Appendix A – Temperature Modeling and Climate Change

This section describes a spatially and temporally continuous temperature model and how it was applied to the Upper Salmon, Pahsimeroi, and Lemhi River watersheds. A combination of modeled temperature predictions and life-stage-specific temperature thresholds are used to evaluate whether current water temperatures might limit the ability of spring-summer run Chinook salmon (hereafter Chinook salmon) and summer run steelhead (hereafter steelhead) to use available habitat. A simple warming scenario is then presented that describes potential increases in stream temperature expected to result from climate change to assess whether the implementation of restoration actions to reduce temperatures may be necessary. With that said, caution must be taken because climate change is likely to impose changes in freshwater habitat beyond simple potential increases in water temperature, including (NOAA 2017):

- Winter flooding, which may scour redds;
- Increases in the frequency of wildfire and insect infestation, which may influence bank stability, upland sediment contribution, and riparian corridors;
- Reduction in summer flow; and
- Changes to mainstem migratory corridors.

Life-Stage-Specific Temperature Thresholds

Life-stage-specific temperature criteria were adopted from Carter (2005) in addition to the transition timing of local Chinook salmon and steelhead life stages (USBWP 2004; Personal Communication, Jude Trapani, Bureau of Reclamation; Personal Communication, Mike Edmondson, Idaho Office of Species Conservation; and Personal Communication, Mike Ackerman, Biomark ABS) to identify minimum, maximum, and acute temperature criteria for various life stages of Chinook salmon (

Table A-1) and steelhead (Table A-2). A 7-day Maximum Weekly Maximum Temperature (MWMT) was adopted as the temperature metric, because it is informative for identifying both chronic and acute temperature effects (Carter 2005).

Table A-1. Life stage timing, and minimum, optimum, maximum, and acute temperature (Celsius) thresholds for Chinook salmon, adopted from Carter (2005). All temperatures are expressed as the 7-day Maximum Weekly Maximum Temperature (MWMT).

Life Stage	Timing	Minimum	Optimum	Maximum	Acute
Adult Holding	4/15 - 6/1	3.3	7.2-14.5	18	20
Spawning	8/10 - 9/30	3.3	7.2-14.5	18	20
Incubation	9/1 - 4/1	4	5-11	14	17.5
Emergence	3/1 - 4/1	2	6-10	16.7	17.5
Summer Parr	6/10 - 10/15	4.5	10-16	20	22
Winter Presmolt	11/14 - 3/1	4.5	10-16	20	22
Spring Smolt	3/1 - 6/9	4.5	10-16	20	22

Table A-2. Life stage timing, and minimum, optimum, maximum, and acute temperature (Celsius) thresholds for steelhead, adopted from Carter (2005). All temperatures are expressed as the 7-day Maximum Weekly Maximum Temperature (MWMT).

Life Stage	Timing	Minimum	Optimum	Maximum	Acute
Adult Holding	10/1 – 3/31	NA	NA	18	20
Spawning	4/1 – 5/31	NA	3.9-12.8	18	20
Incubation	4/1 – 7/1	2	5-10	12	14
Emergence	6/15 – 7/15	2	5-10	12	14
Summer Parr	6/10 – 10/15	4.5	10-18	19	22
Winter Presmolt	11/14 – 3/1	4.5	10-18	19	22
Spring Smolt	3/1 – 6/9	4.5	10-18	19	22

Temperature Model

A temperature model described by McNyset et al. (2015) was used to define existing temperature conditions for the Upper Salmon, Pahsimeroi, and Lemhi River watersheds. The model uses land surface temperature (LST) data obtained from the U.S. National Aeronautics and Space Administration's (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) satellite sensor. The LST data are available daily at a resolution of 1 square kilometer and were summarized over an 8-day NASA "week". McNyset et al. (2015) used LST data as a covariate in a linear model to predict stream water temperatures in a spatially and temporally continuous manner.

Summarization of temperature data was done by Chinook salmon and steelhead life stages for each year and basin for which modeled temperature data were available. The Supplementary Figures to Appendix A contains a series of maps showing the percentage of time for each basin and year that water temperatures were below, within, or above a given temperature threshold (Carter 2005) for seven Chinook salmon and steelhead life stages (winter presmolt, summer parr, spring smolt, spawning, incubation, emergence, adult holding). For the Lemhi River, modeled temperature data were available for 2011 to 2015. For the Pahsimeroi River, modeled temperature data were available for 2011 and 2013. For the Upper Salmon River, modeled temperature data were available for 2011 and 2013.

The main document provides a summary by averaging temperature data across years for which complete modeled data were available and a simple climate change scenario by adding 3° C, a median value based on a series of climate change scenarios (Kyle and Brabets 2001). Because only 2 years of modeled temperature data are available for the Pahsimeroi and Upper Salmon River watersheds, only data from 2013 (and a +3° C scenario) are presented.

Literature Cited

Carter, K. 2005. The effects of temperature on steelhead trout, Coho salmon, and Chinook salmon biology and function by life stage. Implications for Klamath Basin TMDLs. California Regional Water Quality Control Board. North Coast Region. 26pp.

Kyle, R.E. and T.P. Brabets. 2001. Water temperature of streams in the Cook Inlet Basin, Alaska, and Implications of Climate Change. Water-Resources Investigations Report 01-4109. U.S. Department of the Interior. U.S. Geological Survey. 32pp.

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.

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.

USBWP (Upper Salmon Basin Watershed Project). 2004. Upper Salmon River recommended instream work windows and fish periodicity. 29pp.

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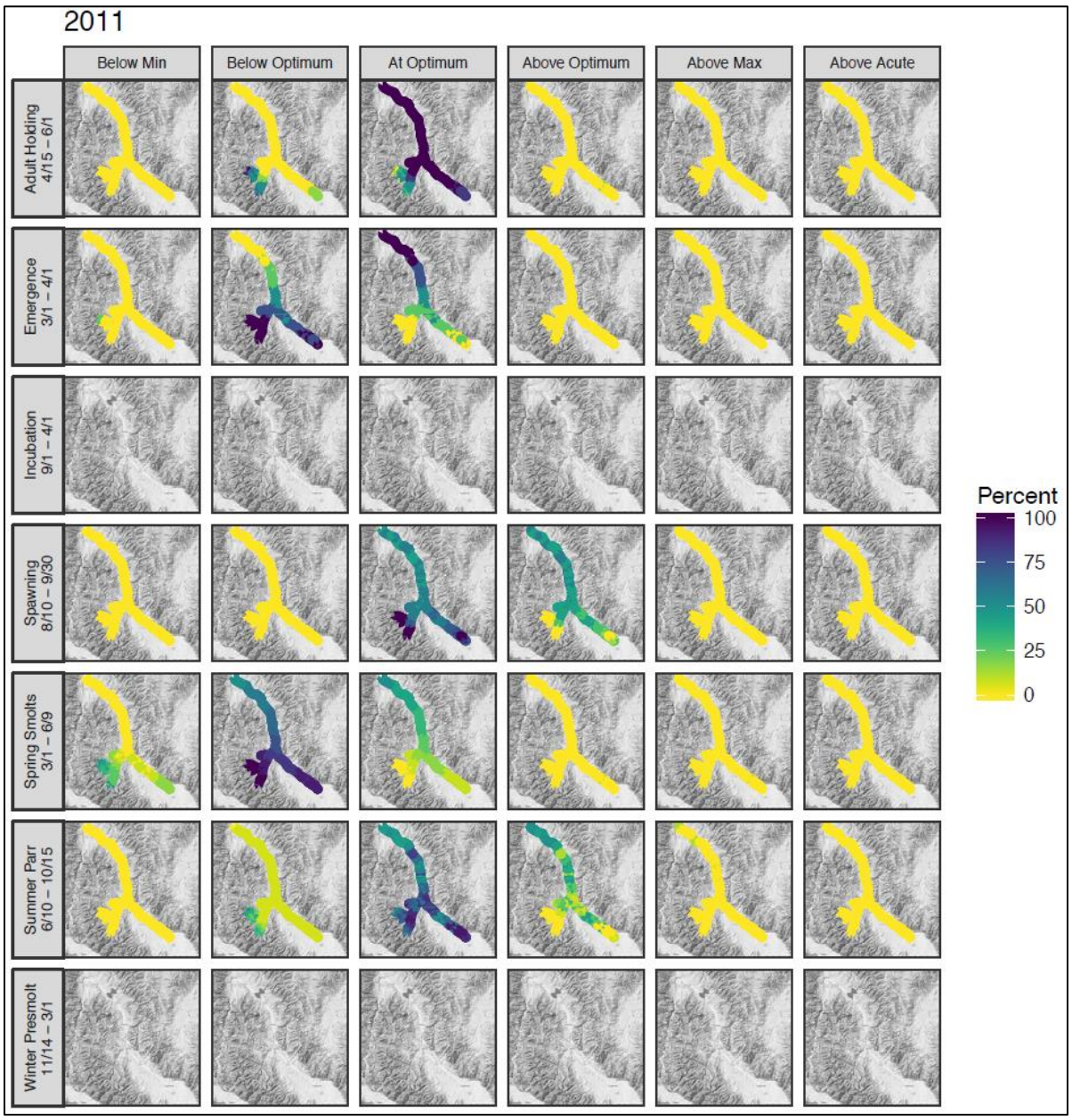
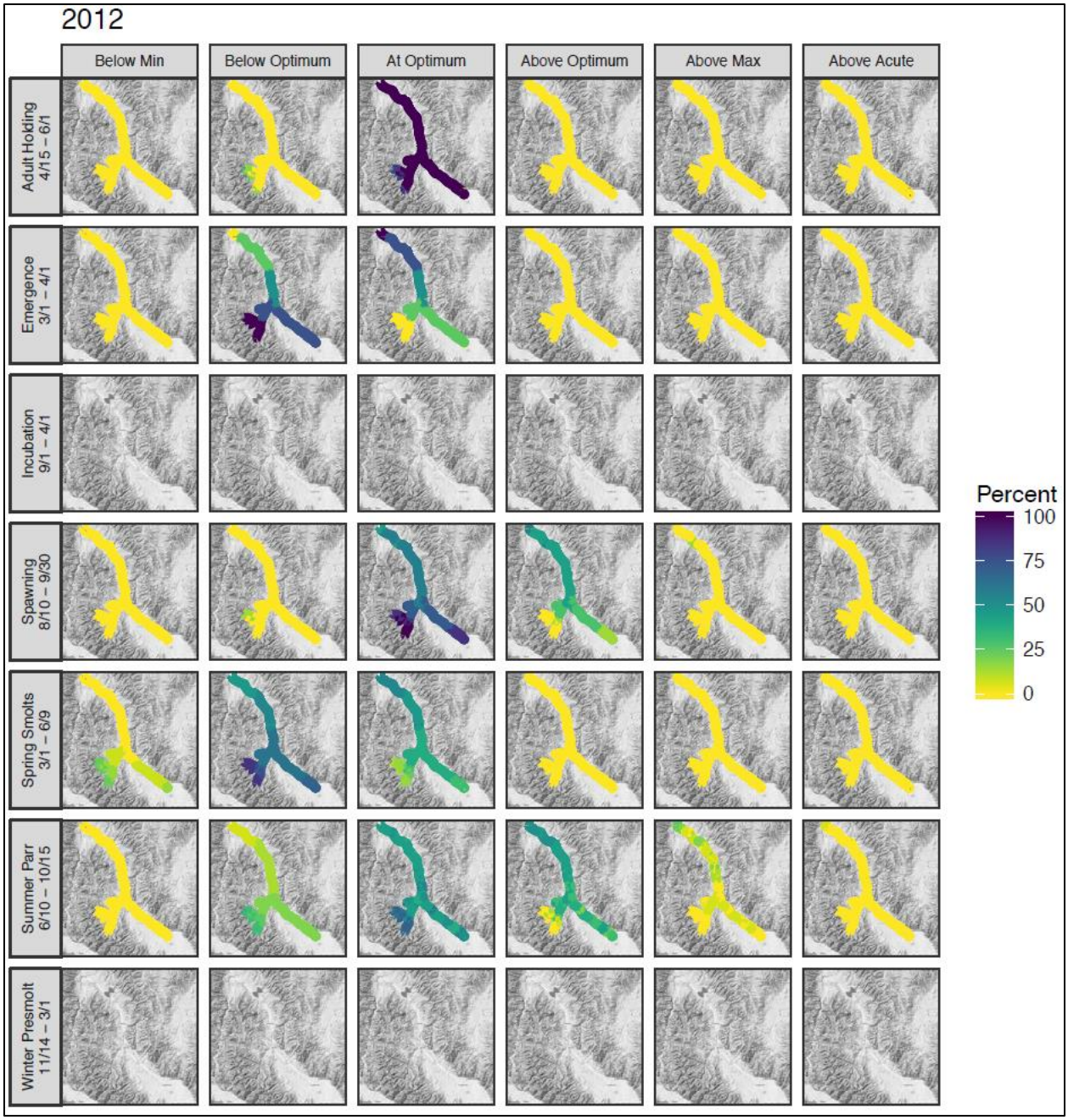
Supplementary Figures to Appendix A – Chinook Salmon Temperature Criteria and Contemporary Water Temperature Maps

