Appendix B – Habitat Capacity Estimation

Introduction

The decline of anadromous Pacific salmonids (*Oncorhynchus* spp.) across the Pacific Northwest has prompted numerous actions aimed at reversing that trend. These actions are often categorized into four Hs – harvest modification, habitat rehabilitation, hydroelectric operations, and hatchery practices. Substantial uncertainty remains regarding the degree of change to salmon populations that can be exerted across and within these categories, and what combination of changes might most cost-effectively and sustainably reduce mortality and recover depleted populations. Recently released delisting criteria (NOAA 2017) identified adult escapement targets at the population scale, providing a quantitative metric useful for evaluating the magnitude of survival improvements (across life stages) required. These abundance targets provide a benchmark against which habitat rehabilitation actions can be measured. In Appendix B, we describe a novel approach for estimating life stage-specific habitat capacity that can be used to quantitatively identify the magnitude of tributary habitat restoration needed to support Endangered Species Act (ESA) delisting. For perhaps the first time, the necessity of tributary habitat restoration actions can be demonstrated, and the magnitude of required change can be placed in context with the other Hs.

We define habitat (carrying) capacity as the maximal abundance or load the habitat can support for a given species and life stage given current resources and habitat quantity and quality. Within fisheries research and management, it has long been recognized that biotic and abiotic factors limit productivity within and across life stages. However, we assume that observed fish density is a poor predictor of habitat capacity owing to both a paucity of individuals and the existence of unmeasured biotic or abiotic variables that may serve to limit capacity. To address this, we have developed a novel approach to estimate the carrying capacity of wadeable streams to support spawning and rearing spring-summer run Chinook salmon (*O. tshawytscha*; hereafter Chinook salmon) and summer run steelhead (*O. mykiss*; hereafter steelhead) using quantile regression forest models (QRF; Meinshausen 2006).

We describe the development and implementation of QRF models to 1) better elicit fish-habitat relationships, and 2) predict habitat carrying capacity for juvenile and adult Chinook salmon and steelhead using paired measurements of fish abundance/density and habitat. The juvenile models pertain to juveniles rearing in wadeable streams during both summer (parr) and winter (presmolt) months; the adult model is to elicit fish-habitat relationships for spawning areas and predict habitat capacity to support redds. The habitat data are from the Columbia Habitat Monitoring Program (CHaMP; https://www.champmonitoring.org). Fish and habitat data were paired at CHaMP sites (200 to 500 meters) where fish survey data were available. The QRF model places no constraints on possible fish-habitat relationships; instead, relationships are estimated from the data regardless of being positive, negative, linear, non-linear, etc. Based on the observed fish-habitat relationships, we then predict habitat capacity at any location using measurements of the same habitat covariates used to populate the model (e.g., at all CHaMP sites). Finally, we extrapolate capacity predictions at CHaMP sites across larger scales (e.g., watershed, population) using globally available attribute data.

In summary, our objectives in Appendix B include:

1. Identify measured habitat characteristics that are most strongly associated with observed Chinook salmon and steelhead juvenile and redd abundance/density. This objective will use fish and habitat data from CHaMP sites from across the Columbia River Basin.
2. Use paired fish and habitat measurements to elicit fish-habitat relationships for those habitat characteristics identified as most important for determining juvenile or redd abundance/density. Again, this objective will use fish and habitat data from CHaMP sites across the Columbia River Basin.
3. Predict contemporary habitat carrying capacity at all sites in the Upper Salmon River Subbasin where CHaMP habitat characteristics are measured. This includes predictions for both species (Chinook salmon and steelhead) and three life stages (summer parr, winter presmolts, redds).
4. Extrapolate capacity predictions from CHaMP sites across larger scales (e.g., watershed, population) in the Upper Salmon River Subbasin using globally available attribute data to estimate Chinook salmon and steelhead juvenile and redd capacity at those larger scales. Watersheds include: Upper Salmon River (above Redfish Lake Creek), Valley Creek, Yankee Fork Salmon River, East Fork Salmon River, Pahsimeroi River, Lemhi River, North Fork Salmon River, and Panther Creek.

For summer parr capacity models, we predict capacity at the reach (200- to 500-meter) scale. For overwintering presmolt capacity, we modeled capacity at the channel unit scale, but then combined channel units up to the reach scale. For the redd model, we predict capacity at a slightly larger reach (1 river kilometer [rkm]) scale. In doing so, we elicit data-driven fish-habitat relationships from the data. Moreover, we describe a method to extrapolate capacity estimates to larger spatial scales (e.g., basin, population). Estimates of available habitat capacity for a given life stage (e.g., summer parr, winter presmolt, redds) at any given scale (e.g., watershed, population) can then be compared to estimates of life-stage-specific abundance necessary to achieve delisting or recovery goals (described in Appendix C). Doing so provides a quantitative means to elucidate the relative amount of habitat rehabilitation needed to provide sufficient habitat (quantity and quality) for recovery. Carrying capacity models based on QRF and habitat data, like those presented here, provide managers with a framework to guide the identification, prioritization, and development of habitat rehabilitation actions to recover salmon populations.

Methods

Study Site

Fish and habitat data used in the QRF models were collected from 11 watersheds within the interior Columbia River Basin: Asotin, Entiat, Grande Ronde (upper), John Day, Lemhi, Methow, Minam (tributary of Grande Ronde), Secesh, Tucannon, Wenatchee and Yankee Fork. Juvenile fish and redd data collected at CHaMP survey sites were provided by several collaborators and projects and included the Integrated Status and Effectiveness Monitoring Program (ISEMP).

Data

Habitat Data

The habitat data were collected by CHaMP (ISEMP/CHaMP 2017) and were downloaded from the CHaMP website. CHaMP sites are 200- to 500-meter reaches within wadeable streams across select watersheds within the interior Columbia River Basin and were selected based on a spatially balanced Generalized Random Tesselation Stratified (GRTS) sample selection algorithm (Stevens and Olsen 1999, 2004). Habitat data within CHaMP sites are collected using the CHaMP protocol (CHaMP 2016), which calls for field data collection during the low-flow period, typically from June through October. CHaMP habitat data include, but are not limited to, measurements describing channel complexity, channel units, disturbance, fish cover, large woody debris, riparian cover, size (depth, width, discharge), substrate, temperature, and water quality.

Temperature data collected using in-stream temperature loggers were only available for a small portion of CHaMP survey sites over appropriate time intervals. Therefore, modeled temperature data (McNyset et al. 2015) was provided by South Fork Research, Inc. Modeled temperature data summarizing the mean of 8-day means and the maximum of 8-day means for CHaMP sites during summer months (August and September) were available for the years 2011 through 2014.

Juvenile Fish Data

Juvenile fish surveys were conducted for Chinook salmon and steelhead during the summer and winter low-flow seasons at many of the same sites that were surveyed for habitat using the CHaMP protocol. Juvenile fish data included in this analysis were collected during summers of 2011 to 2014, and in the winter of 2017-2018. Fish survey methods to estimate juvenile abundance included mark-recapture, three-pass removal, two-pass removal, and single-pass electrofishing, as well as snorkeling. Survey data were used to estimate juvenile abundance at all sites where data were available. See et al. (2018) provide further detail on methods used to generate juvenile abundance estimates. Summer sampling and data collection were conducted at the site scale, whereas winter sampling was conducted at the channel unit scale, primarily using snorkel surveys.

Juvenile abundance estimates at all sites were translated into linear fish densities (parr/m) for the summer, and areal densities (parr/m^2) in the winter, and density estimates were paired with the associated CHaMP habitat data. For sites that were sampled in multiple years, only the fish and habitat data from the year with the highest observed fish density were retained to avoid possible pseudo-replication.

Redd Data

Chinook salmon and steelhead redd data were graciously provided by the Idaho Department of Fish and Game, Nez Perce Tribe Department of Fisheries Resources, Oregon Department of Fish and Wildlife, U.S. Fish and Wildlife Service, and the Washington Department of Fish and Wildlife and span the years 1995 to 2016. Redd data were available for the following CHaMP watersheds: Asotin, Entiat, John Day, Lemhi, Methow, Minam, Secesh, Tucannon, upper Grande Ronde, Wenatchee, and Yankee Fork.

To pair the redd and habitat data, the number of redds that occurred within a 1 rkm buffer of the central point (i.e., x-site) for each CHaMP site were tallied. The latitude and longitude of each CHaMP site and each redd were snapped to a route in ArcGIS and the number of redds that occurred within 500 meters upstream or downstream of each CHaMP site for each year in which redds were observed were counted and transformed into linear densities (redds/m). For each CHaMP site, we identified the year in which the maximum number of redds were observed because we are ultimately interested in redd capacity, and therefore used the highest observed redd density at each CHaMP site.

Habitat Covariate Selection

A crucial step in developing a QRF model to predict habitat capacity to support juveniles or redds is selecting the habitat covariates to include in the model. Random forest models naturally incorporate interactions between correlated covariates, which is essential because nearly all CHaMP habitat variables are correlated to one degree or another. However, we aimed to avoid including redundant variables (i.e., variables that measure similar aspects of the habitat). Including too many habitat covariates can result in overfitting of the model (e.g., including as many covariates as data points).

The CHaMP protocol produces more than 100 metrics describing the quantity and quality of fish habitat for each survey site, as well as number of metrics at the channel unit scale. To decide which habitat metrics to use in each QRF model, we considered first the association between the habitat metric and observed juvenile or redd densities and second the correlation among habitat metrics. We used the Maximal Information-Based Nonparametric Exploration (MINE) class of statistics (Reshef et al. 2011) to determine those habitat characteristics most highly associated with observed juvenile or redd densities. MINE statistics were employed using the R package *minerva* (Albanese et al. 2013). Within the MINE statistics, we used the maximal information coefficient (MIC) to measure the strength of the linear or non-linear association between fish density and each habitat characteristic (Reshef et al. 2011). The MIC value was used to inform decisions on which habitat covariates to include in the model. Habitat metrics were grouped into broad categories that include channel unit, complexity, cover, disturbance, riparian, size, substrate, temperature, water quality, and woody debris. Within each category, metrics were ranked according to their MIC value. Our strategy was to select one or two variables with high MIC scores within each category so that covariates describe different aspects of the spawning and juvenile rearing habitat. Additionally, we measured pairwise correlations among all habitat metrics and attempted to avoid covariates that were highly correlated and include covariates that describe potentially meaningful fish-habitat relationships.

Table B-1 provides a summary of habitat covariates used in each of the QRF models.

QRF Model Fitting

In total, six QRF models were fit including combinations of two species (Chinook salmon and steelhead) and three life stages (summer parr, winter presmolt, redd). Each of the QRF models were fit using the selected habitat covariates and using the *quantregForest* function from the *quantregForest* package (Meinshausen 2016) in R software (R Core Team 2015). The individual predictions from each tree, viewed collectively, describe the entire distribution of the predicted response. Therefore, the random forest model can be used in the same way as other quantile regression methods to predict any quantile of the response. The 90th quantile of the predicted distribution was used as a proxy for habitat carrying capacity. We chose to use the 90th quantile, instead of something higher, to avoid using predictions that are aimed at the very upper tails of observed fish density, which may be influenced by sampling issues.

Chinook salmon and steelhead summer parr, winter presmolt, and redd densities and associated habitat data were paired by site and year; this habitat data contained some missing values. Within each dataset, any site visit with more than three missing covariates was dropped from the dataset; the remaining missing habitat values were imputed using the *missForest* R package (Stekhoven and Buehlmann 2012; Stekhoven 2013).

After model fitting, each QRF model can then be used to predict Chinook salmon or steelhead summer parr, winter presmolt, or redd capacity using measurements of the habitat covariates used to fit each model. In our case, this includes all sites in the Columbia River Basin surveyed using the CHaMP protocol (CHaMP 2016). For CHaMP sites surveyed in multiple years, we first calculated the mean among years prior to making predictions. For overwintering capacity, QRF predictions were made at the channel unit scale, and then combined to estimate capacity at the CHaMP site scale.

Results

Habitat Covariate Selection

We categorized 150 habitat measurements collected using the CHaMP habitat protocol (CHaMP 2016) into 11 habitat groups. For each model, an MIC value was calculated for each habitat covariate based on the strength of association between the habitat covariate and the response variable (fish or redd density). Covariates were then ranked within each habitat group, and we selected one or two covariates within each habitat group, taking into consideration their MIC rank and number of missing values. Our strategy was to 1) consider pairwise correlations among habitat covariates to minimize redundant covariates measuring similar aspects of habitat, and 2) select covariates that describe habitat characteristics likely important towards spawning or rearing.

We focused on each life stage in turn, examining the MIC statistics of each habitat covariates for both Chinook and steelhead. We selected between eight and 14 metrics to use in each life stage.

Table B-1 shows the CHaMP habitat covariates used to fit each of the QRF models.

Table B-1. Habitat metrics and descriptions of metrics included in each of the QRF capacity models. Numbers indicate where each metric ranked in relative importance for each model. Dashes indicate a metric was not used for a given model.

Metric Category	Metric	Description	Chinook			Steelhead		
			Sum. Juv.	Win. Juv.	Redd	Sum. Juv.	Win. Juv.	Redd
Channel Unit	Channel Unit Frequency	Number of channel units per 100 meters.	8	2	–	12	3	–
Channel Unit	Fast Turbulent Frequency	Number of Fast Water Turbulent channel units per 100 meters.	–	–	13	–	–	6
Channel Unit	Fast Turbulent Percent	Percent of wetted area identified as Fast Water Turbulent channel units.	–	–	11	–	–	8
Channel Unit	Tier1	Tier 1 channel unit type.	–	8	–	–	8	–
Complexity	Sinuosity	Ratio of the thalweg length to the straight-line distance between the start and end points of the thalweg.	–	4	–	–	6	–
Complexity	Thalweg Depth CV	Coefficient of Variation (CV) of thalweg depths at a site.	9	–	–	7	–	–
Complexity	Wetted Width To Depth Ratio Avg	Average width to depth ratio of the wetted channel measured from cross-sections. Depths represent an average of depths along each cross-section.	4	–	12	5	–	2
Complexity	Wetted Width To Depth Ratio CV	Retired. Coefficient of Variation of wetted width to depth ratios derived from cross-sections.	–	–	9	–	–	14
Cover	Fish Cover: LW	Percent of wetted area that has woody debris as fish cover.	–	6	–	–	4	–
Cover	Fish Cover: Total	Percent of wetted area with the following types of cover: aquatic vegetation, artificial, woody debris, and terrestrial vegetation.	5	–	–	9	–	–
Land Classification	Disturbance Index	Disturbance index that includes measures of % urban, % agricultural, % impervious surface and road density (Whittier et al. 2011).	14	–	6	4	–	3
Land Classification	Natural PC 1	A natural index that describes watershed slope, precipitation, growing season (growing degree day), and low-gradient streams (Whittier et al. 2011).	–	–	3	–	–	7
Riparian	Riparian Cover: Ground	Percent of groundcover vegetation.	6	–	–	14	–	–

Metric Category	Metric	Description	Chinook			Steelhead		
			Sum. Juv.	Win. Juv.	Redd	Sum. Juv.	Win. Juv.	Redd
Riparian	Riparian Cover: No Canopy	Percent of riparian canopy devoid of vegetation.	–	–	8	–	–	13
Size	Discharge	The sum of station discharge across all stations. Station discharge is calculated as depth x velocity x station increment for all stations except first and last. Station discharge for first and last station is 0.5 x station width x depth x velocity.	–	–	7	–	–	1
Size	Discharge - Fish	Discharge at time of fish survey	–	1	–	–	1	–
Size	Gradient	Site water surface gradient is calculated as the difference between the top of site (upstream) and bottom of site (downstream) water surface elevations divided by thalweg length.	–	–	2	–	–	4
Size	Thalweg Depth Avg	Average thalweg depth of the wetted channel.	1	–	–	2	–	–
Size	Thalweg Exit Depth	Depth of the thalweg at the downstream edge of the channel unit.	–	3	–	–	2	–
Substrate	Substrate < 6mm	Average percentage of pool tail substrates comprised of sediment <6 mm.	11	–	–	13	–	–
Substrate	Substrate Est: Boulders	Percent of boulders (256-4000 mm) within the wetted site area.	–	–	4	–	–	5
Substrate	Substrate Est: Coarse and Fine Gravel	Percent of coarse and fine gravel (2-64 mm) within the wetted site area.	10	7	5	10	5	11
Substrate	Substrate: D50	Diameter of the 50th percentile particle derived from pebble counts.	12	5	–	8	7	–
Temperature	Max7dAM	Highest 7-day average of daily maximum (7dAM) value between July 15th - August 31st.	7	–	10	6	–	12
Temperature	Summer Hourly Average Temp	Average of all hourly temperature measurements collected July 15th - August 31st.	2	–	–	3	–	–
Water Quality	Conductivity	Measure of the concentration of ionized materials in water, or the ability of water to conduct electrical current.	3	–	1	1	–	9

Metric Category	Metric	Description	Chinook			Steelhead		
			Sum. Juv.	Win. Juv.	Redd	Sum. Juv.	Win. Juv.	Redd
Wood	Large Wood Frequency: Wetted	Number of large wood pieces per 100 meters within the wetted channel.	13	–	14	11	–	10

QRF Model Fitting

QRF models were fit for each of the species and life stages using the chosen habitat covariates (

Table B-1) and the *quantregForest* package (Meinshausen 2016) in R (R Core Team 2015).

Table B-1 provides the relative importance of each habitat covariate included in each of the QRF models, after model fit. Additionally, QRF models allow one to visually examine the marginal effect of each habitat covariate on the quantile of interest using partial dependence plots. These plots show the marginal effect of changing a single covariate on the response variable while maintaining all other covariates at their mean values (see Supplemental Figure B-1 to Supplemental Figure B-6).

