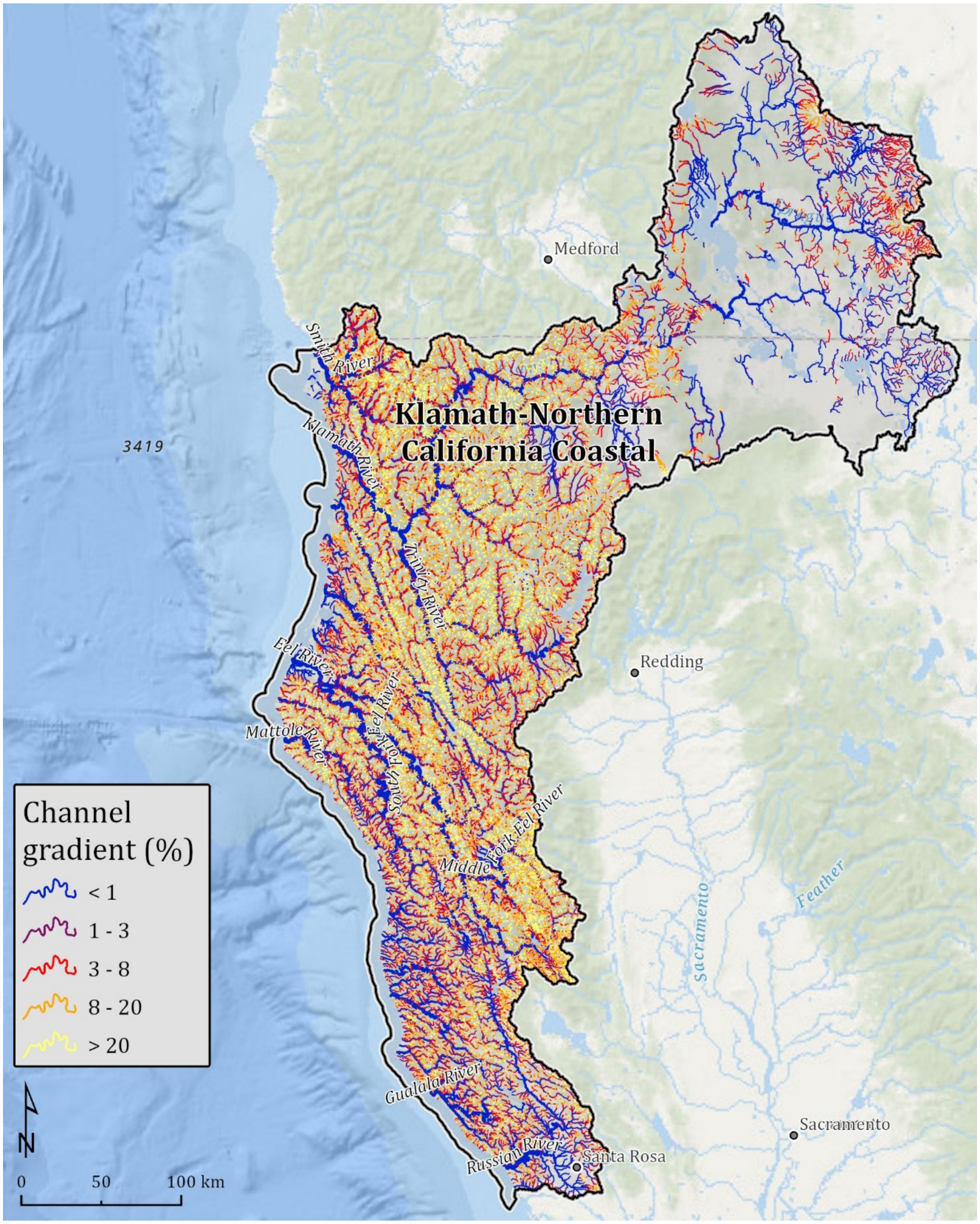


Figure A12. Spatial distribution of channel gradient (%) in the Klamath–Northern California Coastal subregion.

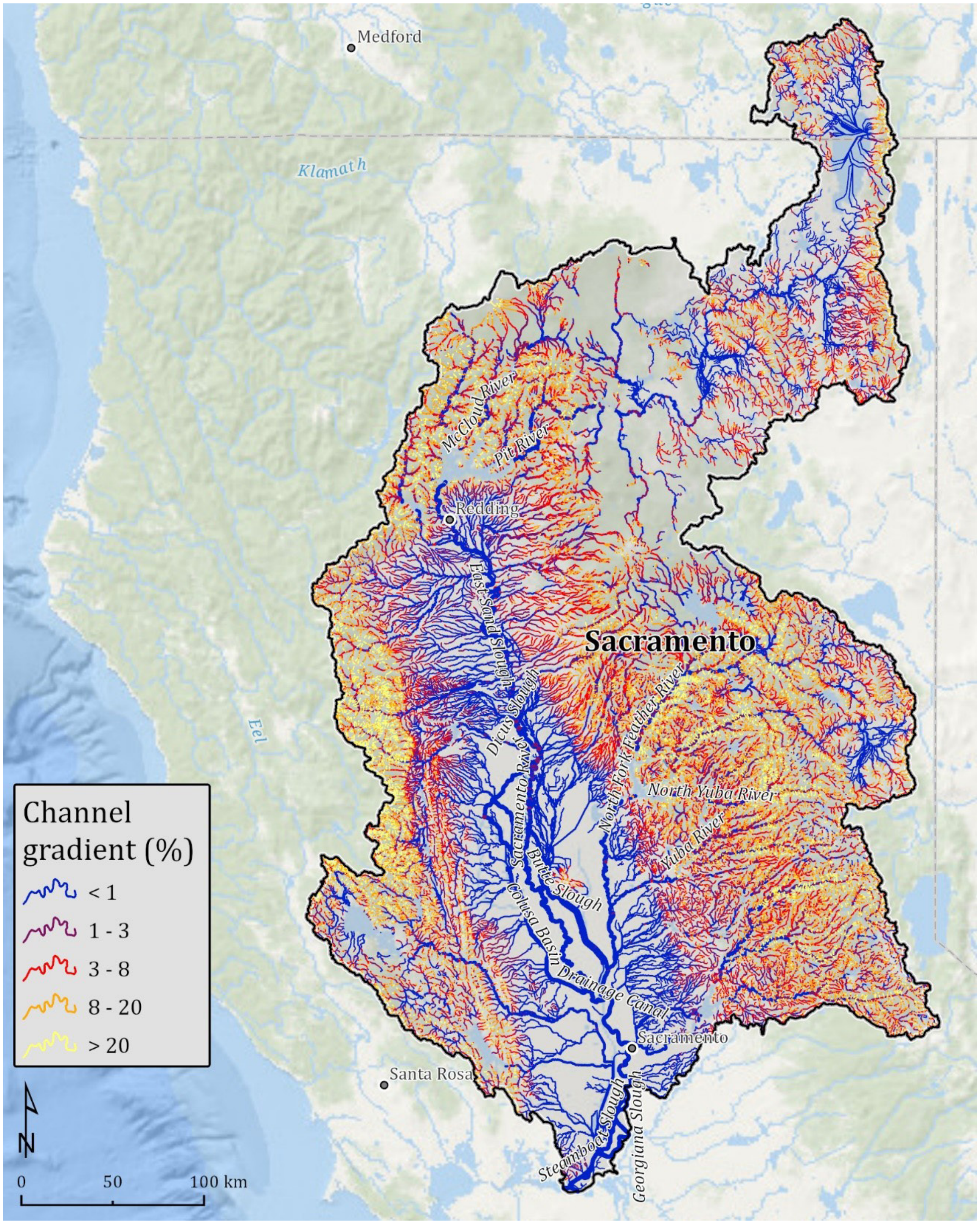


Figure A13. Spatial distribution of channel gradient (%) in the Sacramento subregion.

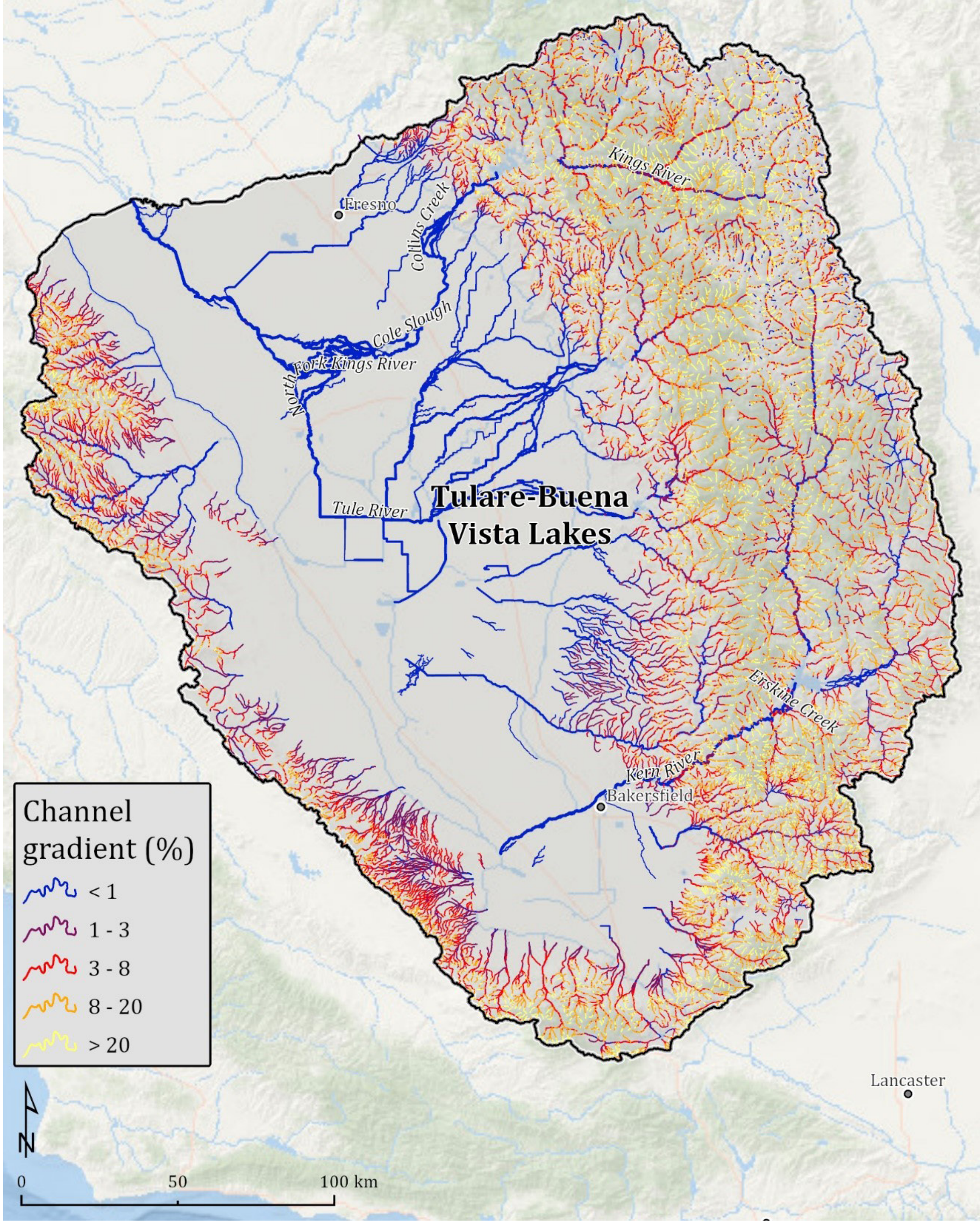


Figure A14. Spatial distribution of channel gradient (%) in the Tulare–Buena Vista Lakes subregion.