Chinook salmon

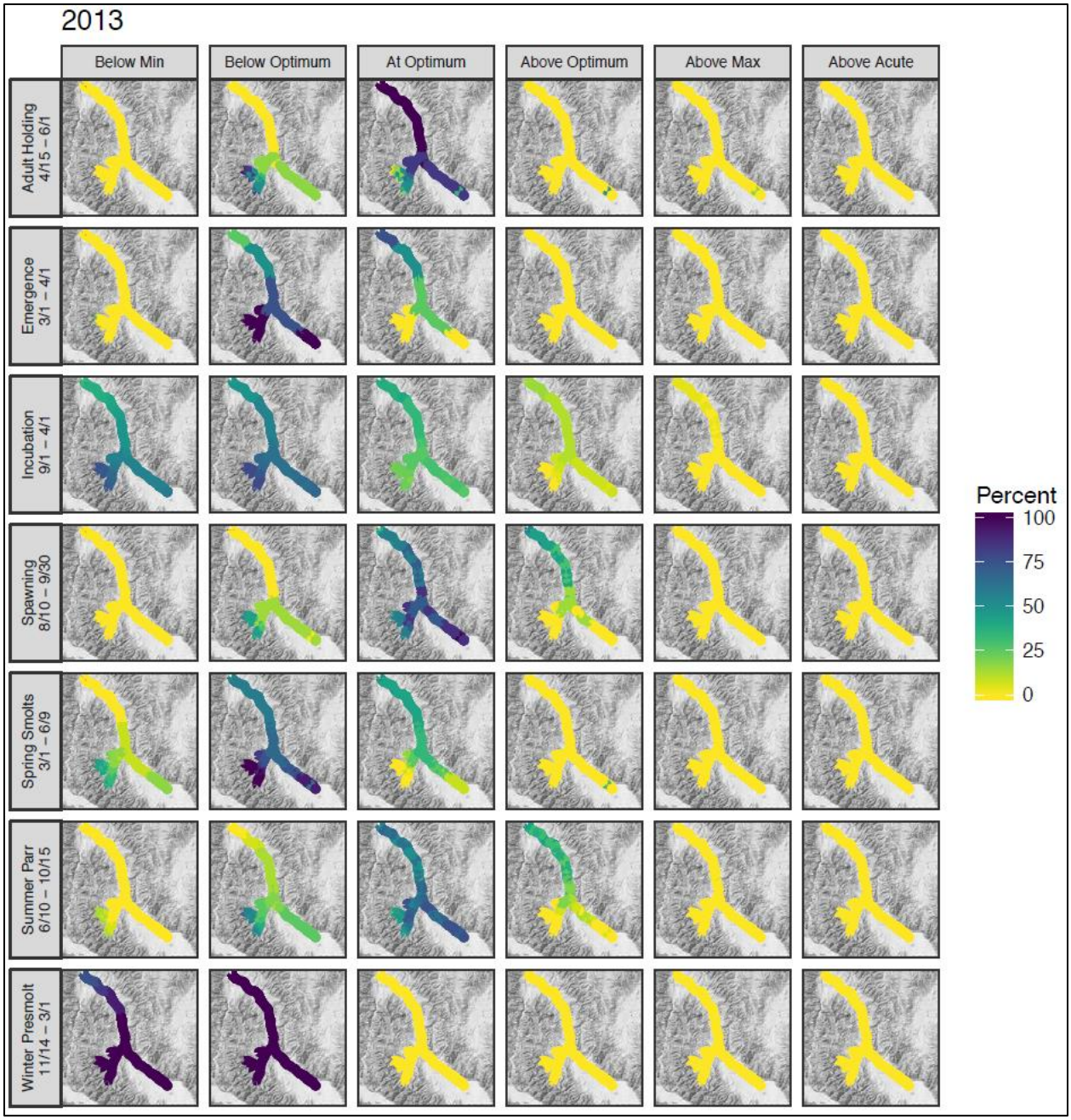
Lemhi River



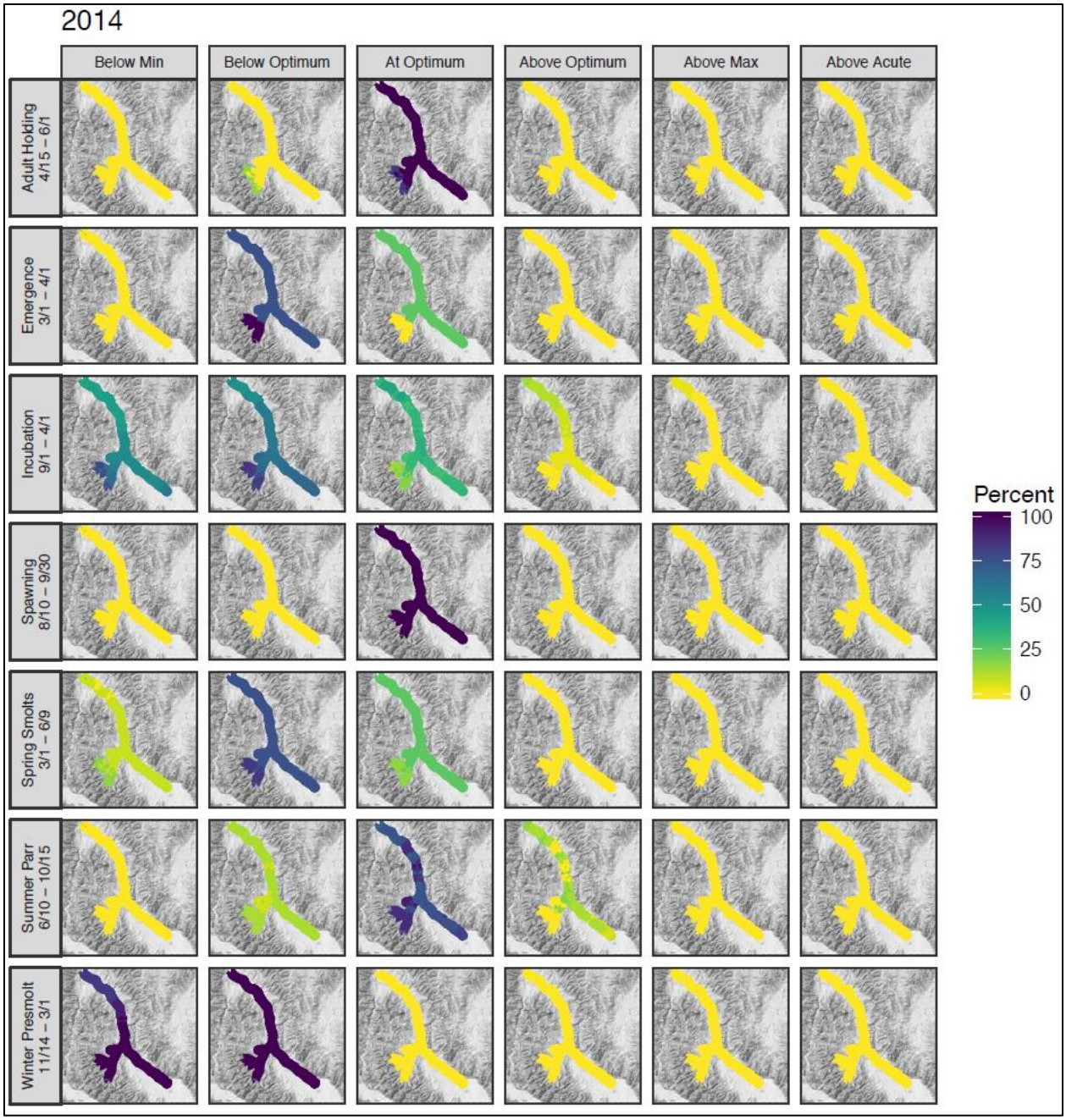
Supplemental Figure A-1. The percentage of time that 2011 water temperatures in the Lemhi River were below, within, or above a given temperature threshold (Carter 2005) for seven Chinook salmon life stages. For facets with no data, modeled temperature data were unattainable for that timespan.



