



## **Oregon Department of Fish & Wildlife 2025 Statewide Fish Passage Barrier Priority List**

Oregon Department of Fish and Wildlife | Fish Screening and Passage Program

A ranked list of priority fish passage barriers for use as an assessment tool where fish passage would provide the greatest benefit to native migratory fish for enforcement and habitat restoration purposes.

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## Executive Summary

It is the policy of the State of Oregon to provide for upstream and downstream passage of native migratory fish (NMF). NMF are fish species native to Oregon that migrate for their life cycle needs (OAR 635-412-0005 (33)). Oregon has approximately 41,839 inventoried artificial obstructions (AOs) that are fish passage barriers and can potentially inhibit or delay fish movement. An AO is any dam, diversion, culvert, or other human-made device placed in the waters of this state that precludes or prevents the migration of NMF. (ORS 509.585). Due to the volume of these AOs and the associated cost of repairing them, only a small proportion are addressed each year. Oregon Department of Fish and Wildlife (ODFW) has constructed a list of 611 priority fish passage barriers to identify locations that would maximize the return of NMF to critical habitats if addressed. (Appendix A) Previous priority barrier lists approved by the Oregon Fish and Wildlife Commission in 2013 and 2019 were developed by ODFW staff selecting priority AOs and using a scoring methodology to rank them. Of the 582 barriers on the 2019 priority list, 85 have been addressed, improving access to over 1,460 miles of NMF habitat.

In developing the 2025 priority list, ODFW updated the scoring equation to add two new factors to address climate change concerns. Climate change presents significant challenges for NMF populations, affecting habitat availability and quality, which can increase competition and strain to vulnerable NMF species. In response, the 2025 priority barrier list incorporates new scoring factors that account for current access to cold water and areas resilient to climate change. This allows ODFW to better target restoration efforts that enhance resilience in fish populations and their habitats.

The specific details of these changes are explained in this paper's ranking methodology section and Appendix D. Ultimately, this list continues to use a robust procedure that builds upon the previous efforts to rank priority barriers for NMF passage in the state of Oregon.

## Introduction

Connectivity of aquatic habitats is important to Pacific Northwest fish populations because access to stream habitats is a critical element for sustained fish populations and ecosystem functions. When streams are fragmented, the restricted movement of fish is one of many repercussions to the natural environment that in turn impact fish population viability. Habitat fragmentation caused by AOs also affects water temperature and flow patterns. It alters a stream's capacity to acquire, move, and deposit sediment, and changes a stream's ability to modify the streambed through erosion and deposition. Improving connectivity between habitat types, supports increased production of NMF populations because fish require different physical and chemical conditions to grow and reproduce. Loss and degradation of fish habitats via increasing fish passage barriers has reduced the capacity of many Pacific Northwest fisheries to achieve maximum sustainable productivity. The intent of this priority barrier list is to identify the highest priority fish passage AOs in Oregon and to promote improved fish passage at these priority AOs. Addressing passage at these priority locations will enhance and contribute towards the restoration of Oregon's NMF populations while recognizing that cooperation and collaboration between public and private entities that own and manage AOs is necessary to accomplish this policy goal as envisioned by the Oregon Plan (ORS 541.898).

This document outlines the approach that was used to score and then rank high-priority barriers created by AOs identified by ODFW District Fish Biologists. Fish passage barriers include AOs that prevent or delay the migration of NMF. AOs are defined in OAR 635-412-005 (4) "as any dam, diversion, dike, berm, levee, tide or flood gate, road, culvert, or other human-made device placed in the waters of this state that precludes or prevents the migration of native migratory fish." Preventing the migration of NMF includes causing a significant delay in their passage. Natural barriers such as waterfalls, estuary sedimentation, beaver dams, and

debris jams are omitted from this ranking as directed in ORS 509.585 (3) and OAR 635-412-0015 (1) to prioritize AOs that are human-made structures.

### Policy Framework in Oregon:

Fish passage prioritization and inventory is a requirement of the ODFW’s Fish Passage Program through Oregon Revised Statute (ORS) 509.585 (3). This statute states that ODFW shall “complete and maintain a statewide inventory to prioritize enforcement actions based on the needs of NMF.” Furthermore, the statute states that the Department shall update the priority list every 5 years. The last fish passage priority list was approved by the Oregon Fish and Wildlife Commission in 2019. More specifically, the requirements for the components of the priority list are identified in Oregon Administrative Rule (OAR) 635-412-0015 (6). When determining the placement of an artificial obstruction on the priority list, the Department shall consider the following factors relative to each artificial obstruction for all NMF currently or historically in waters of this state where the artificial obstruction is located. These factors include but may not be limited to:

- The current and future quantity of NMF habitat which is inaccessible;
- The current and future quality of NMF habitat which is inaccessible;
- The reasonably foreseeable future quantity and quality of NMF habitat given known trends in climate change (e.g., changes in timing and quantity of streamflow and stream temperatures);
- Unique or limited NMF habitat which is inaccessible, or should remain inaccessible for fish management purposes;
- The biological status of the NMF;
- The level of fish passage currently provided at the artificial obstruction;
- The presence of other AOs upstream or downstream and the timeframe NMF will be able to use restored passage; and
- Existing agreements with the Department regarding fish passage.

These rules were updated in 2022 to consider future habitat conditions and known trends in climate change. These rule revisions reflect the heightened importance of fish passage and habitat connectivity, particularly given the predicted effects of climate change on local watersheds, including increased water temperatures and lower flows. One of the most cost-effective tools for mitigating the impacts of climate change is to provide connectivity to refuge habitats during periods of high temperatures/low flows and to provide access to additional spawning and rearing habitat – thereby improving the productivity and resilience of fish populations. See Appendix B for the complete text of OAR 635-412-0015.

### Priority Barrier Ranking Methodology

To rank AOs, each barrier received a score from an equation based on the associated habitat and fish species metrics. The equation is devised so that habitat is a multiplicative portion and fish species are an additive portion. Additional additive scores are determined for unquantifiable metrics and climate change factors including future change in thermal suitability and access to cold water habitat. The list was then sorted by score to identify projects that maximize the benefit to NMF.