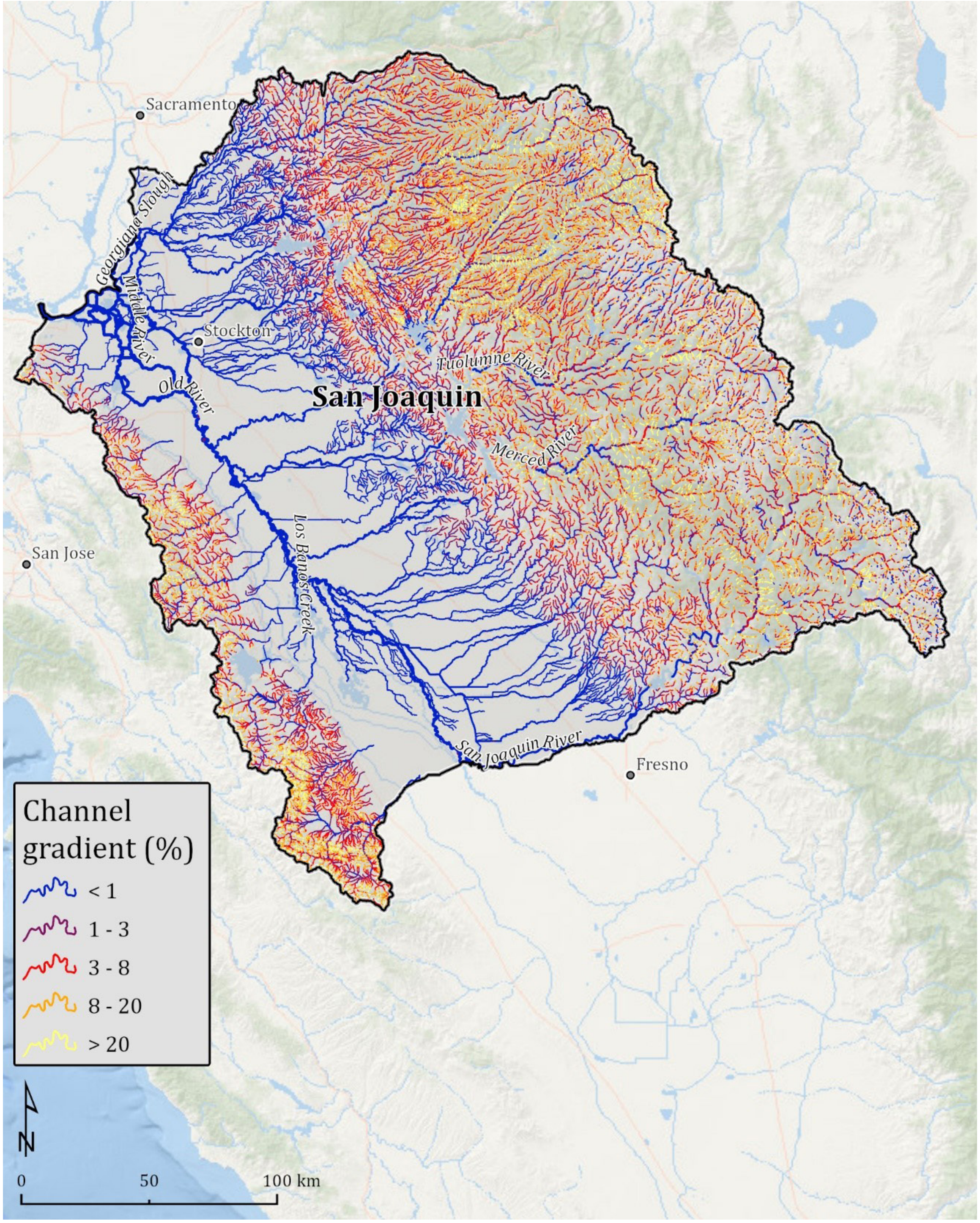


Figure A15. Spatial distribution of channel gradient (%) in the San Joaquin subregion.

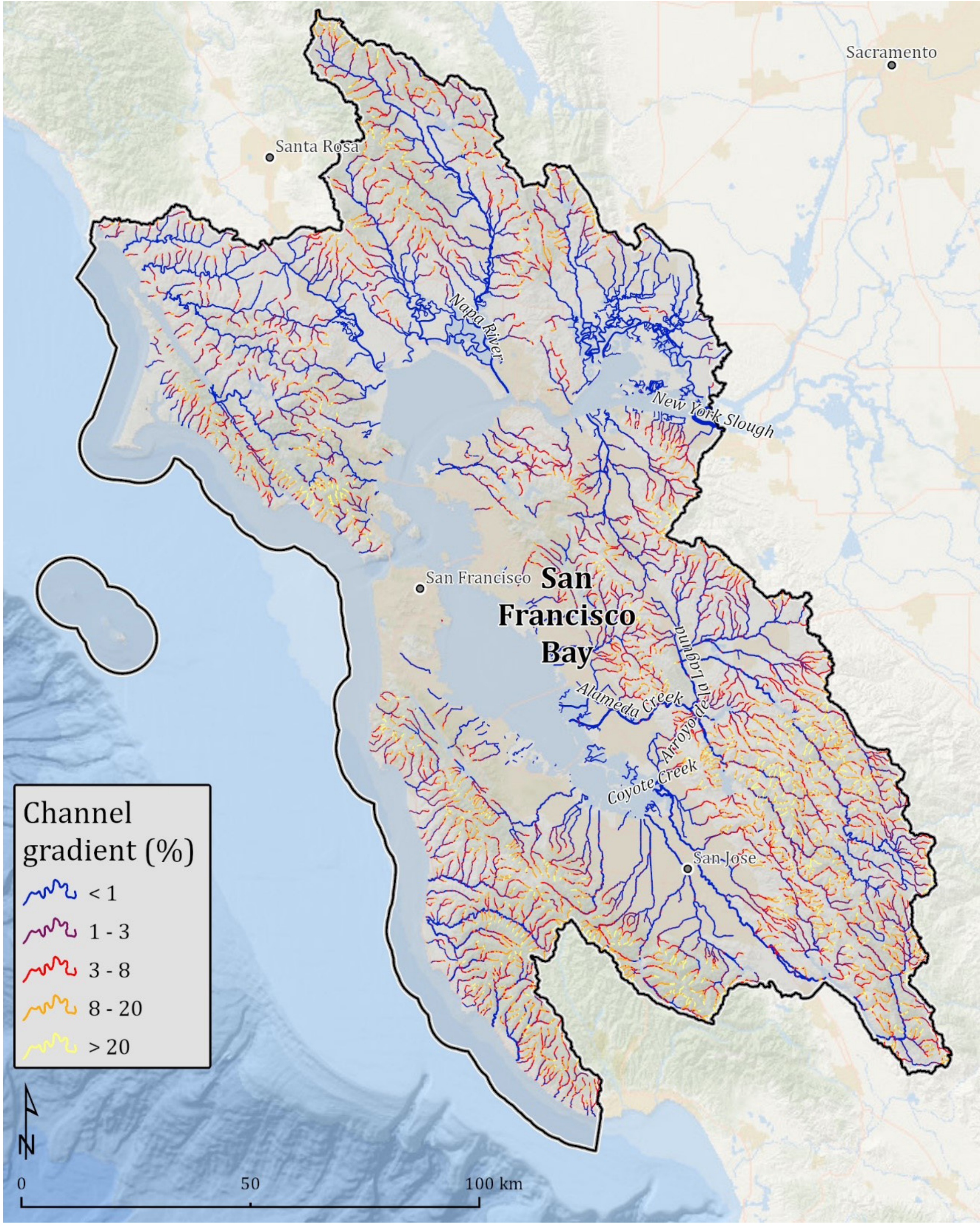


Figure A16. Spatial distribution of channel gradient (%) in the San Francisco Bay subregion.

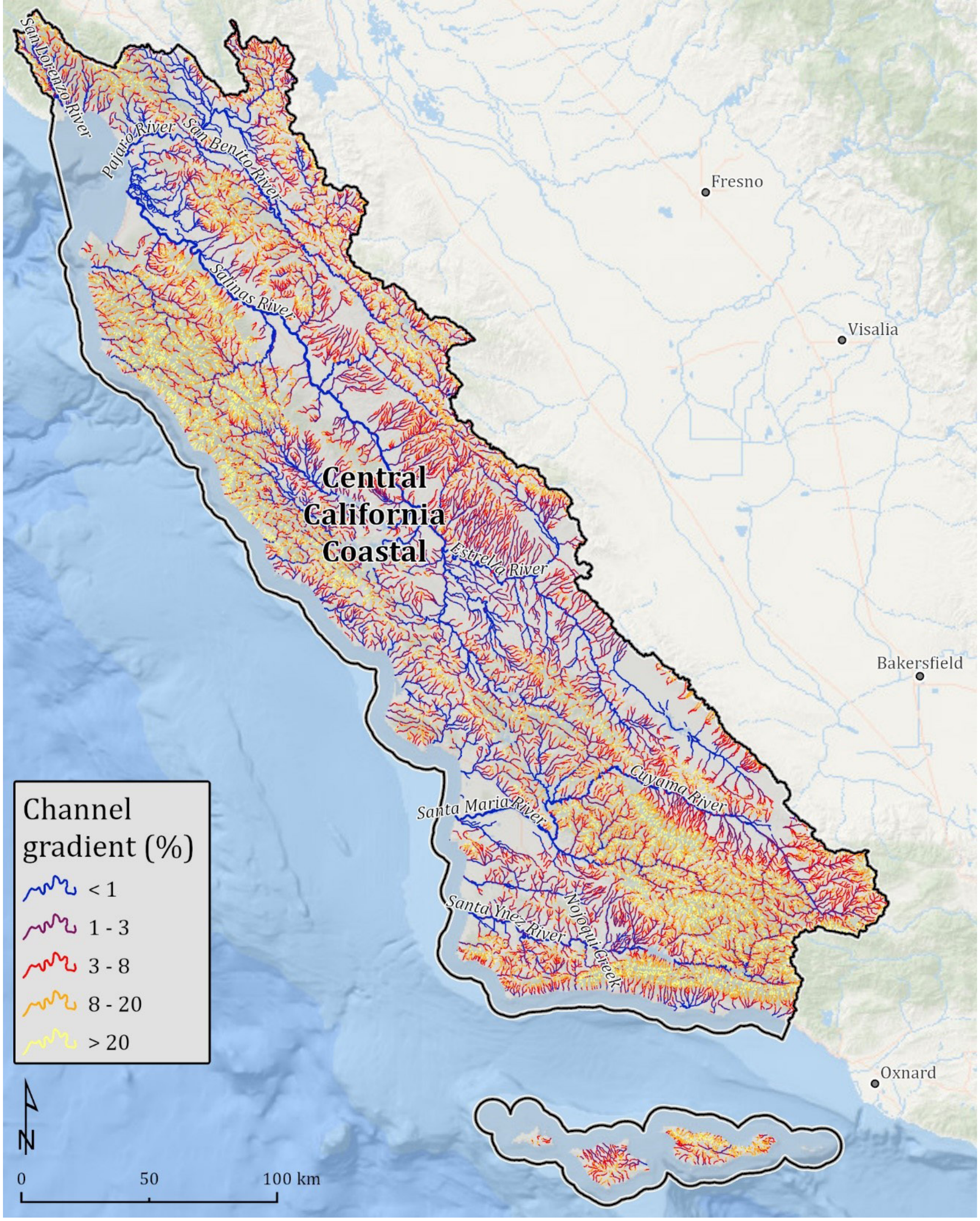


Figure A17. Spatial distribution of channel gradient (%) in the Central California Coastal subregion.