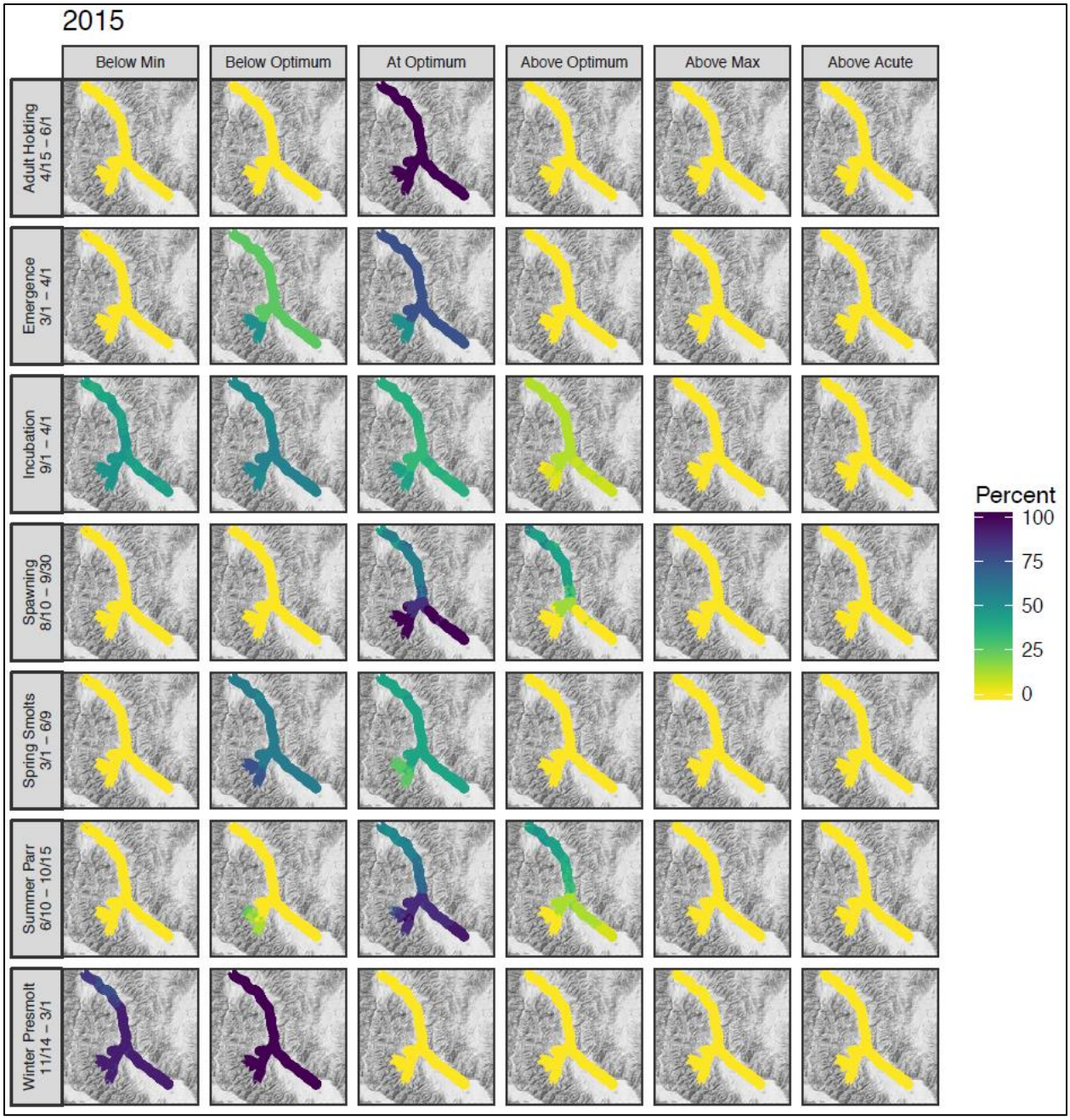
Supplemental Figure A-2. The percentage of time that 2012 water temperatures in the Lemhi River were below, within, or above a given temperature threshold (Carter 2005) for seven Chinook salmon life stages. For facets with no data, modeled temperature data were unattainable for that timespan.



Supplemental Figure A-3. The percentage of time that 2013 water temperatures in the Lemhi River were below, within, or above a given temperature threshold (Carter 2005) for seven Chinook salmon life stages.

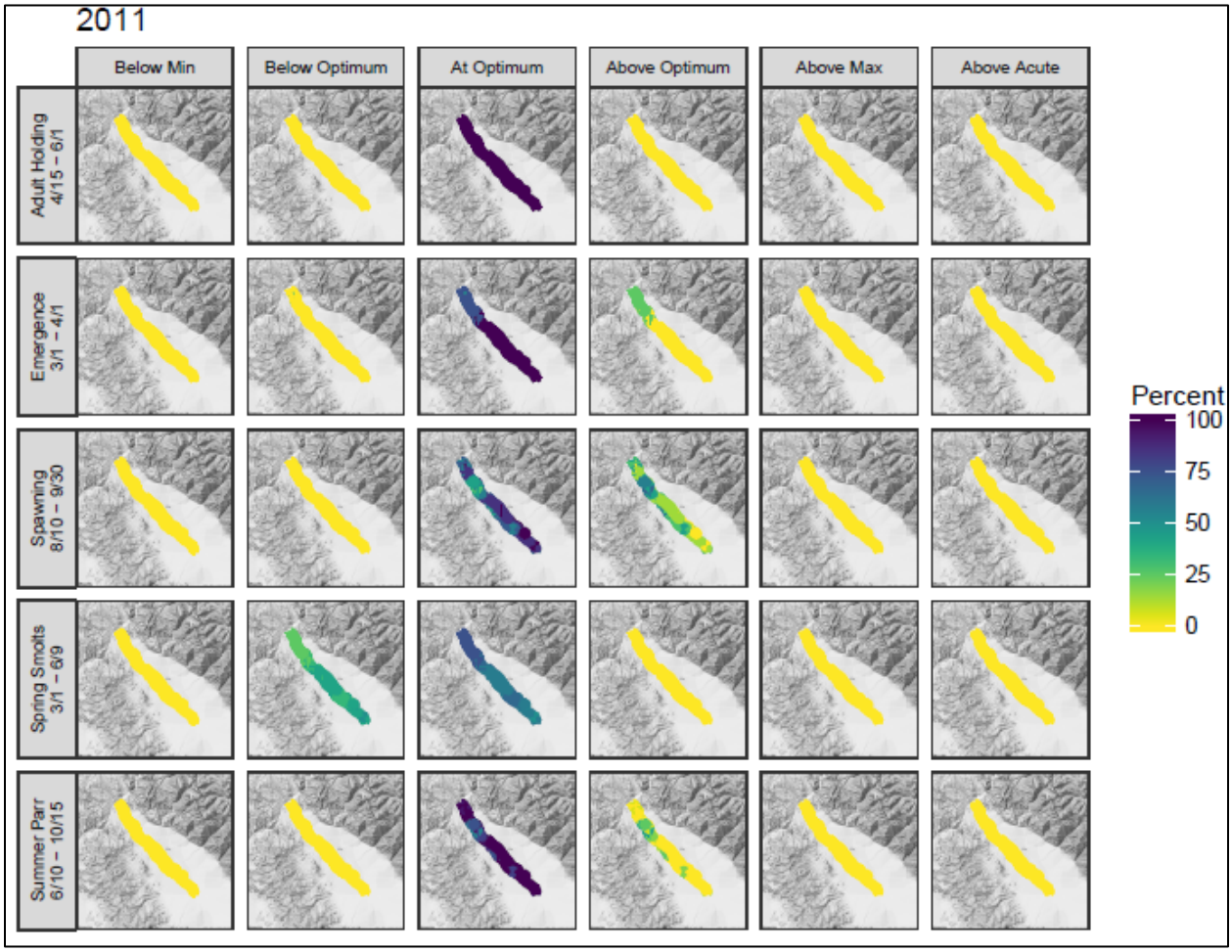


Supplemental Figure A-4. The percentage of time that 2014 water temperatures in the Lemhi River were below, within, or above a given temperature threshold (Carter 2005) for seven Chinook salmon life stages.