Model Extrapolation

After model fitting, QRF models can be used to predict capacity for a given species and life stage at all CHaMP sites within the interior Columbia River Basin, using the 90th quantile of the predicted distribution as a proxy for carrying capacity. CHaMP site carrying capacity predictions from each of the six QRF models (Chinook salmon/steelhead; summer parr, overwinter presmolt, and redds) were extrapolated to larger scales (e.g., watershed, population) using GAA covariate data. In the Supplementary Tables and Figures to Appendix B, we provide estimates of habitat capacity, by life stage and species, for tributaries and mainstem habitats in eight watersheds of the Upper Salmon River Subbasin. Watersheds include the Upper Salmon River (above Redfish Lake), Valley Creek, Yankee Fork Salmon River, East Fork Salmon River, Pahsimeroi River, Lemhi River, North Fork Salmon River, and Panther Creek (see Supplementary Tables and Figures). Moreover, we provide maps to visualize predictions of parr and redd capacity at all master sample points in these watersheds using the extrapolation model. These capacity tables and maps provide an example of outputs available from our current QRF and extrapolation models.

Discussion

We have described a novel approach to estimate the capacity of habitat in wadeable streams to support Chinook salmon and steelhead juveniles (during summer and winter months) and redds in the interior Columbia River Basin. We have built QRF models for three different life stages (summer parr, overwintering juveniles, and redds) for two different species. The approach is entirely empirical, allowing fish-habitat relationships to emerge from the input data, even if they are non-linear in nature (as most ecological relationships are). For these species and life stages, we have generated estimates of capacity where similar habitat data are available (i.e., at all CHaMP sites). In this appendix, we further extrapolated those predictions to larger spatial scales using globally available attribute data and have provided estimates of habitat capacity and capacity maps for eight watersheds in the Upper Salmon River Subbasin. The habitat capacity predictions for each of the watersheds can then be compared to estimates of habitat capacity necessary to support ESA delisting (described in Appendix C) to identify life-stage-specific capacity limitations. To date, we have validated the QRF estimates of Chinook summer parr with spawner-recruit curves from a variety of watersheds in the Columbia River Basin and found them to match up very well, despite being based on entirely different data (See et al. 2018). Additionally, QRF predictions of capacity can be built on habitat sampling conducted over a handful of years (or a single year with enough effort), whereas spawner-recruit curves, while often considered a gold standard for estimating capacity, require many years of data with plenty of contrast to be considered valid.

There are potential limitations to our approach that should be considered when interpreting results. First, we assume that at least some sites in our empirical dataset are at or near carrying capacity at the site level. Having at least some sites near capacity allows the random forest model to more accurately provide classification and regression trees, which, in turn, allows better approximation of quantiles and capacity. However, this assumption may not be true in this case, especially since juvenile fish abundance/density and redd data used in the model have been collected during recent years of low escapement. If this assumption is not met, the QRF models will likely produce conservative (low) estimates of capacity (but the framework of the model is not wrong). To address this limitation, we hope to add paired fish-habitat data in the future from areas of increased escapement or that are likely near rearing or spawning capacity (e.g., Secesh River, Idaho, or regions outside of the Columbia River [e.g., Alaska]) to provide more accurate estimates of capacity. Adding fish-habitat data from additional areas has the benefit of providing additional contrast in habitat data to the model, which can improve model predictions and extrapolation.

Our QRF models are populated using CHaMP habitat data and juvenile fish or redd abundance and density information collected within those CHaMP sites. Predictions of habitat capacity can then be made at locations where similar habitat data are available (i.e., all CHaMP sites) and then extrapolated to larger spatial scales using globally available attributes or similar. However, there are a few issues related to the extrapolation of QRF estimates of capacity to larger spatial scales that should be noted. For example, determining the downstream extent of wadeable streams can be a challenge, and whether all the master sample points we include meet that definition is unclear. Fish-habitat relationships may change in deeper rivers, and these QRF models should currently only be applied to wadeable areas of a watershed. In the future, we hope to explore the ability to apply QRF models to larger river systems where desired.

We recognize that, occasionally, estimates of winter capacity for a particular stream or watershed are higher for winter juveniles than summer parr (e.g., upper Grande Ronde steelhead), which was contrary to our expectations. Although this may be true, there are other alternative potential expectations for these results. First, we assumed that the spatial extent for rearing during summer and winter months was the same. In reality, the winter extent for each species is likely not as broad as the summer rearing extent, so even if more fish could be supported at some sites during winter, there may be extents of the watershed not available to overwintering fish. However, without knowing the true winter distributional extent, it is difficult to correct for varying summer/winter extents. To date, our winter fish sampling has focused on areas within the domain of Chinook salmon, so we do not have the observational data to restrict a species' winter range appropriately, and such data would be difficult to obtain.

Next Steps

The QRF models presented here are currently populated using habitat data collected by CHaMP (CHaMP 2016). However, with the reduction in effort of on-the-ground habitat data collection (i.e., CHaMP), habitat data and covariates used in the model may become outdated as habitat evolves year-to-year via natural and/or anthropogenic changes. As a result, the need for a broader, watershed-scale, cost-effective approach to sampling riverine habitat to populate fish-habitat models has become apparent. Remote sensing techniques paired with minimal, streamlined, on-the-ground sampling may allow for more rapid habitat data collection, at increased scale, and in a more cost-effective manner. Fish-habitat models, including QRF, would benefit by incorporating habitat data collected via remotely sensed platforms and at a greater spatial scale. Emerging techniques, such as multi-spectral analysis, bathymetric LiDAR, and high-resolution RGB cameras are becoming more affordable and attainable for watershed-scale habitat data collection. Further, if data availability via remotely sensed habitat information is adequate in detail and spatial scale, the need for extrapolation models may be removed completely. Use of continuous, remotely sensed habitat data at the watershed scale would provide accurate habitat data that can be used in QRF and similar fish-habitat models, while decreasing costs and potentially removing the need for extrapolation models where remotely sensed data are available.

Habitat rehabilitation groups have requested further guidance on identification of limiting factors for Chinook salmon and steelhead and paths to address those limiting factors. Currently, fish and habitat data metrics used in our QRF models are collected at the reach (200- to 500-meters) scale. However, fish and habitat can be heterogeneous within that scale, and thus, identifying fine-scale (channel unit) fish-habitat relationships within the data can be difficult. Ideally, we would like to better understand fish-habitat relationships within individual channel units (e.g., pools, riffles, runs). Understanding relationships within individual channel units would allow us to identify what characteristics provide a high-capacity pool, riffle, or similar, and further, would provide information on appropriate configuration of channel units to increase habitat capacity. We hope to build QRF models for estimating summer parr rearing capacity at the channel-unit scale, similar to the winter presmolt capacity model we present here. A channel-unit-scale model would help to better translate fish-habitat relationships and allow for a more applicable assessment of restoration evaluation at a finer spatial scale. The channel-unit-scale is closer to the biological patches that fish occupy. Therefore, we hope to collect fish and habitat data at the channel unit scale in the future, and data can be lumped to larger scales if desired. Channel-unit-scale information can be directly applied to restoration design and evaluation and assist engineers and geomorphologists.

Conclusions

In this appendix, we provide estimates (and maps) of contemporary habitat capacity for two species (Chinook salmon, steelhead), three life stages (summer parr, winter juveniles, redds), and eight watersheds in the Upper Salmon River Subbasin. Estimates of available habitat capacity from QRF models can then be compared to estimates of habitat necessary to support ESA delisting goals. Carrying capacity models based on QRF and habitat data, like those presented here, provide managers a framework to guide the identification, prioritization, and development of habitat rehabilitation actions to recover salmon populations. For perhaps the first time, the necessity of tributary habitat restoration actions can be demonstrated, and the magnitude of required change can be placed in context with the other Hs.

Acknowledgements

QRF development efforts have been funded by the Bonneville Power Administration (BPA) through their ISEMP and CHaMP projects and by the Bureau of Reclamation (Reclamation). Fish sampling work in the Lemhi River was also funded through the State of Idaho Office of Species Conservation (OSC) Pacific Coast Salmon Recovery Fund. Redd QRF model development was funded by BPA and through the OSC through a cooperative agreement with Reclamation. Special thanks to staff from the following agencies for providing spatial redd data: Idaho Department of Fish and Game, Nez Perce Tribe Department of Fisheries Resources, Oregon Department of Fish and Wildlife, U.S. Fish and Wildlife Service, and Washington Department of Fish and Wildlife. Special thanks to staff from the following agencies for providing data to calculate juvenile fish abundance and density estimates: Columbia River Inter-Tribal Fish Commission, Oregon Department of Fish and Wildlife, Washington Department of Fish and Wildlife and U.S. Fish and Wildlife Service. The models described in this study were improved by conversations with Eric Buhle.

Literature Cited

Albanese, D., M. Filosi, R. Visintainer, G. Jurman, and C. Furlanello. 2013. Minerva and minepy: a C engine for the MINE suite and its R, Python, and MATLAB wrappers. Bioinformatics. 29(3):407-408.

Carle, F.L. and M.R. Strub. 1978. A new method for estimating population size from removal data. Biometrics. 34:621-630.

CHaMP (Columbia Habitat Monitoring Program). 2016. Scientific protocol for salmonid habitat surveys within the Columbia Habitat Monitoring Program. Prepared by CHaMP for the Bonneville Power Administration. Available at https://www.monitoringresources.org/Document/Protocol/Details/416.

Chapman, D.G. 1951. Some properties of the hypergeometric distribution with applications to zoological sample censuses. University of California Press.

Hedger, R.D., E. De Eyto, M. Dillane., O.H. Diserud, K. Hindar, P. McGinnity, R. Poole, and G. Rogan. 2013. Improving abundance estimates from electrofishing removal sampling. Fisheries Research. 137:104-115.

ISEMP/CHaMP. 2017. Integrated Status and Effectiveness Monitoring Program (ISEMP) and Columbia Habitat Monitoring Program (CHaMP) Annual Combined Technical Report, January – December 2016. BPA Projects 2003-017-00 and 2011-006-00, 93 Electronic Pages.

McNyset, K.M., C.J. Volk, and C.E. Jordan. 2015. Developing an Effective Model for Predicting Spatially and Temporally Continuous Stream Temperatures from Remotely Sensed Land Surface Temperatures. Water. 7:6827-6846.

Meinshausen, N. 2016. quantregForest: Quantile Regression Forests. R package version 1.3-5. https://CRAN.R-project.org/package=quantregForest

Meinshausen, N. 2006. Quantile regression forests. Journal of Machine Learning Research. 7:983-999.

Ogle, D.H, P. Wheeler, and A. Dinno. 2018. FSA: Fisheries Stock Analysis. R package version 0.8.22, https://github.com/droglenc/FSA

NOAA Fisheries. 2017. ESA Recovery Plan for Snake River Spring/Summer Chinook Salmon (*Oncorhynchus tshawytscha*) & Snake River Basin Steelhead (*Oncorhynchus mykiss*). U.S. Department of Commerce. National Oceanic and Atmospheric Administration. National Marine Fisheries Service. West Coast Region. November 2017.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reshef, D.N., Y.A. Reshef, H.K. Finucane, S.R. Grossman, G. McVean, P.J. Turnbaugh, E.S. Lander, M. Mitzenbacher, and P.C. Sabeti. 2011. Detecting Novel Associations in Large Data Sets. Science. 334:1518-1524.

Rivest, L.P. and S. Baillargeon. 2014. Rcapture: Loglinear models for capture-recapture experiments. R package version 1.4-2.

Robson, D. and H. Regier. 1964. Sample size in Peterson mark-recapture experiments. Transactions of the American Fisheries Society. 93:215-226.

Seber, G. 2002. The estimation of animal abundance and related parameters. Blackburn Press Caldwell, New Jersey.

See, K., M.W. Ackerman, R. Carmichael, B. Lott, and C. Beasley. 2018. Quantile Regression Forest Models to Estimate Habitat Capacity for Spring-Summer Chinook and Steelhead. December 2017 – November 2018, BPA Project 2003-017-00, pp:1-37.

Stekhoven, D.J. 2013. missForest: Nonparametric Missing Value Imputation using Random Forest. R package version 1.4.

Stekhoven, D.J. and P. Buehlmann. 2012. MissForest – non-parametric missing value imputation for mixed-type data. Bioinformatics. 28(1):112-118.

Stevens, D. and A. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association. 99:262-278.

Stevens, D.L., Jr., and A.R. Olsen. 1999. Spatially Restricted Surveys Over Time for Aquatic Resources. Journal of Aquatic, Biological, and Environmental Statistics. 4:415-428.

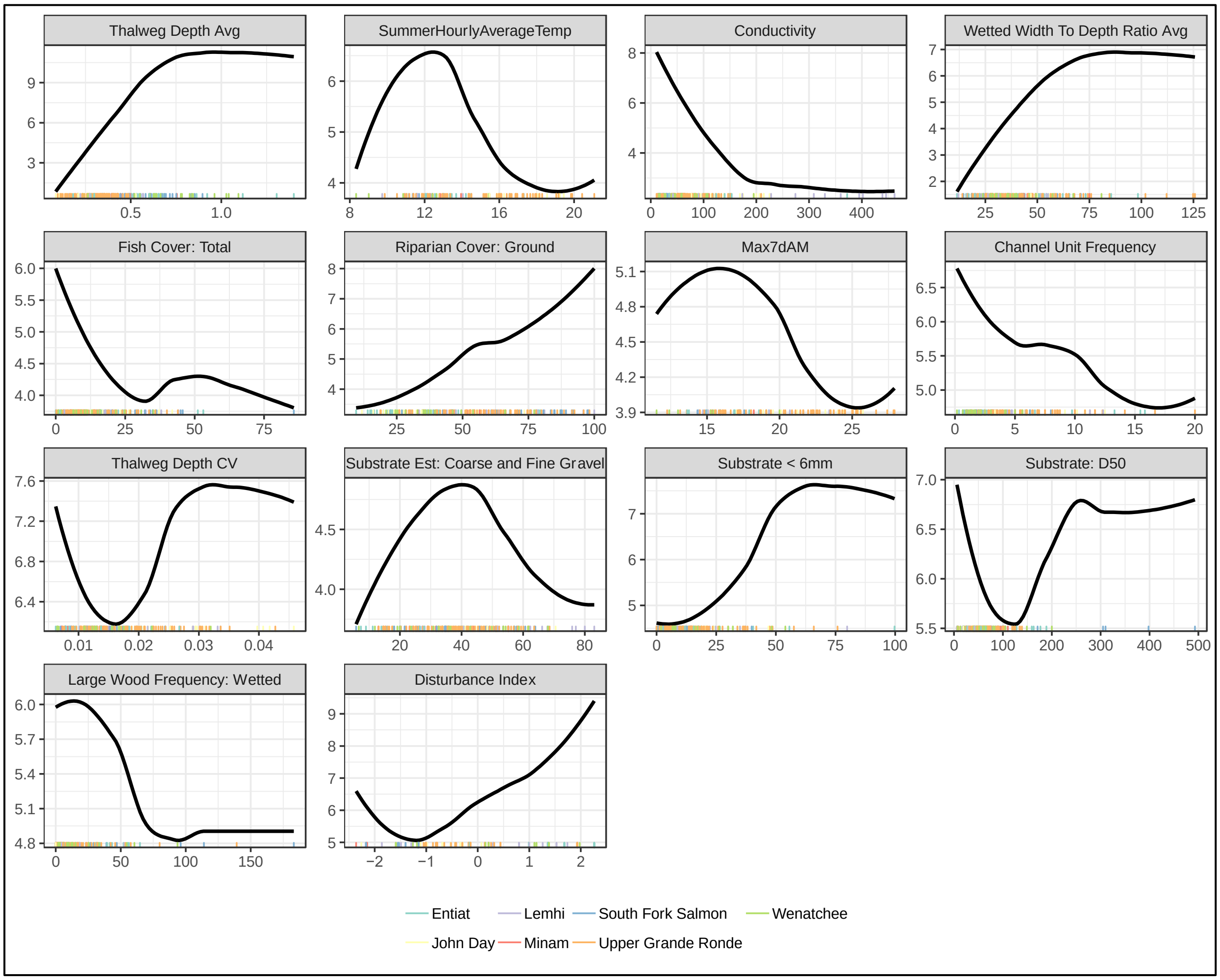
Whittier, T., A. Herlihy, C. Jordan, and C. Volk. 2011. Landscape classification of Pacific Northwest hydrologic units based on natural features and human disturbance to support salmonid research and management. NOAA, National Marine Fisheries Service. NOAA Contract #AB1133F10SE2464. Pp. 39.

This page intentionally left blank.

