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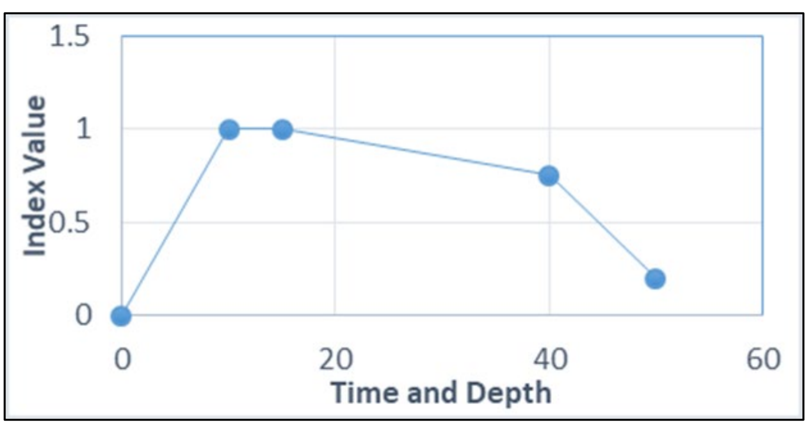
Ecosystem Management and Restoration Research Program

Development of a General Anadromous Fish Habitat Model

Phase 2: Initial Model Quantification

Brook D. Herman, Todd M. Swannack, Nathan S. Richards, Nancy C. Gleason, and Safra Altman

September 2020



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Ecosystem Management and Restoration
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Draft Report

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Under Project SON-13, Critical Species Modeling: Methods Development, Standardization, and Certification for USACE Restoration and Planning

Abstract

The General Anadromous Fish Habitat Model (now the General Salmonid Habitat Model) was developed to assist in the plan formulation process for ecosystem restoration and mitigation projects. The model generates relative differences in habitat quality between proposed alternative future scenarios. In order to provide model development transparency, this report presents the initial quantification phase of the model development process. The draft model depicted in this report is scalable, meaning various parameters may be measured at different landscape scales (for example, reach vs. watershed). The model can be applied (model domain) in watersheds that currently or previously supported salmonid fish species. Application outside of the model domain would need further evaluation to ensure appropriate sensitivity to the new system of interest. Although the model is being developed to explicitly capture changes in fish habitat in response to restoration actions, this model would be appropriate for use in any planning project focused on the restoration of streams, rivers and, estuaries (for example, dam removals, in-stream habitat enhancement), because the parameters are measures of ecosystem level structure, function, and process.

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Preface

This study was conducted for the Ecosystem Management and Restoration Research Program (EMRRP) under Project SON-13, “Critical Species Modeling: Methods Development, Standardization, and Certification for the US Army Corps of Engineers (USACE) Restoration and Planning.” The technical monitor was Dr. Trudy Estes.

The work was performed by the Wetlands and Coastal Ecology Branch of the Ecosystem Evaluation and Engineering Division, US Army Engineer Research and Development Center (ERDC) Environmental Laboratory (EL). At the time of publication, Ms. Patricia M. Tolley was the Branch Chief for the Wetlands and Coastal Ecology Branch, Mr. Mark D. Farr was the Division Chief for the Ecosystem Evaluation and Engineering Division, and Mr. Warren Lorentz was the Acting Technical Director for Ecosystem Management and Restoration Research Program. The Deputy Director of EL was Dr. Jack E. Davis, and the Director was Dr. Edmond J. Russo Jr.

COL Teresa Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director.

1 Introduction and Background

1.1 Background

This report presents the results of steps taken to further the development of a general anadromous fish habitat model that will be used for the US Army Corps of Engineers (USACE) planning process, now known as the General Salmon Habitat Model, and includes the results of the quantification phase in the model development process. The first steps in conceptualization for this model are documented in Herman at al. (2018). This report formulates the model objectives, assumptions, and limitations. Model objectives and limitations for this report include

- distinguishing between proposed restoration alternatives;
- including input from other agencies during and after the development of the conceptual model or model framework;
- ensuring scalability considering different points along a regional system or landscape (estuary to tributary) and considering life cycle requirements (that is, spatially and temporally hierarchical along geography and habitat structure and life-cycle lines);
- relevant to habitats of interest and at the ecosystem level, not just the species; and
- communicating benefits derived from a recommended restoration plan.