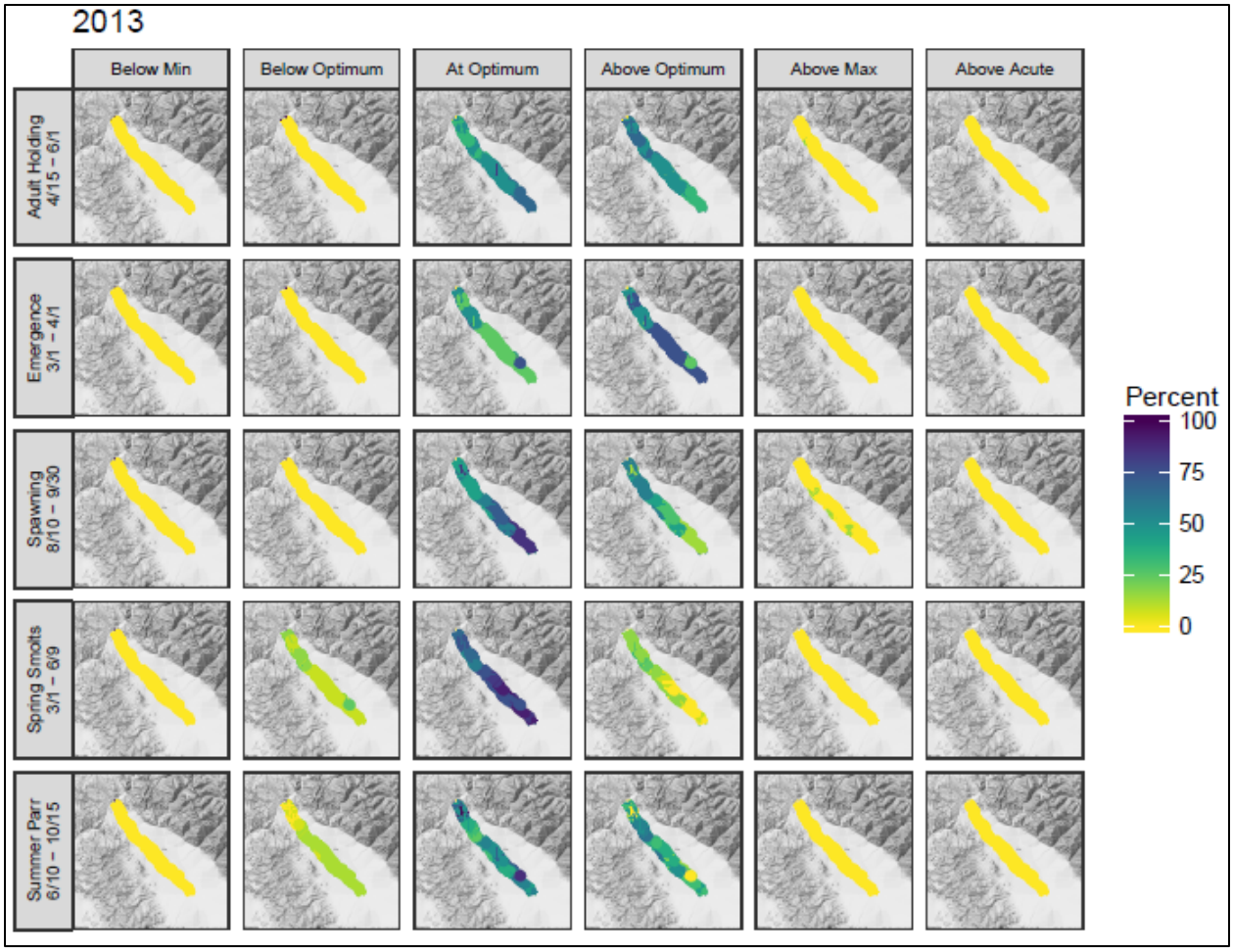


Supplemental Figure A-5. The percentage of time that 2015 water temperatures in the Lemhi River were below, within, or above a given temperature threshold (Carter 2005) for seven Chinook salmon life stages.

Pahsimeroi River

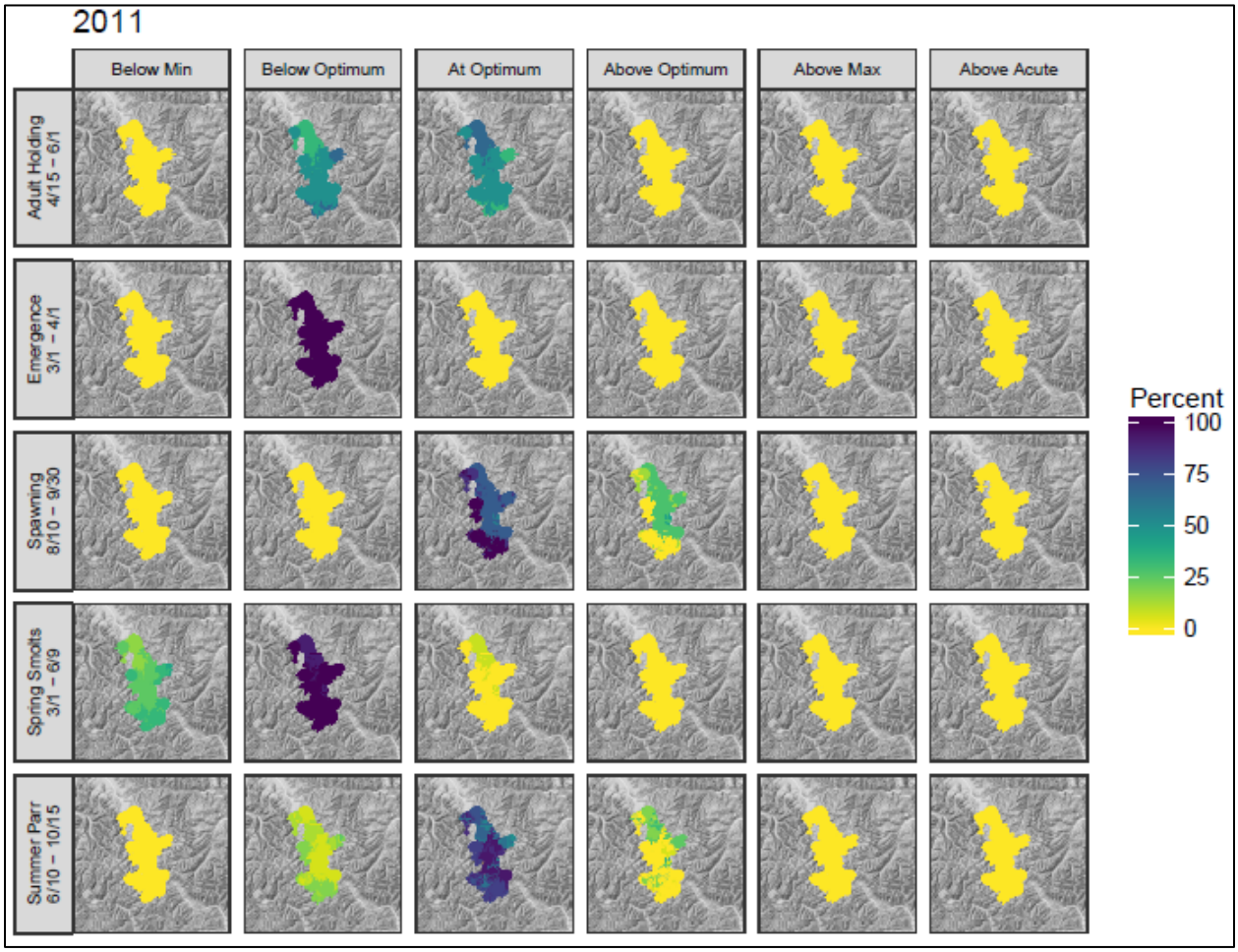


Supplemental Figure A-6. The percentage of time that 2011 water temperatures in the Pahsimeroi River were below, within, or above a given temperature threshold (Carter 2005) for five Chinook salmon life stages. Modeled temperature data for the winter time periods (incubation and winter presmolt life stages) were unattainable.