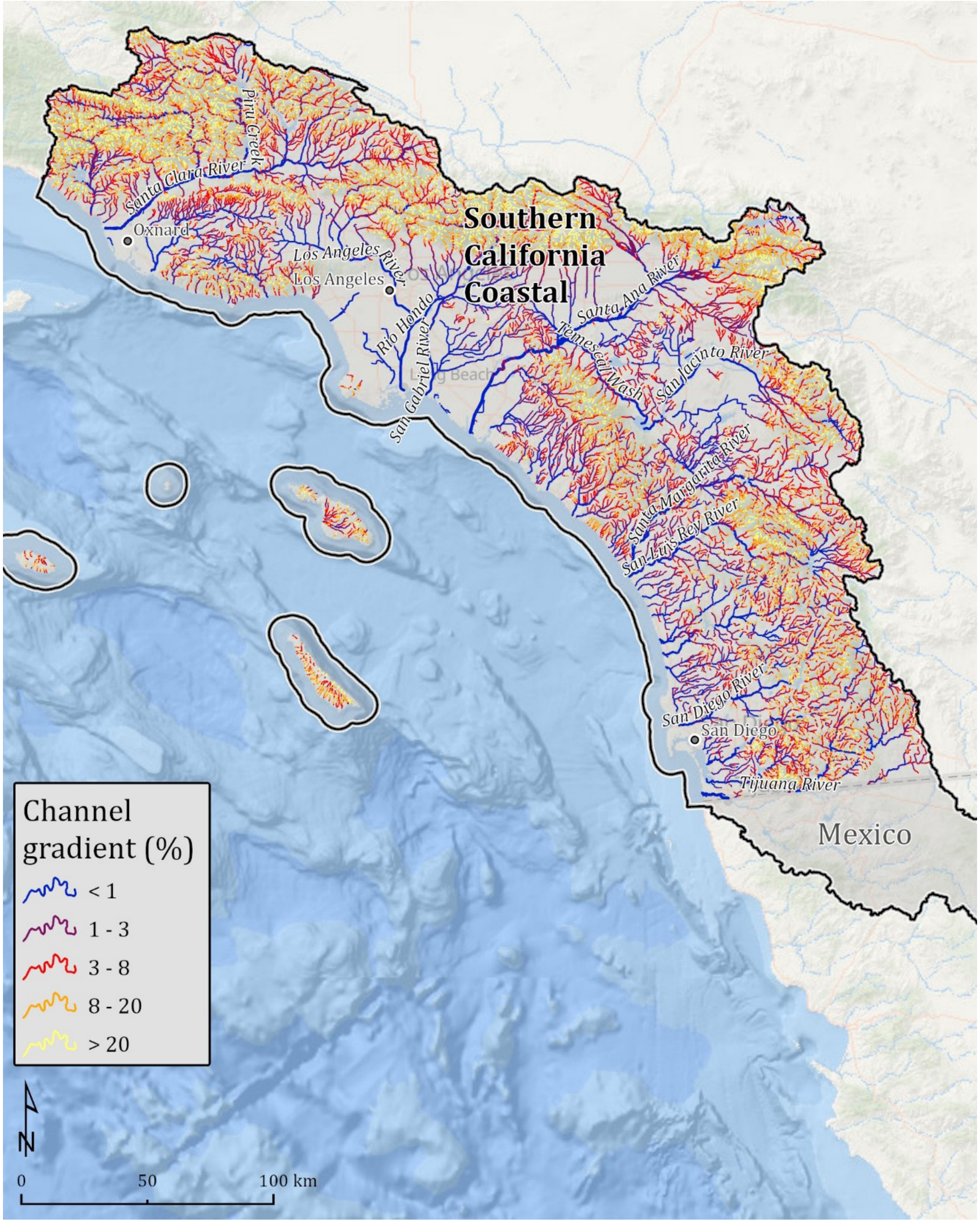


Figure A18. Spatial distribution of channel gradient (%) in the Southern California Coastal subregion.

A.2: Subregional Maps of Channel Confinement

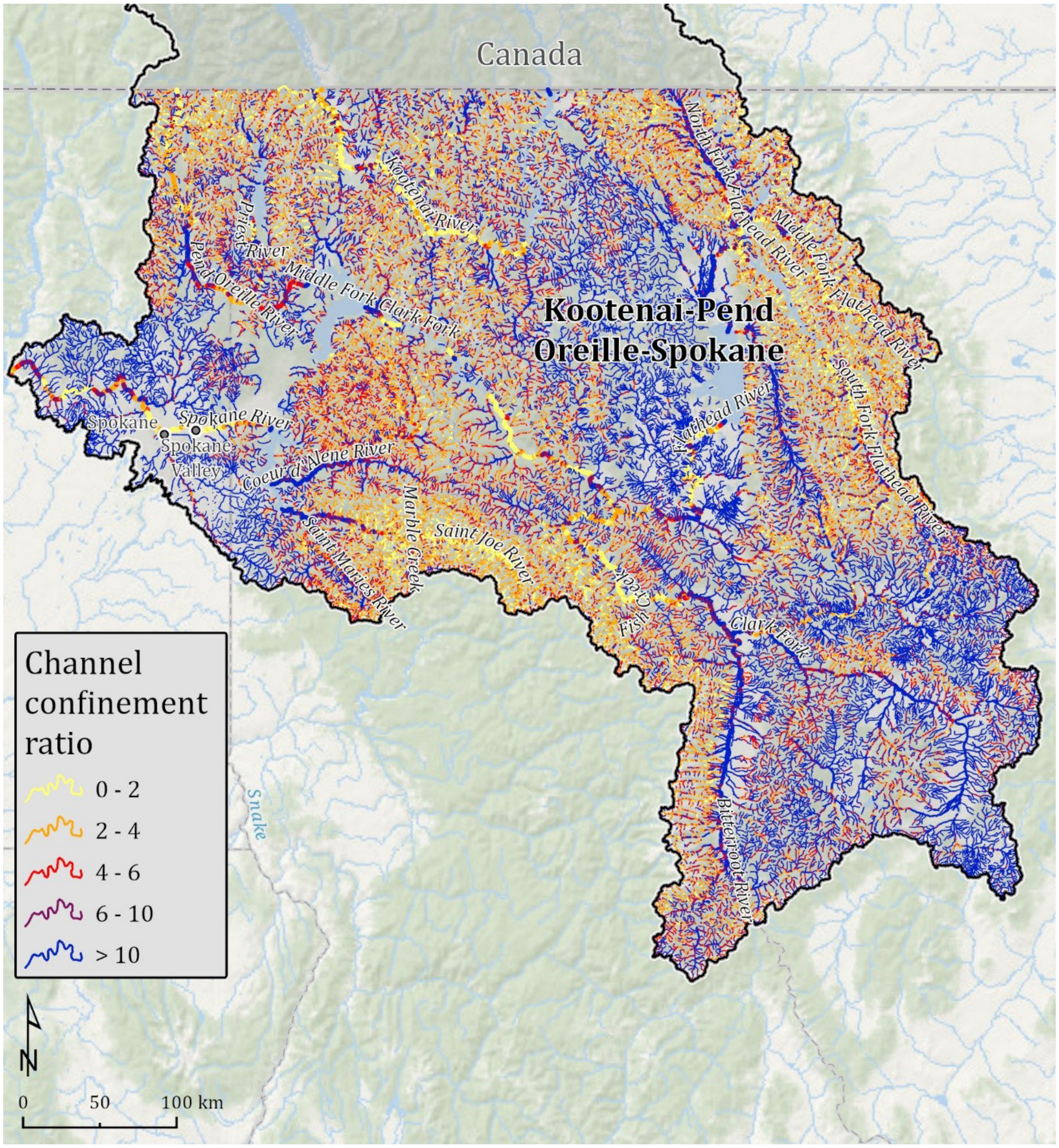


Figure A19. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Kootenai–Pend Oreille–Spokane subregion.

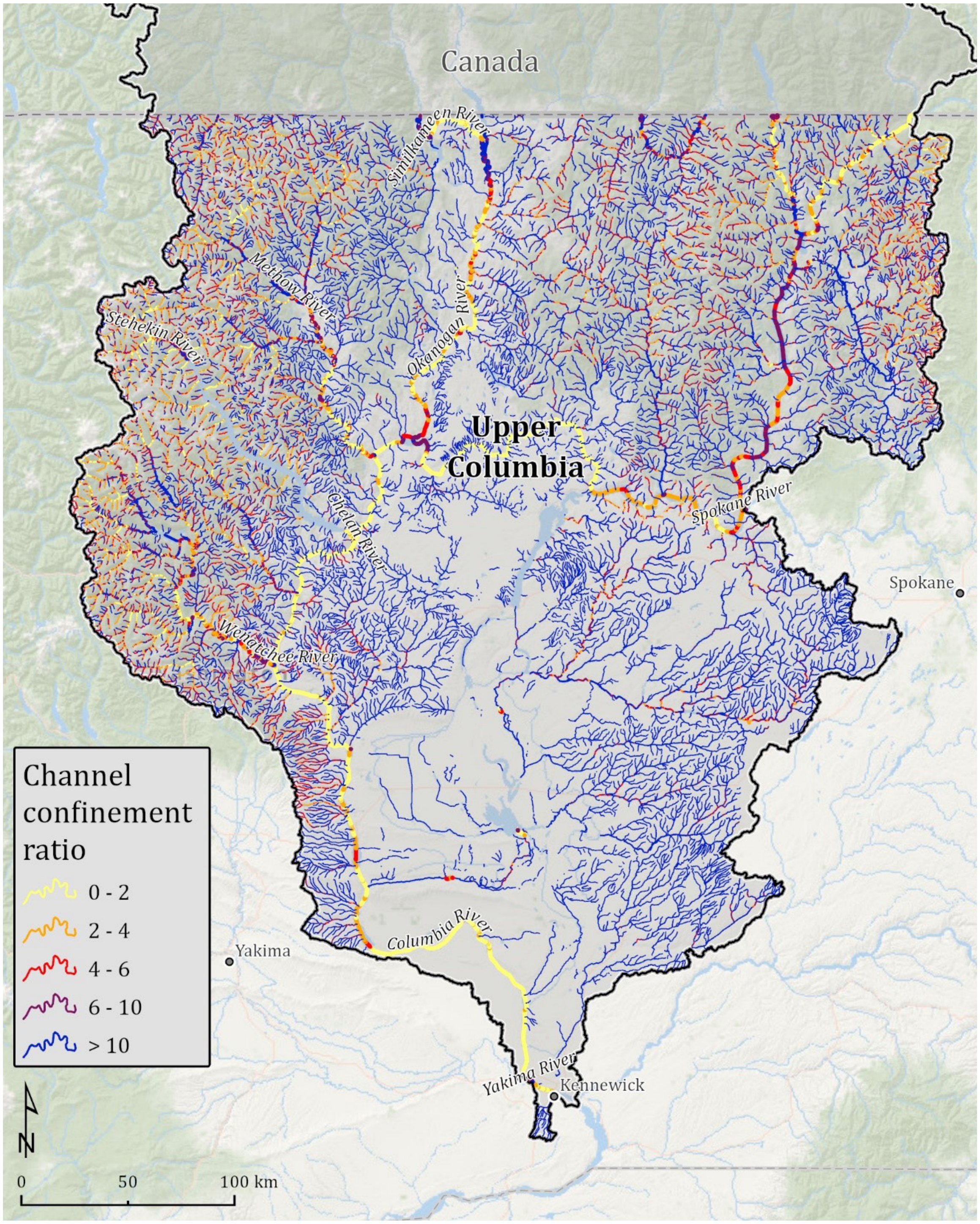


Figure A20. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Upper Columbia subregion.

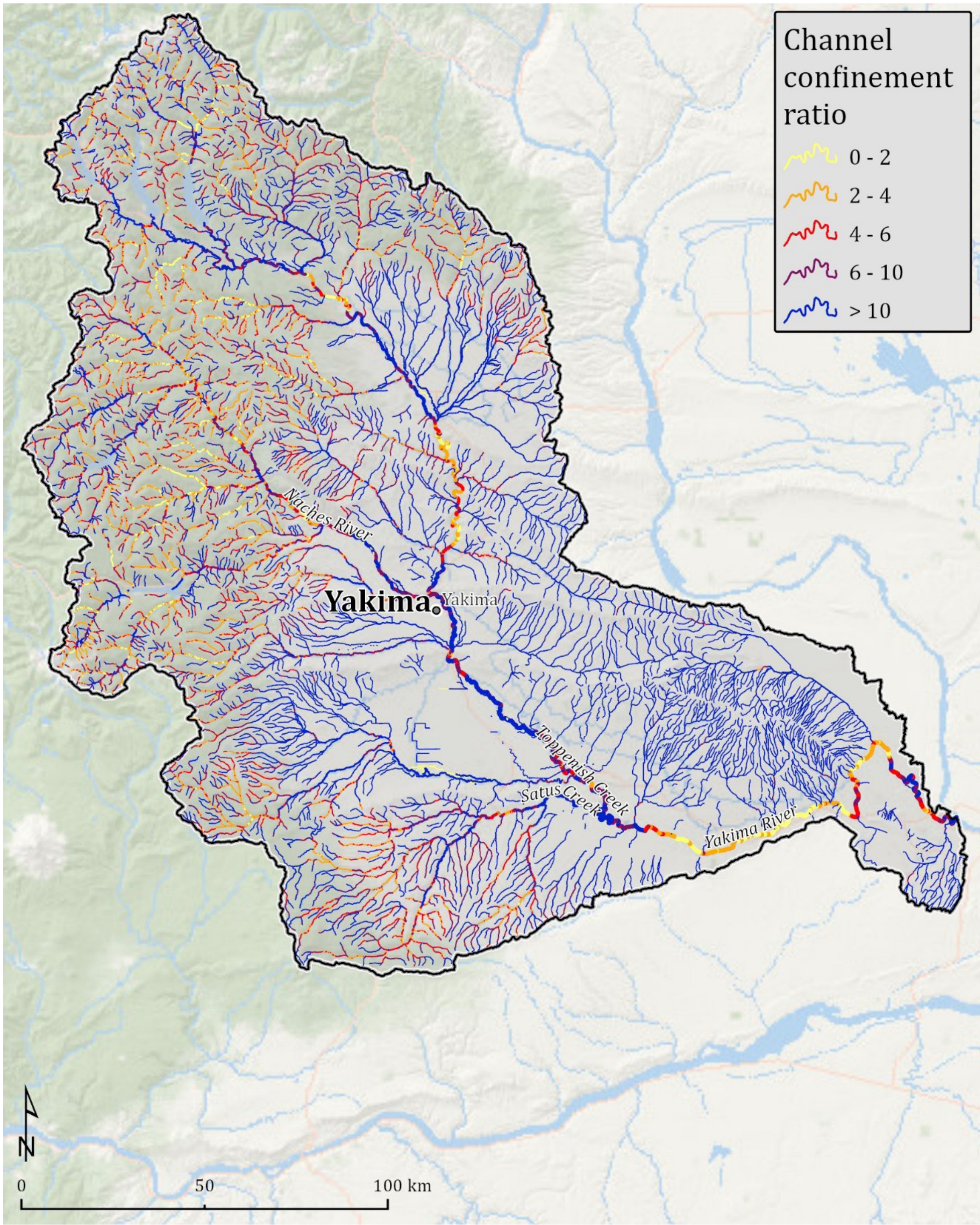


Figure A21. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Yakima subregion.