This model does not project changes in population numbers of any life stage or species. The model captures changes in the ecosystem as result of USACE activities. Also, it does not project absolute system changes but rather relative differences between proposed restoration alternative actions. Finally, although the parameters were chosen and quantified primarily using the life history requisites of salmonid species, at this step in the process, the model represents suitability of the system for all anadromous and other fish species of concern expected to benefit from habitat restoration. However, later efforts scaled back this assumption, and the current Salmon Habitat Model primarily serves projects that involves Pacific Northwest salmonid species.

1.2 Purpose

This model provides planners with a general model applicable to a variety of project types, at multiple spatial scales, that differentiates between various proposed restoration actions. Multiple salmonid models were developed for prior projects, but since the models were project specific, they were not appropriate for other planning projects. These individual modeling efforts resulted in a high level of cost associated with each project, as each consecutive project developed new models. A general, all-purpose restoration planning model will therefore bring down costs and speed up the planning process.

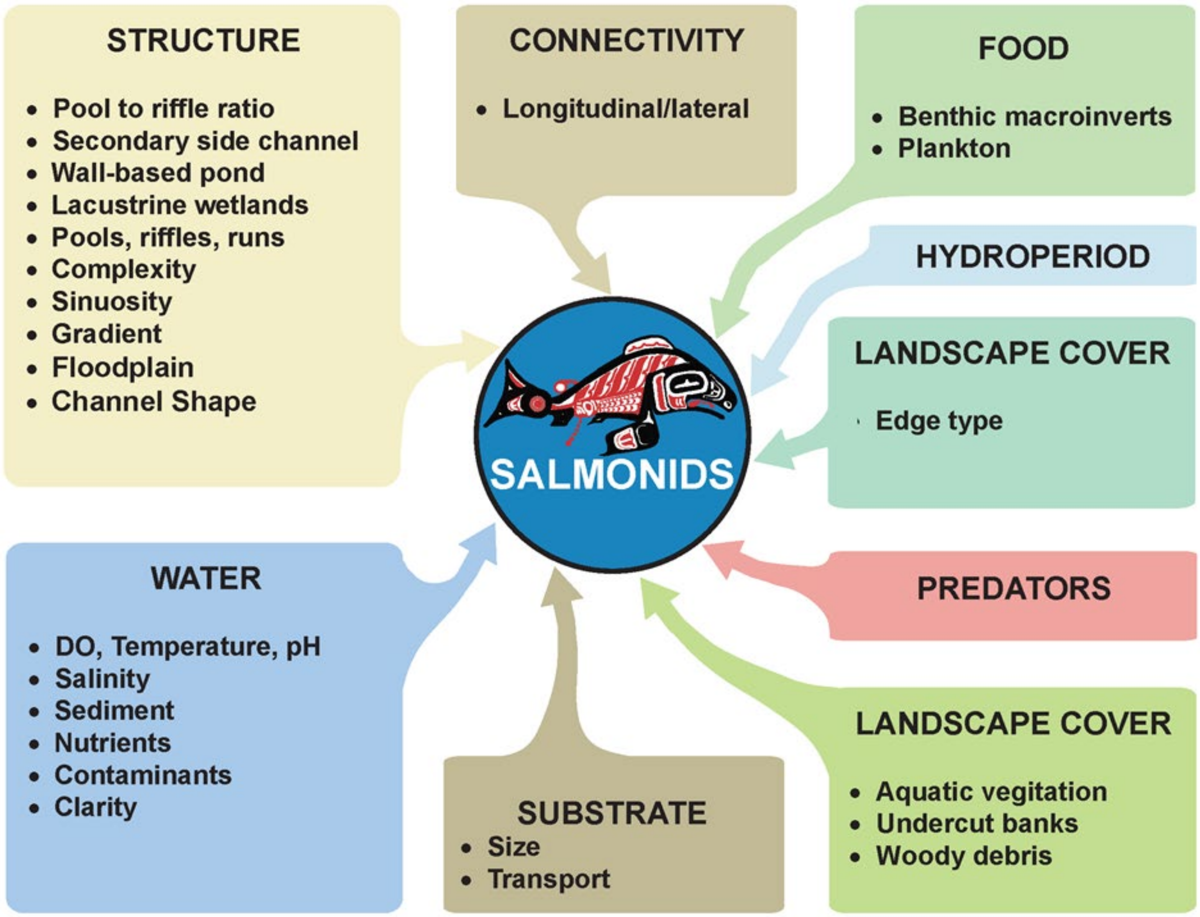
1.3 Objectives

The anadromous fish habitat model (Salmon Habitat Model) was developed to ensure applicability at multiple spatial scales, sensitivity to various proposed restoration actions, and practicability for a variety of project types. Model domain is watersheds that support salmonid fish species along the west coast of the continental United States of America.

1.4 Approach

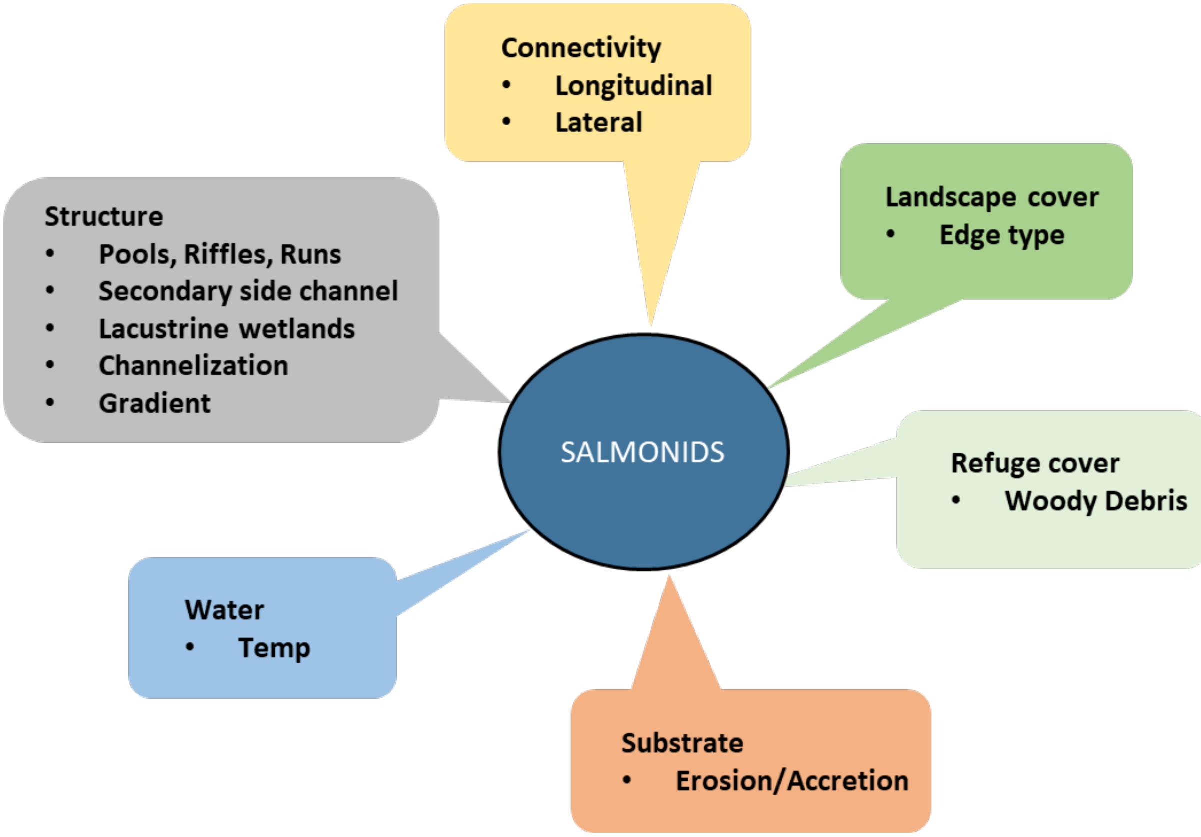
Figure 1 presents an early version of the conceptual anadromous fish habitat model (Herman et al. 2018). In later efforts, the parameters listed in the early conceptual model were qualitatively evaluated to determine if they met the model objectives. The reason to maintain or remove each parameter is documented in Herman et al. (2018). As a result of the parameter refinement, a revised conceptual model was then developed (figure 2).