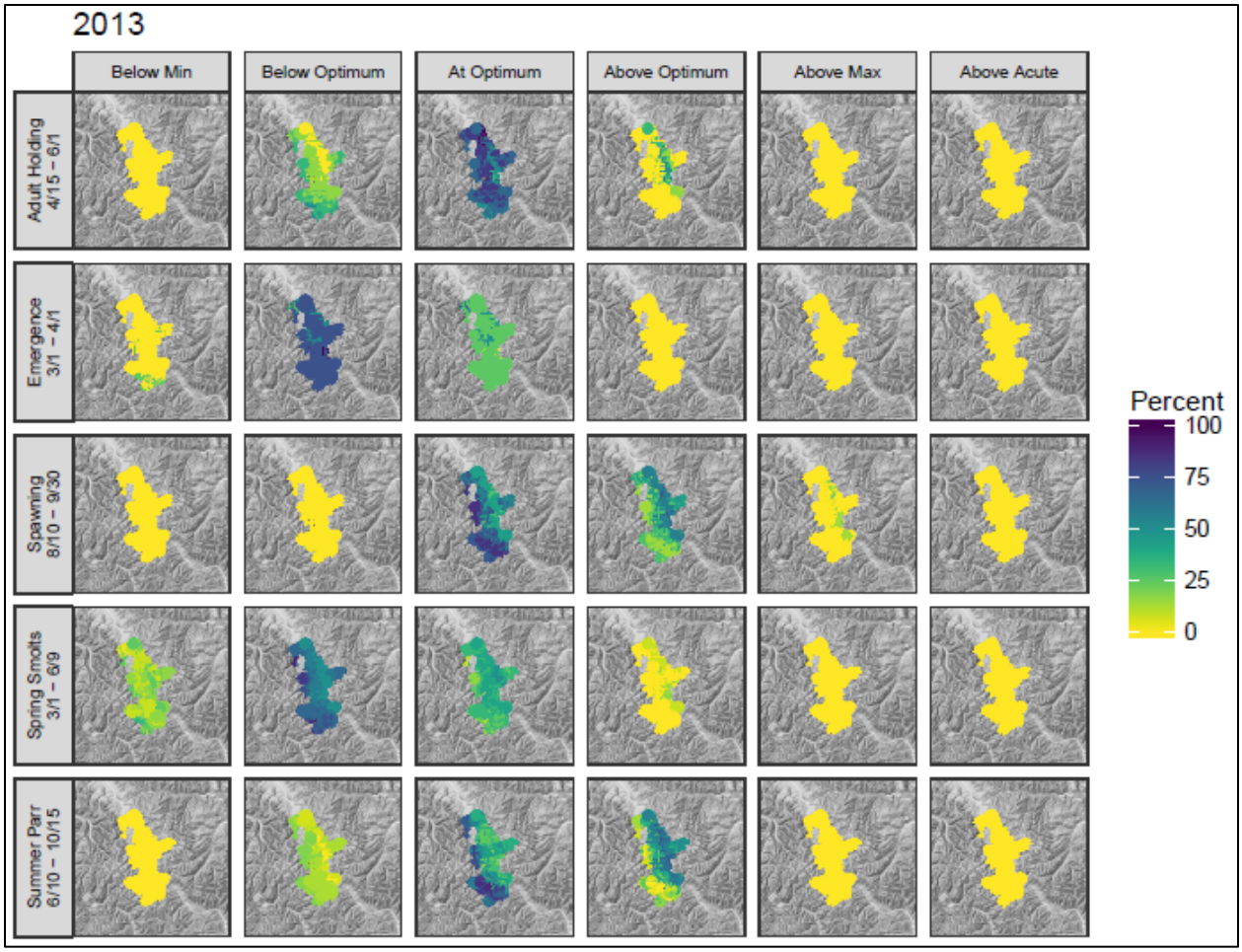


Supplemental Figure A-7. The percentage of time that 2013 water temperatures in the Pahsimeroi River were below, within, or above a given temperature threshold (Carter 2005) for five Chinook salmon life-stages. Modeled temperature data for the winter time periods (incubation and winter presmolt life stages) were unattainable.

Upper Salmon River



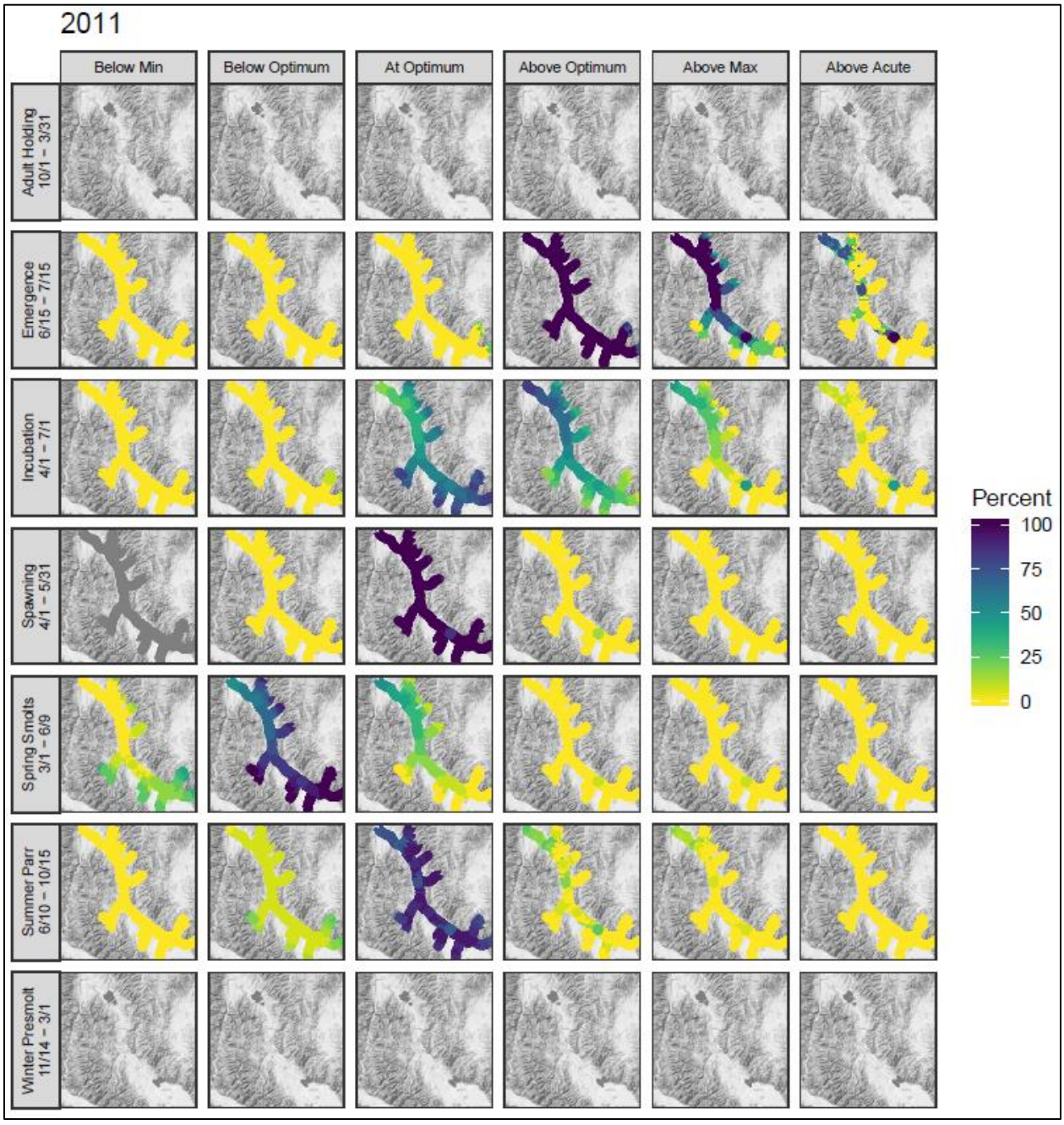
Supplemental Figure A-8. The percentage of time that 2011 water temperatures in the Upper Salmon River were below, within, or above a given temperature threshold (Carter 2005) for five Chinook salmon life-stages. Modeled temperate data for the winter time periods (incubation and winter presmolt life stages) were unattainable.



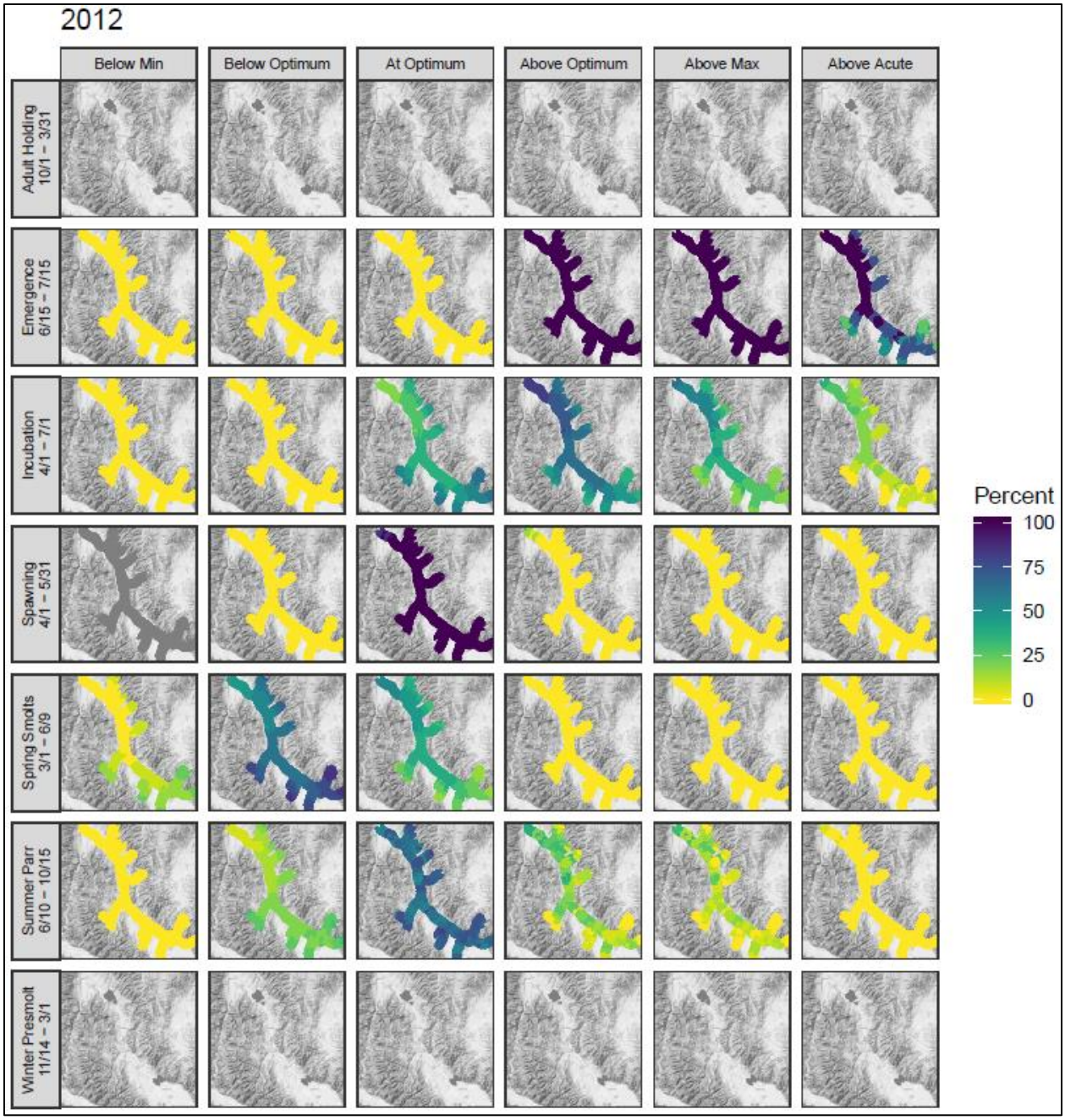
Supplemental Figure A-9. The percentage of time that 2013 water temperatures in the Upper Salmon River were below, within, or above a given temperature threshold (Carter 2005) for five Chinook salmon life-stages. Modeled temperate data for the winter time periods (incubation and winter presmolt life stages) were unattainable.