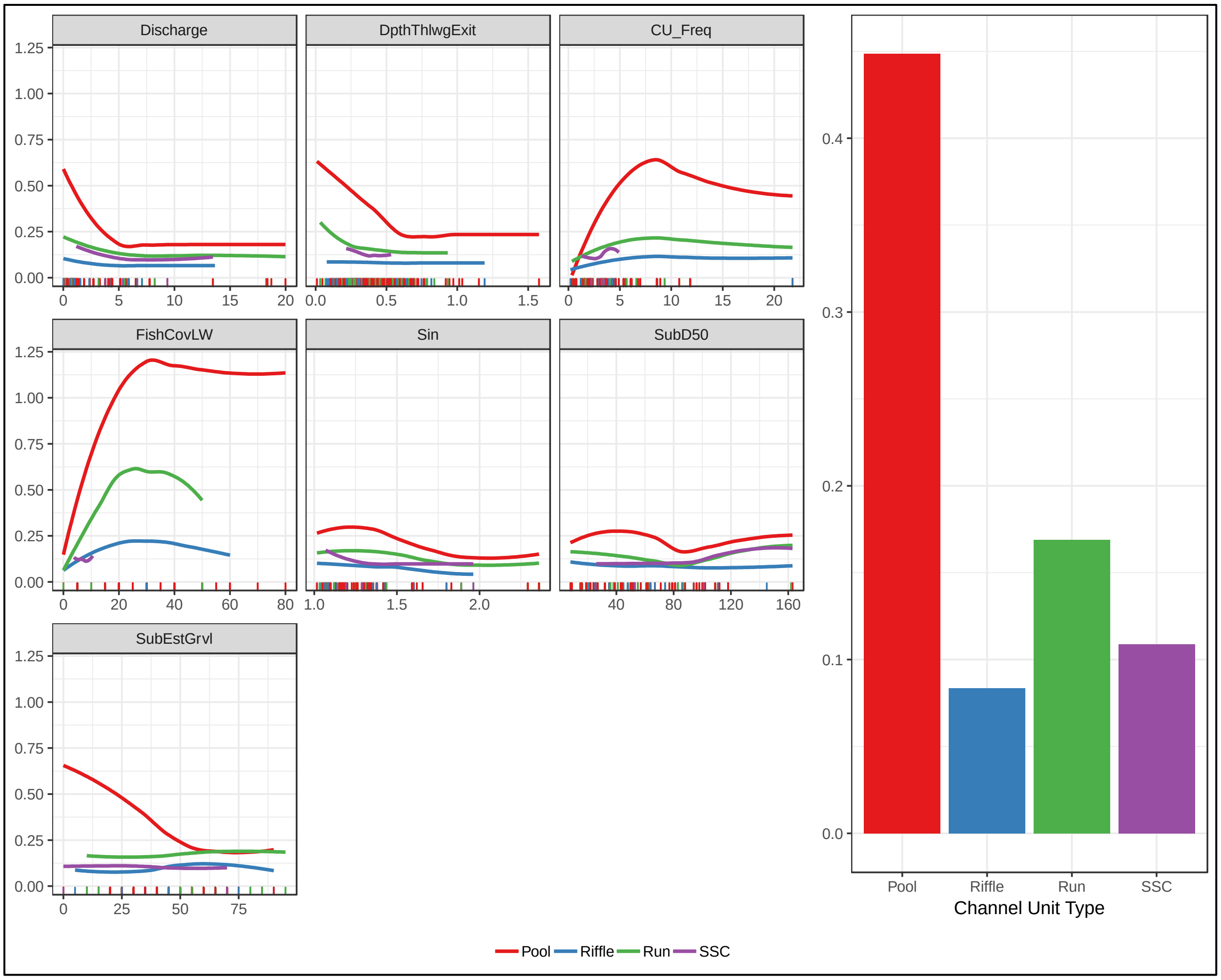
Supplementary Tables and Figures to Appendix B

Partial Dependence Plots

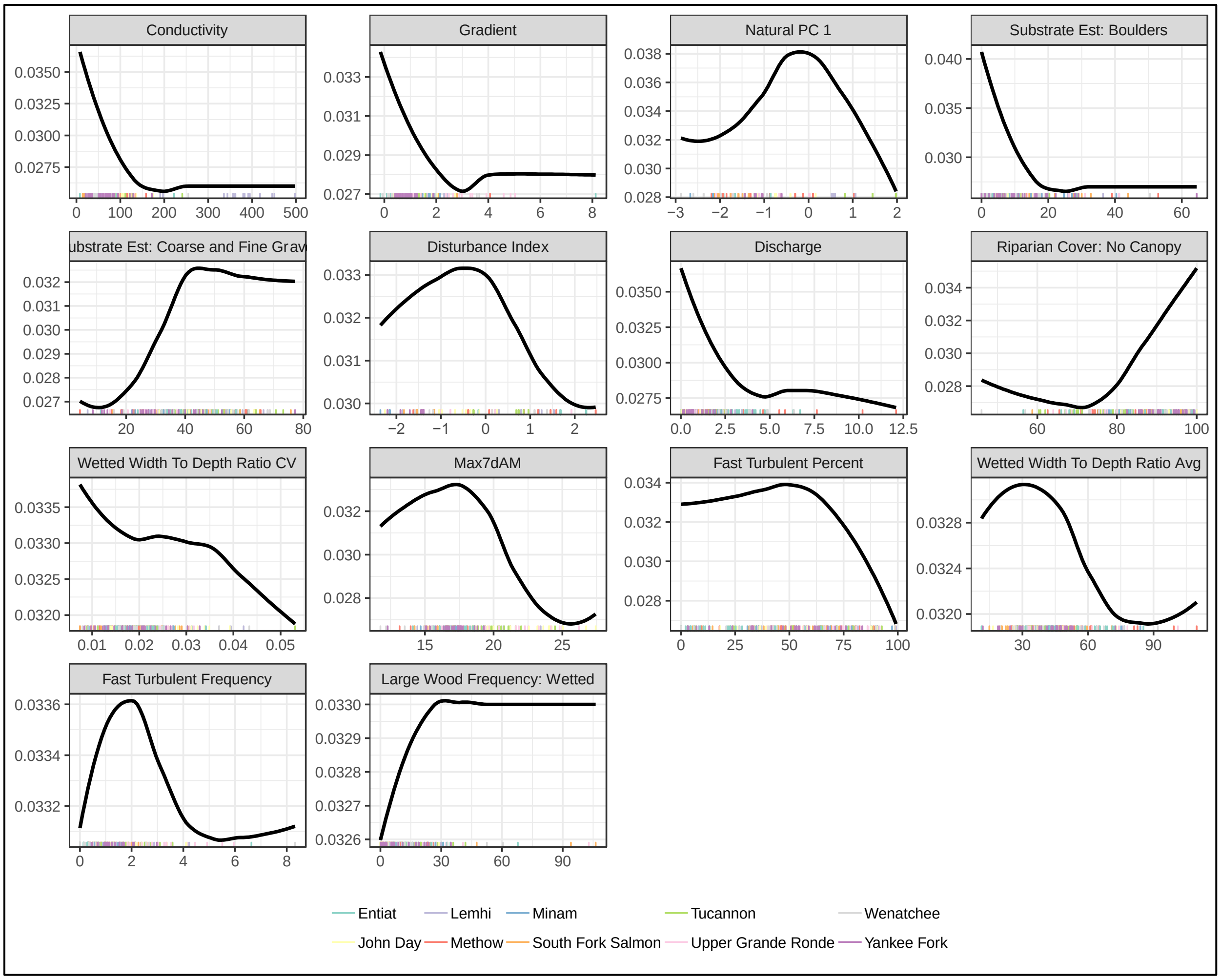
Chinook salmon



Supplemental Figure B-1. Partial dependence plots from the Chinook salmon parr (summer) capacity quantile regression forest (QRF) model, depicting how parr capacity shifts as each habitat metric changes, assuming all other habitat metrics remain at their mean values. Tick marks along the X-axis depict observed values, and the subbasin they came from.

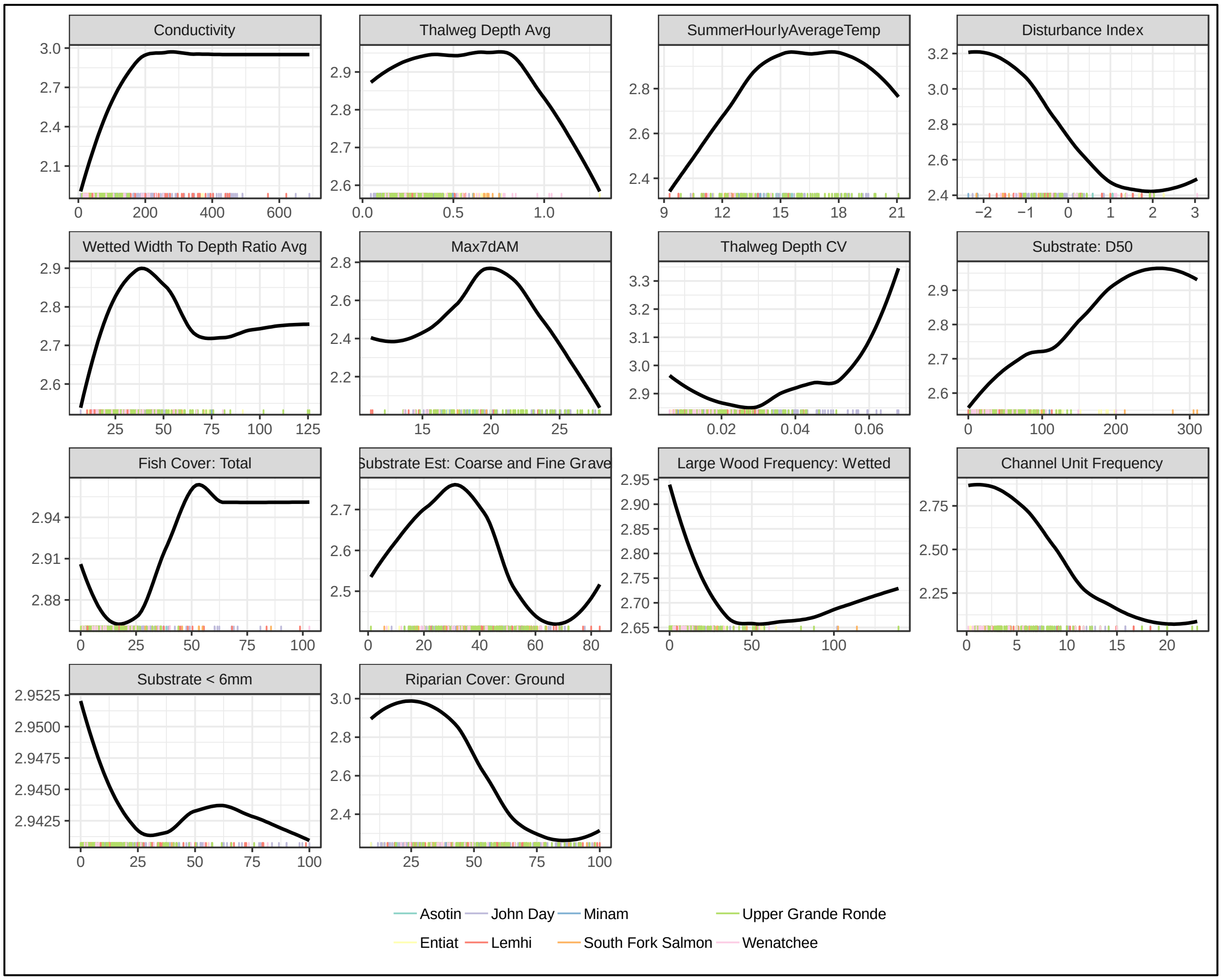


Supplemental Figure B-2. Partial dependence plots from the Chinook salmon parr (winter) capacity quantile regression forest (QRF) model, depicting how parr capacity shifts as each habitat metric changes, assuming all other habitat metrics remain at their mean values. Tick marks along the X-axis depict observed values. Colors correspond to the type of channel unit (pool, riffle, run or small side channel).

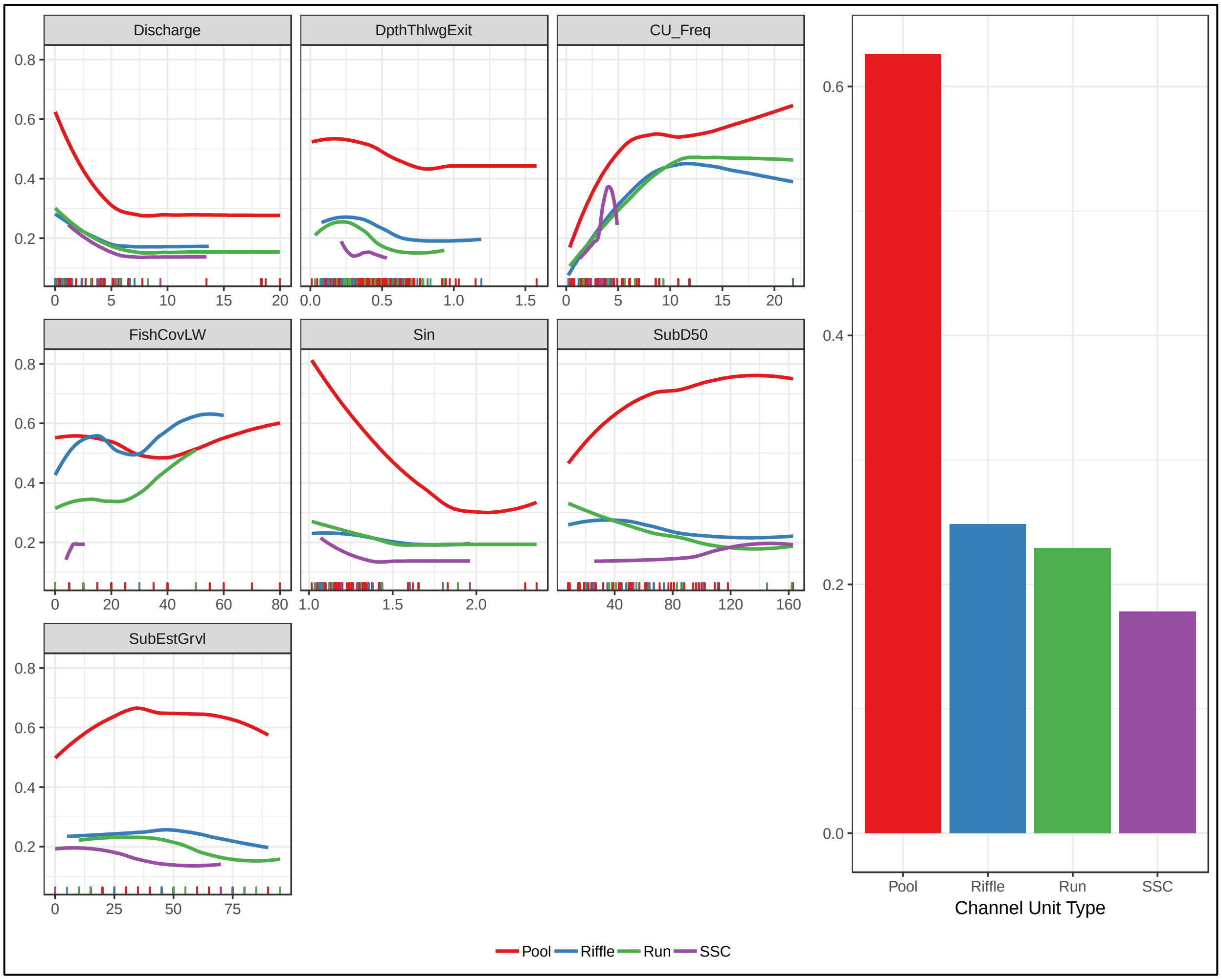


Supplemental Figure B-3. Partial dependence plots from the Chinook salmon redd capacity quantile regression forest (QRF) model, depicting how redd capacity shifts as each habitat metric changes, assuming all other habitat metrics remain at their mean values. Tick marks along the X-axis depict observed values, and the subbasin they came from.

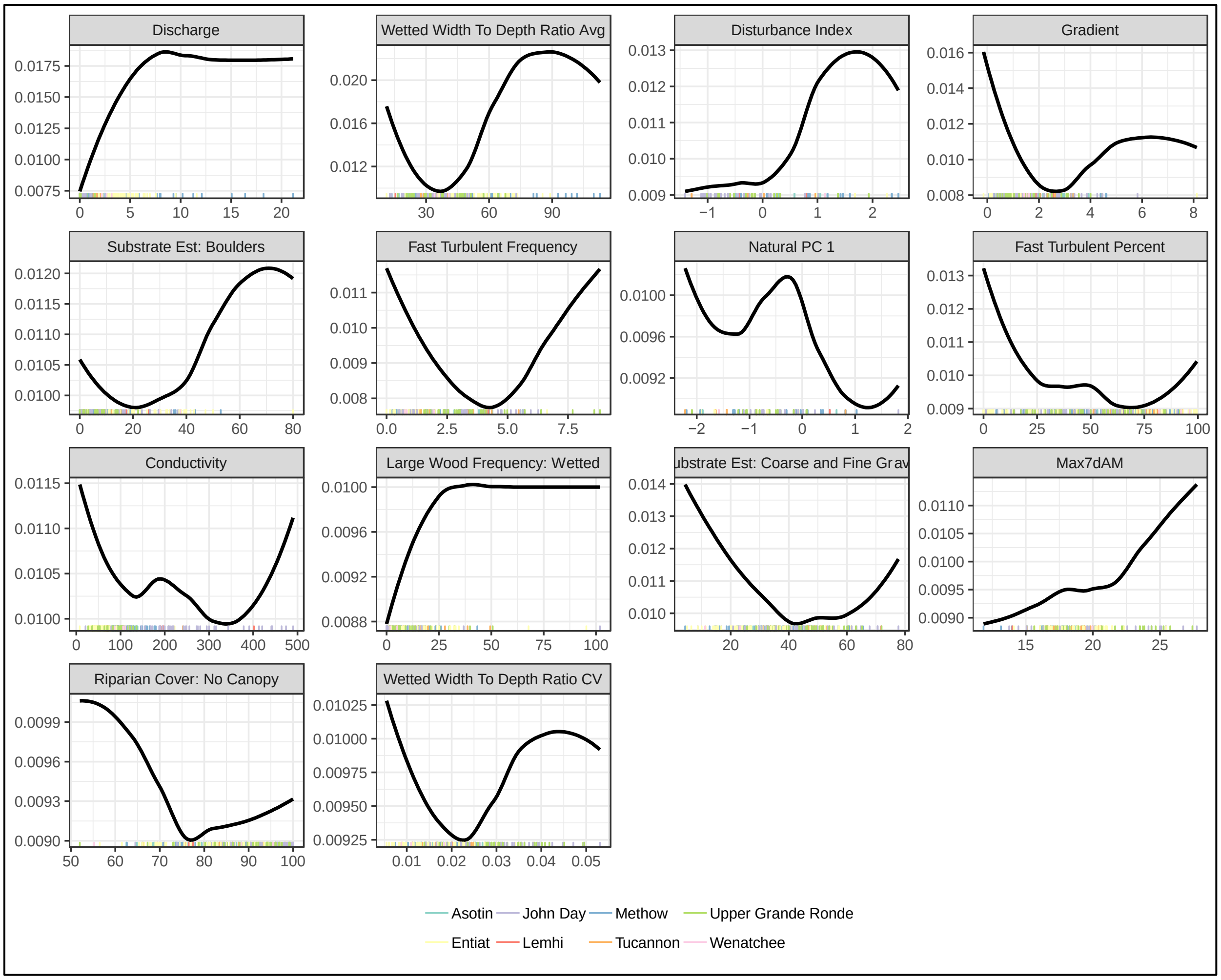
Steelhead



Supplemental Figure B-4. Partial dependence plots from the steelhead juvenile (summer) capacity quantile regression forest (QRF) model, depicting how juvenile capacity shifts as each habitat metric changes, assuming all other habitat metrics remain at their mean values. Tick marks along the X-axis depict observed values, and the subbasin they came from.