Figure 1. Early draft of conceptual habitat model.



A mediated modeling workshop further helped develop the model, resulting in consensus on a final conceptual model and draft quantification of parameters. Challenges overcome during the mediated model development workshop included integrating new members of the model development team, cultivating a collective understanding of the applications and limitations of the model (for example, general enough to be applied in a variety of project types and sensitive enough to generate relative differences between proposed future alternative scenarios), and finding a group consensus with the final conceptual model and model framework.

Figure 1. Second draft conceptual habitat model.



1.5 Scope

The mediated model development workshop was held in July of 2016 in Seattle, Washington, which included USACE planers, modelers, biologists, and a non-USACE academic. Mediated modeling is a process wherein facilitators and stakeholders find consensus at each model development phase, which results in a collective understanding of the model's assumptions, limitations, and applications (van den Belt et al. 2006). The first step in the workshop was to revisit the refined conceptual model (figure 2) and reach consensus on which parameters to carry forward into the quantification phase. The categories under question were structure and connectivity. The remainder of the categories did not require further discussion or revision.

Quantification involves defining the mathematical relationship each parameter has to the system of interest. Typically, this is conducted by agreeing on how the parameter should be measured (for example, mg[1]/L, average depth, ft/s[2], etc.) and mathematically describing the response of this parameter to a change in the system (for example, linear, logistic, truncated). For the purposes of this effort, the expected change in the system is a potential future action undertaken by USACE (for example, restoration of woody debris). The group then quantified the maintained parameters through a consensus process, where the workshop participants were encouraged to talk about their experiences (for example, data collection and analysis) and observations of these parameters (Schmolke et al. 2010). After the discussion, the group then reached a consensus about how to measure the parameters and how to mathematically describe each parameter's relationship to a change in the system. The model development team used a combination of published literature and best professional judgment to create the response curves.

1. For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

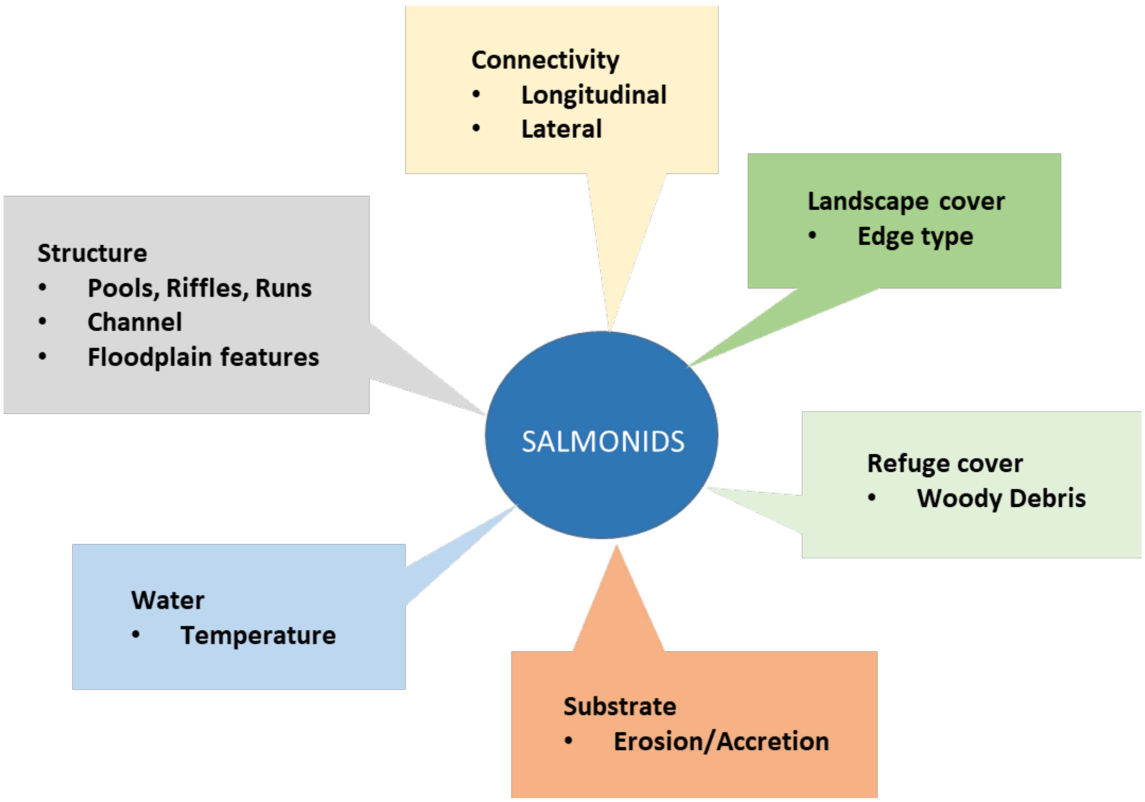
2. For a full list of the unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 345–7, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