Each barrier score is derived with the following equation:

$$(Habitat\ Quantity * Habitat\ Quality) * \left( \frac{Level\ of\ Passage}{5} \right)$$

+

$$(40 * number\ endangered\ NMF\ species) + (30 * number\ threatened\ NMF\ species) + (20 * \#NMF)$$

+

$$(15 * \#Auto\ Down) - (15 * \#Auto\ Up) + (30 * Thermal\ Suitabilty) + (30 * Cold\ Water)$$

### Habitat Quantity

River habitat quantity is quantified using stream length. This factor is based on miles of fish habitat that would become accessible to the native migratory species currently present below the barrier, if passage were provided. This value is measured as the number of miles between the priority barrier and the next complete barrier upstream, due to an artificial obstruction or naturally occurring barrier, or the end of fish use. It is averaged across the species in need of passage at the site. Habitat quantity is scaled by using a ranking system that assigns a point value according to the range of average miles of habitat upstream from the artificial obstruction. The mileage ranking classes are as follows:

- >300 miles = 130 points
- 200-299 miles = 115 points
- 100-199 miles = 100 points
- 50-99 miles = 85 points
- 25-49 miles = 70 points
- 10-25 miles = 55 points
- 3-9 miles = 40 points
- 1-2 miles = 25 points
- < 1 mile = 10 points

This scoring method is unchanged from the 2019 list.

### Habitat Quality

Habitat quality is quantified based on a river segment classification with points associated with biologically meaningful characteristics. This method was derived during the update for the 2019 priority list. Habitat Quality scores were assigned based on the connectivity to upstream habitat within each of the seven river segment types, ranging from 7 points (access to all segment types) to 1 point for connectivity with a single river segment type. Scoring habitat quality based on this system provides an increase in the overall habitat value based on the physical habitat benefits provided by fish passage above the AO. Connectivity to multiple river segments is possible with each segment type contributing to the cumulative habitat quality score. See Appendix C for the detailed 2019 method.

This scoring method is unchanged from the 2019 list.

### Level of Fish Passage

This factor addresses the level of fish passage that is currently provided at a given barrier. In most cases, ODFW district staff provided their recommended fish passage status based on knowledge of the barrier and history of fish passage at the site. The values assigned to each level of fish passage are described below:

- 5 - barrier to all native migratory fish,
- 4 - barrier to some native migratory fish adults and/or species,
- 3 - barrier to some native migratory fish adults and/or species for only part of migration period,
- 2 - barrier to all native migratory fish juveniles,
- 1 - barrier to some native migratory fish juveniles and/or for only part of migration period.

- 0 - Full volitional passage for all native migratory fish species, adults and juveniles.

Any barrier with a passage rating less than 5 will receive a reduced upstream habitat score based on the relative degree of blocked passage. The level of passage is applied to the upstream habitat value (Quantity and Quality) because anything less than a complete barrier indicates that fish are already accessing the habitat upstream at varying degrees depending on the severity of the blockage. Therefore, every value less than 5 for the level of passage will reduce the overall score for habitat upstream by 20 percentage points.

This scoring method is unchanged from the 2019 list.

### Listed Native Migratory Fish

This factor addresses fish in need of passage below the barrier that are listed as “threatened” or “endangered” under state regulations or the federal Endangered Species Act (ESA). The presence of ESA listed fish increases the barrier’s score. For each ESA listed fish species present at the barrier, respective status points will be added to the priority ranking. There is no maximum score possible for this factor. A greater weighting factor was applied to a barrier where the presence of ESA listed species occurs as follows:

- 40 Points associated with “Endangered” status
- 30 Points associated with “Threatened” status

In cases where a fish species had a differing state and federal listing status, the higher point value was used to develop the score. This scoring method changed slightly from the 2019 list. The ranking equation for the 2019 versions of the list allocated 15 points for species of “special concern.” This option was removed from the new version of the equation due to inconsistencies and lack of clear definition, ensuring a more standardized scoring system.

### Species Diversity

This factor addresses the number of NMF species in need of passage at the priority barrier. For each NMF species present, there are 20 points awarded to the score of the barrier. NMF species are identified in OAR 635-412-0005 and include 38 fish species. We also included Westslope cutthroat trout, a species not listed in OAR.

This scoring method is unchanged from the 2019 list. However, we included more species of fish in the 2025 list as a result of the updated list of NMF from OAR 635-412-005 which was revised in 2023.

### Auto Up and Auto Down Factors

These categories allow ODFW District Fish Biologists to add or subtract points values for an artificial obstruction based on unquantifiable factors.

- For each “auto-up” factor identified, 15 points will be added to the score. A maximum of 60 points (4 auto-ups) were allowed for each site.
- For each “auto-down” factor identified, 15 points were subtracted from the score. A maximum of 60 points (4 auto-downs) could be subtracted for each site.

The scoring method for auto-ups and auto-downs is unchanged from the 2019 list. However, this year, the reasons for each auto-up and auto-down adjustment are detailed in the priority barrier list, with explanations available in separate Excel sheet tabs, in Appendix A.

## Climate Change Factors

Climate change poses significant challenges to migratory fish populations, affecting their habitats and the barriers they encounter. As temperatures rise and precipitation patterns shift, the availability and quality of aquatic habitats may decline. Warmer water temperatures can alter the distribution of fish species, forcing them to seek cooler environments. This shift can increase competition for limited resources and strain populations already under stress from habitat loss and fragmentation.

Considering these challenges, the prioritization of barriers for restoration becomes even more crucial. The most substantial change to how a barrier is scored between the 2019 list and the 2025 list is the inclusion of two factors to account for the impacts of climate change. By accounting for climate change, ODFW can better target investments that enhance the resilience of both fish populations and their habitats, ultimately improving the effectiveness of restoration efforts across the state. The methodology developed by ODFW considered the potential impacts of climate change in two ways: current access to cold water and future climate reliance as determined by changes in thermal suitability.