Supplemental Figure B-5. Partial dependence plots from the steelhead juvenile (winter) capacity quantile regression forest (QRF) model, depicting how juvenile capacity shifts as each habitat metric changes, assuming all other habitat metrics remain at their mean values. Tick marks along the X-axis depict observed values. Colors correspond to the type of channel unit (pool, riffle, run or small side channel).



Supplemental Figure B-6. Partial dependence plots from the steelhead redd capacity quantile regression forest (QRF) model, depicting how redd capacity shifts as each habitat metric changes, assuming all other habitat metrics remain at their mean values. Tick marks along the X-axis depict observed values, and the subbasin they came from.

Habitat Capacity Estimates

Chinook salmon

Supplemental Table B-1. Estimates of total Chinook salmon summer parr, overwintering parr, and redd capacity for the Upper Salmon River, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Alpine Creek	1.6	1.0	7,474	1,461	1,854	244	44	2
Alturas Lake Creek	17.4	10.8	61,223	10,516	23,051	3,555	618	36
Beaver Creek	10.2	6.4	46,018	9,423	12,762	1,730	281	11
Champion Creek	7.3	4.5	11,026	2,848	7,890	1,122	185	10
Decker Creek	0.9	0.6	1,142	423	631	132	22	1
Fisher Creek	6.2	3.9	7,233	2,566	6,524	985	155	9
Fishhook Creek	5.7	3.5	26,636	5,359	6,146	1,007	145	7
Fourth of July Creek	12.5	7.7	20,123	5,533	13,273	1,962	337	17
Frenchman Creek	5.4	3.4	24,055	5,007	6,692	914	150	6
Gold Creek	1.7	1.1	7,145	1,597	1,749	295	44	2
Hell Roaring Creek	8.3	5.2	39,280	7,917	9,648	1,475	221	10
Huckleberry Creek	2.9	1.8	13,007	2,703	3,305	524	73	3
Pettit Lake Creek	2.2	1.3	9,859	2,042	2,395	366	60	2
Pole Creek	10.5	6.5	47,350	9,747	12,503	1,697	279	12
Redfish Lake Creek	4.1	2.6	14,945	2,604	4,762	859	138	9
Salmon River	59.3	36.8	265,251	24,534	75,726	10,895	1,438	85
Smiley Creek	14.7	9.1	66,076	13,551	18,038	2,364	404	16
Vat Creek	1.1	0.7	4,817	1,024	1,164	189	30	1
Williams Creek	4.5	2.8	18,275	4,131	4,609	744	113	5
Yellowbelly Creek	6.6	4.1	30,938	6,117	8,117	1,073	172	7
Total	**183.1**	**113.8**	**721,873**	**119,101**	**220,838**	**12,488**	**4,909**	**250**

Supplemental Table B-2. Estimates of total Chinook salmon summer parr, overwintering parr, and redd capacity for Valley Creek, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Crooked Creek	2.4	1.5	9,851	2,161	2,629	389	60	3
East Fork Valley Creek	1.8	1.1	8,125	1,707	2,003	283	47	2
Elk Creek	9.8	6.1	45,978	9,306	12,659	1,769	244	12
Goat Creek	3.1	1.9	12,741	2,855	2,979	514	76	4
Iron Creek	3.6	2.2	15,346	3,297	3,832	605	89	4
Job Creek	2.3	1.4	5,427	1,602	1,796	381	57	3

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Meadow Creek	7.0	4.3	30,964	6,422	8,772	1,184	173	8
Park Creek	2.9	1.8	2,571	1,229	2,631	462	68	4
Stanley Creek	3.2	2.0	13,286	2,887	4,044	596	78	4
Stanley Lake Creek	4.9	3.0	22,357	4,558	6,244	832	122	6
Valley Creek	40.5	25.2	142,654	25,815	49,859	7,853	1,197	71
Total	**81.5**	**50.5**	**309,300**	**61,840**	**97,449**	**8,275**	**2,211**	**121**

Supplemental Table B-3. Estimates of total Chinook salmon summer parr, overwintering parr, and redd capacity for the Yankee Fork Salmon River, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Cabin Creek	2.8	1.7	5,626	1,772	2,912	501	63	5
Eightmile Creek	3.3	2.1	14,655	3,289	4,743	688	79	5
Elevenmile Creek	1.2	0.7	440	539	689	160	28	2
Fivemile Creek	1.9	1.2	4,082	1,167	1,486	259	42	3
Jordan Creek	4.0	2.5	9,684	2,488	3,813	627	89	7
Lightning Creek	5.0	3.1	10,605	3,263	4,840	732	111	9
McKay Creek	1.9	1.2	3,463	1,165	2,544	449	43	3
Ninemile Creek	1.5	0.9	318	797	574	174	35	3
Sevenmile Creek	1.0	0.6	576	522	419	123	25	2
Sixmile Creek	2.1	1.3	1,821	1,001	1,432	252	49	3
Tenmile Creek	2.1	1.3	3,723	1,348	1,813	413	50	4
West Fork Yankee Fork	16.4	10.2	58,308	11,213	20,956	2,855	376	26
Yankee Fork	42.2	26.2	161,831	27,286	56,609	8,478	954	68
Total	**85.4**	**53.0**	**275,132**	**55,850**	**102,830**	**9,069**	**1,944**	**140**

Supplemental Table B-4. Estimates of total Chinook salmon summer parr, overwintering parr, and redd capacity for the East Fork Salmon River, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Big Boulder Creek	8.2	5.1	16,629	6,767	7,260	1,216	210	11
Big Lake Creek	2.6	1.6	4,179	1,064	2,148	370	62	3
East Fork Herd Creek	3.7	2.3	5,403	1,648	2,890	514	92	5
East Fork Salmon River	59.1	36.7	301,555	19,510	78,875	13,118	1,385	84
East Pass Creek	14.3	8.9	23,977	5,783	13,942	2,236	369	19
Germania Creek	7.8	4.8	34,673	3,235	7,422	1,135	197	9
Herd Creek	15.3	9.5	67,829	6,106	18,892	3,038	341	20
Lake Creek	2.3	1.4	6,752	1,495	2,291	345	57	3

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
South Fork East Fork Salmon River	3.3	2.0	5,647	1,319	3,467	571	87	5
Taylor Creek	2.3	1.4	2,603	1,704	1,196	229	56	3
West Fork East Fork Salmon River	1.8	1.1	2,967	1,397	1,149	199	47	3
West Fork Herd Creek	3.4	2.1	5,312	1,339	3,303	522	86	5
West Pass Creek	10.0	6.2	17,338	4,112	9,404	1,521	259	14
Total	**134.1**	**83.1**	**494,864**	**55,479**	**152,240**	**13,878**	**3,248**	**184**

Supplemental Table B-5. Estimates of total Chinook salmon summer parr, overwintering parr, and redd capacity for the Pahsimeroi River, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Pahsimeroi River	37.5	23.3	173,435	13,803	52,332	7,773	668	49
Patterson Creek	30.2	18.8	104,074	19,318	36,493	7,521	863	72
PattersonSideChannel1	8.3	5.2	26,506	5,631	10,029	2,325	241	21
Sulphur Creek	5.5	3.4	7,515	2,300	5,123	999	114	9
Pahsimeroi River	37.5	23.3	173,435	13,803	52,332	7,773	668	49
Total	**81.5**	**50.7**	**311,530**	**41,052**	**103,977**	**11,108**	**1,886**	**151**

Supplemental Table B-6. Estimates of total Chinook salmon summer parr, overwintering parr, and redd capacity for the Lemhi River, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Bear Valley Creek	2.3	1.4	0	0	1,897	449	55	5
Big Eightmile Creek	0.9	0.6	0	0	653	170	20	2
Big Springs Creek	6.8	4.2	15,159	4,293	5,381	1,308	156	9
Big TImber Creek	2.0	1.2	11,012	0	1,886	180	66	0
Bohannon Creek	1.4	0.9	3,950	892	789	121	30	2
Canyon Creek	6.2	3.9	17,946	4,281	5,054	1,045	144	9
Hayden Creek	19.9	12.3	24,123	11,789	21,518	3,331	422	36
Kenney Creek	1.5	0.9	3,176	0	1,533	170	39	0
Lemhi River	99.8	62.0	265,739	47,828	127,672	18,574	2,097	163
Little Springs Creek	5.0	3.1	13,323	2,209	4,510	742	106	8
Wimpey Creek	2.8	1.7	3,520	1,282	2,484	403	57	5
Total	**148.6**	**92.2**	**357,948**	**74,837**	**173,375**	**18,971**	**3,192**	**239**

Supplemental Table B-7. Estimates of total Chinook salmon summer parr, overwintering parr, and redd capacity for the North Fork Salmon River, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Dahlonega Creek	4.0	2.5	6,089	1,544	4,418	640	94	5
Hughes Creek	4.8	3.0	17,425	2,824	4,930	750	100	8
Hull Creek	2.1	1.3	2,891	921	1,593	291	44	3
Moose Creek	5.4	3.4	4,888	4,191	3,407	665	130	7
North Fork Salmon River	39.9	24.8	152,269	14,473	38,545	5,178	868	51
Sheep Creek	10.9	6.8	18,644	4,613	9,784	1,594	263	15
Twin Creek	2.5	1.5	4,218	1,917	1,531	266	53	3
Total	**69.6**	**43.3**	**206,424**	**30,483**	**64,209**	**5,561**	**1,552**	**93**

Supplemental Table B-8. Estimates of total Chinook salmon summer parr, overwintering parr, and redd capacity for Panther Creek, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Big Deer Creek	9.2	5.7	44,878	8,819	8,906	1,539	206	12
Blackbird Creek	3.5	2.2	4,632	2,230	3,259	557	80	5
Clear Creek	10.7	6.7	44,396	5,415	10,223	1,760	198	16
Moyer Creek	5.3	3.3	8,146	2,080	4,787	777	125	7
Musgrove Creek	9.8	6.1	44,242	8,969	10,130	1,608	229	11
Napias Creek	2.1	1.3	8,964	1,117	1,516	343	46	3
Panther Creek	66.4	41.3	284,387	26,699	78,552	10,734	1,434	86
Total	**107.0**	**66.6**	**439,645**	**55,329**	**117,372**	**11,150**	**2,318**	**141**

Steelhead

Supplemental Table B-9. Estimates of total Steelhead summer parr, overwintering parr, and redd capacity for the Upper Salmon River, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Alpine Creek	1.6	1.0	3,140	241	4,108	205	19	1
Alturas Lake Creek	17.4	10.8	47,811	8,719	40,100	4,701	259	16
Beaver Creek	6.6	4.1	13,593	959	17,597	1,015	79	4
Champion Creek	10.6	6.6	23,881	2,089	26,742	1,523	120	7
Decker Creek	0.9	0.6	2,093	212	1,941	168	8	1
Fisher Creek	7.9	4.9	18,052	1,896	18,708	1,048	77	6
Fishhook Creek	5.7	3.5	12,422	968	14,797	1,408	70	4
Fourth of July Creek	13.4	8.3	28,671	2,674	33,070	1,954	137	9
Frenchman Creek	5.4	3.4	10,882	785	14,390	853	63	3
Gold Creek	1.7	1.1	4,069	328	4,190	281	21	1
Hell Roaring Creek	5.8	3.6	12,532	924	15,597	1,253	71	4
Huckleberry Creek	2.9	1.8	6,394	459	8,353	613	35	2
Mays Creek	3.0	1.9	6,672	490	7,622	722	31	2
Pettit Lake Creek	2.2	1.3	4,391	344	5,233	300	26	2
Pole Creek	14.1	8.7	29,831	2,122	36,609	2,217	174	9
Redfish Lake Creek	3.8	2.4	11,387	2,036	8,107	1,328	60	4
Salmon River	61.0	37.9	166,401	11,013	137,274	12,399	846	42
Smiley Creek	11.8	7.3	24,214	1,707	30,209	1,931	143	7
Twin Creek	1.4	0.9	3,060	273	2,974	286	17	1
Vat Creek	3.0	1.9	6,325	431	7,598	550	35	2
Warm Creek	2.0	1.2	4,315	328	5,192	299	24	1
Williams Creek	6.5	4.0	15,217	1,237	15,043	1,124	78	5
Yellowbelly Creek	6.6	4.1	14,656	981	17,749	1,035	82	4
Total	**195.3**	**121.3**	**470,009**	**41,217**	**473,201**	**14,239**	**2,475**	**137**

Supplemental Table B-10. Estimates of total Steelhead summer parr, overwintering parr, and redd capacity for Valley Creek, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Crooked Creek	2.4	1.5	5,519	443	5,960	368	29	2
East Fork Valley Creek	1.8	1.1	4,219	306	4,739	262	23	1
Elk Creek	9.8	6.1	22,452	1,671	28,287	2,143	124	7
Goat Creek	6.2	3.8	14,729	1,245	14,238	1,598	75	5
Iron Creek	5.1	3.2	12,187	1,162	12,334	769	57	4
Job Creek	2.3	1.4	5,415	529	4,889	370	24	2

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Meadow Creek	12.2	7.6	28,302	2,188	30,331	1,807	148	9
Park Creek	2.9	1.8	7,010	789	6,589	436	27	3
Stanley Creek	7.0	4.4	17,026	1,482	18,700	1,262	87	6
Stanley Lake Creek	4.9	3.0	11,499	851	13,615	753	63	3
Trap Creek	4.8	3.0	11,078	788	13,041	734	59	3
Valley Creek	40.5	25.2	106,860	15,970	93,125	9,418	578	33
Total	**99.9**	**62.1**	**246,296**	**27,424**	**245,849**	**10,146**	**1,294**	**77**

Supplemental Table B-11. Estimates of total Steelhead summer parr, overwintering parr, and redd capacity for the Yankee Fork Salmon River, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Cabin Creek	2.8	1.7	7,021	447	7,589	597	30	3
Deadwood Creek	2.6	1.6	6,622	395	5,744	741	28	2
Eightmile Creek	3.3	2.1	7,889	536	9,521	502	43	3
Elevenmile Creek	2.5	1.5	5,457	391	5,056	553	27	2
Fivemile Creek	5.2	3.3	12,630	784	11,497	1,013	56	4
Jordan Creek	6.6	4.1	17,038	1,057	16,484	1,188	71	7
Lightning Creek	5.8	3.6	14,565	909	15,188	1,129	63	6
McKay Creek	2.9	1.8	6,402	522	7,989	685	33	4
Ninemile Creek	1.5	0.9	3,218	258	2,559	285	16	1
Ramey Creek	3.8	2.3	9,733	611	8,788	593	40	4
Sawmill Creek	1.5	0.9	3,875	248	2,886	409	16	1
Sevenmile Creek	1.0	0.6	2,367	177	1,797	217	11	1
Sixmile Creek	3.2	2.0	7,723	484	6,895	669	34	3
Tenmile Creek	3.8	2.4	8,755	603	9,517	874	48	4
Twelvemile Creek	2.6	1.6	5,560	436	6,066	656	30	2
West Fork Yankee Fork	16.1	10.0	42,932	2,608	42,540	3,844	204	15
Yankee Fork	44.0	27.3	113,388	7,356	107,459	9,341	558	45
Unnamed	2.1	1.3	4,467	392	4,483	530	24	2
Total	**111.3**	**69.0**	**279,642**	**18,213**	**272,057**	**10,499**	**1,332**	**109**

Supplemental Table B-12. Estimates of total Steelhead summer parr, overwintering parr, and redd capacity for the East Fork Salmon River, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Big Boulder Creek	8.2	5.1	16,979	1,511	19,243	2,020	91	6
Big Lake Creek	2.6	1.6	6,078	596	6,071	592	25	2
East Fork Herd Creek	3.7	2.3	8,631	872	8,608	844	36	3

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
East Fork Salmon River	59.1	36.7	157,910	8,695	138,357	18,229	804	39
East Pass Creek	14.3	8.9	31,448	2,954	35,407	3,096	140	10
Germania Creek	7.8	4.8	18,999	1,331	16,041	1,863	73	6
Herd Creek	15.3	9.5	41,657	2,586	37,722	4,513	188	10
Lake Creek	5.8	3.6	13,315	942	13,548	913	66	4
Little Boulder Creek	5.5	3.4	10,740	1,396	11,882	2,158	73	5
McDonald Creek	2.2	1.3	4,689	347	4,765	496	23	1
Pine Creek	0.8	0.5	1,656	124	1,750	184	8	1
Road Creek	2.6	1.6	7,733	612	5,992	568	31	2
South Fork East Fork Salmon River	3.3	2.0	6,917	712	8,331	814	33	3
Taylor Creek	5.3	3.3	10,699	837	10,520	1,497	54	3
West Fork East Fork Salmon River	1.8	1.1	3,450	286	3,916	427	20	1
West Fork Herd Creek	3.4	2.1	7,739	764	8,442	748	33	2
West Pass Creek	10.0	6.2	21,548	2,142	24,443	2,310	101	7
Total	**151.7**	**94.0**	**370,188**	**26,708**	**355,039**	**19,645**	**1,799**	**106**