2 Results

2.1 Final conceptual model

For a more detailed and in-depth discussion of the importance of each of the parameters for anadromous fish habitat, see Herman et al. (2017). The final conceptual model is presented in figure 3. The final conceptual model includes six categories and nine parameters.

Figure 2. Final conceptual habitat model.



2.2 Parameters reassessed and removed

The following are descriptions of the group consensus reached for each parameter. The consensus resulted in either removing the parameter from further consideration or completing the draft (first effort) quantification phase for the remaining parameters.

2.2.1 Structure

2.2.1.1 Pool-to-riffle ratio

Empirical evidence suggests that there is an optimal pool-to-riffle ratio for salmonid species. However, some stream and river reaches might have never had a naturally occurring mix of pools and riffles, and yet model outputs may indicate that these reaches would provide better salmonid habitat with a mix of pools and riffles. But some reaches would be unsuitable for installing pool-riffle complexes. A model objective was to consider more carefully the restoration of ecological processes vs. static features. The group's concern was that this parameter may be most sensitive to installation of static features and less to restoration of ecological processes. The group decided that this parameter does not support model objectives. In addition, other parameters, such as pools, riffles, and runs, would account for this type of habitat feature; thus, the group removed this parameter from further consideration.

2.2.1.2 Secondary side channel

The presence of naturally occurring or naturalized side channels are a unique feature of the landscape and are a critical need for certain life stages of salmonid species. Removing barriers can create (for example, dredged and armored) or reestablish secondary side channels. These channels are best described as part of a fully functioning floodplain along the tributaries, mainstem, and the tidal zone in estuaries. The group decided that this parameter would be better accounted for under another parameter (floodplain features) removed it from further consideration.

2.2.1.3 Wall-based ponds

Similar to secondary side channels, wall-based ponds are a unique feature and are important for certain life stages (particularly juvenile) of salmonids. Wall-based ponds are also associated with a floodplain. Wall-based ponds' contribution to salmonid habitat would be best accounted for under the floodplain features parameter. Therefore, the group removed this parameter from further consideration.

2.2.1.4 Wetlands (formerly known as lacustrine Wetlands)

Previously, this parameter was named *lacustrine wetlands*, but because wetlands needed for salmonid habitat are found in all landscape units, such as mainstem and estuary, the group agreed to drop *lacustrine* from the title of the parameter. Additionally, because wetlands suitable for salmonid habitat are hydrologically connected to either the floodplain or the tidal surge plain, the group agreed that the benefits from restoring wetlands would be better captured under the floodplain features parameter and removed it from further consideration.

2.2.1.5 Complexity

Complexity is a measure of the number of different in-stream and river/stream bank features present within a reach. The group decided that the same habitat features are accounted for in other parameters, such as channel and pools, riffles, runs; thus, the group removed it from further consideration.