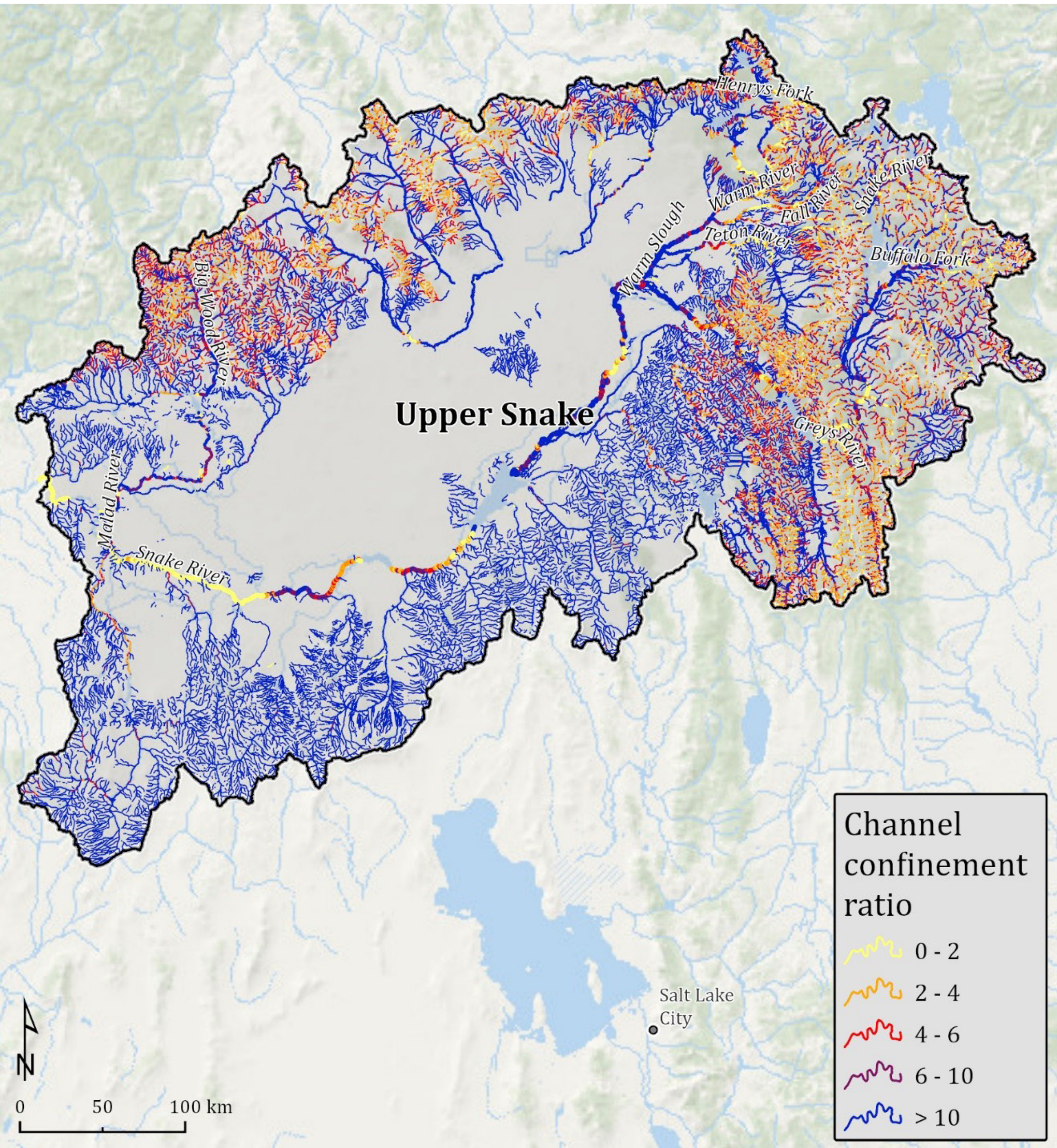


Figure A22. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Upper Snake subregion.

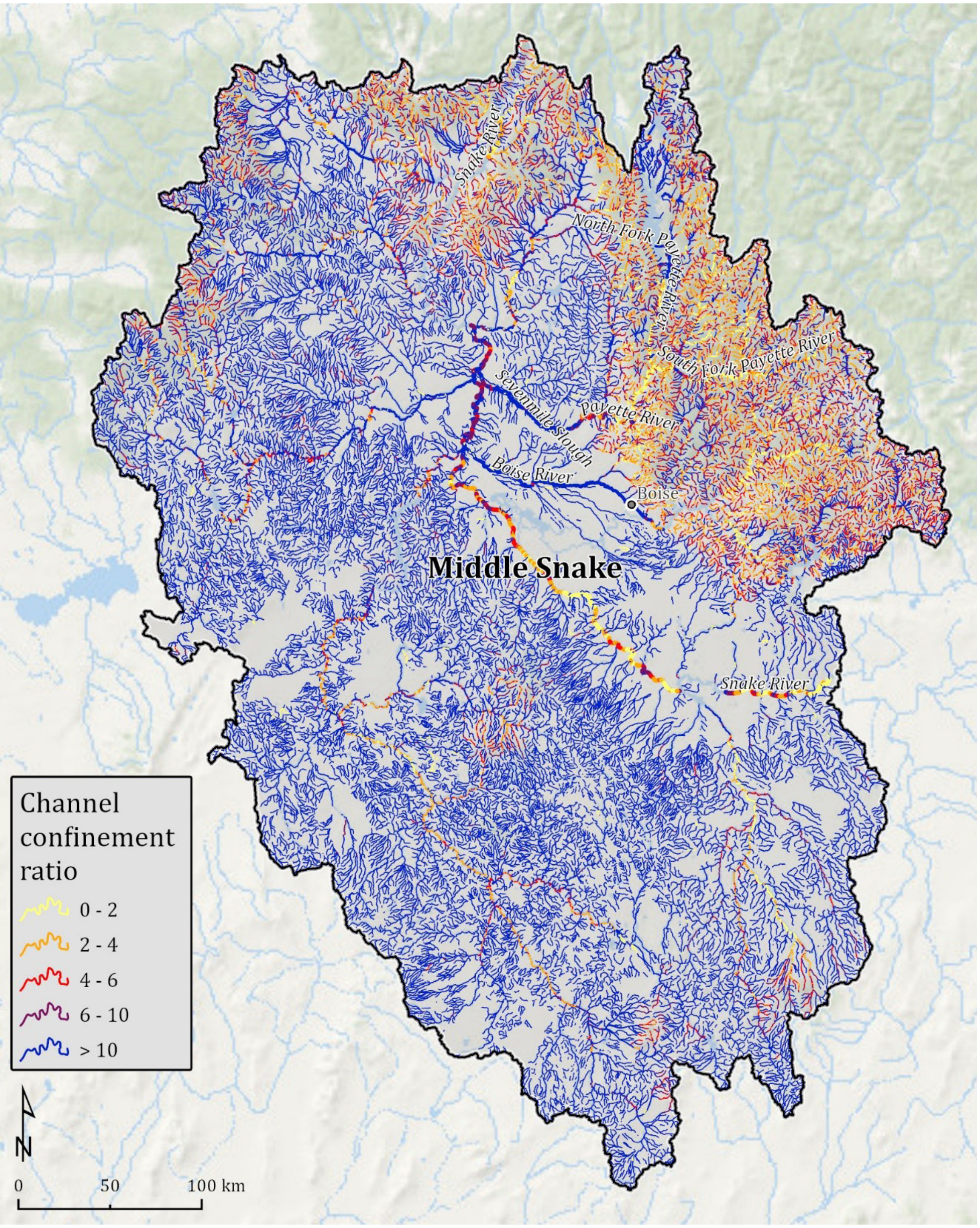


Figure A23. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Middle Snake subregion.

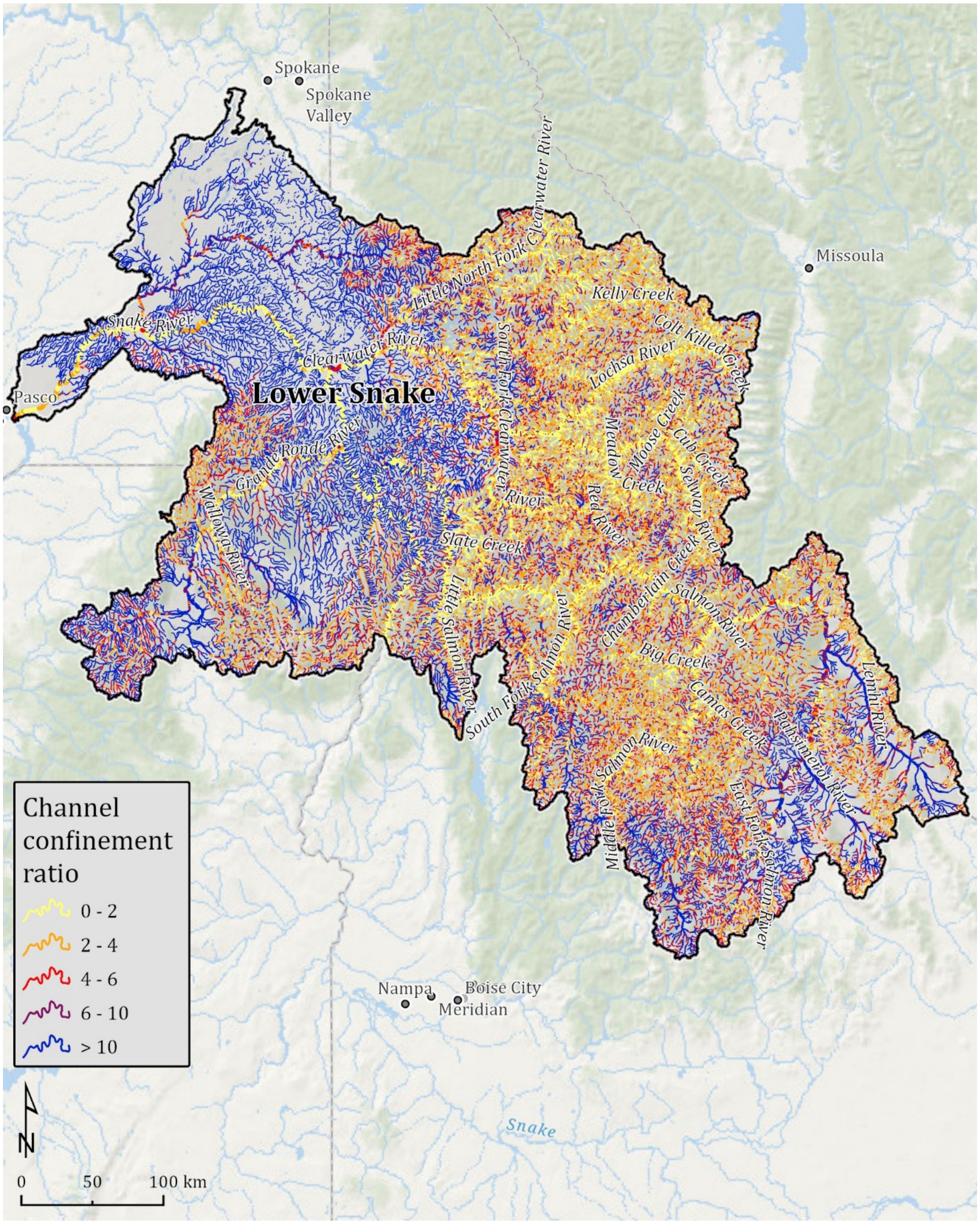


Figure A24. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Lower Snake subregion.