## Cold Water Access

This change to the equation accounts for cold water access above a site (defined as areas above the barrier at least two degrees Celsius colder than the reach to which it flows).

Cold water areas were identified using data derived from two sources: a) the daily stream temperatures developed by Siegel et al. 2023 and b) NorWeST stream temperature dataset (Isaak et al. 2017). Where available, Siegel et al. temperatures were used; however, the model's spatial coverage is restricted to Region 17. Where data were unavailable (e.g. the Klamath basin located in Region 18), NorWeST data were used. Cold water was identified following guidance of Sullivan et al. 2021 which defines a cold-water patch as a discrete area of water temperature cooler (2-10 °C) than ambient streamflow immediately upstream. August mean temperatures were calculated for Siegel et al. data between 2010-2021 for comparison while the only comparable metric for NorWeST was August mean stream temperatures 2002-2011 (S2\_02\_11). Each Oregon reach value of the National Hydrography Dataset 1:100k (NHDPlus version 2) (McKay et al. 2012) was compared to its downstream value to identify differences of 2 or more degrees. To be comparable with the other portions of this equation, the cold water value is multiplied by 30 for the score. The cold water values were assigned as below:

- 0 if there is no upstream access to cold water
- 0.5 for access to upstream cold water
- 1 for direct upstream access to cold water

## Change in Thermal Suitability

This change to the equation accounts for a scaled change in thermal suitability between current and predicted future conditions. The thermal suitability score incorporates species occurrence using native fish species for which we have accurately mapped distributions (ODFW 2024), Maximum Weekly Maximum Temperature (MWMT; Isaak et al. 2017), and empirical evidence regarding life stage specific thermal thresholds (EPA (USEPA 2001, USEPA 2003). Data were associated to the National Hydrography Dataset 1:100k (NHDPlus version 2) (McKay et al. 2012) and analysis was restricted to this spatial extent. A function was created to relate MWMT to biological performance of each guild. Uncertainty (standard error) values included with the MWMT metric were included in the function to account for error in the metric. The suitability value for each guild present was summed for each reach. The final suitability values therefore are interpreted along a continua and do

not represent suitable or unsuitable conditions, but rather greater values indicate more suitable conditions for the guilds present and lower values represent less suitable thermal conditions for guilds currently present. This analysis was performed with two climatic conditions available in the NorWeST dataset: MWMT () to represent historical conditions and MWMT (2080) to represent future conditions. Temperature curves representing preferred and detrimental temperatures were developed for three guilds: Char, Coldwater, and Moderately Coldwater. The most conservative guild present was used to calculate the final thermal suitability score.

The NMF Species Guilds and weights:

1. Char Guild (i.e. Bull Trout)
- 2a. Cold Water Core Guild (i.e. all salmon, Coastal Cutthroat Trout, Rainbow Trout, and Steelhead on < 4th order streams)
- 2b. Cold Water Non-Core (i.e. all salmon, Coastal Cutthroat Trout, Rainbow Trout, and Steelhead on  $\geq$  4th order streams)
3. Moderately Cold Water Guild (i.e. interior Redband Trout and Lahontan Cutthroat Trout)

Thermal Suitability scores were calculated for each HUC12 by a weighted average of stream length. The higher the thermal suitability score, the better the thermal suitability is for guilds present. To compare thermal suitability at each barrier site, the percent change between the future and thermal suitability was calculated for each site and then normalized to a 0 to 1 scale. A site with a value of 1 had the least change among all sites in the state and a value of 0 had the greatest decrease in thermal suitability across the state. Similarly, current thermal suitability scores were normalized to a 0-1 scale. These two values were multiplied together to ensure that thermally suitable habitats that remained thermally suitable were distinguished from thermally unsuitable habitats that remained unsuitable. A final normalized value was then multiplied by 30 to determine the Thermal Suitability score for the site.

See Appendix D for more details on the thermal suitability models.

### Summary

Summary: The final priority list contains 611 high-priority AOs ranked and then partitioned into 17 groups. Of the 41,839 AOs inventoried in Oregon as of October 2024, these high-priority obstructions comprise less than 2% of the overall known barriers to fish passage in the state. The priority list represents the highest priority barriers to fish passage in the state. Providing fish passage at AOs for complete barriers will increase habitat previously inaccessible to NMF. Additionally, addressing passage at partial barriers will provide a greater variety of species and life histories with increased opportunities to access these habitats over an extended migration period.

The list includes barriers from all 18 ODFW fish districts across the state, offering a comprehensive geospatial representation of these barriers. In this current update of the fish passage priority list, we focused on the accuracy of the data used to populate the equation. Special emphasis was placed on reviewing the species associated with each site and verifying the estimated habitat quantity available upstream of barriers.

In addition to ordering each AO by score, the priority list has been organized into 17 groups, with each group representing barriers of similar priority ranking rather than a sequential numbering approach. We used a K-means cluster analysis to partition the data into the respective groupings. This analysis is used to organize the barriers into groups with similar scores on the list. A change in group number between the 2019 and 2025 lists does not necessarily indicate a change in the relative priority of a barrier.

In alignment with Oregon Administrative Rules, the biological needs of NMF serve as the primary determinant for establishing the priority barriers and their ranking. ODFW acknowledges that other factors can also come into play when prioritizing sites for fish passage restoration and enforcement. Whether the other factors are socio-economic in nature, common sense driven, or based on feasibility, they help to provide a more complete picture of important considerations for a given site. The priority ranking serves as a valuable tool to assist in making natural resource decisions based on where the greatest habitat gains can be expected to benefit NMF. ODFW understands that the science surrounding fish passage barriers is continually evolving, and future priority lists will be updated as new information and methods become available.

