Habitat Suitability for Upper Salmon Subbasin Multiple Reach Assessments

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1 Introduction

The Bureau of Reclamation (BOR), Idaho Governor's Office of Species Conservation (OSC), and an interdisciplinary team of partners have assembled an Upper Salmon Assessment Team to complete biologic and geomorphic analyses in support of future project identification, prioritization, and design in the Upper Salmon Subbasin, Idaho. The biologic and geomorphic analyses are being lead by Biomark Inc. (Biomark) and Rio Applied Science and Engineering (Rio ASE), respectively. Past efforts from the team resulted in the development of a watershed-scale Integrated Rehabilitation Assessment (IRA; Idaho OSC Team 2019) in the Lemhi, Pahsimeroi, and Upper Salmon (Sawtooth Valley) watersheds. This initial phase of the project identified the "problem" by spatially quantifying capacity limitations for spring/summer Chinook salmon and summer run steelhead within a geomorphic context across these three watersheds. The second phase, termed the Multiple Reach Assessments (MRA), includes identifying appropriate and focused "solutions" to the identified capacity problems within four valley segments: Upper Lemhi, Lower Lemhi, Lower Pahsimeroi, and Upper Salmon (Decker Flats). To achieve this goal, the team will collaboratively summarize existing and targeted physical habitat conditions relative to documented habitat needs for specific species and life stages, including discussion of high-quality habitat, its creation, and its maintenance to inform future rehabilitation actions.

In the IRA, it was determined that, for Chinook salmon, habitat capacity was limited to support presmolts during winter months, and to a slightly lesser degree, parr during summer months. Habitat was not found to be limiting for adult spawning. For steelhead, habitat capacity was identified as limiting for juvenile rearing, at least in the Pahsimeroi River; again, habitat was not found to be limiting for adult spawning. The available habitat capacity was estimated using quantile regression forest (QRF; IRA Appendix B) whereas habitat requirements were estimated for current escapement and recovery goals using a generalized capacity model (IRA Appendix C).

The goal of this document is to further delve into existing conditions and evaluate the hydraulic suitability, particularly depth and velocity, of the four target valley segments to support select life stages of Chinook salmon and steelhead. By comparing depth and velocity suitability curves for Chinook salmon and steelhead (Maret et al. 2006) to modeled depths and velocities available for the four valley segments, we can further our understanding of how habitat may be limiting recovery of Chinook salmon and steelhead in the Upper Salmon subbasin. This information can help identify geomorphic reaches where existing depth and velocity may be limiting particular species and life stages, which could prove useful for project prioritization.

1.1 Objective

Evaluate the composite suitability of geomorphic reaches in the upper Lemhi, lower Lemhi, lower Pahsimeroi, and upper Salmon (Decker Flat) valley segments based on modeled depth and velocity raster available from Light Detection and Ranging (LiDAR) models available from those areas. Composite suitability is evaluated for both Chinook salmon and steelhead and for adult spawning and juvenile rearing at various discharge scenarios (see Table 1). The proportion of each geomorphic reach classified as simple, mixed, or complex is also provided for reference.

2 Methods

We provide methods for calculating the composite (depth & velocity) suitability, by geomorphic reach, for a single scenario including steps to visualize results. A given scenario includes a watershed, species, life stage, and season combination. Here, we provide detailed methods for Scenario 1 in Table 1: Lemhi River, Chinook salmon, juvenile summer (parr) rearing. The same methods were then applied across all scenarios except each with differing depth and velocity suitability curves (depending on species and adult versus juvenile) or differing input depth and velocity rasters (depending on season). All scenarios evaluated are summarized in Table 1. All data, scripts, outputs, and reports for this analysis are within the `mra_hsi` repository at https://github.com/mackerman44/mra_hsi.

Detailed methods are as follows:

1. Raster .tifs containing depth and velocity values were imported into R (R Core Team 2017). For the Lemhi River, raster pixels were 1m x 1m. As an example, for the Lemhi River, summer, low-flow scenario rasters were named D_Aug_All.tif and V_Aug_All.tif.
2. Import a polygon shapefile delineating the geomorphic reaches as defined in the IRA. The polygon shapefile is used to filter the depth and velocity .tifs to determine the geomorphic reach that each pixel falls in.
3. Read in the depth and velocity habitat suitability curves for Chinook salmon and steelhead from Maret et al. 2006. Depth and velocity habitat suitability index (HSI) curves were available for both species for the adult spawning and juvenile rearing life stages. Functions to calculate the suitability for a given

depth or velocity are available in the `mra_hsi` repository in the R/ directory. The Habitat Suitability section below shows the HSI curves used from Maret et al. (2006).

4. Use the HSI curves to calculate the depth and velocity suitability for each raster pixel. The result is two new rasters each containing the depth and velocity suitability values, respectively.

5. Calculate the composite suitability value for each raster pixel as the geometric mean of the depth and velocity suitability values. The result is a third composite suitability raster.

6. Extract the composite suitability values and geomorphic reach for each pixel into a dataframe. The dataframe can then be used to summarize and visualize the composite suitability by geomorphic reach for the given watershed, species, life stage, and discharge scenario.

7. Write out the composite suitability values and geomorphic reaches for each pixel to a .csv. These results are all stored in the output/hsi_raw/ directory in the `mra_hsi` repository.

Finally, we visualized the composite suitability values by valley segment, species, life stage (adult spawning, juvenile summer rearing, juvenile winter rearing), and geomorphic reach. Violin plots showing the distribution of composite suitability values are provided in the Results section. For reference, the proportion of each reach classified as simple, mixed, or complex is also provided. Further, we provide maps showing the mean of composite suitability values by species and life stage for each valley segment.

The resulting raster .tifs showing depth, velocity, and composite suitability are too large to store in a https://github.com/ repository, but are available from the authors upon request.

2.1 Habitat Suitability

Figures 1 and 2 show HSI curves for Chinook salmon and steelhead from Maret et al. (2006), respectively, used here. These curves are used to calculate the depth or velocity suitability value for each pixel within a scenario. The composite suitability for a pixel is than calculated as the geometric mean of those values. As an example, using juvenile Chinook salmon and depth, if a pixel has a depth of 0m, that pixel is assigned a suitability of 0 whereas if the depth is greater than approximately 0.6m it is assigned a suitability of 1; a depth of 0.5m would be assigned a suitability of ~0.7.