Steelhead

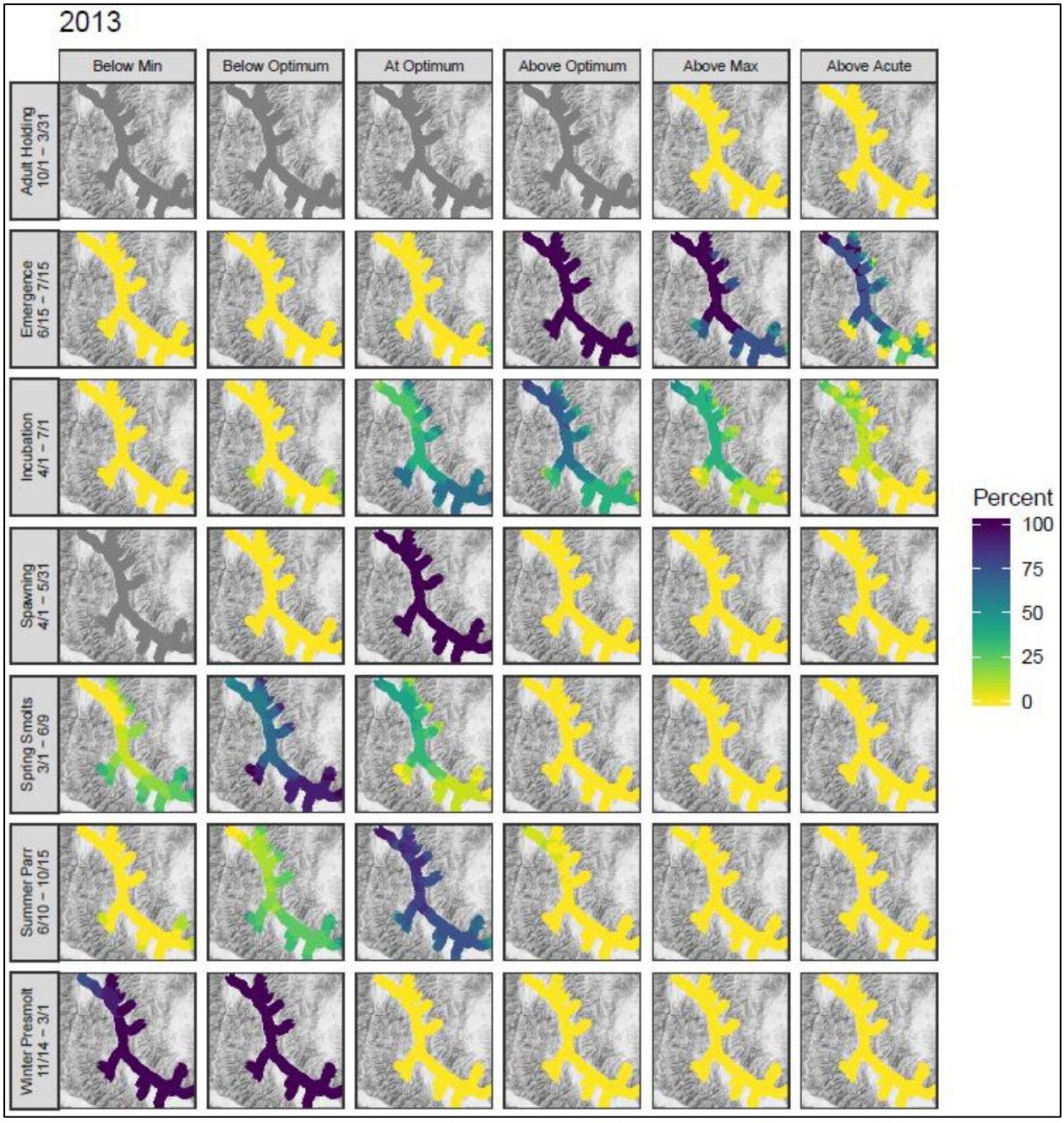
Lemhi River



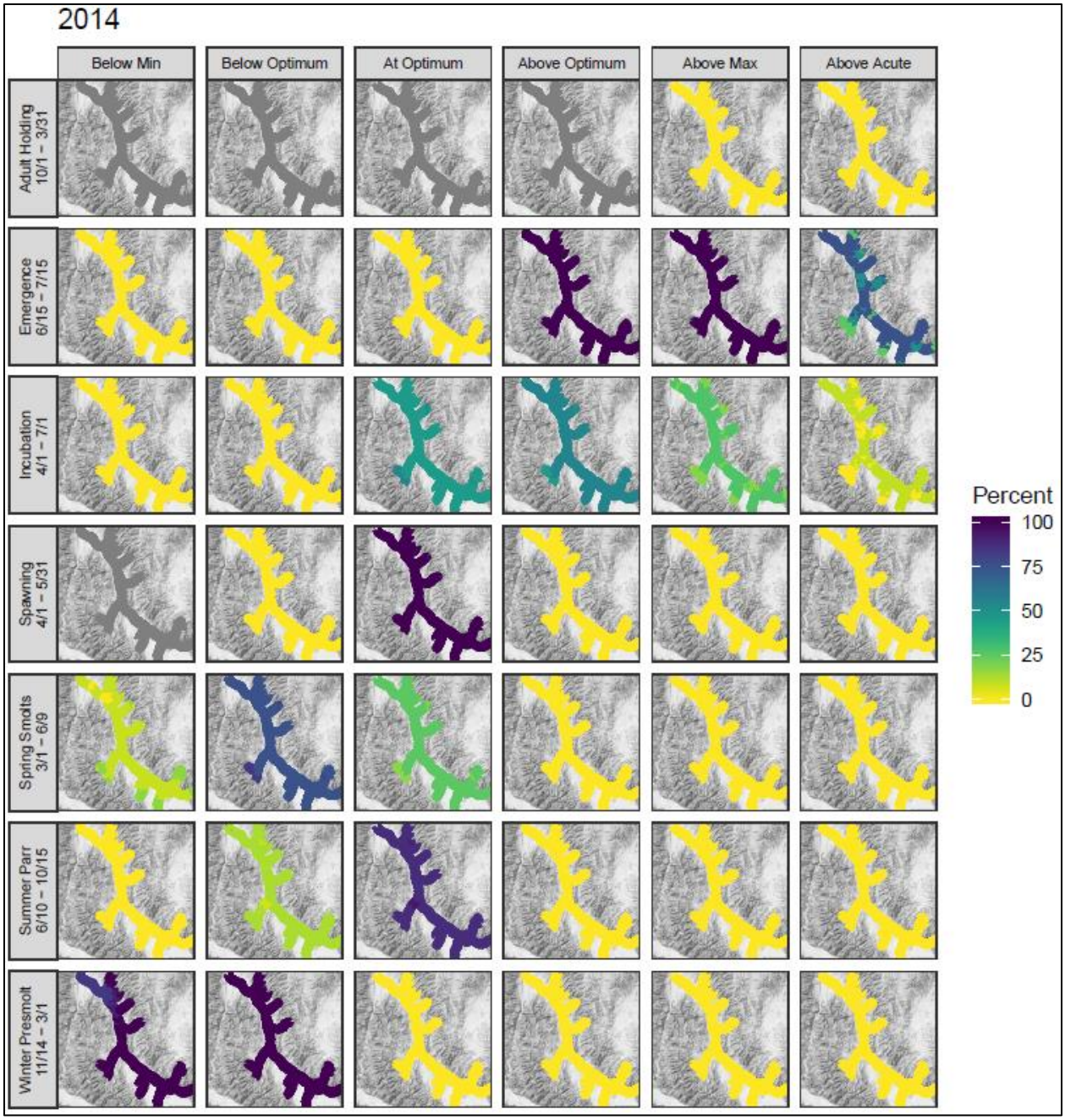
Supplemental Figure A-10. The percentage of time that 2011 water temperatures in the Lemhi River were below, within, or above a given temperature threshold (Carter 2005) for seven steelhead life stages. For facets with no data, modeled temperature data were unattainable for that timespan.