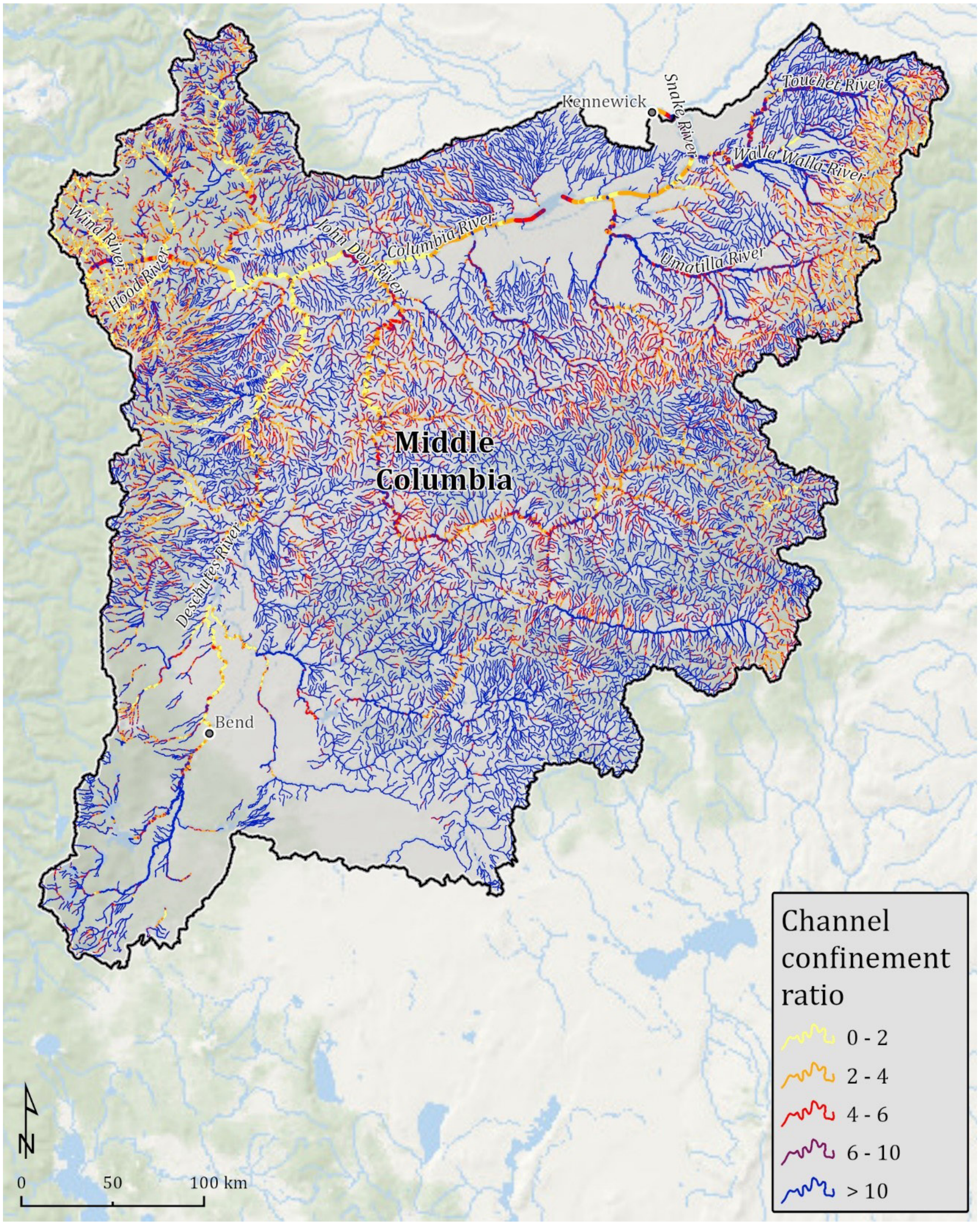


Figure A25. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Middle Columbia subregion.

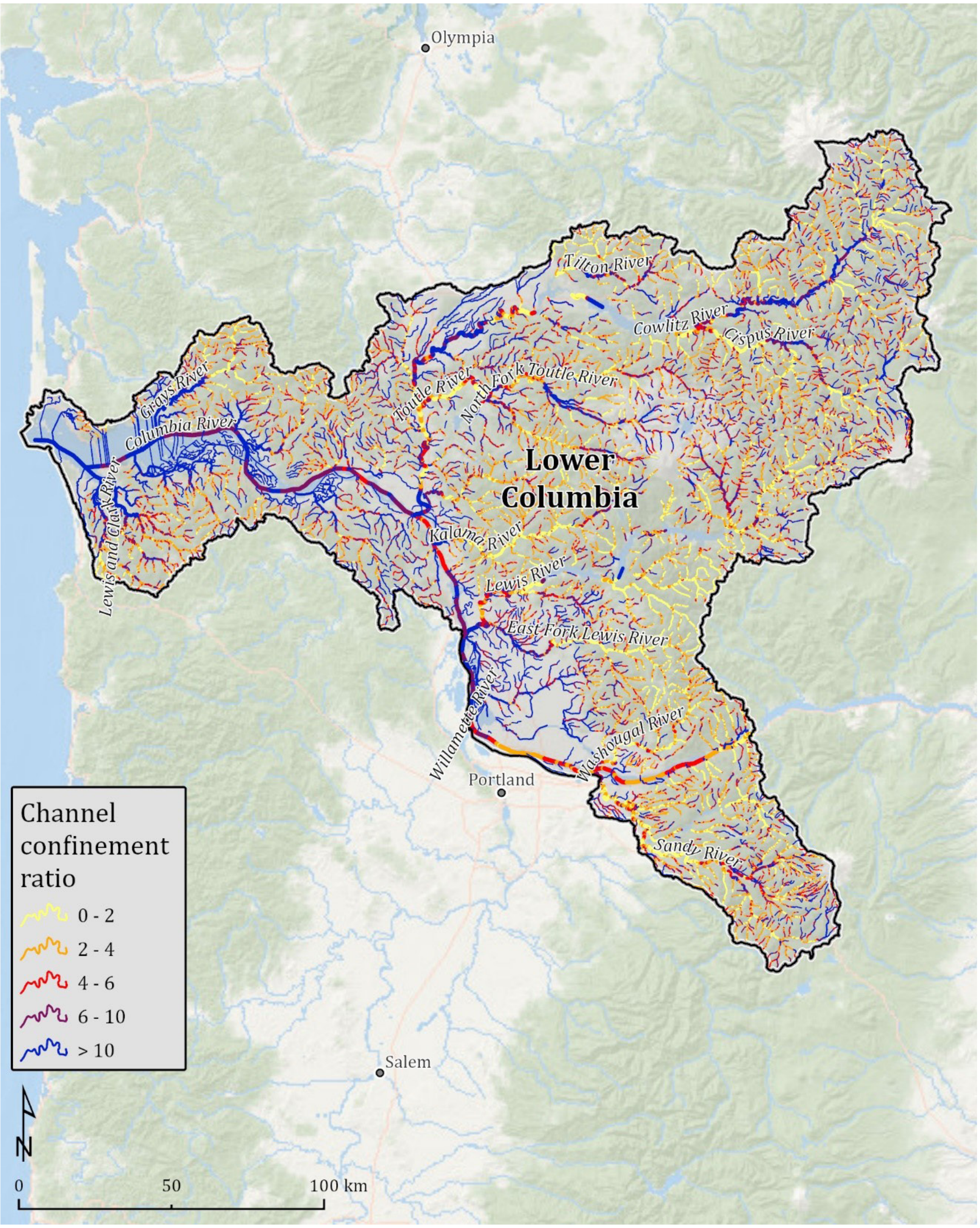


Figure A26. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Lower Columbia subregion.

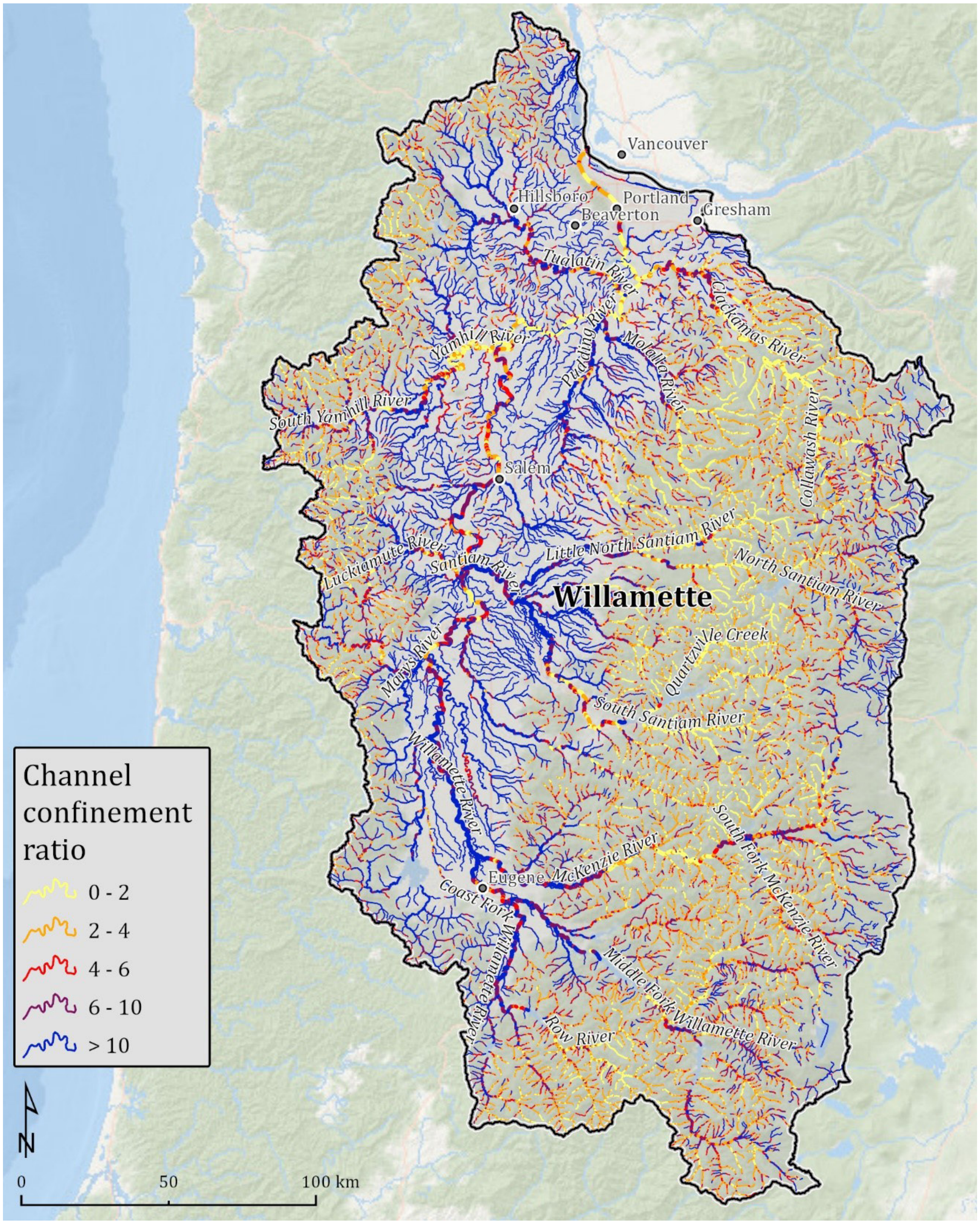


Figure A27. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Willamette subregion.