Supplemental Table B-13. Estimates of total Steelhead summer parr, overwintering parr, and redd capacity for the Pahsimeroi River, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Pahsimeroi River	37.5	23.3	120,049	7,953	76,645	7,610	556	26
Patterson Creek	30.2	18.8	101,791	17,108	62,729	9,019	484	29
Patterson Side Channel	8.3	5.2	28,107	5,022	14,806	2,918	133	9
Sulphur Creek	5.5	3.4	14,793	1,125	12,756	822	55	4
Total	**81.5**	**50.7**	**264,740**	**31,209**	**166,936**	**12,184**	**1,228**	**69**

Supplemental Table B-14. Estimates of total Steelhead summer parr, overwintering parr, and redd capacity for the Lemhi River, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Agency Creek	14.4	8.9	40,302	4,670	39,807	1,699	171	12
Bear Valley Creek	6.2	3.8	14,615	1,735	14,354	971	66	6
Big Eightmile Creek	11.5	7.1	32,723	3,790	29,809	1,745	120	10
Big Springs Creek	6.8	4.2	20,428	2,442	17,594	1,470	80	6
Big Timber Creek	22.7	14.1	63,252	7,490	56,256	4,039	273	20
Bohannon Creek	12.2	7.6	34,454	4,054	24,230	1,786	129	10
Canyon Creek	17.9	11.1	49,159	6,750	40,720	3,079	221	15

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Cruikshank Creek	2.2	1.3	5,388	646	4,388	210	22	2
East Fork Bohannon Creek	2.7	1.7	7,602	981	3,760	305	25	3
Eighteenmile Creek	4.4	2.7	13,385	2,118	7,245	738	68	5
Hawley Creek	17.4	10.8	47,711	5,744	41,928	2,919	216	15
Hayden Creek	19.9	12.3	52,785	6,256	43,626	3,290	219	19
Kenney Creek	8.7	5.4	24,784	2,877	20,388	999	90	7
Lemhi River	99.8	62.0	295,988	32,307	211,151	17,965	1,572	79
Pratt Creek	7.0	4.3	19,331	2,308	13,981	1,128	75	7
Reservoir Creek	1.5	0.9	3,508	437	1,876	0	15	1
Wimpey Creek	5.7	3.5	16,179	1,878	12,328	802	63	5
Total	**261.0**	**161.7**	**741,594**	**86,484**	**583,442**	**19,588**	**3,425**	**222**

Supplemental Table B-15. Estimates of total Steelhead summer parr, overwintering parr, and redd capacity for the North Fork Salmon River, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Anderson Creek	2.5	1.6	6,201	608	5,553	363	23	2
Dahlonega Creek	8.4	5.2	20,131	1,997	20,586	1,376	85	6
Hughes Creek	7.8	4.8	19,616	1,589	18,558	1,271	79	5
Hull Creek	4.2	2.6	10,856	923	9,272	666	41	3
Moose Creek	2.4	1.5	5,094	389	4,560	421	25	2
North Fork Salmon River	39.9	24.8	110,778	7,549	83,526	6,753	421	27
Pierce Creek	2.7	1.7	6,576	559	5,986	306	26	2
Sheep Creek	10.9	6.8	26,445	2,791	25,416	1,996	115	9
Twin Creek	5.7	3.6	12,688	952	12,715	1,395	63	4
Total	**84.5**	**52.6**	**218,385**	**17,356**	**186,170**	**7,476**	**878**	**60**

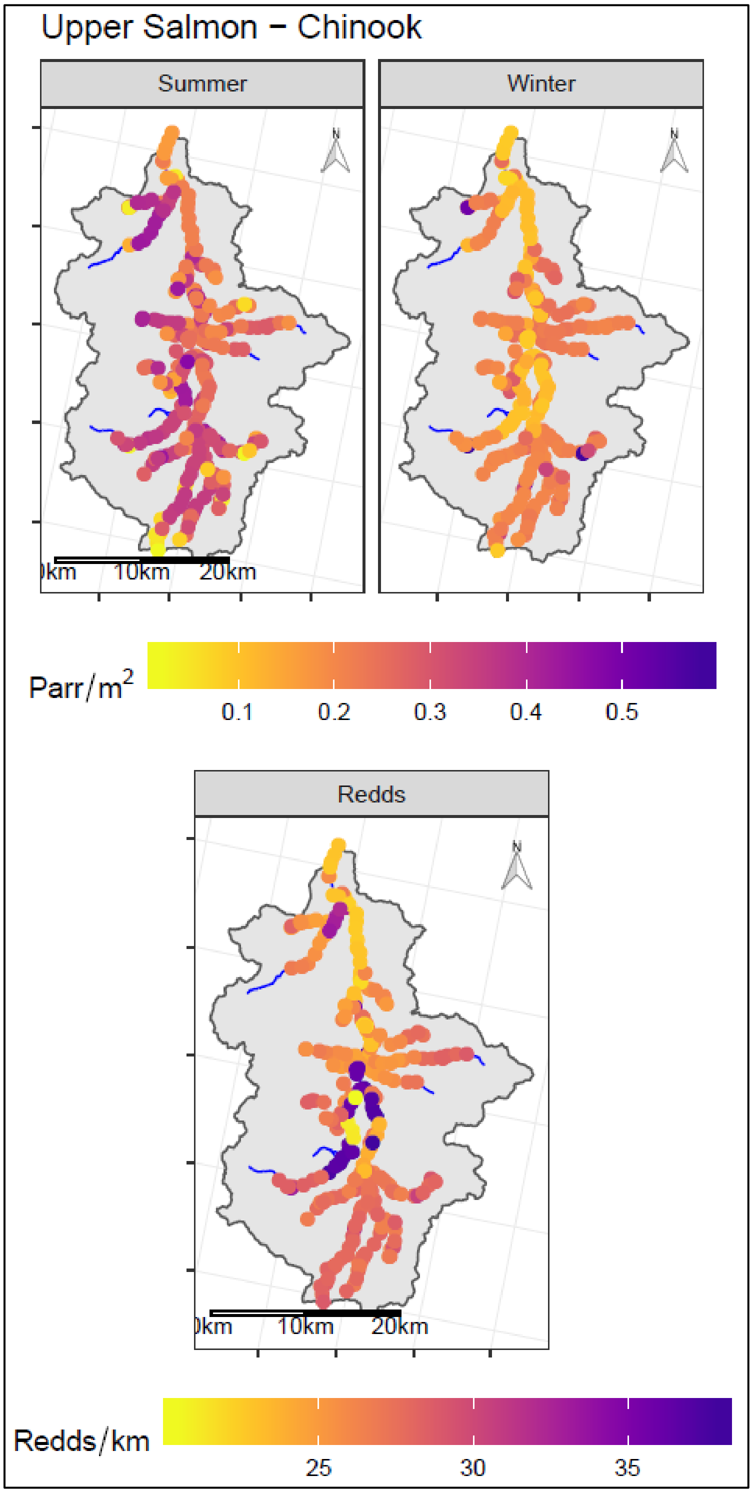
Supplemental Table B-16. Estimates of total Steelhead summer parr, overwintering parr, and redd capacity for Panther Creek, with standard error (SE).

Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Beaver Creek	2.8	1.8	7,274	556	6,421	576	34	2
Big Deer Creek	12.3	7.6	31,433	2,535	30,537	2,390	159	9
Blackbird Creek	3.5	2.2	8,768	776	8,498	644	38	3
Clear Creek	17.9	11.2	49,104	5,015	41,188	4,453	197	16
Deep Creek	4.0	2.5	9,002	743	9,009	877	46	3
Garden Creek	6.9	4.3	18,128	2,202	13,571	2,264	89	8
Moyer Creek	8.4	5.2	20,053	1,994	19,568	1,350	87	6
Musgrove Creek	4.1	2.6	10,074	709	10,195	684	52	3
Napias Creek	7.7	4.8	21,836	1,664	14,380	1,343	76	7
Panther Creek	66.4	41.3	186,821	13,609	154,660	13,136	791	54

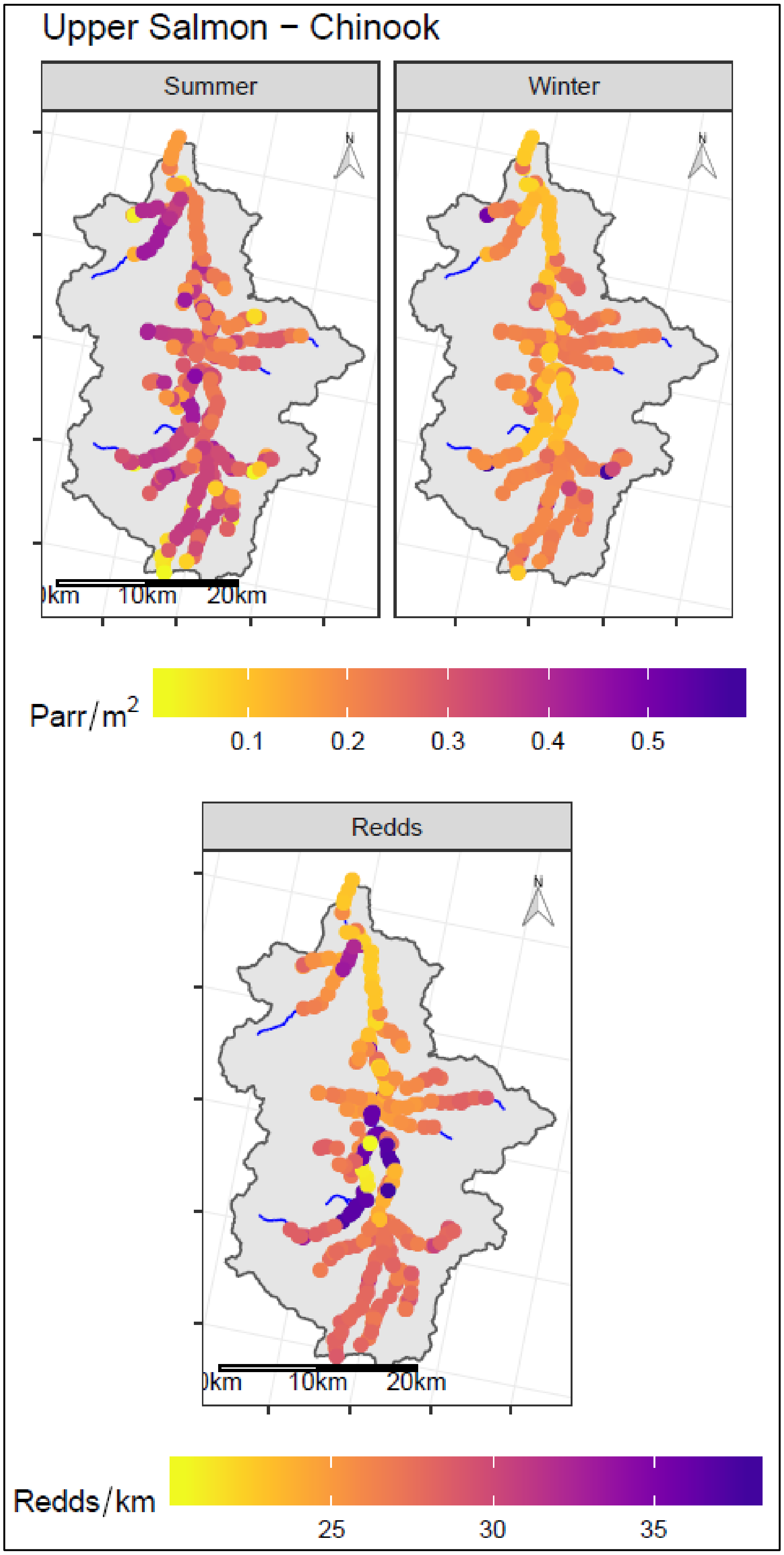
Stream	Stream length		Summer Parr		Winter Parr		Redd	
	km	mi	Capacity	SE	Capacity	SE	Capacity	SE
Trail Creek	5.2	3.3	12,822	1,041	10,854	1,548	59	4
Woodtick Creek	2.2	1.4	5,279	500	4,825	418	23	2
Total	**141.4**	**88.2**	**380,594**	**31,344**	**323,705**	**14,540**	**1,651**	**117**

Habitat Capacity Maps

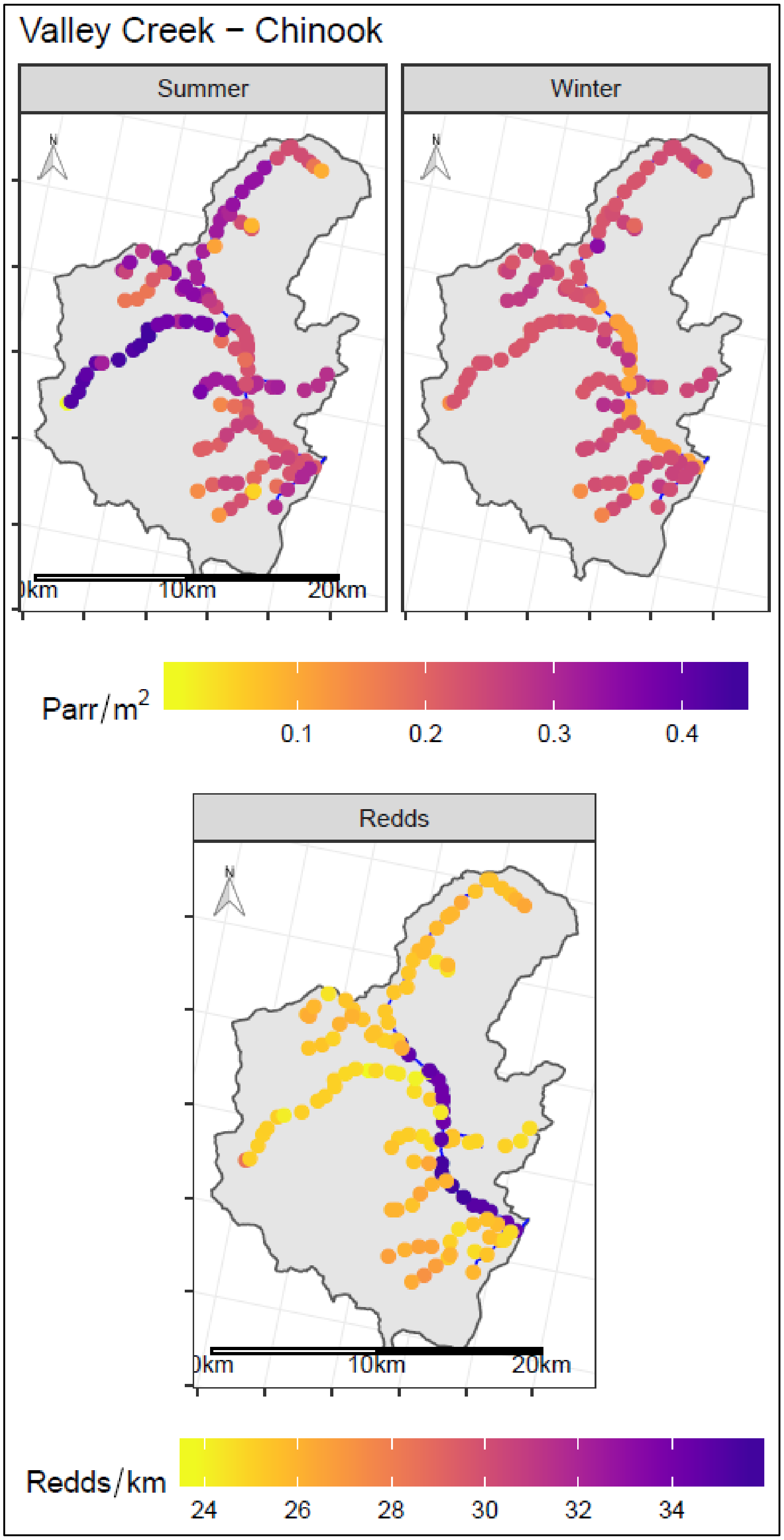
Chinook salmon



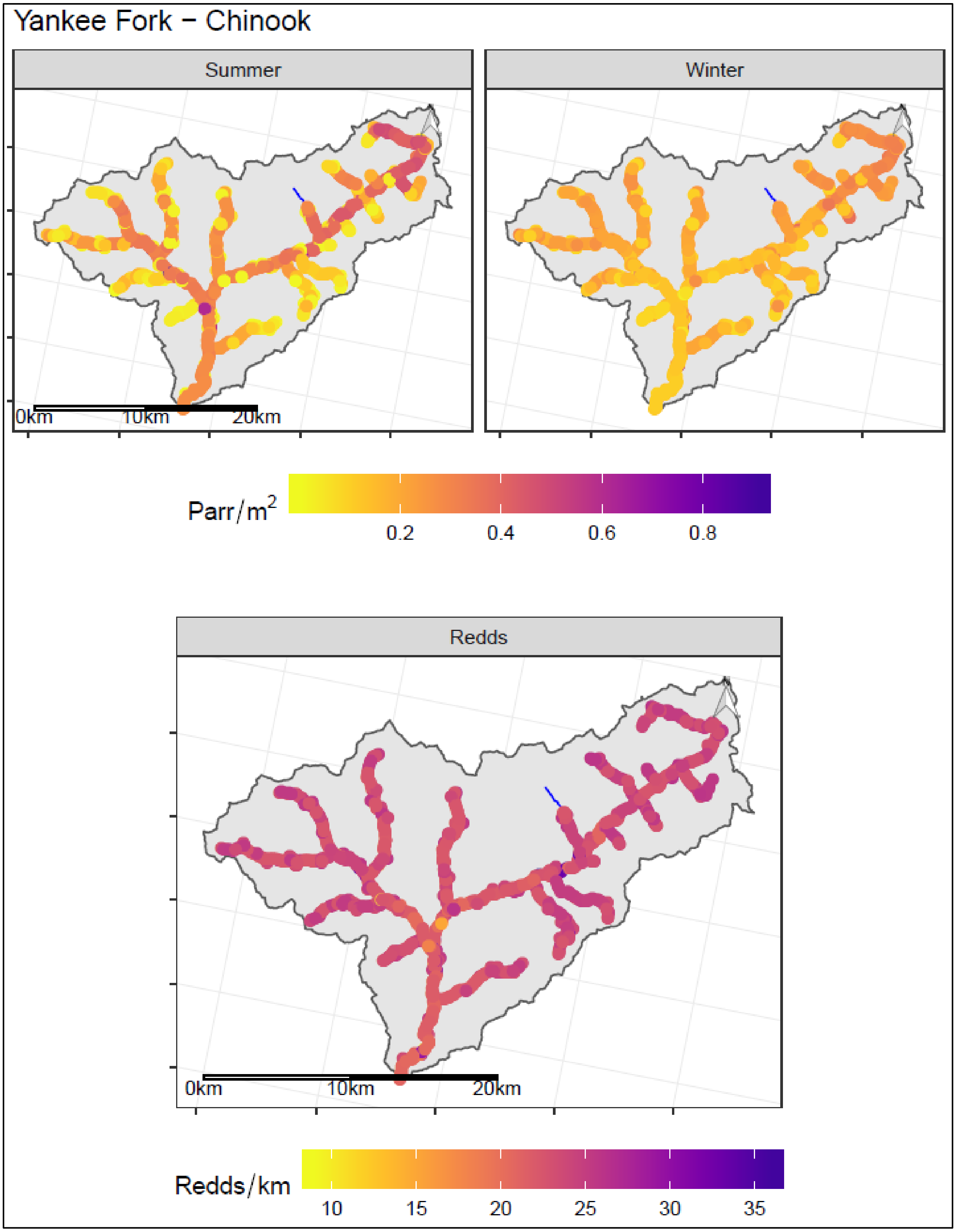
Supplemental Figure B-7. Map showing predictions of Chinook salmon carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in the Upper Salmon River.