2.2 Scenarios

Table 1: Scenarios for which we evaluated the composite suitability (depth & velocity) within geomorphic reaches including the corresponding depth and velocity rasters used for each scenario.

Scenario	Watershed	Species	Life Stage	Season	Depth Raster	Velocity Raster
1	Lemhi	Chinook	Juvenile	Summer	D_Aug_All.tif	V_Aug_All.tif
2	Lemhi	Chinook	Juvenile	Winter	d_jan_v2.tif	v_jan_v2.tif
3	Lemhi	Chinook	Spawning	Summer	D_Aug_All.tif	V_Aug_All.tif
4	Lemhi	Steelhead	Juvenile	Summer	D_Aug_All.tif	V_Aug_All.tif
5	Lemhi	Steelhead	Juvenile	Winter	d_jan_v2.tif	v_jan_v2.tif
6	Lemhi	Steelhead	Spawning	Spring	d_jan_v2.tif	v_jan_v2.tif
7	Pahsimeroi	Chinook	Juvenile	Summer	-	-
8	Pahsimeroi	Chinook	Juvenile	Winter	Pah_WLow_depth.tif	Pah_WLow_velocity.tif
9	Pahsimeroi	Chinook	Juvenile	Spring	Pah_1pt5_depth.tif	Pah_1pt5_velocity.tif
10	Pahsimeroi	Chinook	Spawning	Summer	Pah_WLow_depth.tif	Pah_WLow_velocity.tif
11	Pahsimeroi	Steelhead	Juvenile	Summer	-	-
12	Pahsimeroi	Steelhead	Juvenile	Winter	Pah_WLow_depth.tif	Pah_WLow_velocity.tif

Scenario	Watershed	Species	Life Stage	Season	Depth Raster	Velocity Raster
13	Pahsimeroi	Steelhead	Juvenile	Spring	Pah_1pt5_depth.tif	Pah_1pt5_velocity.tif
14	Pahsimeroi	Steelhead	Spawning	Spring	Pah_1pt5_depth.tif	Pah_1pt5_velocity.tif
15	Upper Salmon	Chinook	Juvenile	Summer	US_Summer75_depth.tif	US_Summer75_velocity.tif
16	Upper Salmon	Chinook	Juvenile	Winter	US_Winter75_depth.tif	US_Winter75_velocity.tif
17	Upper Salmon	Chinook	Juvenile	Spring	US_1pt5year_depth.tif	US_1pt5year_velocity.tif
18	Upper Salmon	Chinook	Spawning	Summer	US_Summer75_depth.tif	US_Summer75_velocity.tif
19	Upper Salmon	Steelhead	Juvenile	Summer	US_Summer75_depth.tif	US_Summer75_velocity.tif
20	Upper Salmon	Steelhead	Juvenile	Winter	US_Winter75_depth.tif	US_Winter75_velocity.tif
21	Upper Salmon	Steelhead	Juvenile	Spring	US_1pt5year_depth.tif	US_1pt5year_velocity.tif
22	Upper Salmon	Steelhead	Spawning	Spring	US_1pt5year_depth.tif	US_1pt5year_velocity.tif

We evaluated 22 scenarios in total which are summarized in Table 1. For all summer scenarios, we used rasters from a discharge scenario representative of low flow conditions. In the case of the Lemhi and Pahsimeroi watersheds, all spring and winter scenarios used rasters from high flow conditions. Alternatively, for the Upper Salmon, winter scenarios were done using a low-flow discharge. Finally, for the Upper Salmon, we added spring scenarios for juvenile rearing to evaluate high-flow conditions, as both summer and winter are typically low-flow in that watershed.

3 Results

Here, we provide a summary of the distribution (as violin plots) and mean (as maps) of composite suitability values by valley segment, species, life stage, and geomorphic reach. Raw outputs and raster .tifs of depth, velocity, and composite suitability values are available in the `mra_hsi` repository or from the authors.

3.1 Upper Lemhi

Figure 3 summarizes the composite hydraulic suitability within the Upper Lemhi valley segment to support Chinook salmon spawning and juvenile rearing (summer and winter) along with the proportion of each geomorphic reach classified as simple, mixed, or complex. In general, the hydraulic suitability for spawning, for both Chinook salmon and steelhead, is high, with a large number of pixels with a suitability of 1. Hydraulic suitability for steelhead juvenile rearing, during both the summer and winter scenario, also tends to be high in the Upper Lemhi valley segment; whereas suitability for juvenile Chinook salmon rearing is low. Interestingly, geomorphic reach 01, the upstream-most reach starting at Leadore, contains more pixels with a suitability above 0 than all other geomorphic reaches for both summer and winter juvenile rearing.

Figure 4 shows the mean composite hydraulic suitability of pixels by species, life stage, and geomorphic reach in the Upper Lemhi valley segment. The map bears a similar story as the violin plot above. Hydraulic suitability for spawning (both species) and for steelhead rearing tends to be high (red) whereas suitability for Chinook salmon rearing tend to be low (blue).

3.2 Lower Lemhi

Figure 5 summarizes the composite hydraulic suitability within the Lower Lemhi valley segment to support Chinook salmon spawning and juvenile rearing (summer and winter) along with the proportion of each geomorphic reach classified as simple, mixed, or complex. Again, similar to the Upper Lemhi, hydraulic suitability for spawning in the Lower Lemhi is high; similar, suitability for steelhead juvenile rearing is high (i.e., a large number of pixels have a composite suitability near or at 1). Suitability for juvenile Chinook salmon rearing in the Lower Lemhi is low. Worth noting is that reaches with a high proportion classified