## References

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APPENDIX A 2025 Priority Barrier List

(See spreadsheet)

## APPENDIX B Fish Passage Rules

[Chapter 635](#)

[Division 412](#)

[FISH PASSAGE](#)

**635-412-0015**

### **Prioritization**

- (1) The Department shall establish a list of priority artificial obstructions at which fish passage would provide the greatest benefit to native migratory fish for restoration and enforcement purposes.
- (2) The priority list may exclude artificial obstructions where a legal agreement with the Department or Commission specifically indicates fish passage is not required.
- (3) The Department will prioritize working collaboratively with the owners or operators of artificial obstructions on the priority list to establish fish passage.
- (4) The priority list shall be based on the current and future needs of native migratory fish.
- (5) When determining placement of an artificial obstruction on the priority list, the Department may use existing Department information or professional judgment.
- (6) When determining placement of an artificial obstruction on the priority list, the Department shall consider the following factors relative to each artificial obstruction for all native migratory fish currently or historically in waters of this state where the artificial obstruction is located. These factors include but may not be limited to:
  - (a) The current and future quantity of native migratory fish habitat which is inaccessible;
  - (b) The current and future quality of native migratory fish habitat which is inaccessible;
  - (c) The reasonably foreseeable future quantity and quality of native migratory fish habitat given known trends in climate change (e.g., changes in timing and quantity of streamflow and stream temperatures);
  - (d) Unique or limited native migratory fish habitat which is inaccessible, or should remain inaccessible for fish management purposes;
  - (e) The biological status of the native migratory fish;
  - (f) The level of fish passage currently provided at the artificial obstruction;
  - (g) The presence of other artificial obstructions upstream or downstream and the timeframe native migratory fish will be able to use restored passage; and
  - (h) Existing agreements with the Department regarding fish passage.
- (7) The Department shall field verify the information used for prioritization prior to initiating any enforcement action.
- (8) The Department shall make changes to the priority list using the most recent information after enforcement occurs at five priority artificial obstructions or as directed by the Commission.
- (9) The Commission shall review and amend the priority list when the Department changes the ranking of barriers on the list, and at least once every five years.
- (10) The Department may order an owner or operator of an artificial obstruction on the priority list who has been issued a water right, owns a lawfully installed culvert or owns another lawfully installed obstruction to install fish passage or to provide mitigation within a defined timeframe under any of the following circumstances:
  - (a) The owner or operator of an artificial obstruction refuses to work cooperatively with the Department;
  - (b) The Department can arrange for non-owner or non-operator funding of at least 60 percent of the cost for fish passage design, construction, and installation; or
  - (c) The artificial obstruction is ranked in the top ten within a Department Region on the priority list.

(11) Once the Department has arranged for non-owner or non-operator funding of at least 60 percent of the cost for fish passage design, construction, and installation at an artificial obstruction the owner or operator of an artificial obstruction has two years from the Department's order to:

(a) Install a fish passage structure according to a fish passage plan approved by the Department;  
or

(b) Provide mitigation that the Commission determines is a net benefit to native migratory fish.

(12) The relative position of an artificial obstruction on the priority list should not be used as a basis for approving or denying an application for an exemption.

## APPENDIX C Habitat Quality

(Methods from the 2019 List)

We developed a multivariate regression tree analysis based on environmental variables including catchment area, mean summer water temperature, and species association abundances. Mean summer water temperature was the highest 30 day average water temperature between the months of July and August. Regression tree analyses distinguished seven segment types based on mean summer temperature and network catchment area (Figure 1). Nonmetric multidimensional scaling analyses suggested that fish assemblages differed among segment types. Species that were indicative of specific segment types generally had habitat requirements that matched stream segment attributes. The classification system we developed performed significantly better than subjective weighting of habitat quality metrics.

We developed four categories of species associations (SA I–IV) that represented distinct thermal and physical characteristics of Oregon Rivers based on known fish species distributions. Species associations were truncated based on 32 species of NMF as defined under OAR 635-007-0501. Development of the first level of the classification system was a multi-step process in which differences in fish abundance in SA I–IV (Table 1) were related to differences in mean summer stream temperature and catchment area using regression trees. Multivariate regression tree analysis was used to relate differences in fish abundance to differences in mean summer stream temperature and catchment area with regression tree sizes constructed using a complexity parameter of 0.01 (Figure 1). Because of the connection between rivers and the Pacific Ocean, drastically different ocean-influenced fish assemblages can occur within large rivers depending on habitat conditions and therefore the similarity of species associations in large river habitats was a result of the non-migratory behavior where coefficient of concordance tests allowed to test whether the species associations in large rivers were significantly co-occurring. This resulted in a distinct tree for species associations in medium to large rivers (Figure 1).

After running the multi-variate regression tree analysis, river segment classification was determined using a nonmetric multidimensional scaling (NMDS) technique to summarize patterns of fish assemblage structure and habitat variables. Multivariate analysis of variance was used to test for differences in segment scores. SA I was the most abundant assemblage at summer stream temperatures less than 18.1 °C (Figure 1). SA I was also the most abundant species association at temperatures as cool as 16.1 °C for segments with catchment areas between 74 and 250 km<sup>2</sup>. Similarly, SA III was the most abundant species association when catchment areas were less than 74 km<sup>2</sup> and summer stream temperatures were warmer than 19.0 °C; it was also the most abundant species association at catchment areas between 250 and 735 km<sup>2</sup> with summer stream temperatures warmer than 18.1 °C (Figure 1). Based upon the attribute partitions identified by multivariate regression tree and the resulting changes in presence of the species associations, seven river segment types were identified as: cold headwater (CDH), cold stream or river (CDS), cool headwater (CLH), cool stream (CLS), warm headwater (WH), medium river (MR), and large river (LR). Three additional segment types were eliminated based on nonconcordance. Because physical habitat provides the template for evolution of organisms and organization of communities, physical attributes are considered adequate for developing biologically meaningful classifications (Frissell et al. 1986; Imhof et al. 1996). Additionally, the wide availability of GIS databases of landscape attributes (e.g., catchment area, surficial geology, landscape topography, and climate conditions) that control instream features, such as water temperature and discharge, makes it possible to classify streams across large areas such as the state of Oregon.