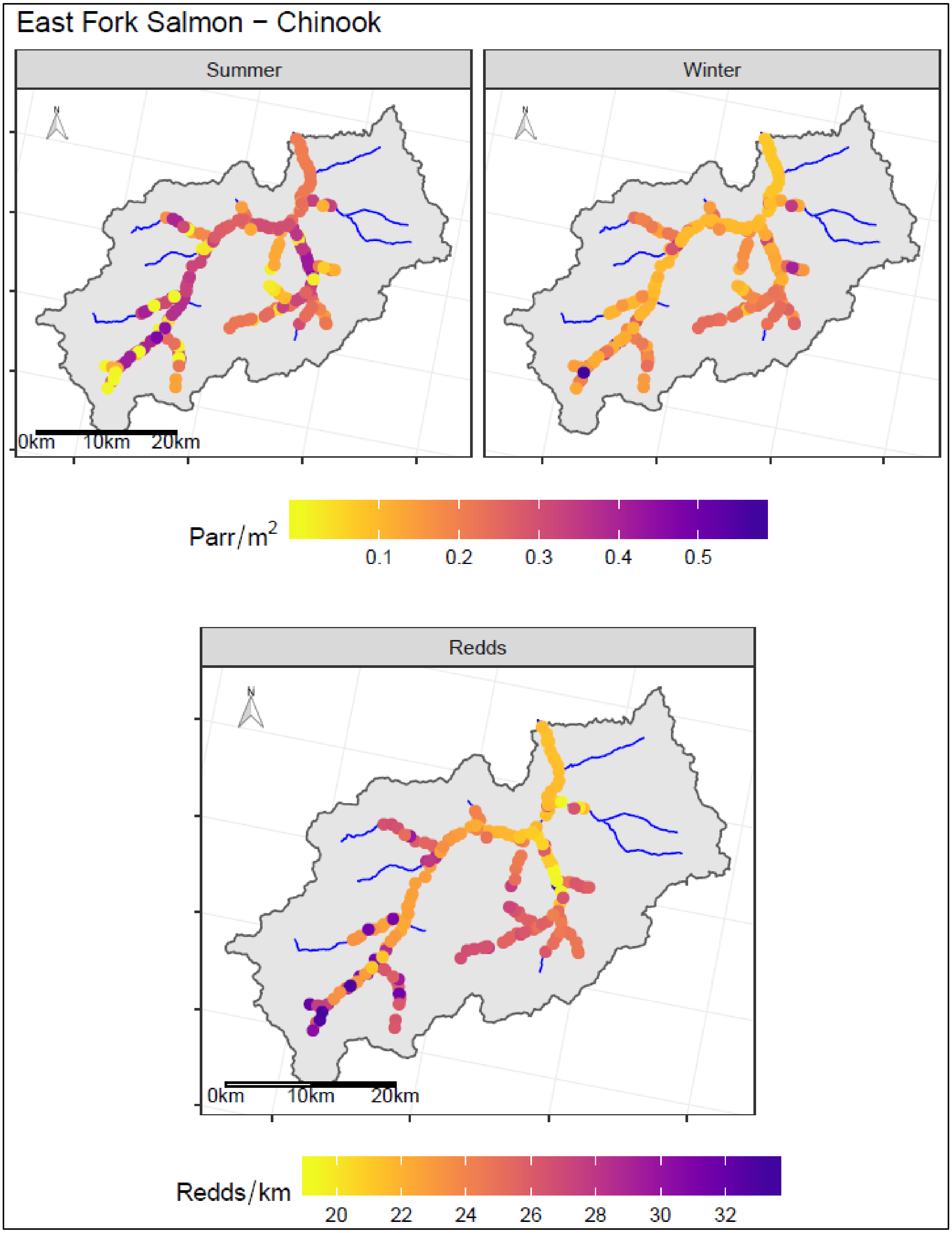
Supplemental Figure B-8. Map showing predictions of Chinook salmon carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in the Upper Salmon River.



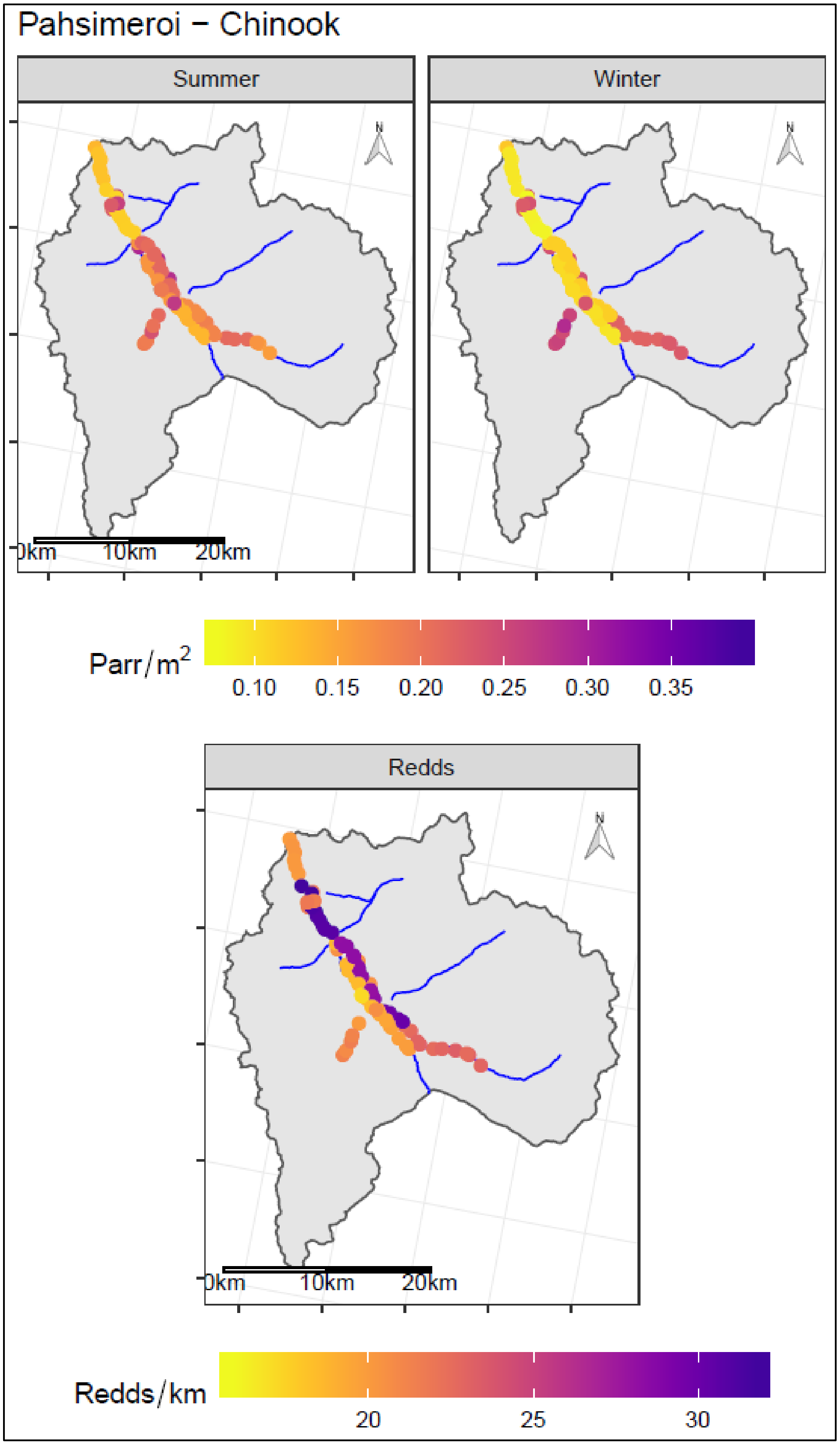
Supplemental Figure B-9. Map showing predictions of Chinook salmon carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in Valley Creek.



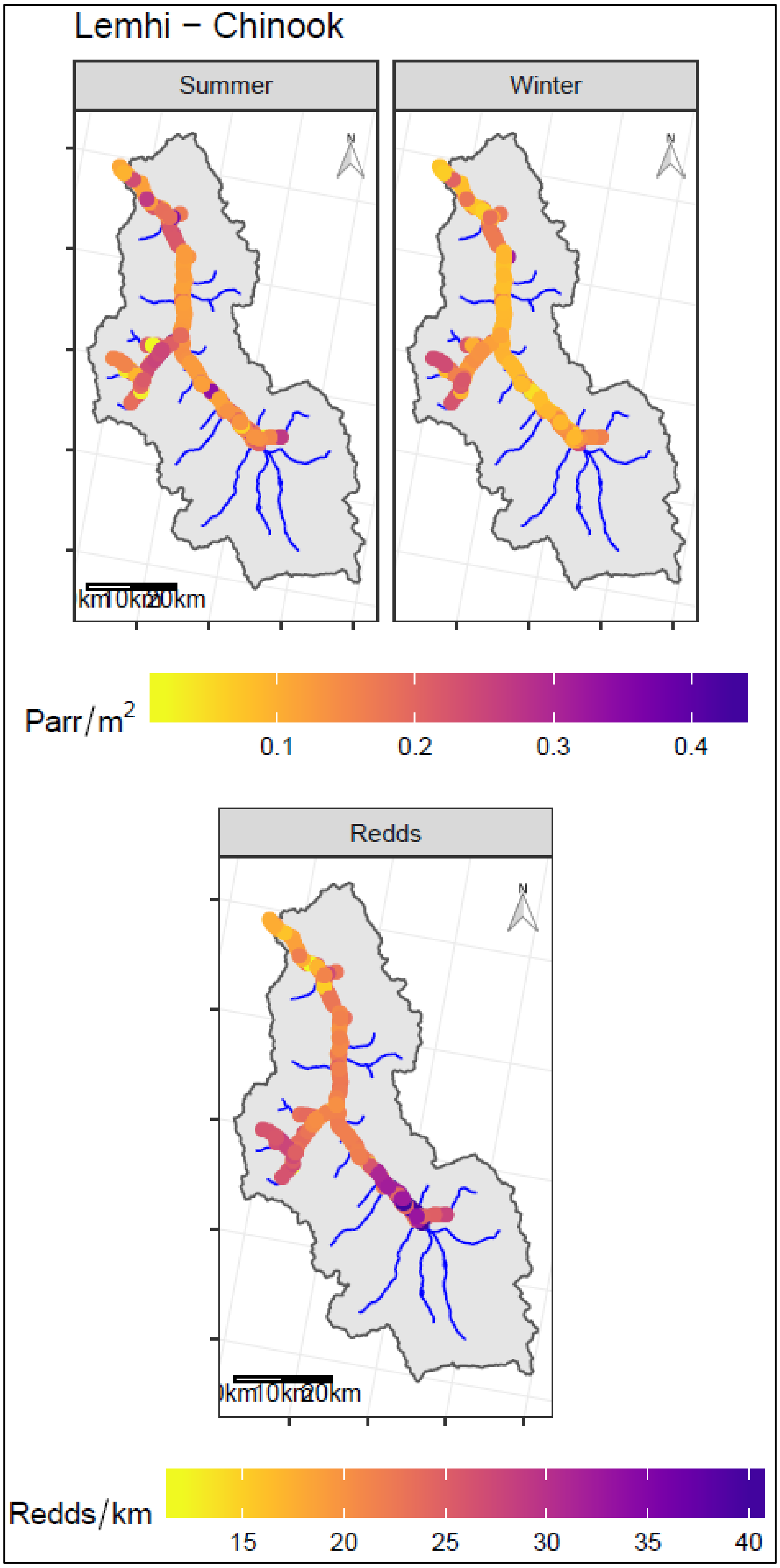
Supplemental Figure B-10. Map showing predictions of Chinook salmon carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in the Yankee Fork Salmon River.



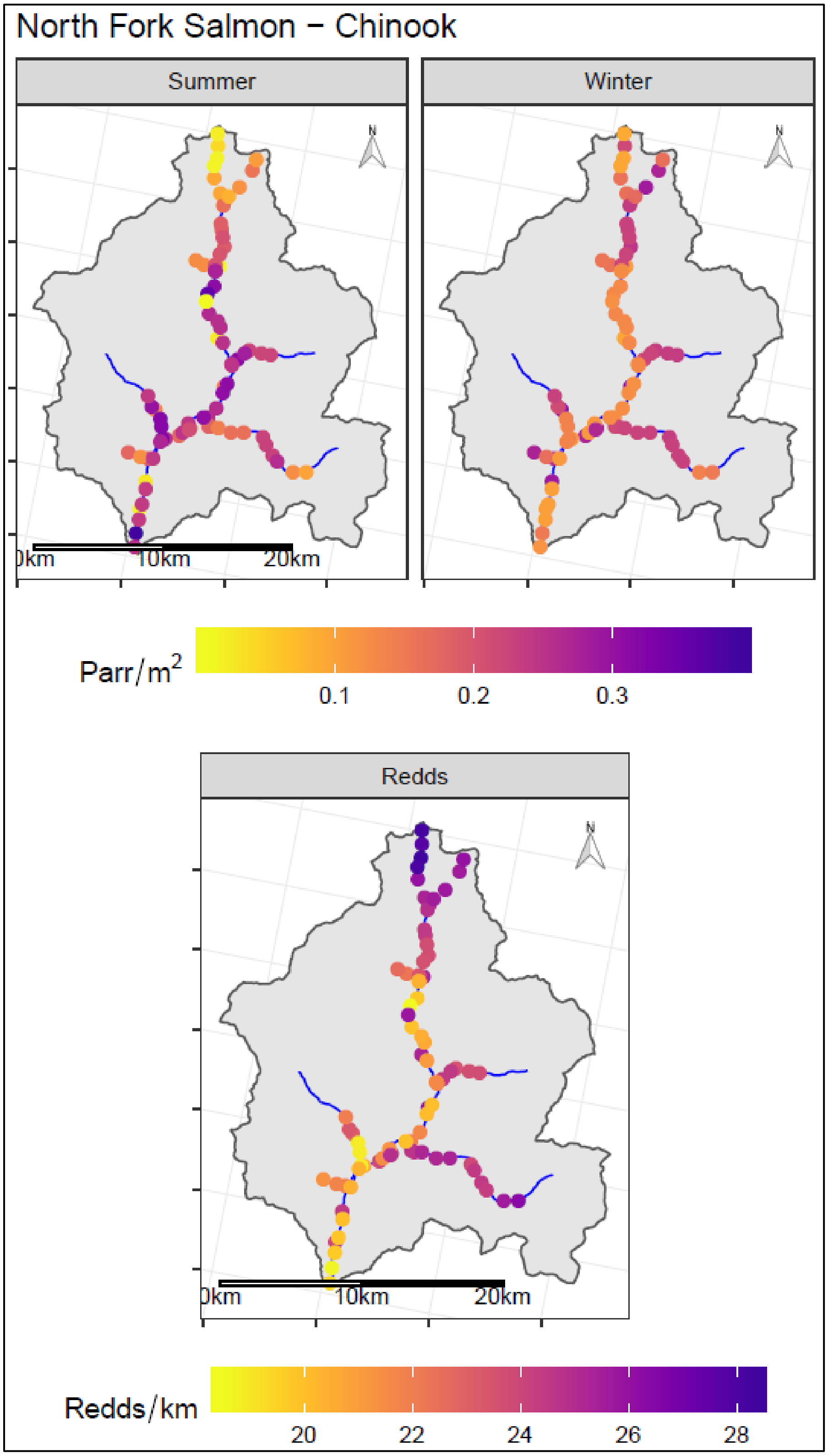
Supplemental Figure B-11. Map showing predictions of Chinook salmon carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in the East Fork Salmon River.