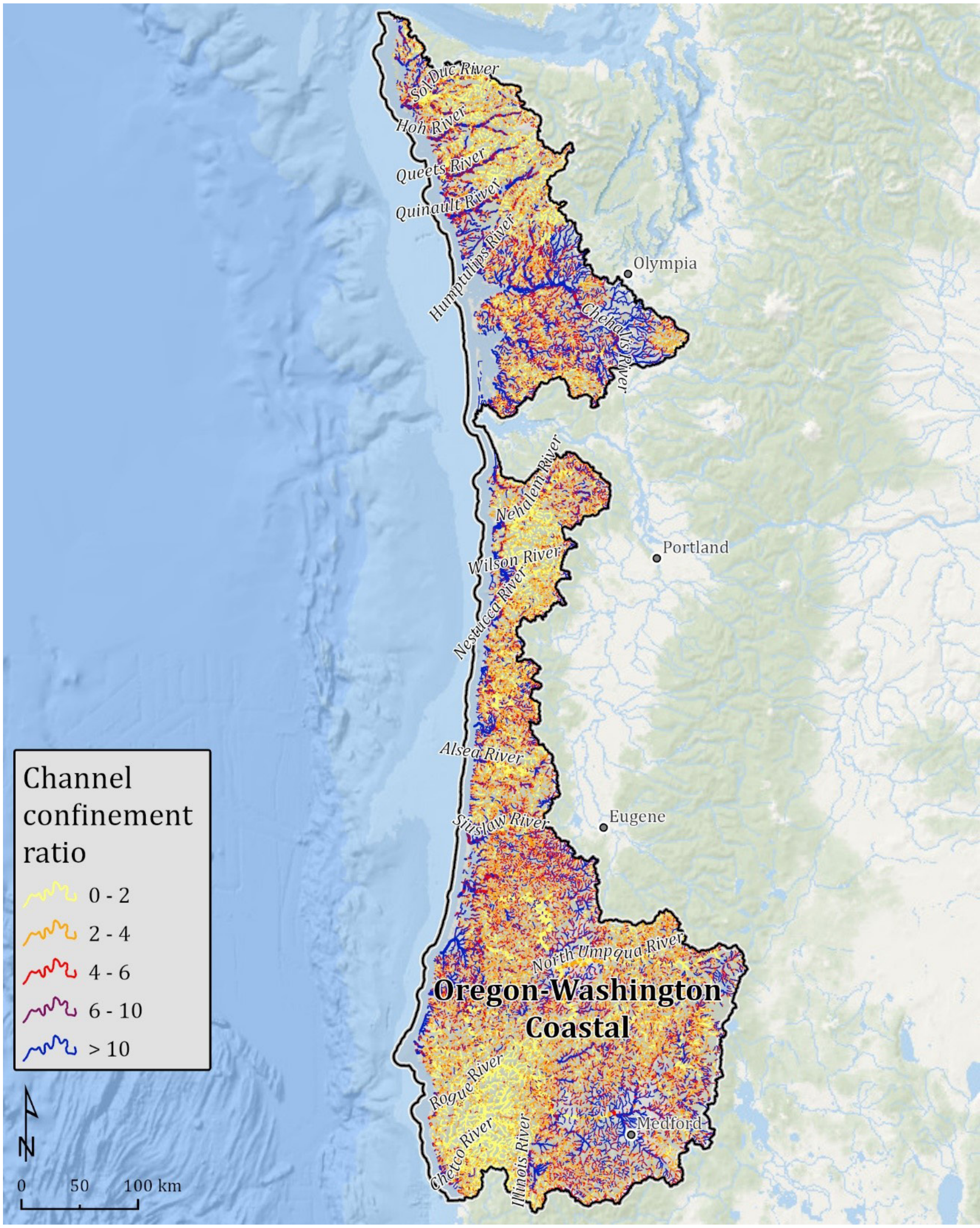


Figure A28. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Oregon–Washington Coastal subregion.

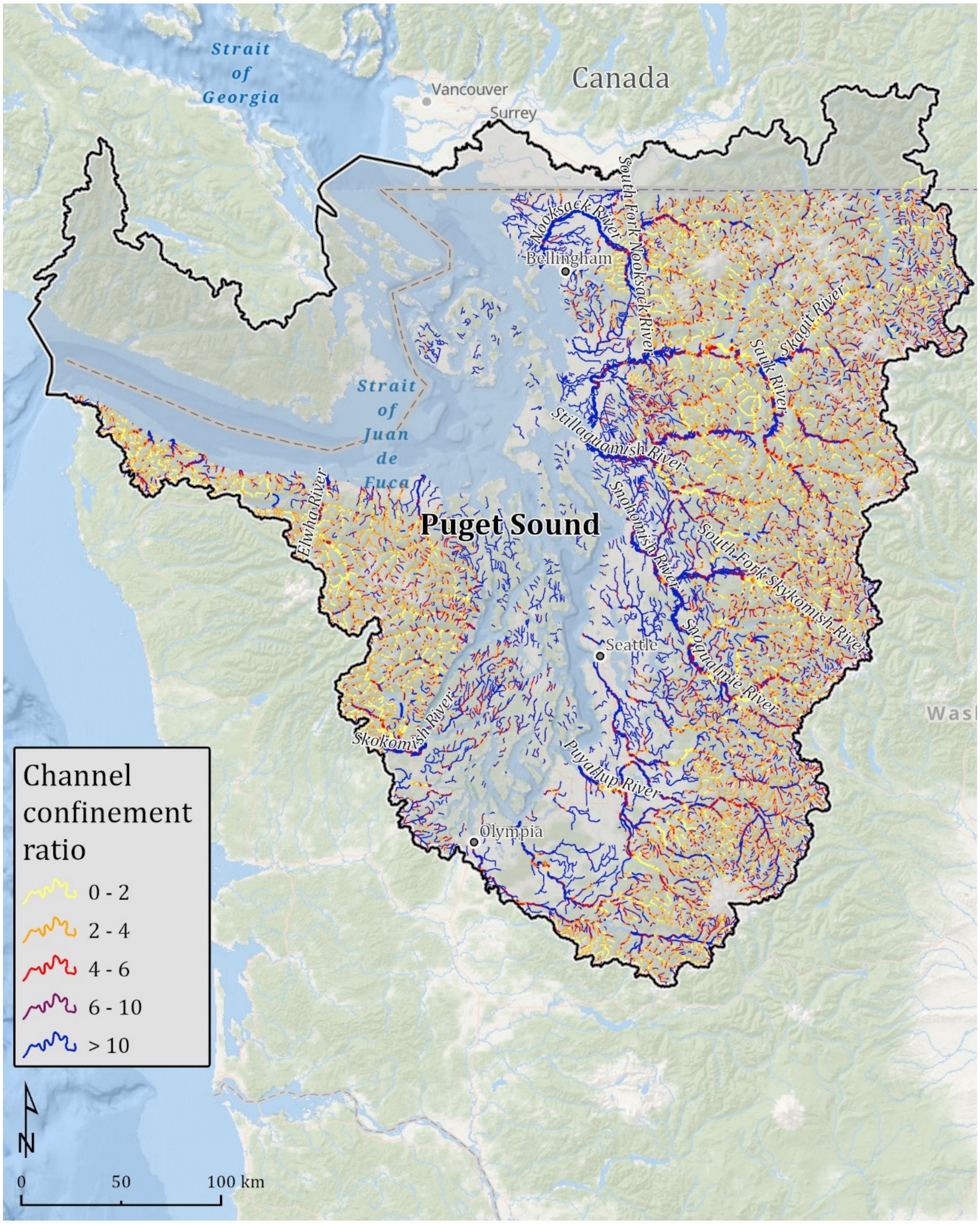


Figure A29. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Puget Sound subregion.

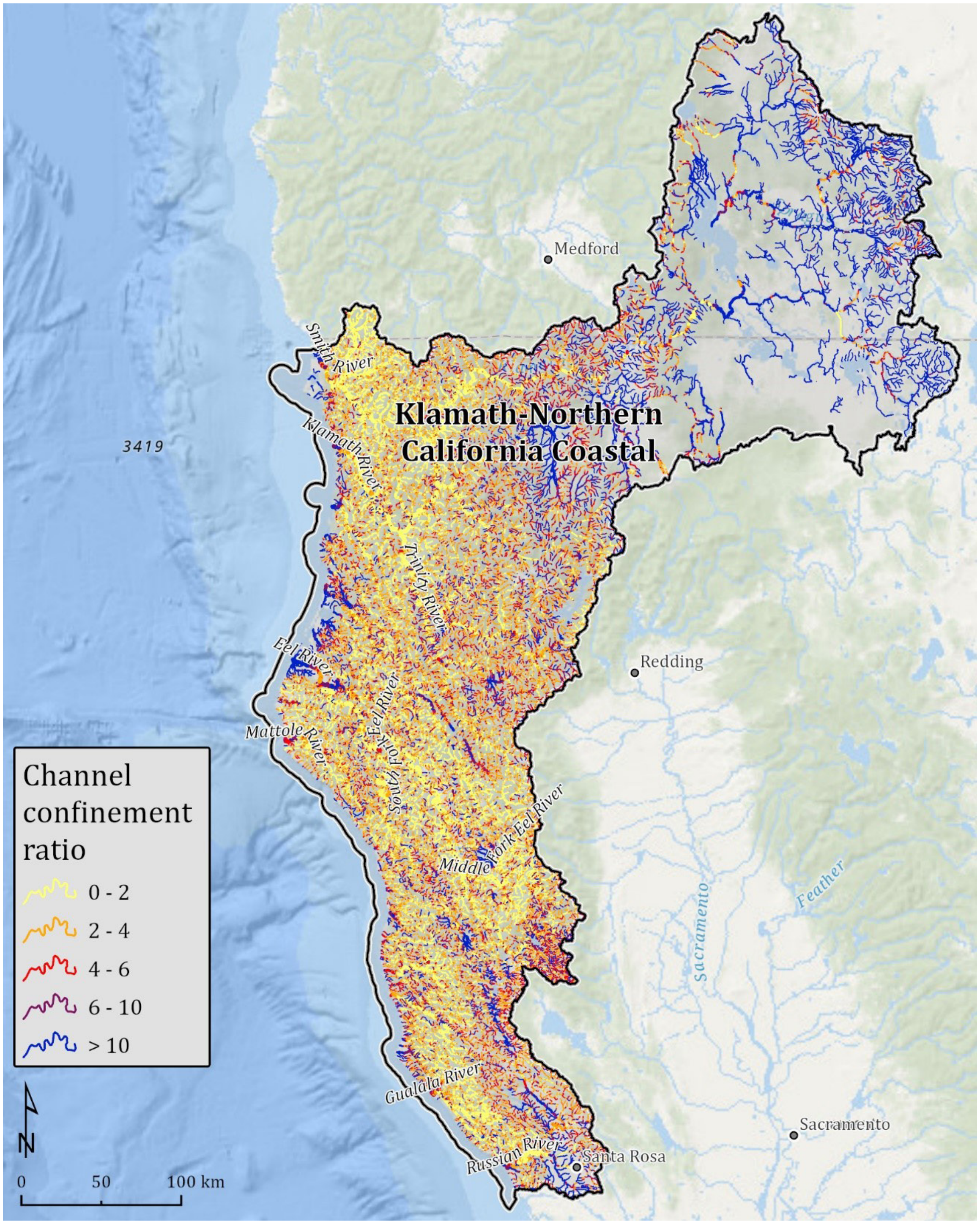


Figure A30. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Klamath–Northern California Coastal subregion.