This parameter of the priority ranking represents the quality of habitat upstream of the priority barrier that fish would gain access to if the barrier were passable. Habitat quality is quantified based on the river segment classification with points associated with biologically meaningful characteristics. Habitat Quality scores are assigned based on the connectivity to upstream habitat within each of the seven river segment types from 7

points (access to all segment types), 6 points (access from Warm River to multiple upstream segment types) to 1 (point) for connectivity with a single river segment type. Scoring habitat quality based on this system provides an increase in the overall habitat value based on the physical habitat benefits provided by fish passage above the artificial obstruction. Connectivity to multiple river segments is possible with each segment type contributing to the cumulative habitat quality score. The assumption is made that the more accessible specific and varied stream habitats (number of different segment types) above the barrier, the higher the value of habitat gained and therefore potential fish production is increased. Furthermore, the cumulative scoring of habitat quality provides benefits to barriers that increase access to cold water refuge that may benefit fish stocks under future climate change scenarios.

Figure 1. Multivariate regression tree showing the habitat quality divisions within Oregon rivers.

Abbreviations are as follows: CDH = cold headwater, CDS = cold stream or river, CLH = cool headwater, CLS = cool stream, WH = warm headwater, MR = medium river, LR = large river, JUL is mean summer stream temperature between the months of July and August (°C), and AREA is stream catchment area (km<sup>2</sup>).

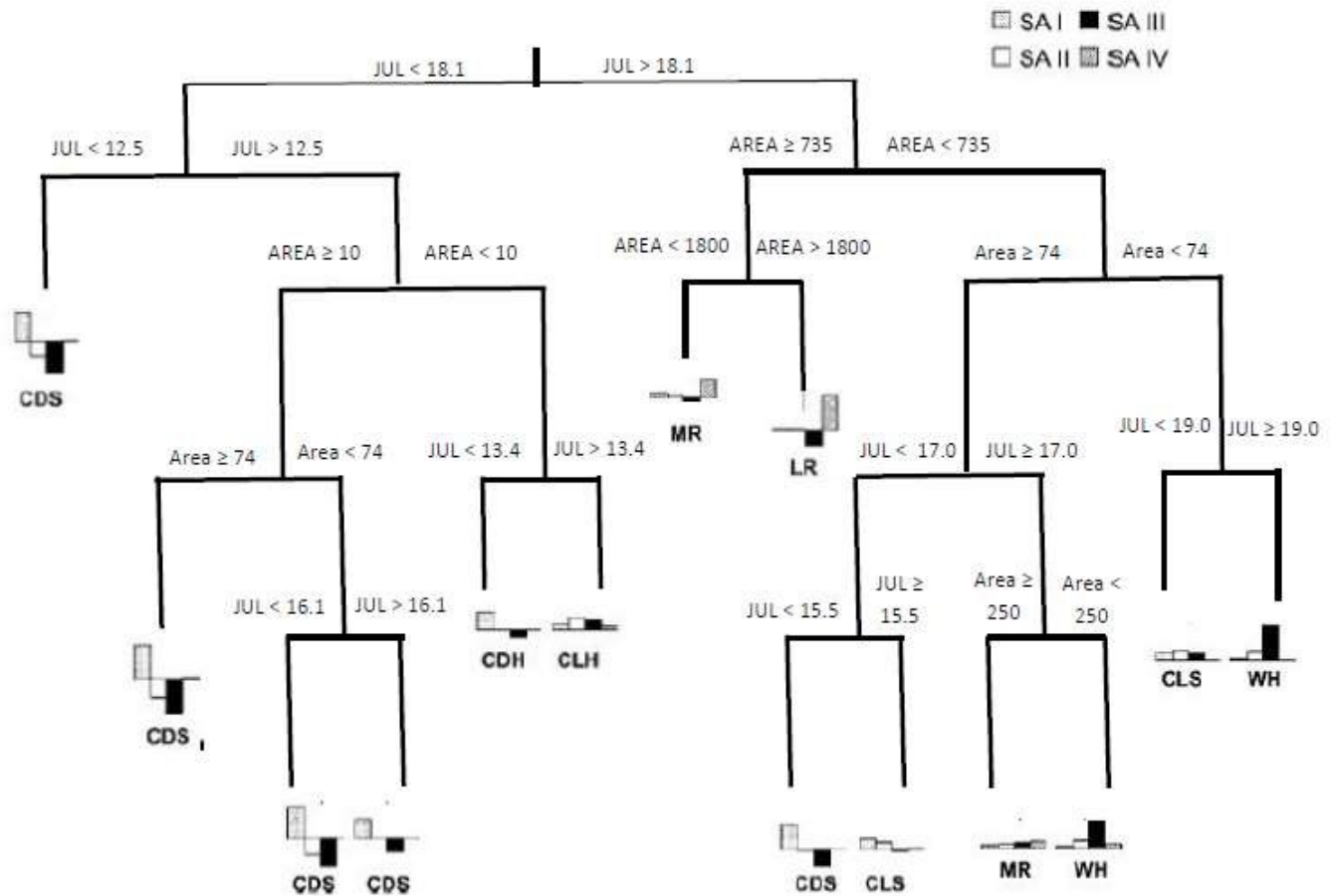


Table 1. Fish species associations (SA) used in developing habitat quality metrics for Oregon river segments. SAII, low species associations had a significantly low level of concordance, but were clustered in proximity to each other.