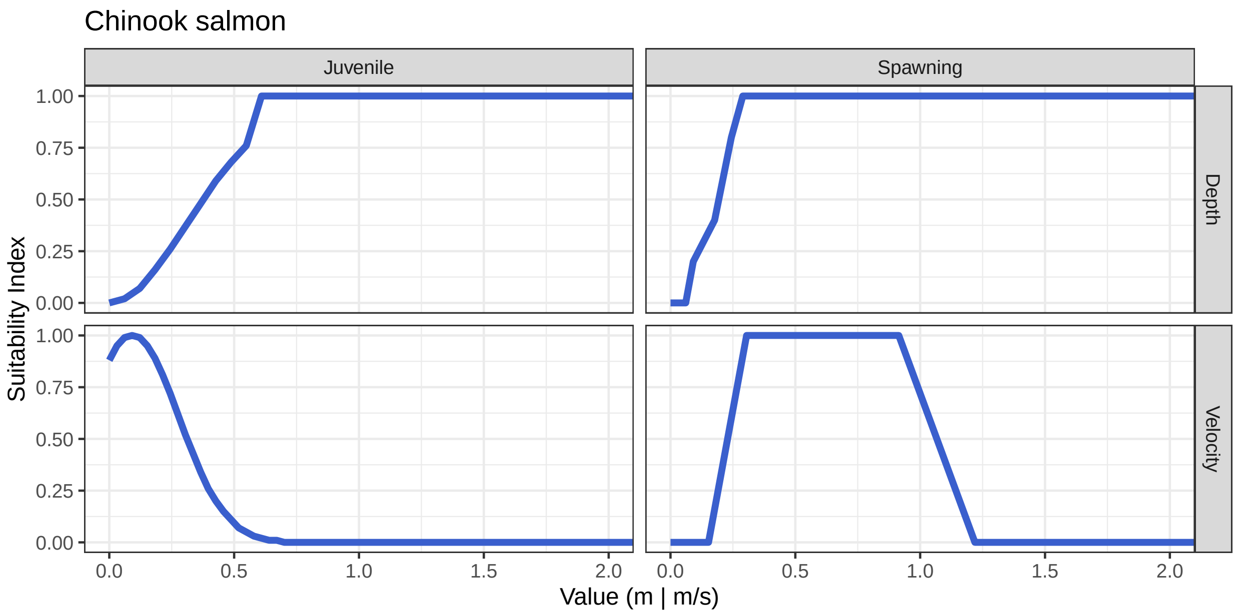

Figure 1: Suitability indices at varying depths and velocities for juvenile rearing and adult spawning for Chinook salmon from Maret et al. (2006).

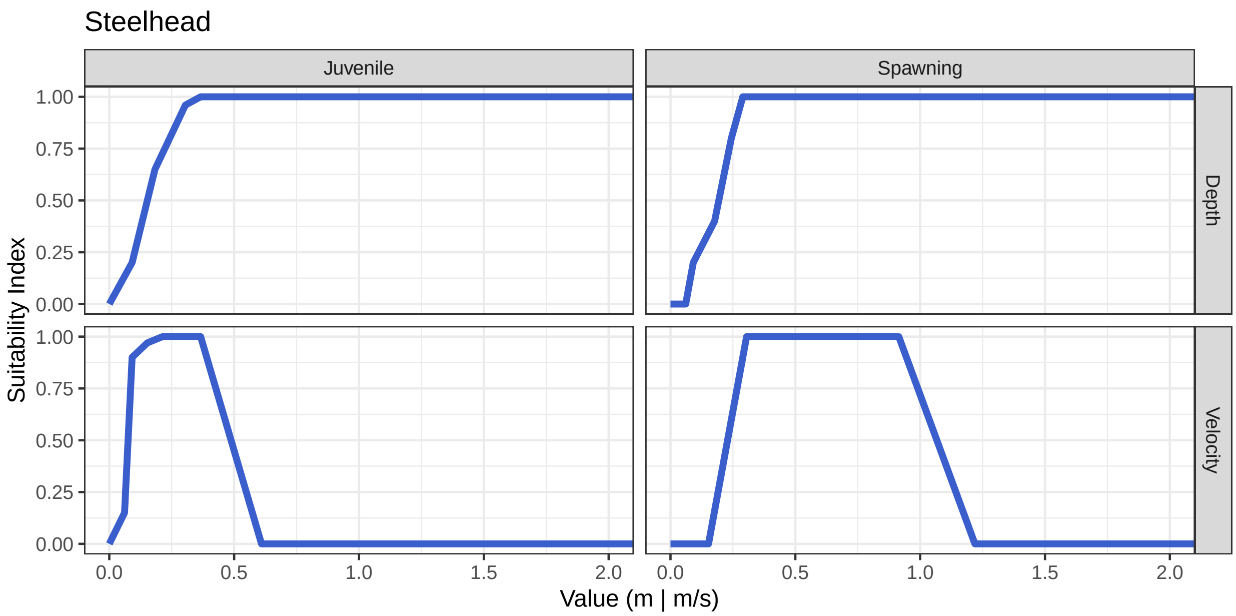

Figure 2: Suitability indices at varying depths and velocities for juvenile rearing and adult spawning for steelhead from Maret et al. (2006).

Figure 3: Violin plots showing the distribution of composite suitability values (geometric mean of depth and velocity suitability) across geomorphic reaches in the Upper Lemhi valley segment. Results for both Chinook salmon and steelhead and for three lifestages (adult spawning, juvenile summer rearing, juvenile winter rearing) are shown. The bottom panel shows the proportion of each geometric reach classified as simple, mixed, or complex.