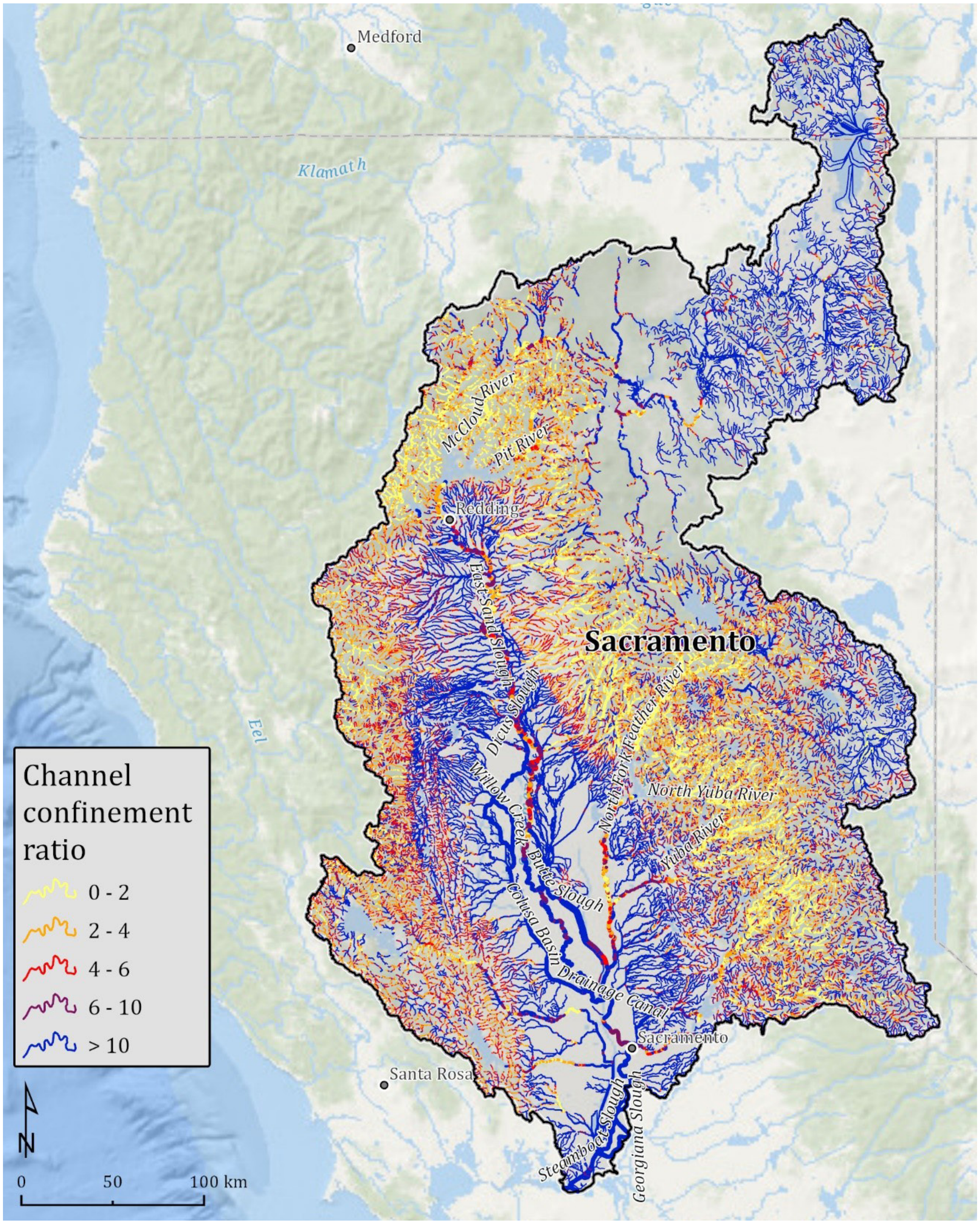


Figure A31. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Sacramento subregion.

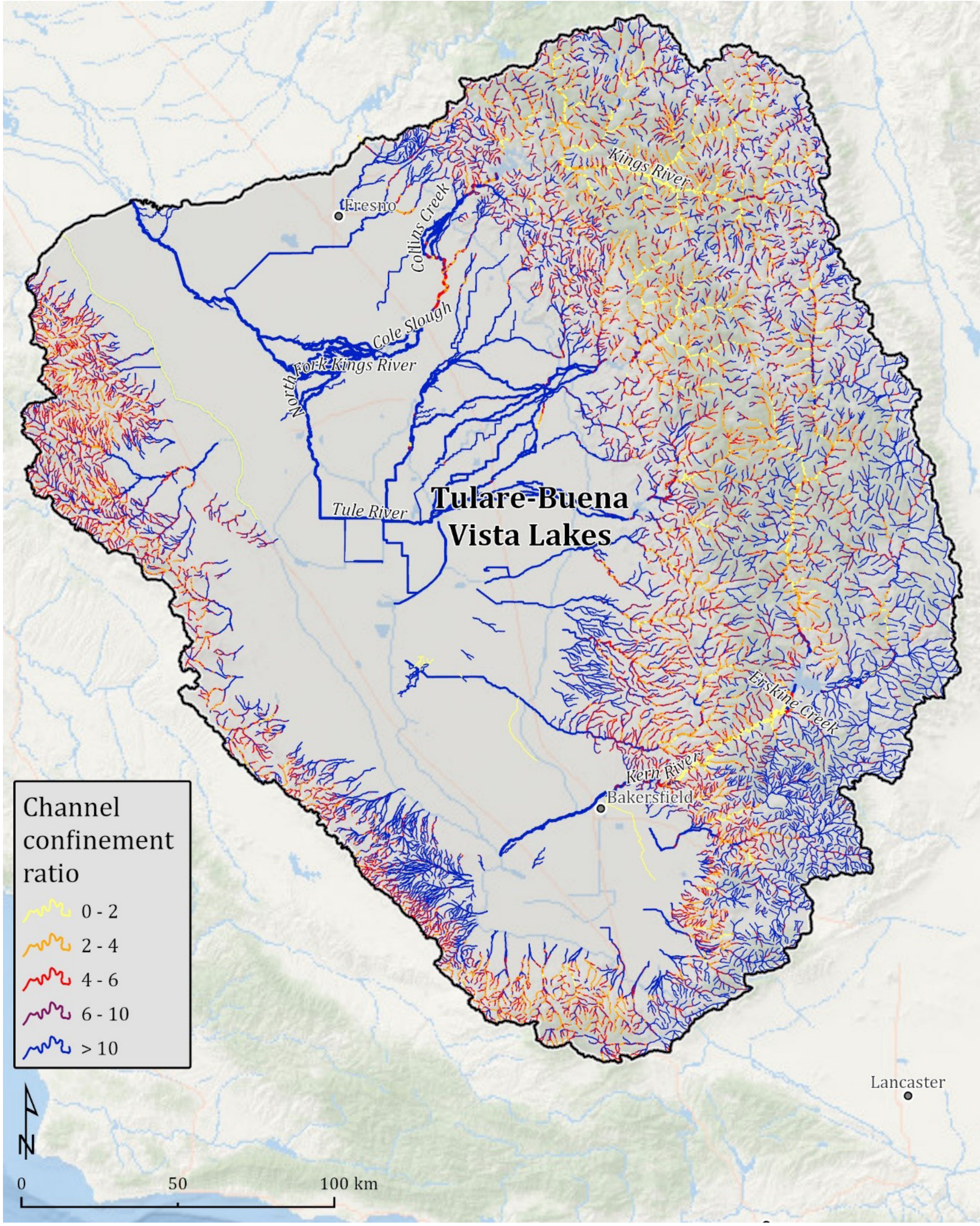


Figure A32. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Tulare–Buena Vista Lakes subregion.

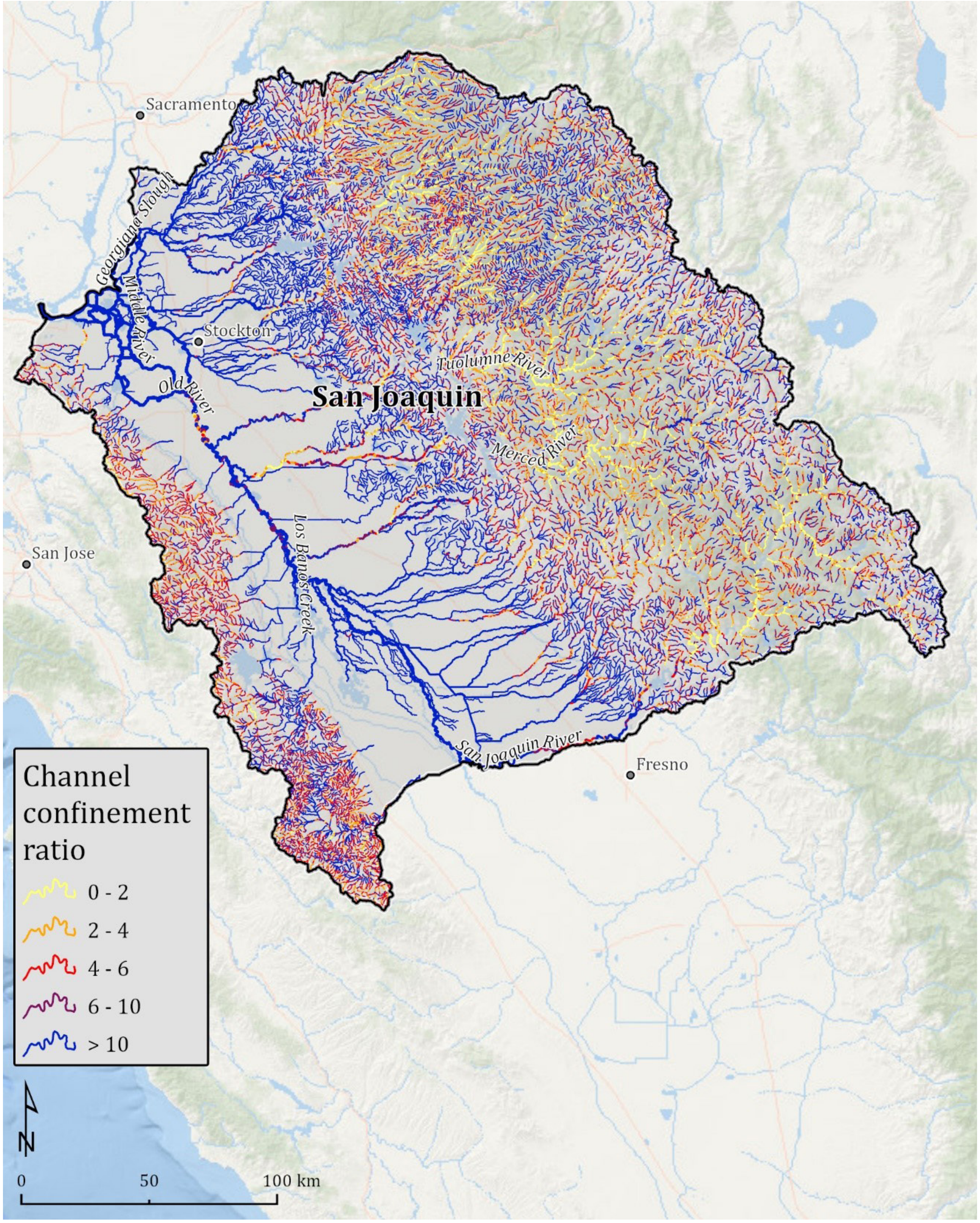


Figure A33. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the San Joaquin subregion.

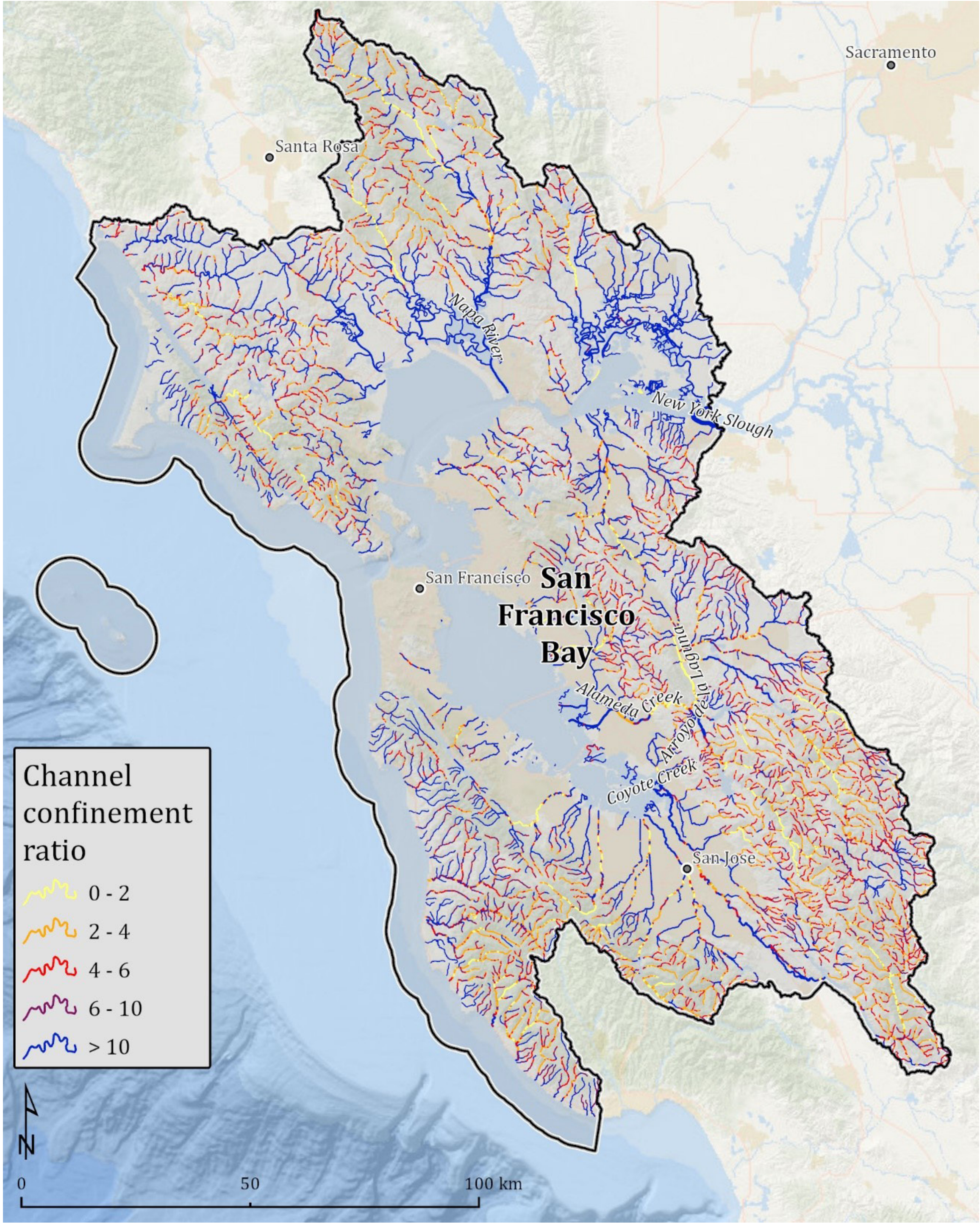


Figure A34. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the San Francisco Bay subregion.