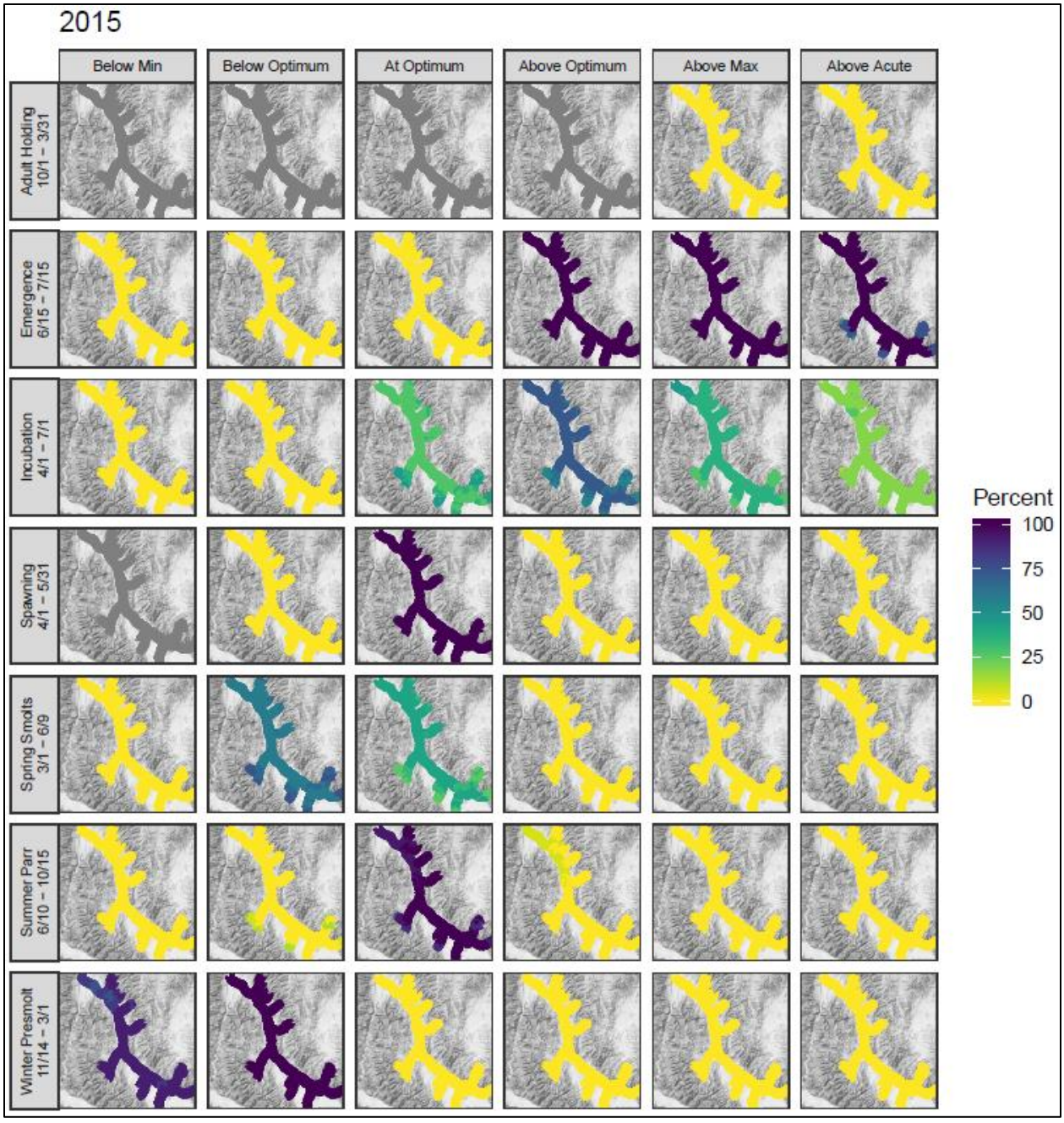
Supplemental Figure A-11. The percentage of time that 2012 water temperatures in the Lemhi River were below, within, or above a given temperature threshold (Carter 2005) for seven steelhead life stages. For facets with no data, modeled temperature data were unattainable for that timespan.



Supplemental Figure A-12. The percentage of time that 2013 water temperatures in the Lemhi River were below, within, or above a given temperature threshold (Carter 2005) for seven steelhead life stages.

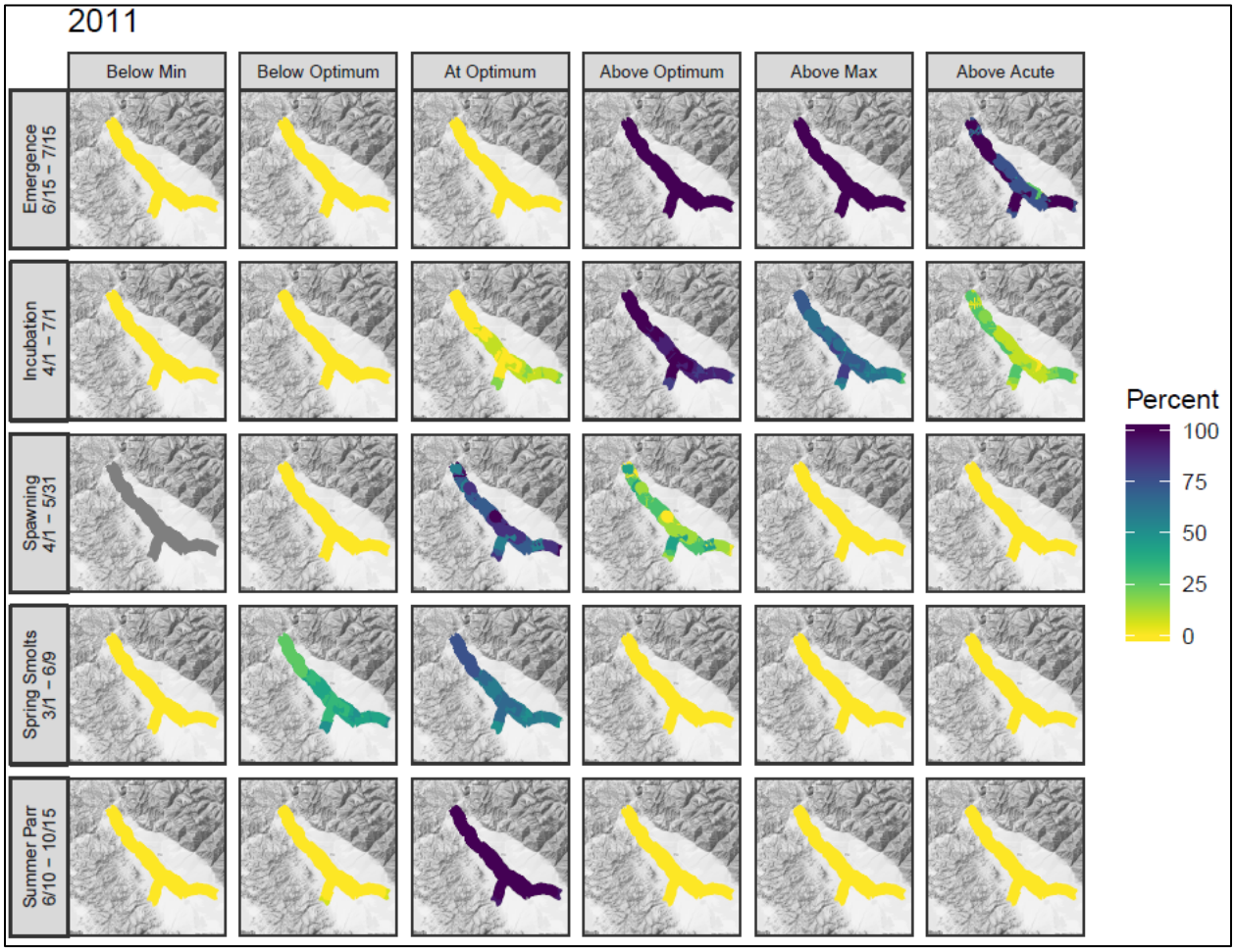


Supplemental Figure A-13. The percentage of time that 2014 water temperatures in the Lemhi River were below, within, or above a given temperature threshold (Carter 2005) for seven steelhead life stages.

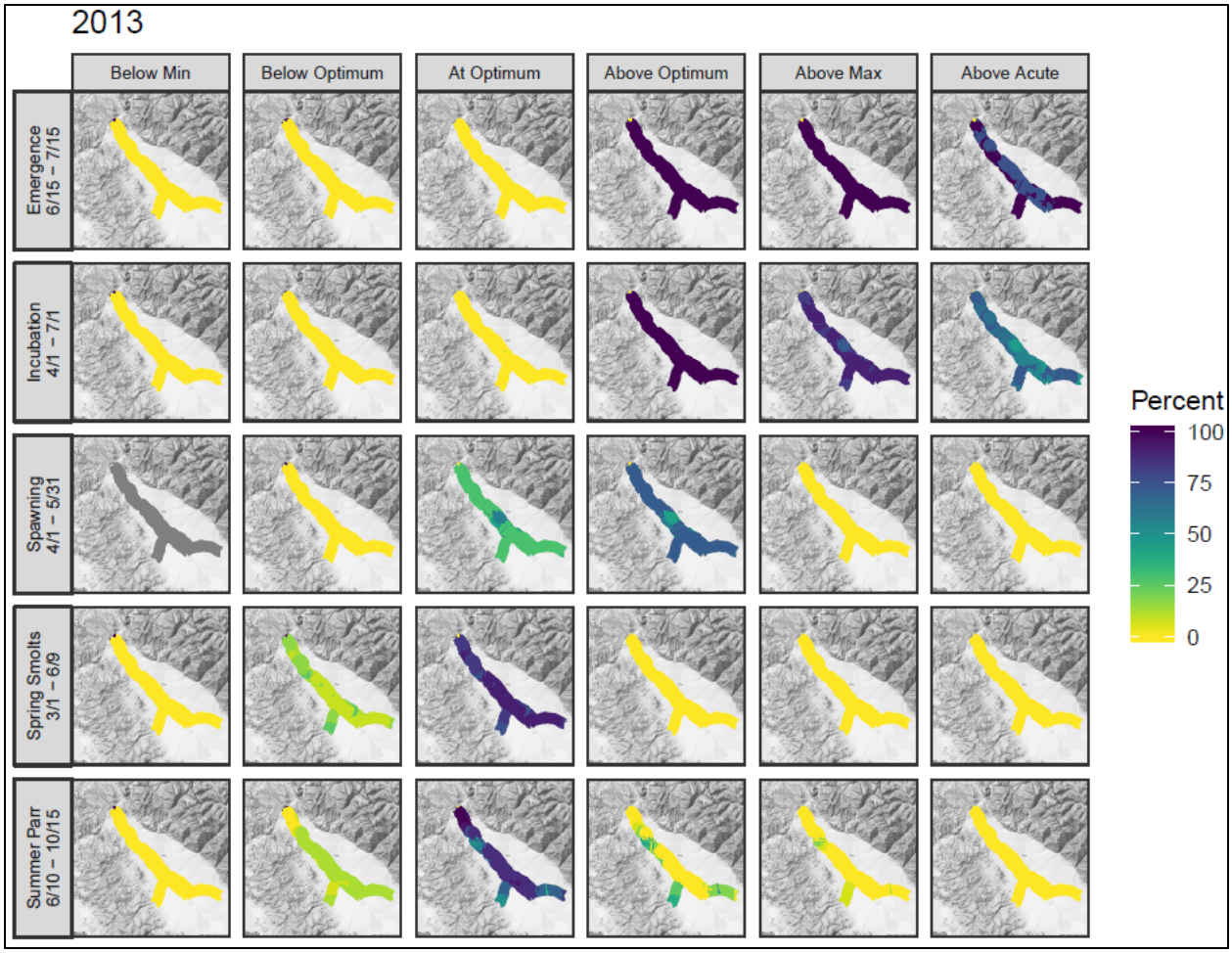


Supplemental Figure A-14. The percentage of time that 2015 water temperatures in the Lemhi River were below, within, or above a given temperature threshold (Carter 2005) for seven steelhead life stages.