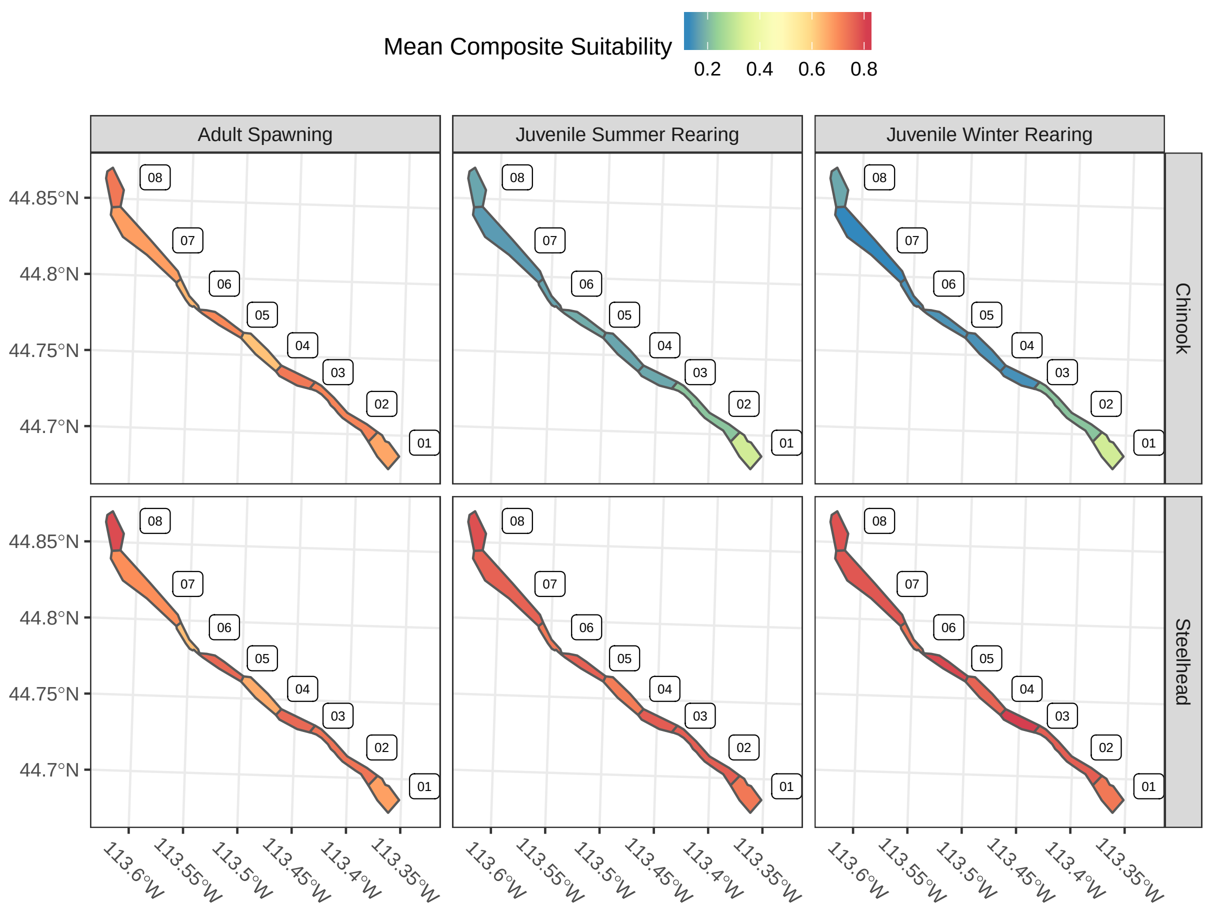

Figure 4: Map showing the mean composite suitability by life stage and across geomorphic reaches for Chinook salmon and steelhead in the Upper Lemhi valley segment.