SA I	SAII	SAII, low	SA III	SA IV
Bull trout	Chum Salmon		Bridgelip Sucker	Green Sturgeon
Cutthroat trout	Coho Salmon	Pit-Klamath lamprey	Lost River Sucker	White Sturgeon
Rainbow trout	Chinook Salmon	Sockeye salmon	Largescale Sucker	Redtail Surfperch
Miller Lake Lamprey	Pacific lamprey	Klamath lamprey	Modoc Sucker	Eulochan
Mountain whitefish		Northern Pikeminnow	Klamath smallscale Sucker	Surf smelt
Redband Trout			Klamath Largescale Sucker	
Mountain Sucker			Tahoe Sucker	
Goose Lake Sucker			Warner Sucker	
			Shortnose Sucker	
			River lamprey	
			Redband Trout	

# APPENDIX D Thermal Suitability Methods

## Defining Thermal Suitability for Native Fish in Oregon Methods

### Thermal metrics

The maximum weekly maximum temperature (MWMT) is the temperature metric used in all spatial analyses. This metric, also known as the seven-day average of the daily maximum temperatures (7-DADM), describes the maximum seasonal or monthly value of the daily maximum temperatures over a running seven-day consecutive period. This metric is recommended by the USEPA as it is not overly influenced by the maximum temperature in a single day but describes maximum temperatures in a stream and the maximum temperatures fish are exposed to over a week-long period. The MWMT is generally 3° C higher than the weekly mean. This metric can be protective for both acute (e.g. lethality, migration blockage) and chronic effects (e.g. effects on growth, smoltification) of temperature. All MWMT stream temperatures were derived from NorWeST (Isaak et al. 2017).

Standard error of individual stream reach temperature predictions were used to weight the probability of a particular temperature estimate being within the thermal optimum of a particular species at the relevant life stage in August. Sites with relatively large standard errors would get weighted to account for the variability that exists around each modeled temperature estimate.

### Thermal optima

Our goal was to identify reaches that were within the thermal optima for particular species life stage needs while also considering the maximum temperature at which a survival and productivity of a species will decline. There is an optimal range of stream temperatures within which fish species can effectively thrive (e.g. rear, reproduce, forage for food, digest a meal, etc.). These optimal temperature ranges vary across species and life stages. After reviewing the literature, we ultimately settled on using the numeric criteria recommended by the EPA (USEPA 2001, USEPA 2003). We followed the EPA Guild MWMT values and EPA recommendations during summer maximum temperatures to construct temperature ranges representing preferred and detrimental temperatures within each guild and life stage within a guild. We identified temperature ranges (lower, upper, maximum) that are protective by guild. Three guilds were identified by the EPA: Char, Coldwater, and Moderately Coldwater. Thermal optima were set within a set of life stages (specifically those life stages present in August) within each guild (Table 1; Table 2).

Using existing fish distribution layers, we attributed each stream reach based on the spatial extent of the species. We then noted the life stage represented by those species in August (see example Table 4), noting whether migration or holding, rearing only, or both could be present. Based on the species present we then assigned them to a particular guild (Table 1). For the Coldwater guild, rearing habitat was designated as Core or Non-core, where Core rearing habitats were those with moderate to high density rearing use and Noncore were designated as low density rearing use. To differentiate these Core and Non-core habitats, we used Strahler stream order. Non-core rearing habitats were often paired with adult migration/holding reaches. Non-core rearing habitats and adult migration/holding were in 4<sup>th</sup> order or greater stream reaches within the distribution of a given species while core rearing habitats were in 4<sup>th</sup> order or less stream reaches. Thermal optimums were not specific to particular species run types, e.g. summer steelhead versus winter steelhead. While thermal optima were described for the Char, Coldwater, and Moderately Coldwater guilds (Table 2), only the Core and Non-Core Coldwater guilds occur in the Rogue and South Coast basins.

### GIS Methods and NorWeST Data

When associating the NorWeST MWMT temperature data with the NSI linework using the COMID, we encountered issues related to NHD 100k version discrepancies between the NSI stream linework and the NorWeST temperature attribution linework (NorWeST was completed on the NHD100k version 1 while the NSI was completed on the NHD100k version 2). There were some very small segments that were excluded from the attribution process. We therefore needed to extrapolate some of the data by attributing the missing segment with the data from the upstream segment. When we evaluated the final feature linework, there were additional segments that were not attributed. We overlaid the NorWeST predicted points and attributed these segments by hand based on these points.

The MWMT values were not available for all regions in Oregon. From the USFS, we were able to acquire MWMT scenarios for those regions that based the MWMT values on the strong relationship between MWMT and August means. We used those for the South Central and Mid-Snake regions. For the Lahontan region of the Great Basin, we were only able to use August temperatures so for species in that region, relationships between thermal optima and stream temperatures will be based on average August values.

## GIS Methods and Siegal et al. Daily Temperature Data

Daily stream temperature data were not available for all of Oregon as they were restricted to a) the Pacific Northwest Region 17 and b) data were only modeled for freely flowing streams. For no data values, NorWeST data were used (see above).

## Defining the distribution of thermal optima

We developed a function to model the relationship between stream temperature and biological performance. The function approximates the shape of the curve which characterizes the range of temperatures (on the x-axis) and the biological performance (y-axis) across those temperatures, with higher biological performance within the optimal temperature range identified for a particular guild (Char, Coldwater-Core, Coldwater-Non-Core, and Moderately Cold as defined above and in Table 2). To do this, the function defines several parameters that describe the maximum temperature that would likely be included in the entire distribution (outside of the optimal temperature range but a realistic temperature encountered by the species) and parameters that compose the shape of the curve including the gradient of the ascending and descending limbs and the radius of the curvature. Each temperature estimate has an associated standard error (as a result of the modeling process, see Isaak et al. 2017) which represent a distribution of possible values. Uncertainty is integrated across this distribution effectively weighting the final probabilities of optimum based on the magnitude of the error.

We used an algebraic function (Eq. 1) to model the relationship between temperature,  $T$ , and the biological performance,  $P$ , of a given species/life stage.

$$P(T|T_{max}, b, g, q) = \frac{(-T+T_{max})D}{(1+bD)^g}; D = \left(1 - e^{\left(\frac{\ln(0.5)(-T+T_{max})}{qT_{max}}\right)}\right) \quad (Eq. 1)$$

Model parameters are given in Table 1. We scaled the output of Eq. 1 to the interval [0, 1] by dividing  $P$  by its maximum (Eq. 2).

$$\hat{P} = \frac{(-T+T_{max})D}{(1+bD)^g} \frac{1}{P_{max}}; D = \left(1 - e^{\left(\frac{\ln(0.5)(-T+T_{max})}{qT_{max}}\right)}\right) \quad (Eq. 2)$$

where  $P_{max}$  is found by taking the first derivative of Eq. 1 with respect to  $T$ , setting the result equal to zero, solving for  $T$  (Appendix 1), and then using the result in Eq. 1. The rescaled Performance curves for all guilds is given in Figure 1.