Pahsimeroi River

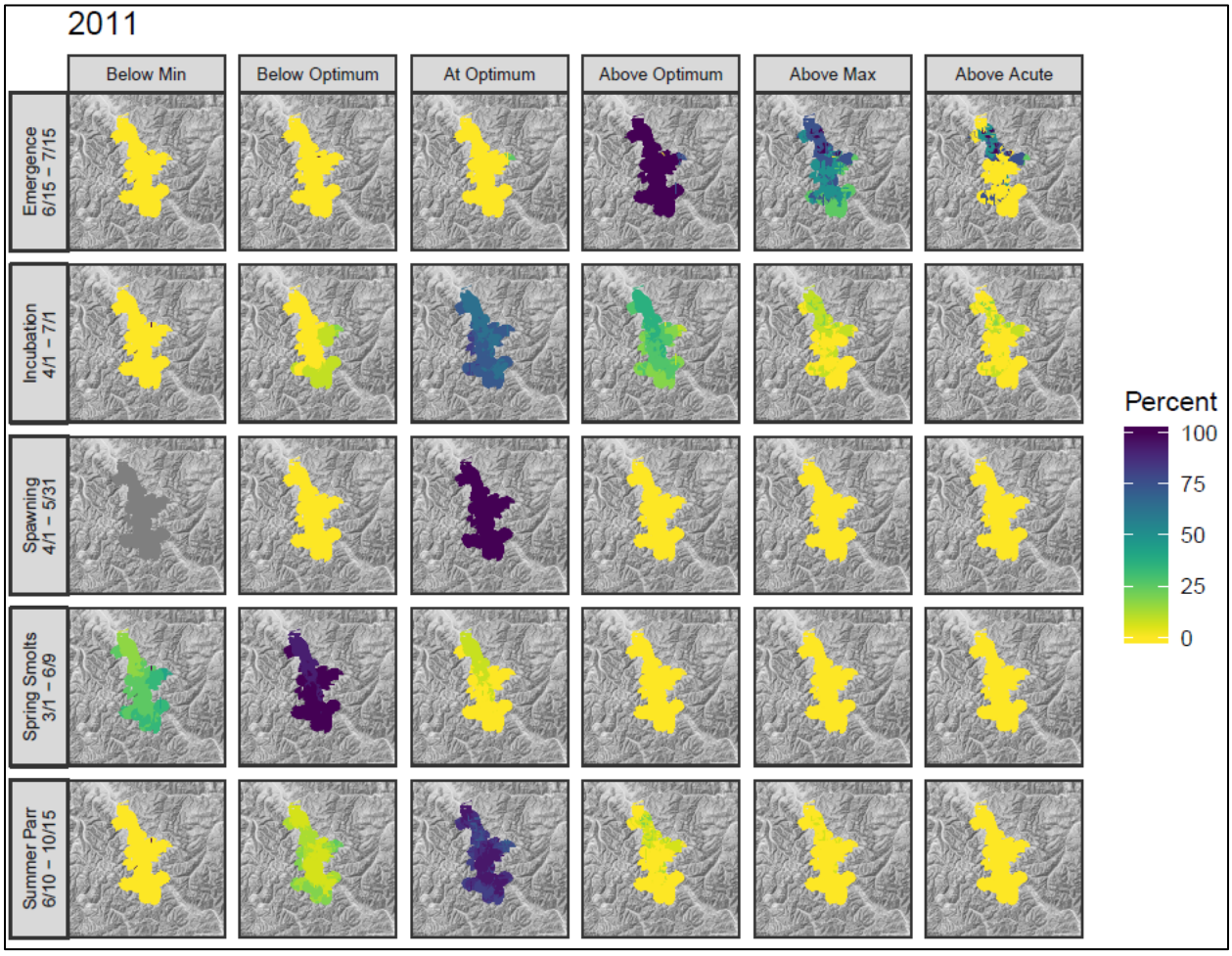


Supplemental Figure A-15. The percentage of time that 2011 water temperatures in the Pahsimeroi River were below, within, or above a given temperature threshold (Carter 2005) for five steelhead life stages. Modeled temperature data for the winter time periods (incubation and winter presmolt life stages) were unattainable.

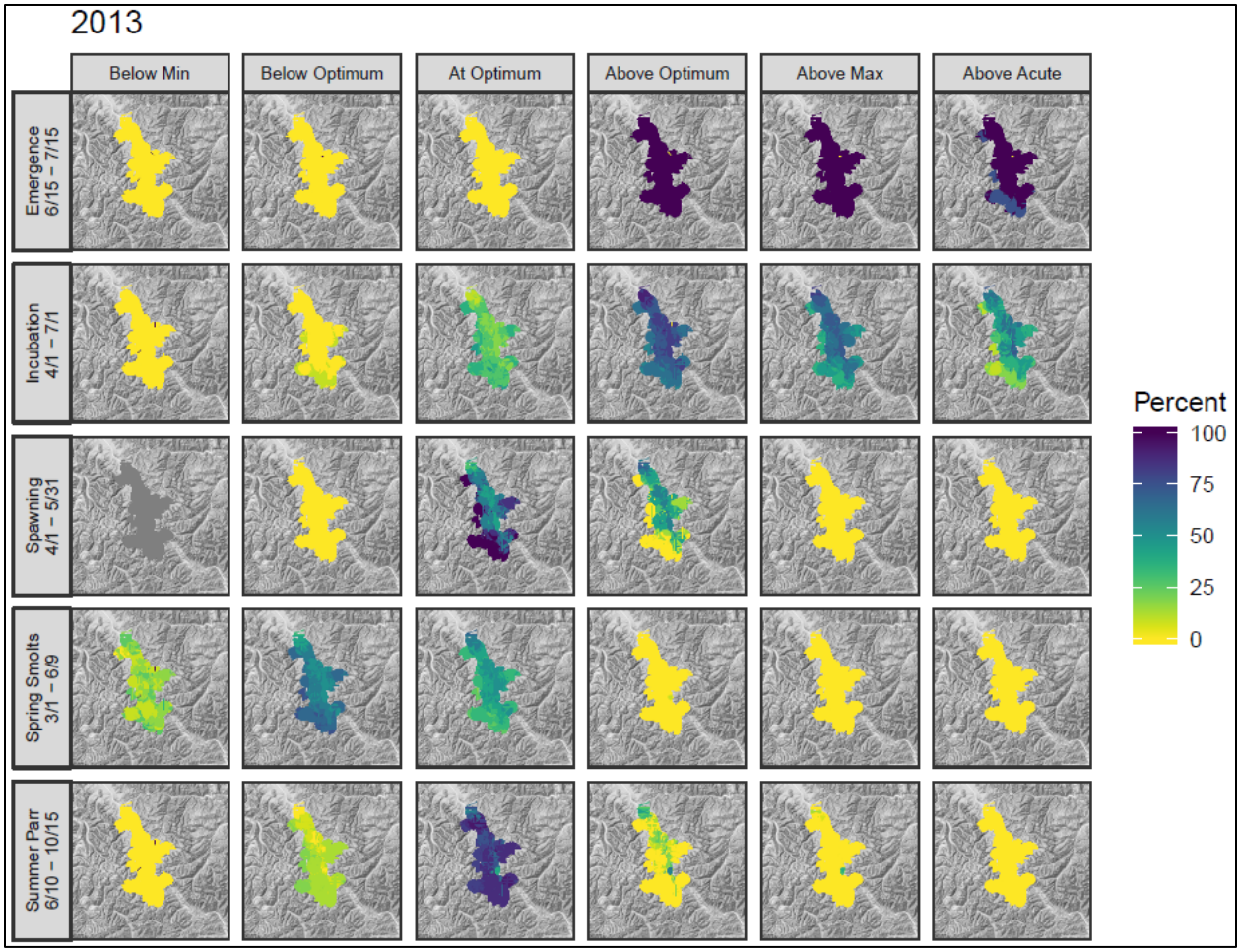


Supplemental Figure A-16. The percentage of time that 2013 water temperatures in the Pahsimeroi River were below, within, or above a given temperature threshold (Carter 2005) for five steelhead life stages. Modeled temperature data for the winter time periods (incubation and winter presmolt life stages) were unattainable.

Upper Salmon River



Supplemental Figure A-17. The percentage of time that 2011 water temperatures in the Upper Salmon River were below, within, or above a given temperature threshold (Carter 2005) for five steelhead life stages. Modeled temperate data for the winter time periods (incubation and winter presmolt life stages) were unattainable.



Supplemental Figure A-18. The percentage of time that 2013 water temperatures in the Upper Salmon River were below, within, or above a given temperature threshold (Carter 2005) for five steelhead life stages. Modeled temperate data for the winter time periods (incubation and winter presmolt life stages) were unattainable.