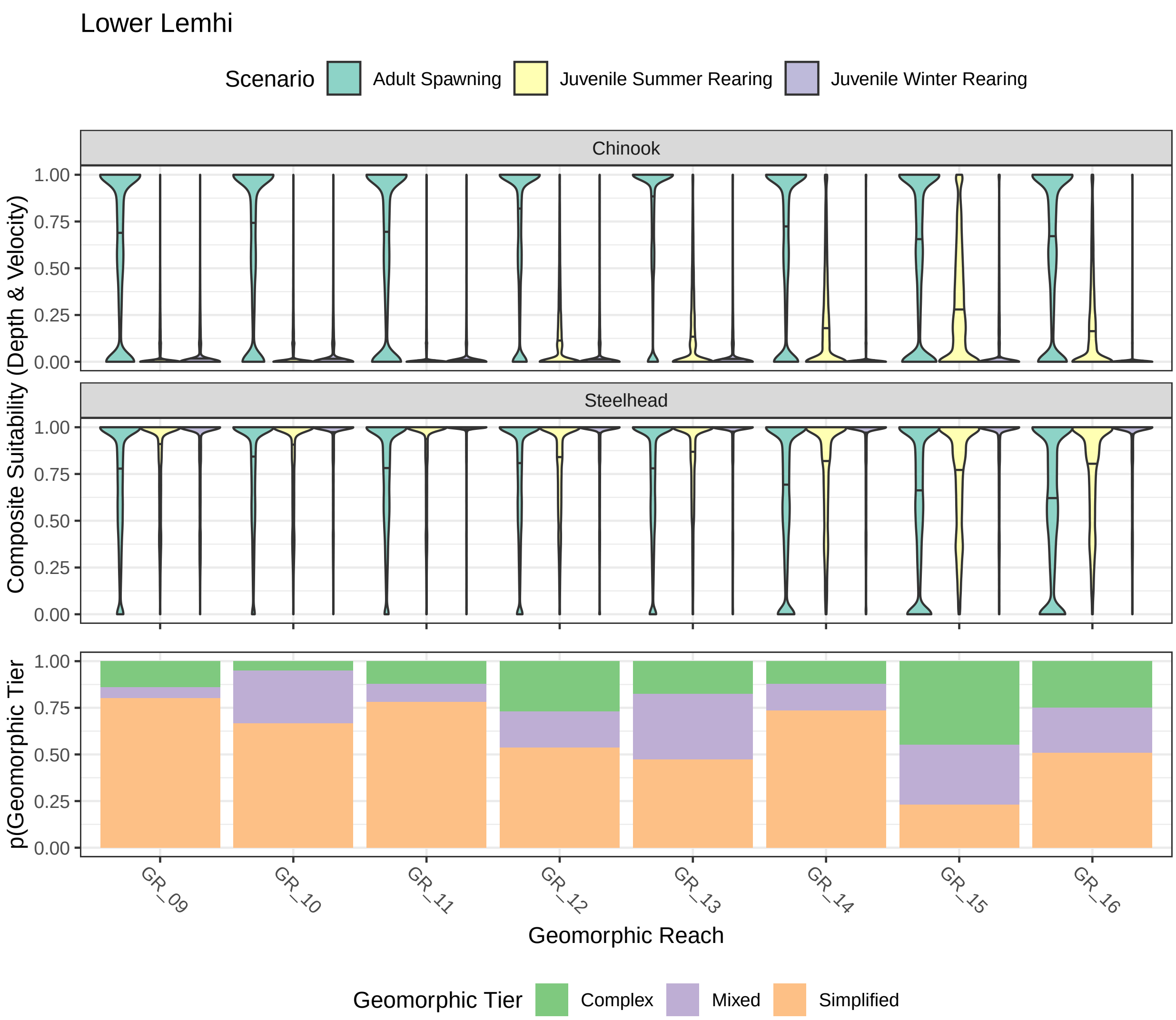

Figure 5: Violin plots showing the distribution of composite suitability values (geometric mean of depth and velocity suitability) across geomorphic reaches in the Lpper Lemhi valley segment. Results for both Chinook salmon and steelhead and for three lifestages (adult spawning, juvenile summer rearing, juvenile winter rearing) are shown. The bottom panel shows the proportion of each geometric reach classified as simple, mixed, or complex.

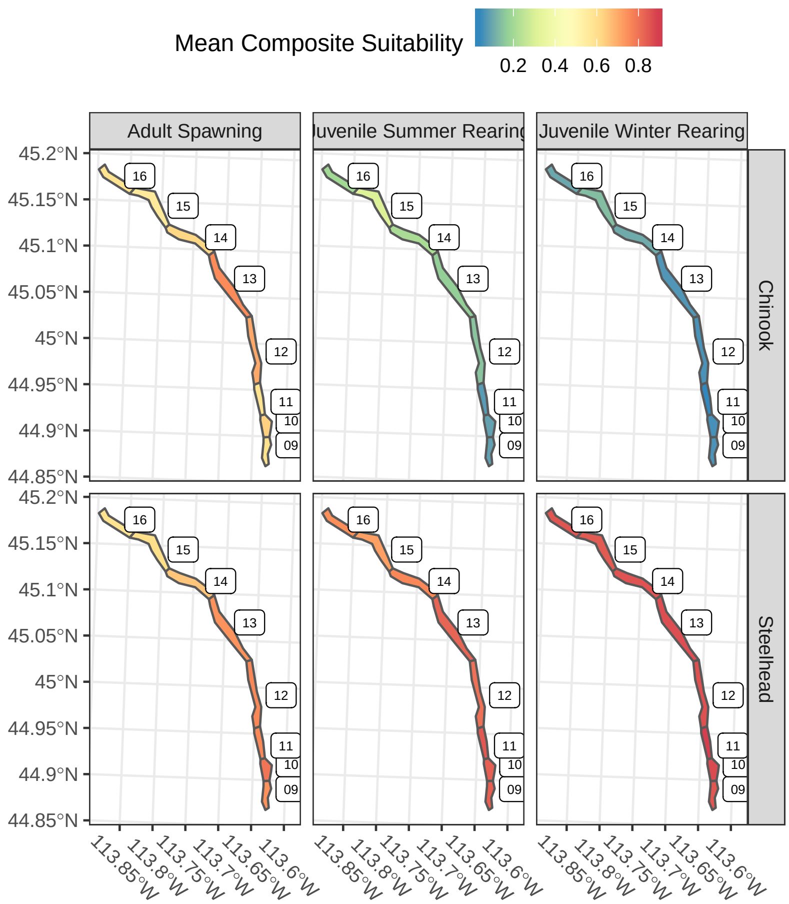

Figure 6: Map showing the mean composite suitability by life stage and across geomorphic reaches for Chinook salmon and steelhead in the Lower Lemhi valley segment.

as simple (e.g., GR_09-11) have a very high proportion of pixels with a suitability at 0; whereas the most complex reach, GR_15, has a much larger proportion of pixels higher in the violin distribution.

Figure 6 shows the mean composite hydraulic suitability of pixels by species, life stage, and geomorphic reach in the Lower Lemhi valley segment. The Lower Lemhi map shows the same trends as the Upper Lemhi map. Hydraulic suitability for spawning and juvenile steelhead rearing is good; suitability for juvenile Chinook rearing is poor. Note that the upstream simple reaches (GR_09-11) are the deepest blue whereas the 'more' complex GR_15 seems to be more suitable (lighter blue) for the juvenile Chinook rearing.

3.3 Pahsimeroi

Figure 7 summarizes the composite hydraulic suitability within the Pahsimeroi valley segment to support Chinook salmon spawning and juvenile rearing (summer and winter) along with the proportion of each geomorphic reach classified as simple, mixed, or complex. Composite suitability for spawnin in the Lower Pahsimeroi tends to be low for both species, especially in the upper geomorphic reaches, GR_08 and GR_09. Although one would have to examine the depth and velocity suitability results and .tifs more closely to determine the reason, it is presumably due to high velocities given the relationships in Figures 1 and 2. Suitability for juvenile Chinook rearing is still low for the Lower Pahsimeroi valley segment (same as Lemhi); however, suitability for juvenile steelhead rearing is also low, especially for GR_08 and GR_09. The mean suitability for steelhead juvenile rearing in those reaches is near 0.35 (shown in the violin plots); lower than in the Lemhi.

Figure 8 shows the mean composite hydraulic suitability of pixels by species, life stage, and geomorphic reach in the Pahsimeroi valley segment. The map shows a similar story as the violin plots. Hydraulic suitability for spawning is lower in the Lower Pahsimeroi valley segment than it is in either Lemhi River valley segments, presumably due to increased velocities (again, this would need to be verified by closer inspection of velocity .tifs or suitability values and/or empirical velocity data). Also, suitability for juvenile steelhead rearing is lower than in the Lemhi, at least for GR_08 and GR_09. Suitability for juvenile Chinook rearing remains low.