2.2.1.6 Sinuosity

Sinuosity is the amount of nonlinear contouring a shoreline exhibits within a reach of concern. The group decided sinuosity is accounted for under the channel parameter and removed it from further consideration.

2.2.1.7 Gradient

Gradient is the change in elevation over the length of a reach. Gradient is a useful indicator of a number of other habitat features, such as sinuosity and complexity. Gradient is also useful in selecting sites for appropriate restoration measures. However, because gradient is closely tied to other measures of salmonid habitat, such as channel, the group decided to remove it from further consideration.

2.2.1.8 Channel shape

A wide (subjective to reach type) distance between banks, coupled with medium to shallow depth of a channel, supports critical ecosystem functions (for example, hydrology and hydraulics) and features (for example, pools and riffles) that form suitable habitat for salmonid species. Similar to the channel parameter, as the channel’s shape is altered by human activities (for example, straightened and deepened), its ability to form suitable salmonid habitat degrades. Because channel shape was very similar to the channel parameter, the group decided to remove it from further consideration.

2.3 Parameters retained and initially quantified

The results of the initial parameter quantification phase are presented as figures that show the change of parameters in relation to an index value that ranges from 0–1. This relationship reflects how change in the parameter impacts the ability of the system to support healthy ecosystem structure and function, otherwise known as habitat quality. An index value of zero (0) indicates very poor quality habitat; an index value of 1 indicates optimum habitat quality. Each parameter will be further refined based on an in-depth review of published literature and consultation with subject matter experts.

Note that each of the parameters are notated by T—tributary/mainstem, W—watershed, E—estuary. These indicate the spatial scale that is most appropriate for the application of that specific parameter. Many parameters are appropriate at multiple scales. Also, the relationships depicted as the change in habitat suitability with change in parameter are in a draft form and will be further refined in future model development phases.

2.3.1 Structure

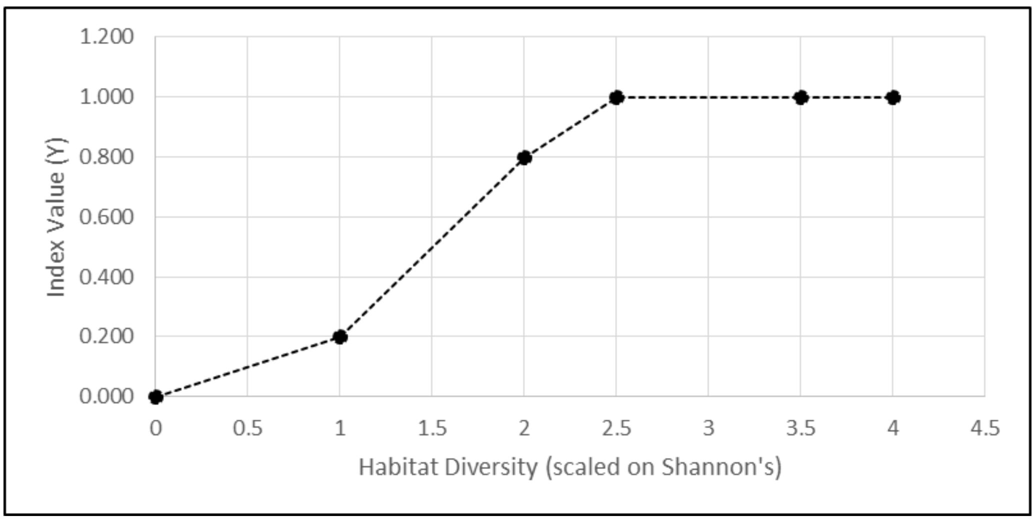
2.3.1.1 Channel (T, W, E) (formerly known as Channelization)

The channel parameter quantifies the diversity of in-stream habitat types that result from the shape and geomorphic contours of a channel (figure 4). When a channel is straightened, the diversity of habitats is lost. The group decided that this parameter represents diversity of in-stream habitats, including secondary and main stem channels, alcoves, sloughs, backwaters, and sinuosity of shoreline. The parameter is measured as an index of diversity (for example, habitat diversity). As the richness (number of total features) and evenness (abundance of features) of channel features increases, so does the quality of anadromous fish habitat. Evenness is calculated as the abundance of one feature in relation to other habitat features in the area of concern. As the abundance of each feature becomes similar to the abundance of the other features, the diversity will increase.