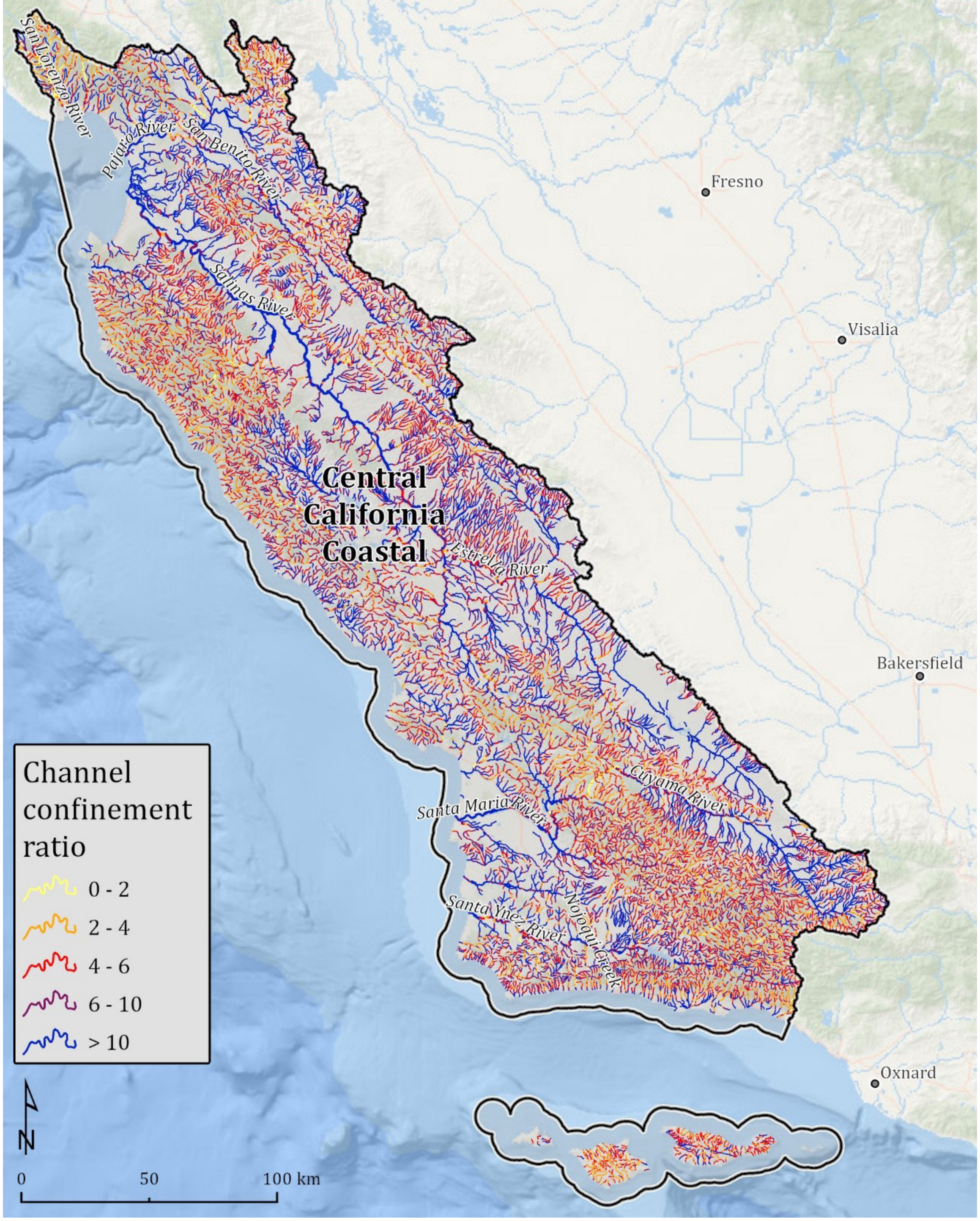


Figure A35. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Central California Coastal subregion.

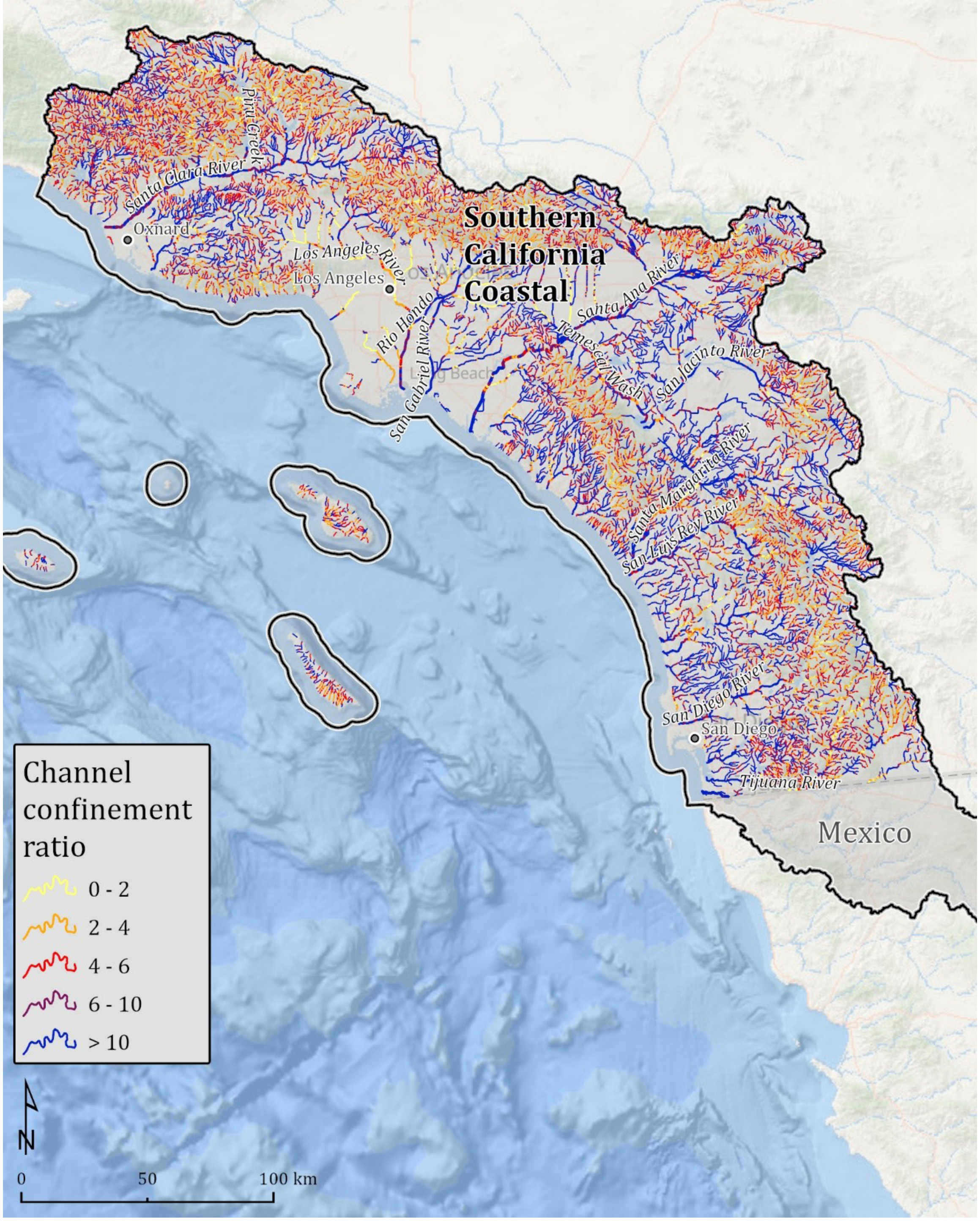


Figure A36. Spatial distribution of channel confinement (ratio of valley floor width to bankfull channel width) in the Southern California Coastal subregion.

Recently published by the Northwest Fisheries Science Center

NOAA Technical Memorandum NMFS-NWFSC-

180 **Rhodes, L. D., K. L. Parrish, and M. L. Willis. 2023.** Review of Best Practices for Biosecurity and Disease Management for Marine Aquaculture in U.S. Waters. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-180. https://doi.org/10.25923/b4qp-9e65

179 **Gustafson, R., K. E. Richerson, K. A. Somers, V. J. Tuttle, and J. E. Jannot. 2022.** Information in Support of a Five-Year Status Review of Eulachon (*Thaleichthys pacificus*) Listed under the Endangered Species Act: Southern Distinct Population Segment. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-179. https://doi.org/10.25923/p7mr-sk77

178 **Richerson, K. E., J. E. Jannot, J. T. McVeigh, K. A. Somers, V. J. Tuttle, and S. Wang. 2022.** Observed and Estimated Bycatch of Green Sturgeon in 2002–19 U.S. West Coast Groundfish Fisheries. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-178. https://doi.org/10.25923/tkp7-mj29

177 **Morzaria-Luna, H., I. C. Kaplan, C. J. Harvey, R. Girardin, E. A. Fulton, P. MacCready, B. Chasco, P. Horne, and M. Schmidt. 2022.** Design and Parameterization of a Spatially Explicit Atlantis Ecosystem Model for Puget Sound. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-177. https://doi.org/10.25923/tnp6-mf67

176 **Jannot, J. E., K. A. Somers, V. J. Tuttle, J. Eibner, K. E. Richerson, J. T. McVeigh, J. V. Carretta, N. C. Young, and J. Freed. 2022.** Marine Mammal Bycatch in U.S. West Coast Groundfish Fisheries, 2002–19. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-176. https://doi.org/10.25923/h6gg-c316

175 **Somers, K. A., J. E. Jannot, K. E. Richerson, V. J. Tuttle, and J. T. McVeigh. 2022.** Estimated Discard and Catch of Groundfish Species in the 2020 U.S. West Coast Fisheries. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-175. https://doi.org/10.25923/e6es-0r06

174 **Somers, K. A., C. E. Whitmire, E. Steiner, J. E. Jannot, K. E. Richerson, V. J. Tuttle, and J. T. McVeigh. 2022**. Fishing Effort in the 2002–19 U.S. Pacific Coast Groundfish Fisheries. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-174. https://doi.org/10.25923/gc2k-5893

173 **Jannot, J. E., K. E. Richerson, K. A. Somers, V. J. Tuttle, C. M. Colway, and J. T. McVeigh. 2022.** Pacific Halbut Bycatch in U.S. West Coast Groundfish Fisheries, 2002–20. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-173. https://doi.org/10.25923/w5qy-w078

172 **Connelly, K., E. Steiner, and A. Vizek. 2022.** Quota Share Owner Survey: Initial Results and Analysis. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-172. https://doi.org/10.25923/xqt7-2d91

NOAA Technical Memorandums NMFS-NWFSC are available from the NOAA Institutional Repository, https://repository.library.noaa.gov.

U.S. Secretary of Commerce
Gina M. Raimondo

Under Secretary of Commerce for
Oceans and Atmosphere
Dr. Richard W. Spinrad

Assistant Administrator for Fisheries
Janet Coit

March 2023

fisheries.noaa.gov

OFFICIAL BUSINESS

National Marine
Fisheries Service
Northwest Fisheries Science Center
2725 Montlake Boulevard East
Seattle, Washington 98112