3.4 Upper Salmon

Figure 9 summarizes the composite hydraulic suitability within the Upper Salmon valley segment to support Chinook salmon spawning and juvenile rearing (summer and winter) along with the proportion of each geomorphic reach classified as simple, mixed, or complex. Results in the Upper Salmon valley segment certainly differ from those in the Lemhi and Pahsimeroi. Composite suitability for adult spawning is mixed, although for both species there appears to be a fair distribution of pixels near 1; for Chinook, suitability seems to be better in downstream reaches (GR_07-10). Suitability for juvenile steelhead rearing tends to be high among reaches, although reaches GR_05 and GR_06 have a mean composite suitability lower than the others. Composite suitability for juvenile Chinook salmon, although mean < 0.5 in all geomorphic reaches, is much higher than observed in the Lemhi or Pahsimeroi, at least for the summer and winter scenarios (spring high-flow suitability is still low). Further, juvenile Chinook rearing suitability is consistently > 0.3 among all geomorphic reaches. This is likely related to geomorphic reaches in the Upper Salmon valley segment also consistently having a higher proportion of geomorphic reaches classified as complex.

Figure 10 shows the mean composite hydraulic suitability of pixels by species, life stage, and geomorphic reach in the Upper Salmon valley segment. Spawning suitability appears to be lower in the Upper Salmon than in the Lemhi and Pahsimeroi; however, all reaches still seem to have areas (pixels) with high suitability. Suitability for steelhead rearing appears to be moderate. Finally, although still not high, composite suitability for juvenile Chinook salmon rearing in the Upper Salmon appears to be much greater than in the Lemhi or Pahsimeroi.

4 Discussion

4.1 Spawning

Using the HSI curves available from Maret et al. (2006) and the modeled depth and velocity rasters in Table 1 hydraulic habitat does not appear to be limiting for spawning for Chinook salmon or steelhead in the three watershed evaluated. This corroborates the findings in the IRA (Idaho OSC Team 2019) where they did not find spawning habitat capacity to be limiting to support contemporary escapement estimates in those areas or recovery goals. The results provided here provide an additional line of evidence that a lack of available spawning habitat or conditions does not appear to be limiting for the recovery of Chinook salmon or steelhead in the watersheds of interest. However, although out of the scope of this document, that is not to say that the incubation or emergence life stages following spawning may not be limited. Fine sedimentation in the target watersheds and in the Upper Salmon Subbasin as a whole remains a concern as it can reduce oxygenation of eggs and affect hyporheic flow.

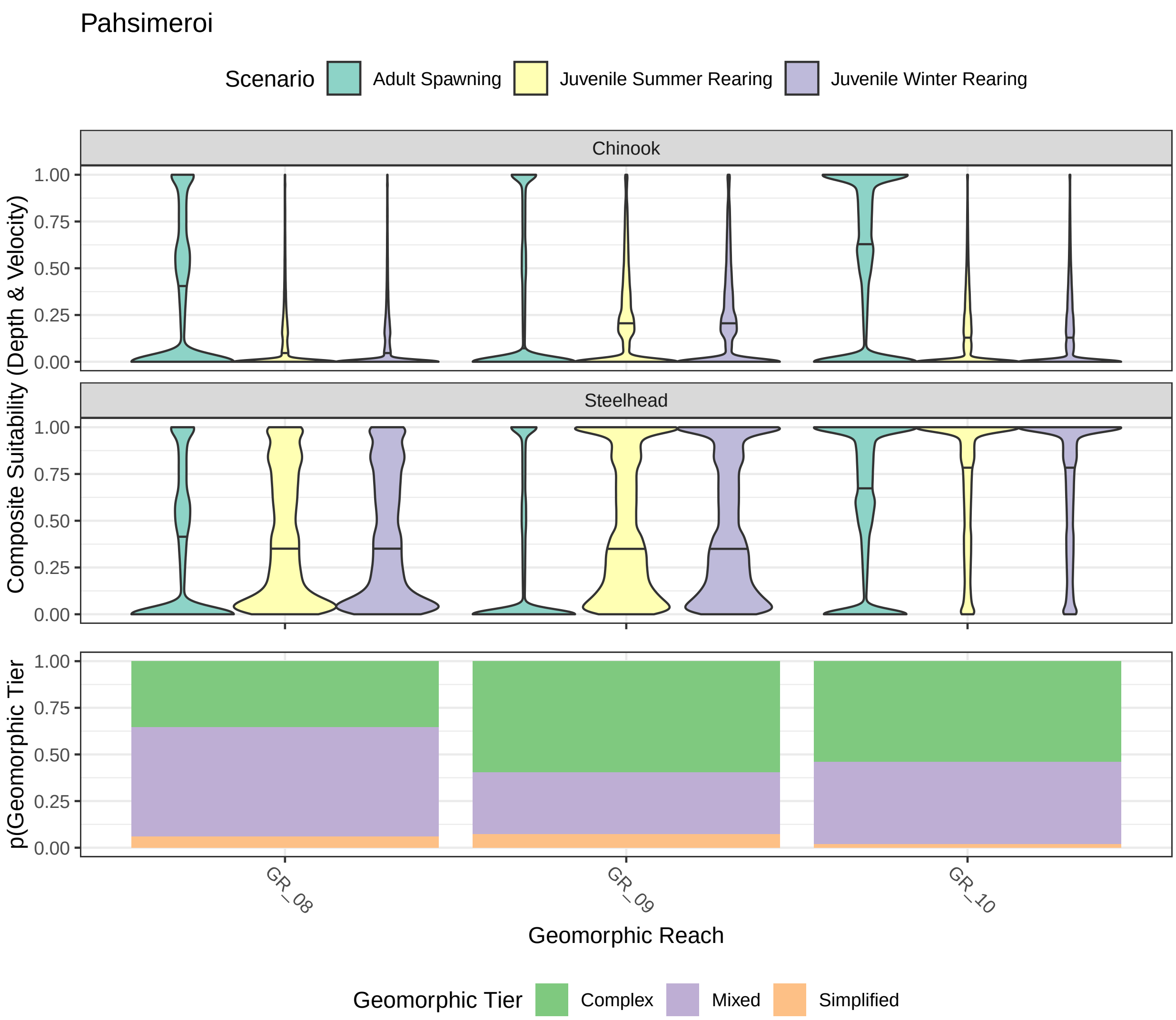

Figure 7: Violin plots showing the distribution of composite suitability values (geometric mean of depth and velocity suitability) across geomorphic reaches in the Lower Pahsimeroi valley segment. Results for both Chinook salmon and steelhead and for three lifestages (adult spawning, juvenile summer rearing, juvenile winter rearing) are shown. The bottom panel shows the proportion of each geometric reach classified as simple, mixed, or complex.