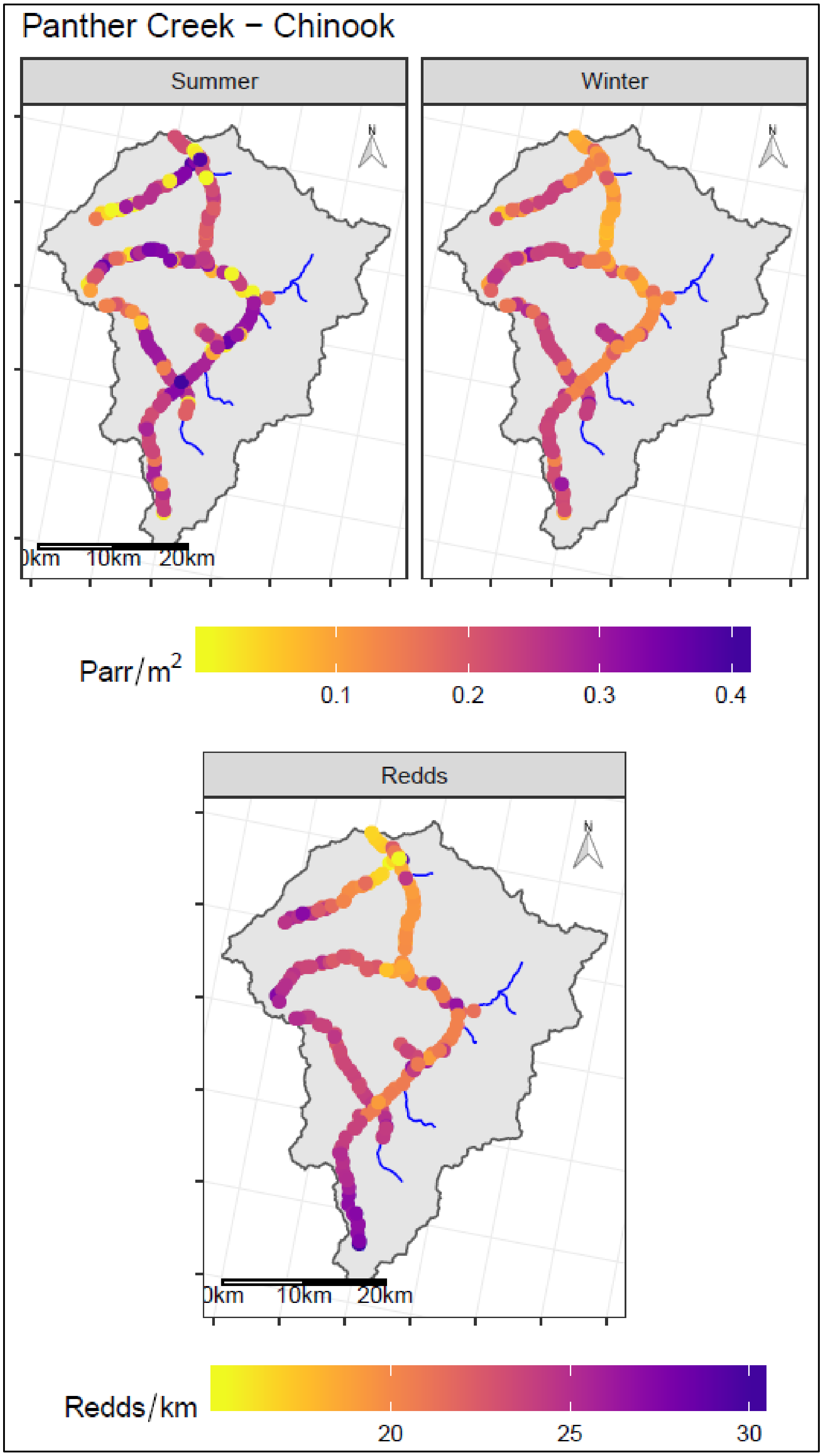
Supplemental Figure B-12. Map showing predictions of Chinook salmon carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in the Pahsimeroi River.



Supplemental Figure B-13. Map showing predictions of Chinook salmon carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in the Lemhi River.

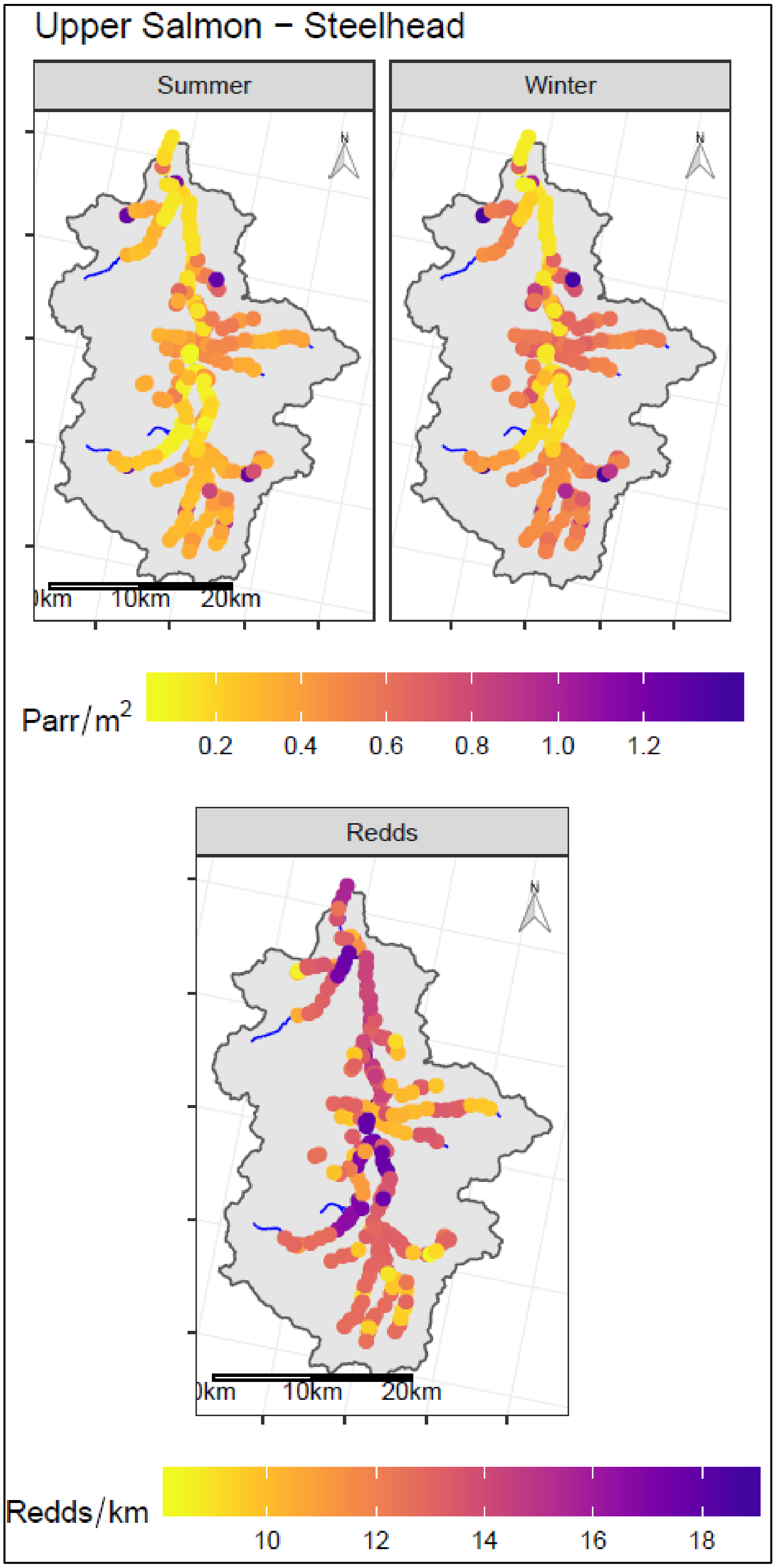


Supplemental Figure B-14. Map showing predictions of Chinook salmon carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in the North Fork Salmon River.

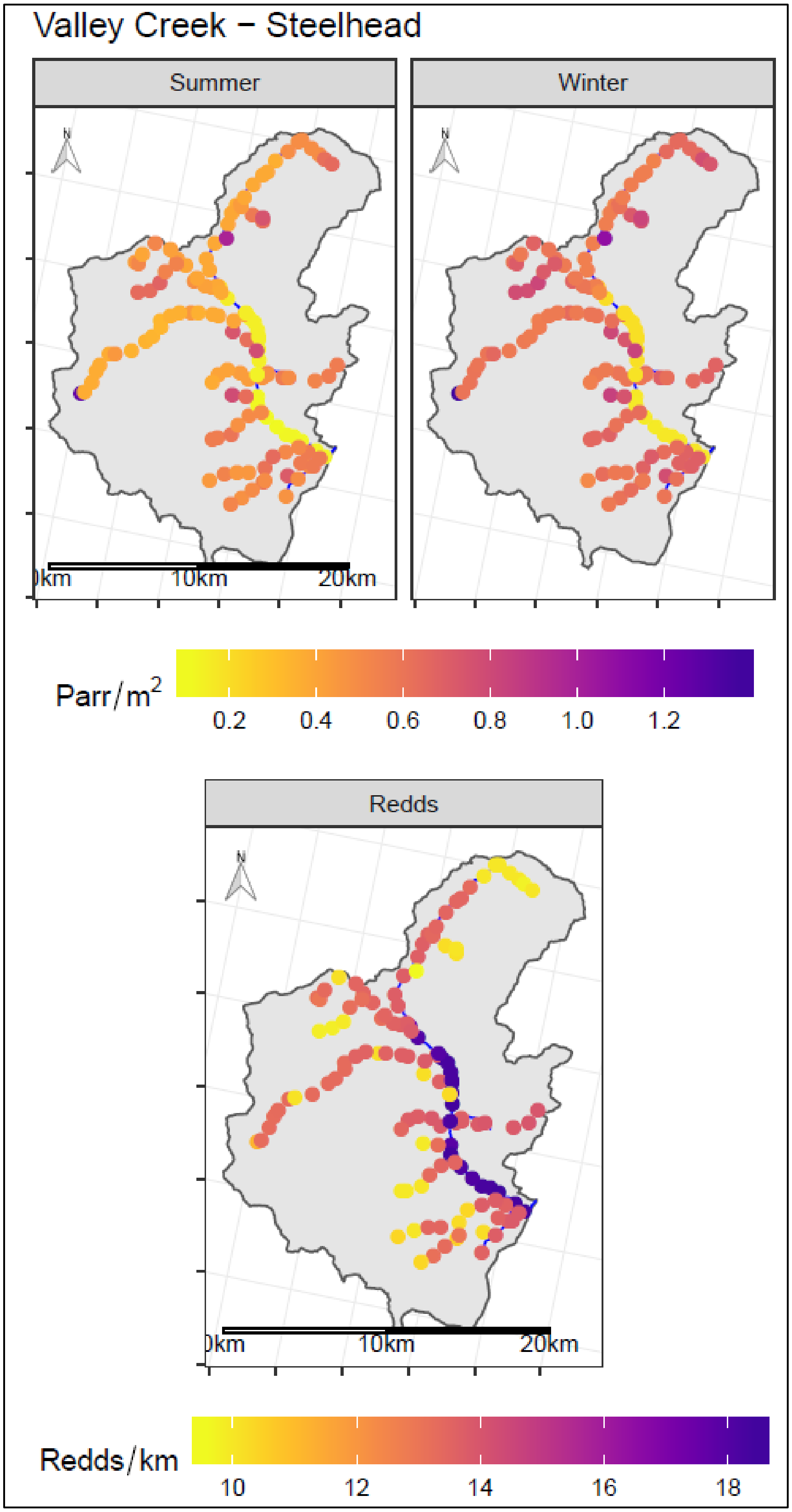


Supplemental Figure B-15. Map showing predictions of Chinook salmon carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in Panther Creek.

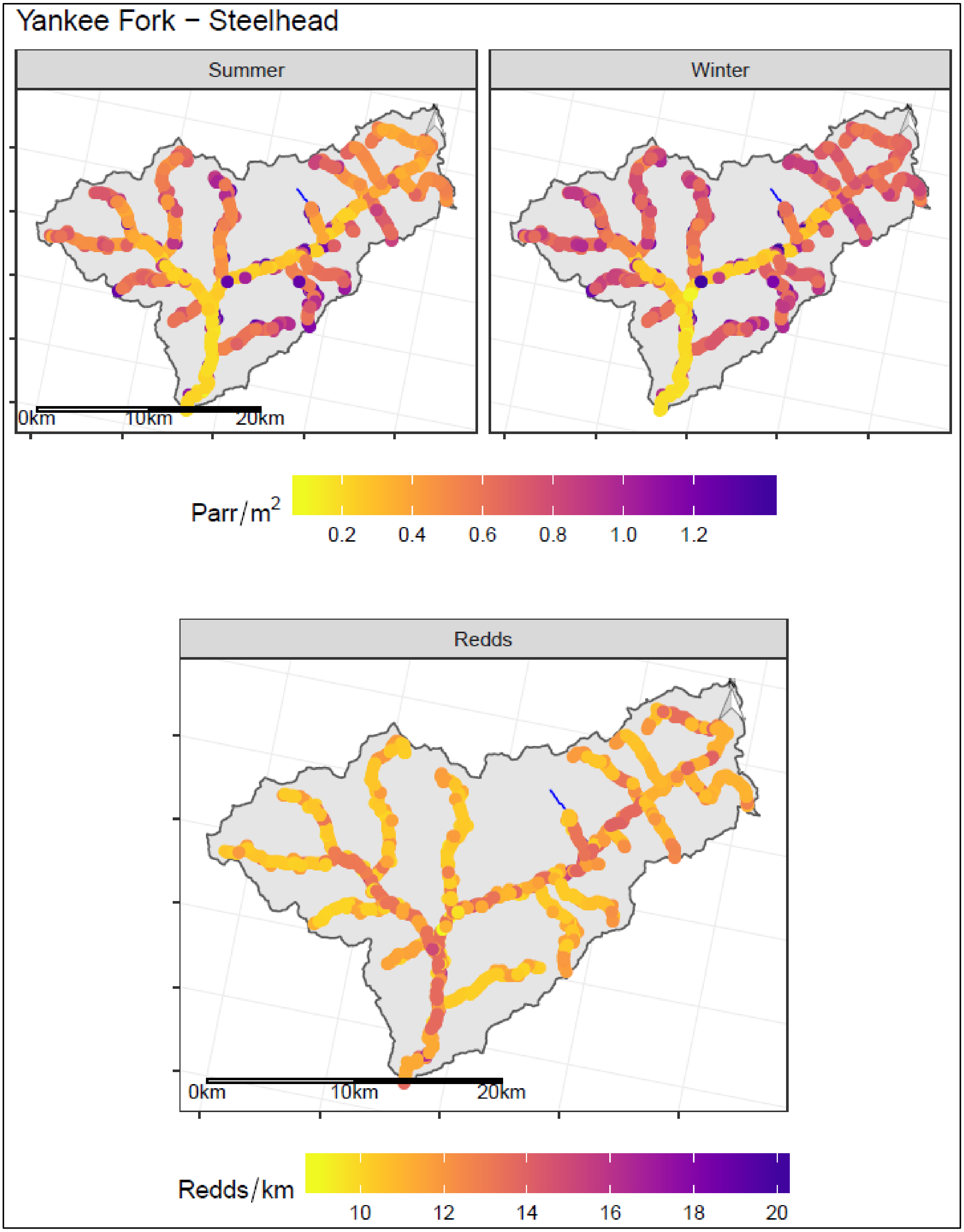
Steelhead



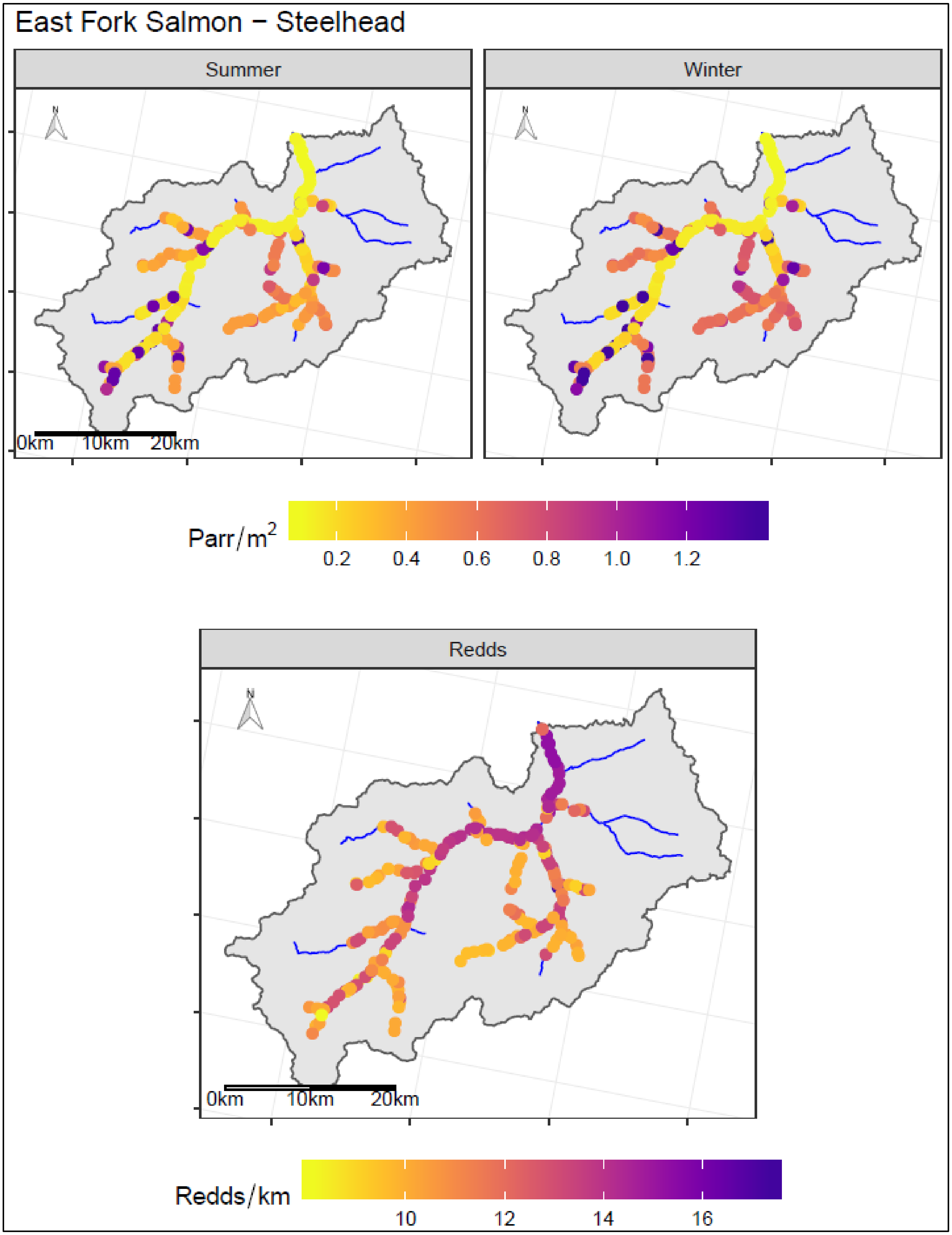
Supplemental Figure B-16. Map showing predictions of steelhead carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in the Upper Salmon River.