## Integrating Measurement Uncertainty

To incorporate this uncertainty, we calculated the expected value of Performance. The expected value of Performance,  $\tilde{P}$ , is like a weighted average where weights come from a Gaussian probability density function centered on the point estimate of temperature ( $T$ ) with standard error,  $\sigma$ :

$$\tilde{P} = \int_{x=T-5*SE}^{T+5*SE} \frac{(-x + T_{max}) \left(1 - e^{\left(\frac{\ln(0.5)(-x+T_{max})}{qT_{max}}\right)}\right)}{\left(1 + b \left(1 - e^{\left(\frac{\ln(0.5)(-x+T_{max})}{qT_{max}}\right)}\right)\right)^g} \frac{1}{P_{max}} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-T}{\sigma}\right)^2} dx \quad (Eq. 3)$$

## Prioritization

Each reach was assigned a weight based on the occurrence of a particular guild in that reach. The weightings were based on the temperature sensitivity of species within the guild with the higher weighting assigned to the more sensitive guild. The weightings were as follows: Char (4), Cold CORE (3), Moderate (2), Cold NONCORE (1), and for streams outside species distribution (0.5). Next, for each guild, the product of guild occurrence, performance, and weight was obtained. A value was obtained for each guild regardless of the occurrence of that reach in a particular guild. However if occurrence was 0, the value for that reach, for that guild was also 0. For reaches currently outside the distribution of the species considered, we wanted to account for performance across guilds therefore for these reaches, we took the sum of all performance values and multiplied that value by the weight 0.5. Finally, to calculate the final value assigned to each reach, the value that was to be fed into the Bayesian Belief Network, the reach values for each guild were summed.

We calculated a base suitability using MWMT values (or August temperature when not available) for each NorWeST region: Oregon Coast, Mid-Columbia, South Central, Mid-Snake, Lahontan, and Northern California/Klamath (Table 4).

There were a total of 68,085 reaches throughout the state for which we could estimate thermal suitability.

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Table 1. Example fish species by guild and life stage in August. Note: This table was developed specifically for species for which we have spatial distribution extents developed.

<b>EPA Guild</b>	<b>Species</b>	<b>Species Abbreviation</b>	<b>Life Stage</b>	<b>Life Stage Activity</b>
Char (1)	Bull trout	BT	Adult	Migrate, hold
Char (1)	Bull trout	BT	Juvenile	Rear
Cold (2)	Coho salmon	CO	Juvenile	Rear
Cold (2)	Chinook, fall	CHF	Juvenile	Rear
Cold (2)	Chinook, spring	CHS	Adult	Migrate, hold
Cold (2)	Steelhead, summer	STS	Adult	Migrate, hold
Cold (2)	Steelhead, winter	STW	Juvenile	Rear
Cold (2)	Chum	CHM	N/A	N/A
Cold (2)	Coastal cutthroat	CCT	Both	Rear
Cold (2)	Pacific Lamprey	PL	Both	Migrate, rear
Moderate (3)	Redband	RED	Both	Rear
Moderate (3)	Lahontan	LAH	Both	Rear

Table 2. Simplified summary of temperature ranges including the lower and upper temperature optimums and the maximum temperature for the life stage composites: growth (juveniles), migration and holding (adults) or spawning, egg incubation, fry emergence. While spawning, egg incubation and fry emergence are listed in the table, this life stage is generally not present in August based on the species for which we have distribution data. Temperature is presented as the Maximum Weekly Maximum Temperature (MWMT).

Guild	Species	Life stage	Stream Order	Temperature Optimal Range	Temperature Maximum		
Char	Bull trout	Initiation of Spawning	Any	7 – 14	16		
		Migration and hold		10 – 13			
		Juvenile rearing		6 – 12			
Coldwater	Salmon and Trout	Spawn, egg incubation, fry emergence		7 – 14			
		CORE juvenile rearing		<4		10 – 16	22
		Adult holding/NONCORE juvenile rearing		≥ 4		16 – 18	24
		Adult migration only				16 – 20	
Moderately Coldwater	Redband and Lahontan cutthroat trout	Resident adult and juvenile rearing	Any	13 – 20	24		

Table 3. Parameters used in Equation 1 to model biological response to temperature. Function parameters are nonlinearly related, so parameters cannot be interpreted independently of one another.

Parameter	Defintion	Char	Salmonid Core	Salmonid NonCore	Moderate
Tmax	Chronic high temperature	16	22	22	24
b	Specificity of response to temperature	0.08	0.08	0.09	0.09
g	Cold tolerance	800	800	1000	900
q	Steepness toward chronic high temperature	5	8	8	8

Table 4. Regional data sources and attribution.

NorWeST Region	Major Basins Included (Region ID)	Temperature Data
Oregon Coast	Oregon Coast (8), SONC (9), Lower Columbia (2), Willamette (6)	MWMT
Northern CA/Klamath	Upper Smith, Klamath (5)	MWMT
Mid-Columbia	John Day, Deschutes, Umatilla, Grand Ronde, Crooked (7)	MWMT
South Central	Klamath, Silvies, Chewaucan (3)	MWMT correlation
Lahontan	Rincon Cr (4)	August temperature
Mid-Snake	Powder, Burnt, Malheur, Owyhee, Snake (1)	MWMT correlation