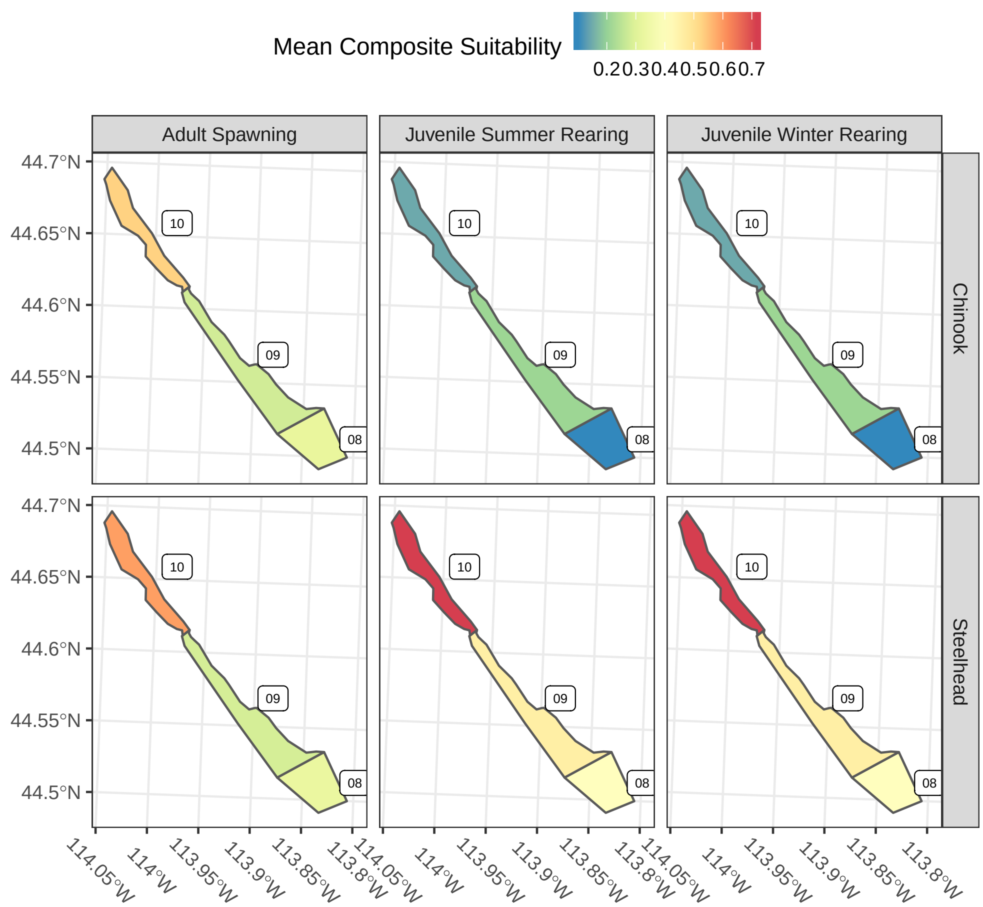

Figure 8: Map showing the mean composite suitability by life stage and across geomorphic reaches for Chinook salmon and steelhead in the Lower Pahsimeroi valley segment.