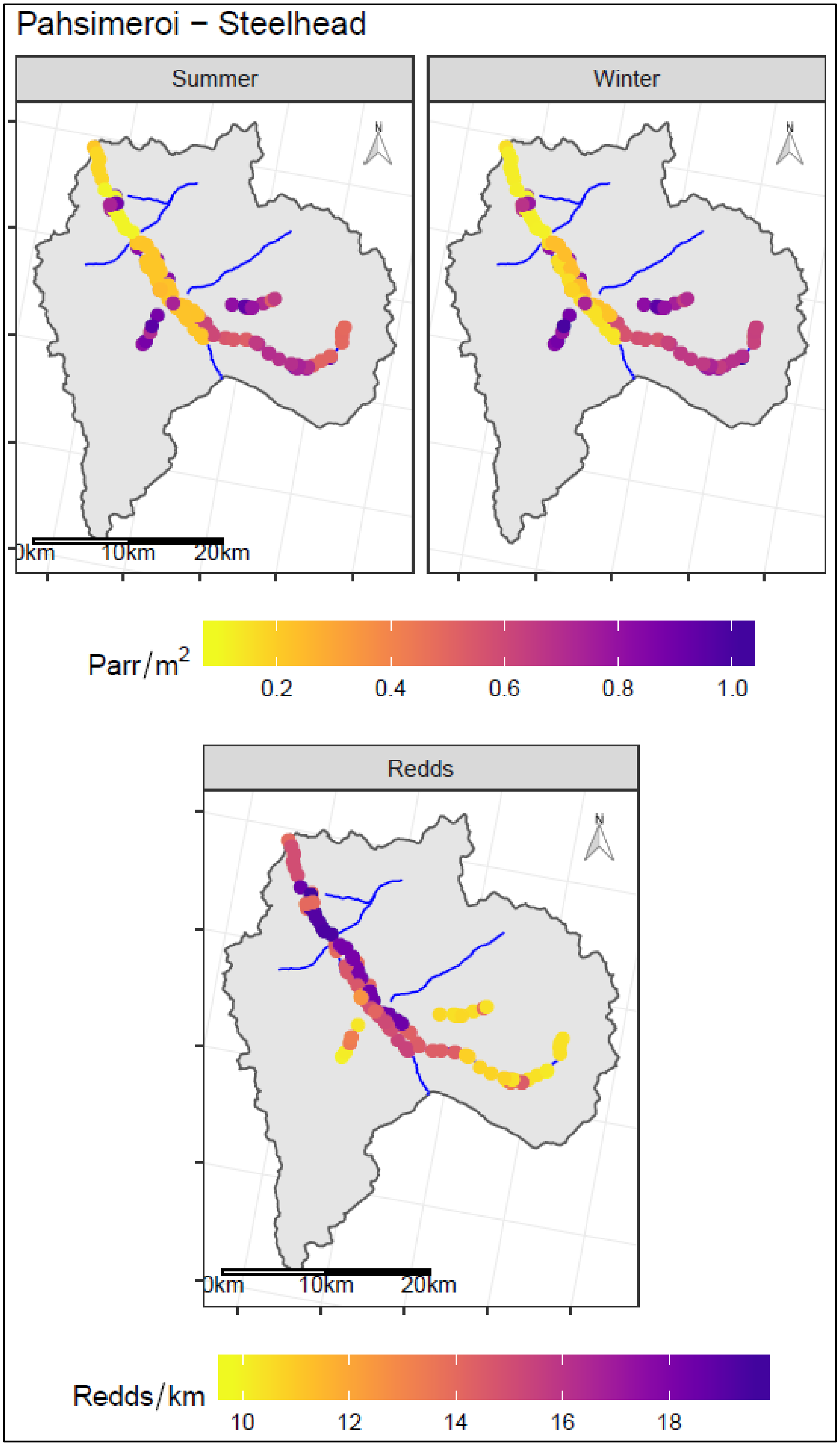
Supplemental Figure B-17. Map showing predictions of steelhead carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in Valley Creek.



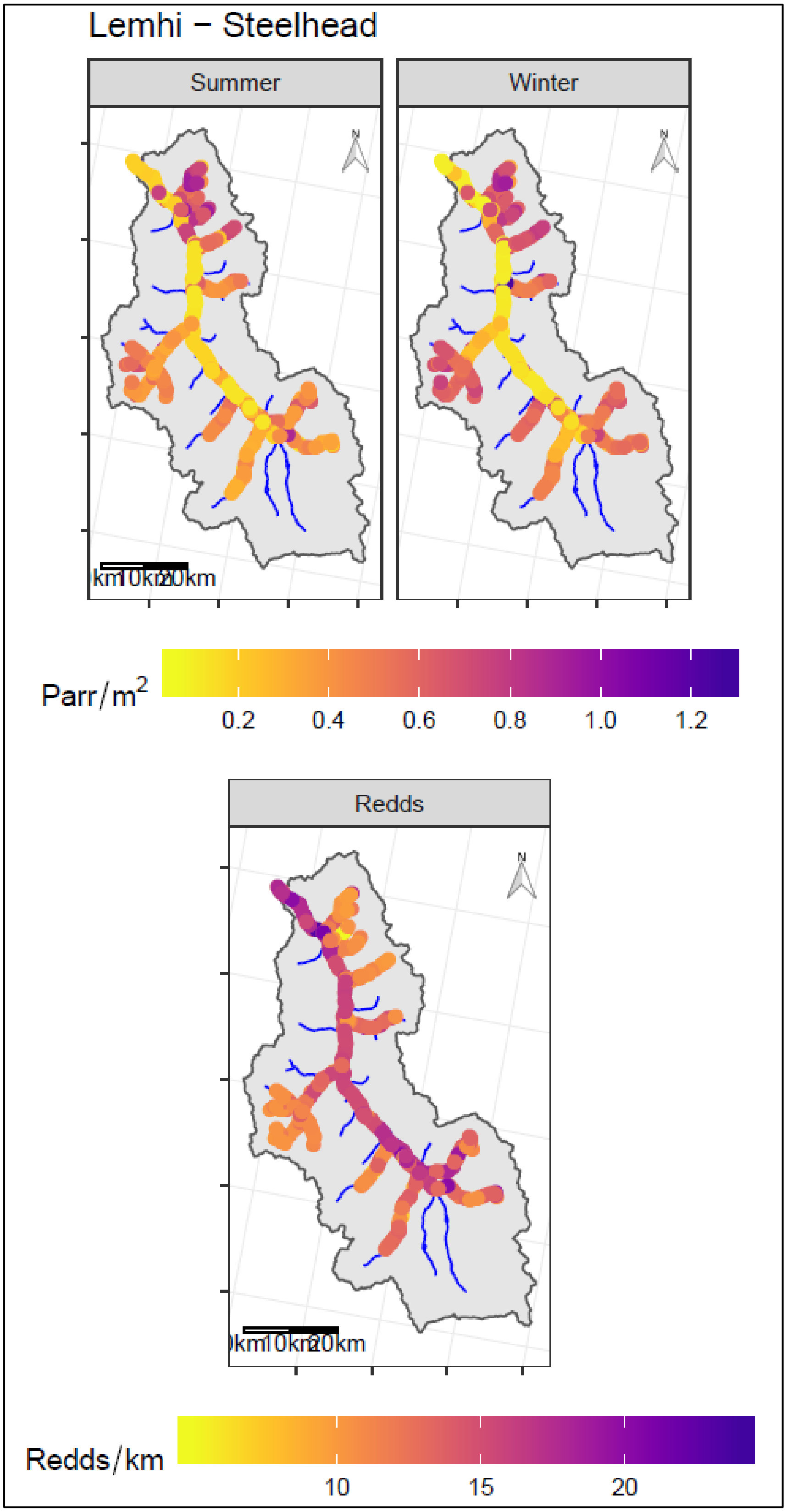
Supplemental Figure B-18. Map showing predictions of steelhead carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in the Yankee Fork Salmon River.



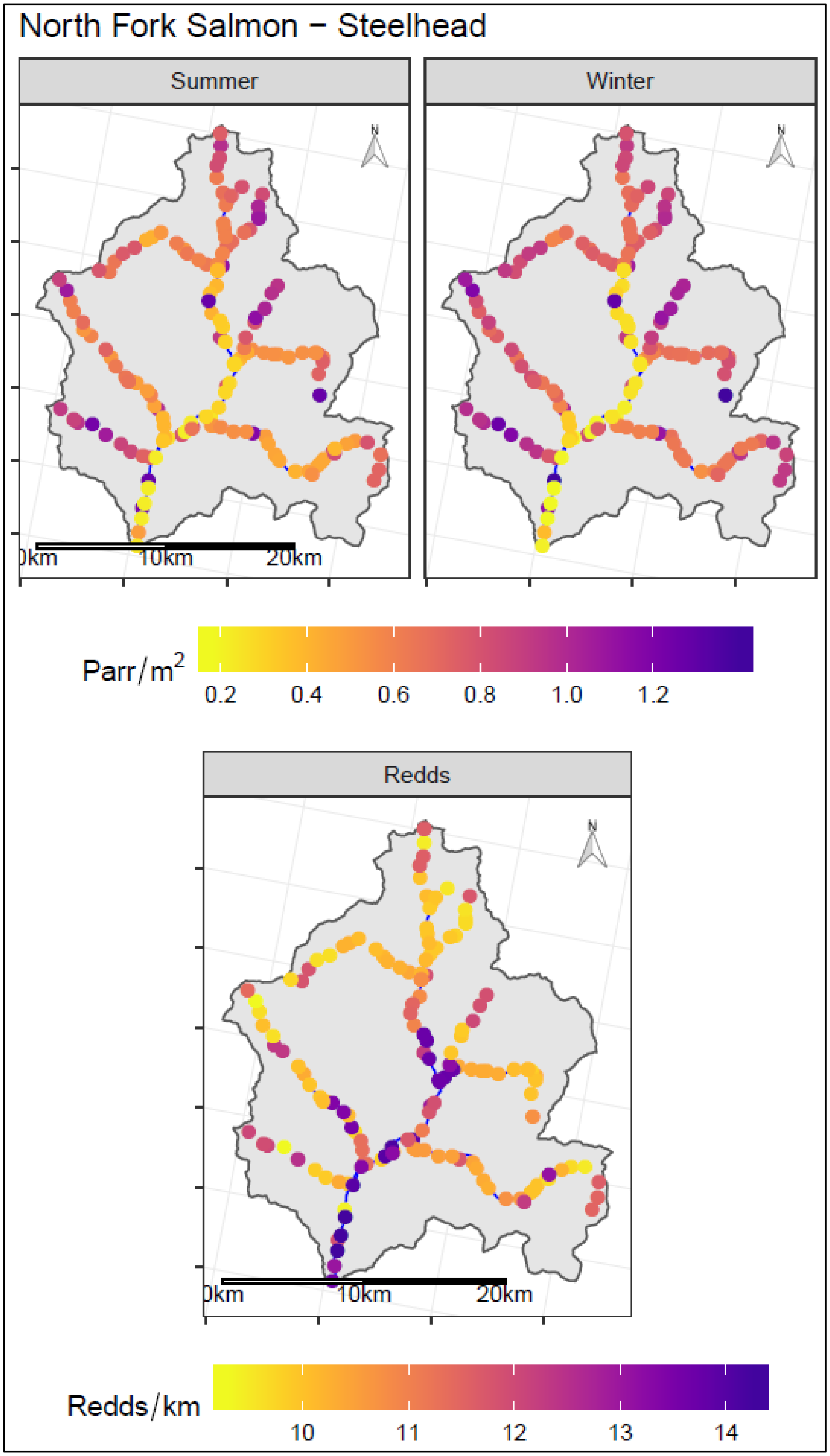
Supplemental Figure B-19. Map showing predictions of steelhead carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in the East Fork Salmon River.



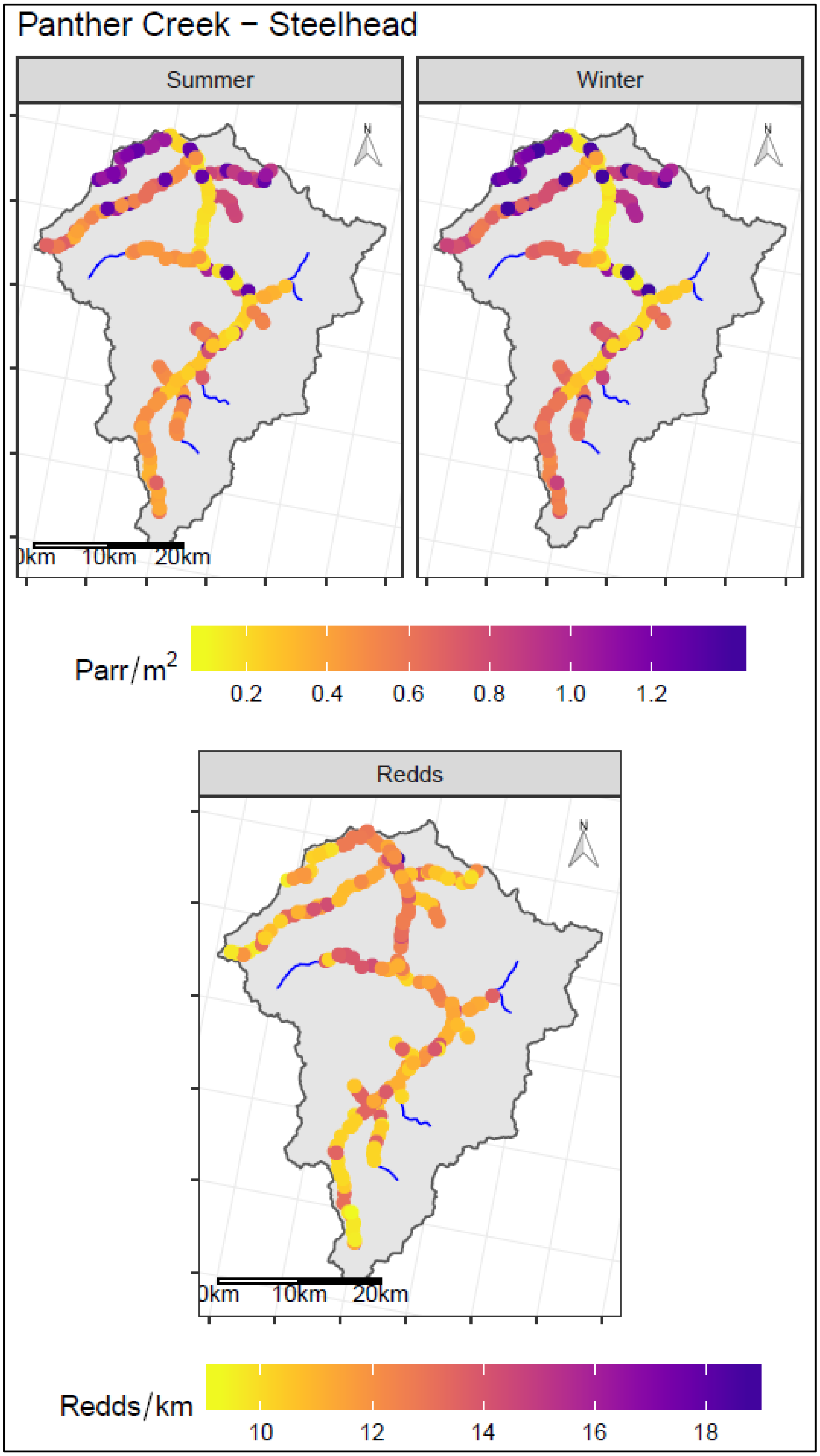
Supplemental Figure B-20. Map showing predictions of steelhead carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in the Pahsimeroi River.



Supplemental Figure B-21. Map showing predictions of steelhead carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in the Lemhi River.



Supplemental Figure B-22. Map showing predictions of steelhead carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in the North Fork Salmon River.



Supplemental Figure B-23. Map showing predictions of steelhead carrying capacity for three life stages (summer juveniles, winter juveniles, redds) at master sample points in Panther Creek.