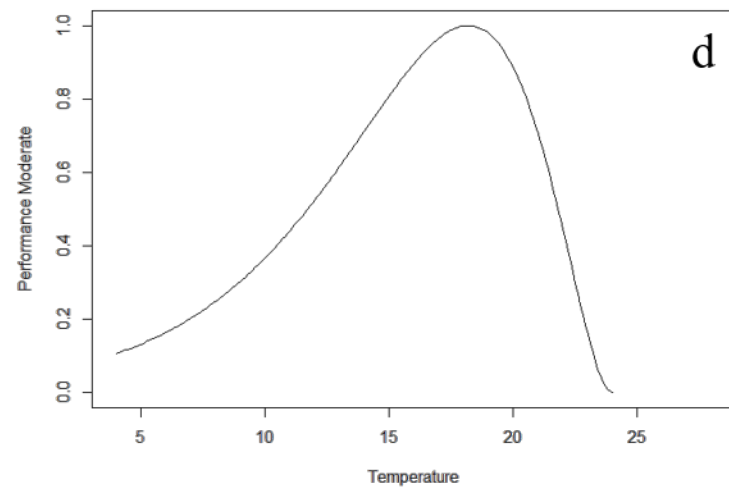
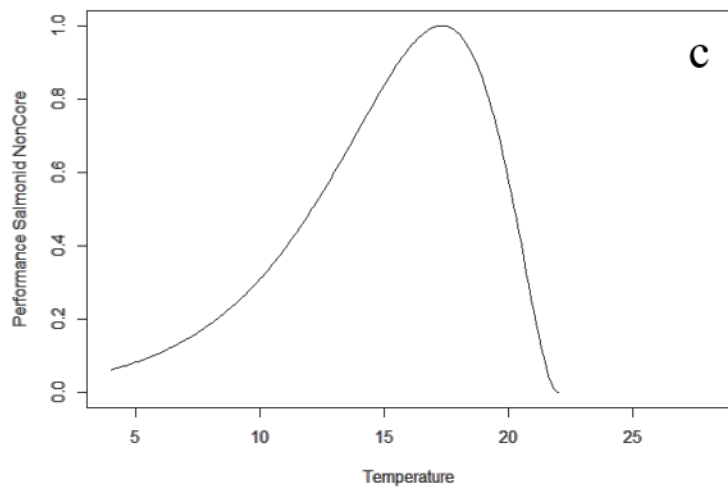
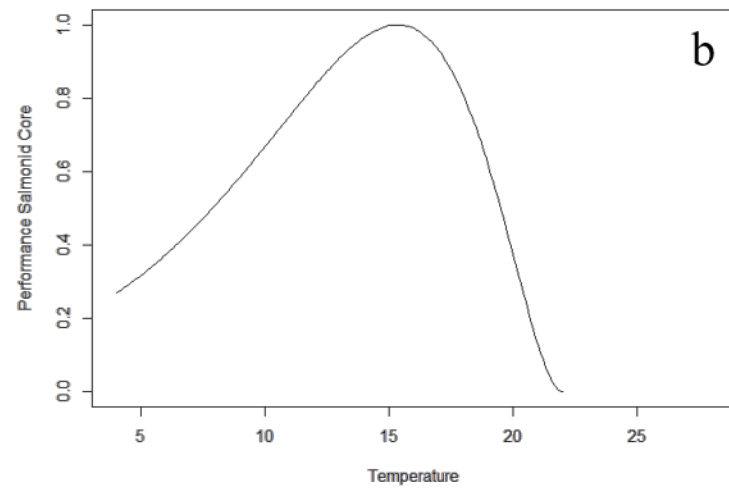
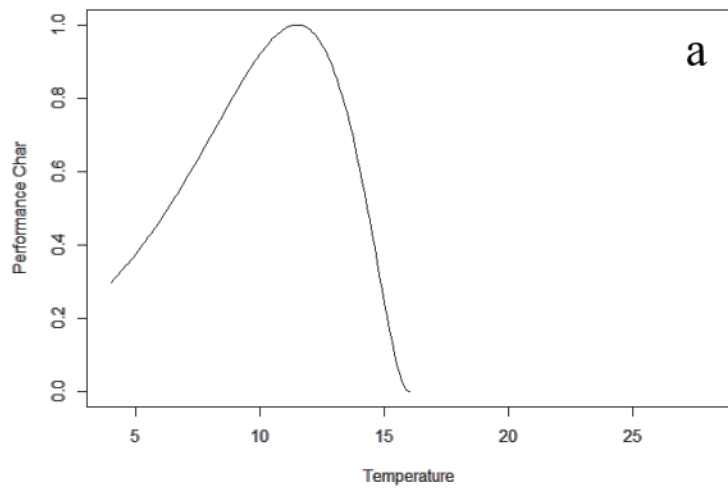


Figure 1. Performance profiles for each of the four guilds: a) Char , b) Coldwater CORE, c) Coldwater NONCORE, and d) Moderate

Appendix 1. Equation for first derivative of  $Eq. I$  with respect to  $T$ , setting the result equal to zero, solving for  $T$  (Appendix 1),

$$\frac{\partial}{\partial z} \left( \frac{(-x+z) \left( 1 - \exp\left(\frac{\log(0.5)(-x+z)}{qz}\right) \right)}{\left( 1 + b \left( 1 - \exp\left(\frac{\log(0.5)(-x+z)}{qz}\right) \right) \right)^g} \right) =$$

$$b g (z-x) e^{-0.693147(z-x)/(qz)} \left( 1 - e^{-0.693147(z-x)/(qz)} \right) \left( \frac{0.693147(z-x)}{qz^2} - \frac{0.693147}{qz} \right)$$

$$\left( b \left( 1 - e^{-0.693147(z-x)/(qz)} \right) + 1 \right)^{-g-1} - (z-x) e^{-0.693147(z-x)/(qz)}$$

$$\left( \frac{0.693147(z-x)}{qz^2} - \frac{0.693147}{qz} \right) \left( b \left( 1 - e^{-0.693147(z-x)/(qz)} \right) + 1 \right)^{-g} +$$

$$\left( 1 - e^{-0.693147(z-x)/(qz)} \right) \left( b \left( 1 - e^{-0.693147(z-x)/(qz)} \right) + 1 \right)^{-g}$$