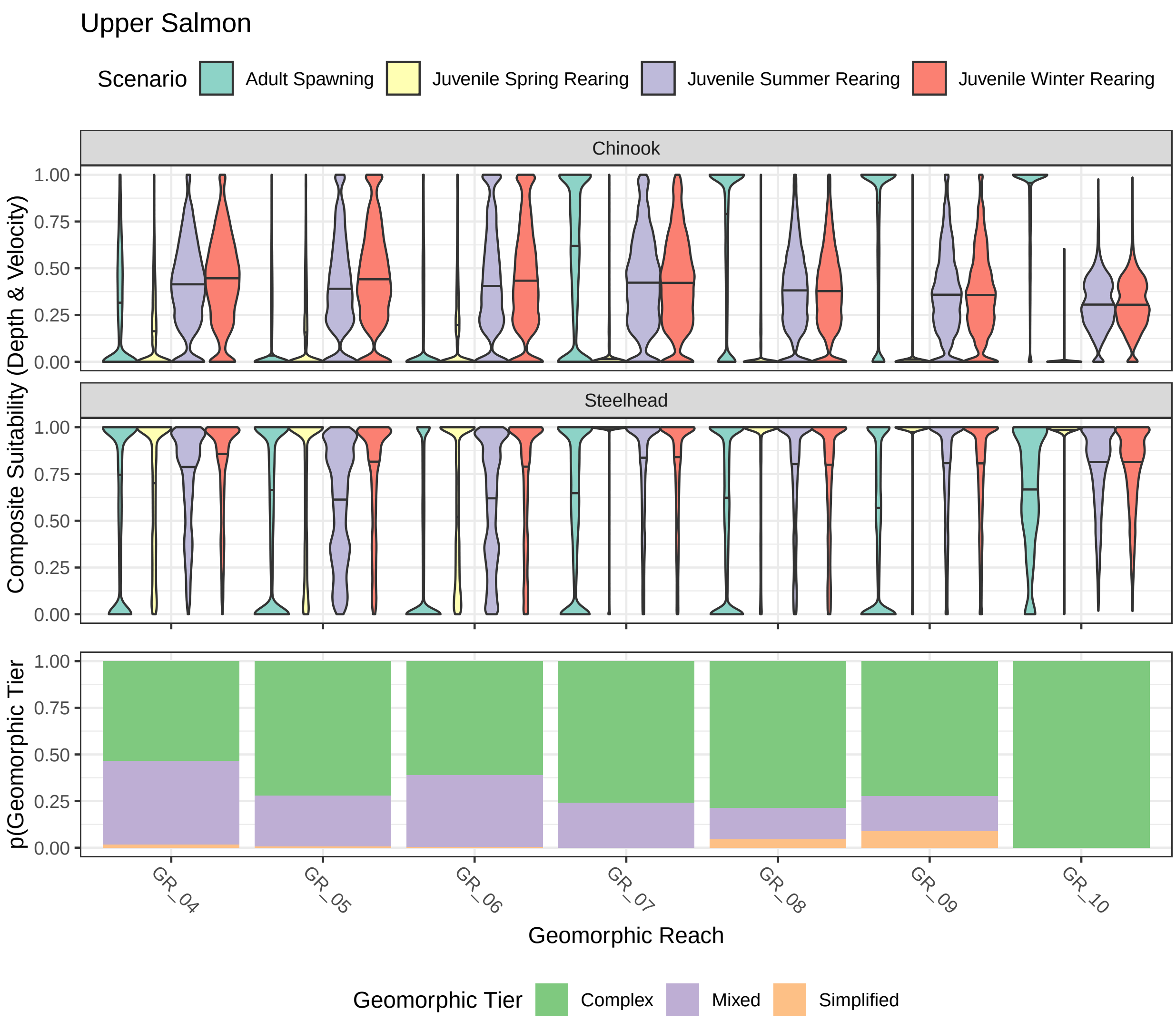

Figure 9: Violin plots showing the distribution of composite suitability values (geometric mean of depth and velocity suitability) across geomorphic reaches in the Upper Salmon (Decker Flat) valley segment. Results for both Chinook salmon and steelhead and for four lifestages (adult spawning, juvenile spring rearing, juvenile summer rearing, juvenile winter rearing) are shown. The bottom panel shows the proportion of each geometric reach classified as simple, mixed, or complex.

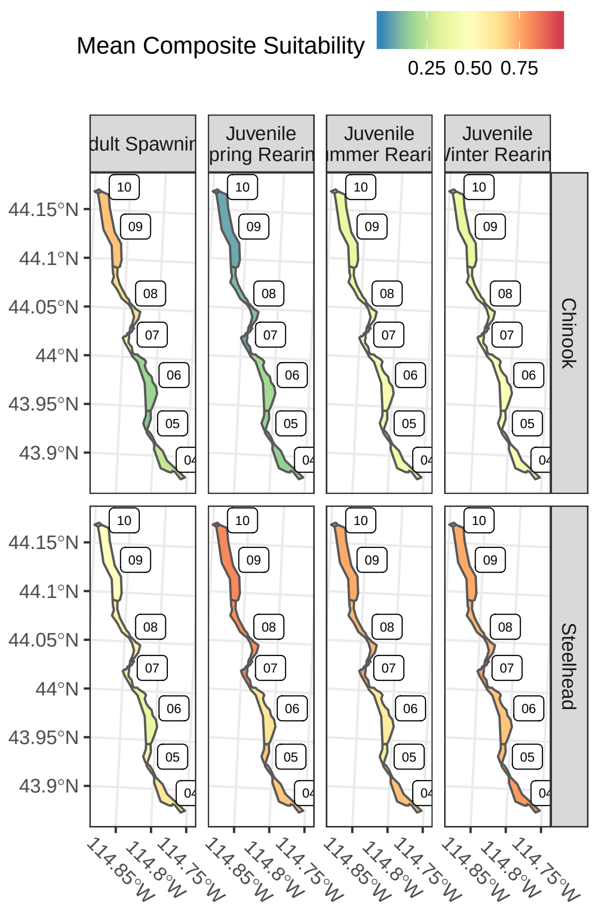

Figure 10: Map showing the mean composite suitability by life stage and across geomorphic reaches for Chinook salmon and steelhead in the Upper Salmon (Decker Flat) valley segment.

4.2 Juvenile rearing

4.2.1 Steelhead

For steelhead, hydraulic habitat, for the most part, does not appear to be limiting for either summer or winter rearing; again, this is assuming the depth and velocity suitability curves from Maret et al. (2006) and the depth and velocity rasters from Table 1. Modeled depths and velocities within the scenarios evaluated appear to be largely within the ranges considered suitable for steelhead rearing in the target watersheds. An exception appears to be the GR_08 and GR_09 reaches in the lower Pahsimeroi where the mean composite suitability values fall below 0.5 (Figure 7), presumably due to high velocities there. In addition, there are two reaches in the Upper Salmon (GR_05 and GR_06) where mean suitability is decreased; however, mean composites there remain above 0.5 (Figure 9). Further evaluation of the depth and velocity suitability values or .tifs in those geomorphic reaches would reveal wether high velocities or low depths (or both) are the culprit for decreased suitabilities in those reaches.

4.2.2 Chinook salmon

Hydraulic habitat appears to be poor for juvenile Chinook salmon rearing in all three watersheds with the exception being the Upper Salmon valley segment during the summer and winter scenarios evaluated, although mean composite suitability values remained below 0.5 even there (Figure 9). Composite suitability values in the Lemhi and Pahsimeroi watersheds were largely near 0 with few exceptions (Figures 3, Figures 5, and Figures 7). This corroborates findings in the IRA where Chinook salmon juvenile rearing was identified as the most limited species by life stage combination evaluated there and provides an additional line of evidence that a lack of suitable habitat for juvenile Chinook salmon is a concern in the Upper Salmon Subbasin. It is of interest that areas of suitable modeled depths and velocities were identified among geomorphic reaches in the Upper Salmon valley segment (at least for the summer and winter low-flows); the resulting depth, velocity, and composite suitability .tifs for those reaches could be further inspected to identify characteristics that allow for suitable depths and velocities. With that said, composite suitabilities in the spring high-flow scenario evaluated in the Upper Salmon subbasin were poor.

4.3 Conclusions

This document provides a baseline of existing hydraulic conditions for the 4 MRA valley segments of interest. Summaries provided here could be used, if desired, for project prioritization. The raw composite suitability values are available in the `mra_hsi` repository at https://github.com/mackerman44/mra_hsi and the resulting depth, velocity, and composite suitability raster .tifs are available from the authors. Further, inspection of areas with high composite suitabilities for a given species by life stage combination could be used to identify characteristics that may provide for suitable depths and velocities, and perhaps, be used to describe target condtions (recognizing that the baseline of 'target conditions' given contemporary habitat may still be poorer than habitat that was available before anthropogenic influence). Results provided here can be used in the upcoming MRA reports to help describe existing and target conditions.

5 Literature Cited

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