This parameter was developed to be flexible and measurable at any spatial scale. The recommended diversity indices, Shannon's (H´) and Simpson's (D2) (Begon, Harper, and Townsend 1996; Magurran 1988; Rosenzweig 1995), have been well researched and their properties well known. The outputs from the Shannon Index range between 1.5 and 3.5, rarely above 4 (Magurran 1988). Simpson's range from 0 to 1. The use of either of these indices would require the *x* axis to be rescaled, but the response curve would remain the same. The curve would maintain an increase from 0 to 1.00 along the *y* axis, then plateau, with the reason being that any increase beyond 60%–75% maximum habitat diversity (~2.5) may not be as significant as the increase between 0 and 60%–75%.

References: Langler and Smith (2001), Rosenfeld, Porter, and Parkinson (2000), Anlauf-Dunn et al. (2014), Smorkorowski and Pratt (2007), Geist and Daubble (1998), Wippelhauser and Squiers (2015), and McMahon and Hartman (1989).

Figure 3. Draft channel.

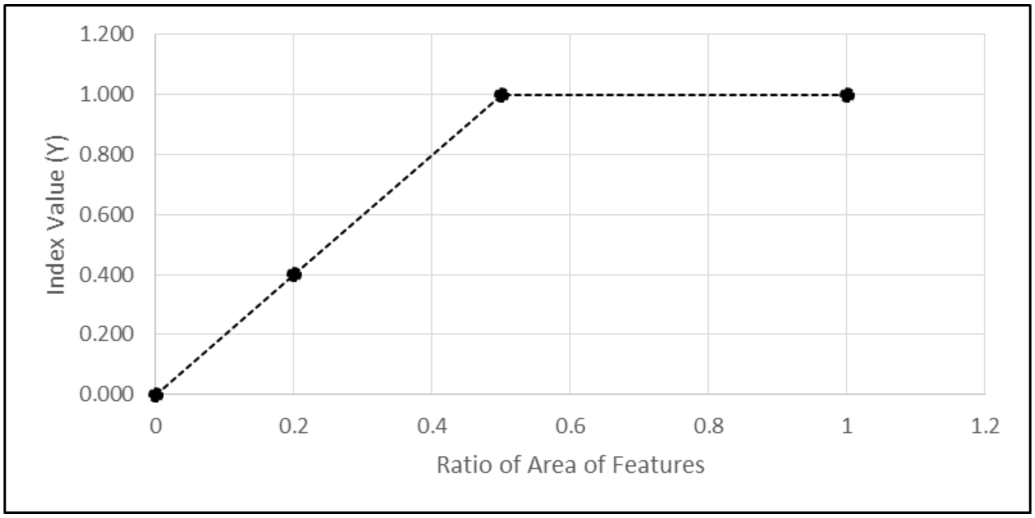


2.3.1.2 Pools, Riffles, Runs (T)

Similar to the parameter pools-to-riffles ratio, this parameter quantifies the relationship of specific in-stream features (for example, pools) to the quality of anadromous fish habitat (figure 5). The group decided that the most appropriate way to measure this parameter is to measure the amount of area each feature covers within a reach and calculate the ratio of area of features. As the ratio becomes more even, the quality of habitat increases, with a plateau in suitability at 0.5. This parameter was developed for the reach scale (T). An important note about this parameter is that not all features are equally important. Pools and riffles are prioritized above runs for restoration planning. This is because of the relative scarcity of appropriate pool-riffles complexes relative to runs currently present within many of the watersheds supporting anadromous fish species of concern. Thus, the application of this parameter should weight the pools and riffles as more important than runs. This relationship will be further refined in future model development phases.

References: Rosenfeld (2014), Muhlfeld, Bennett and Marotz (2001), Bell, Duffy, and Roelofs (2001), and Roper et al. (1994).

Figure 4. Draft pools, riffles, runs.

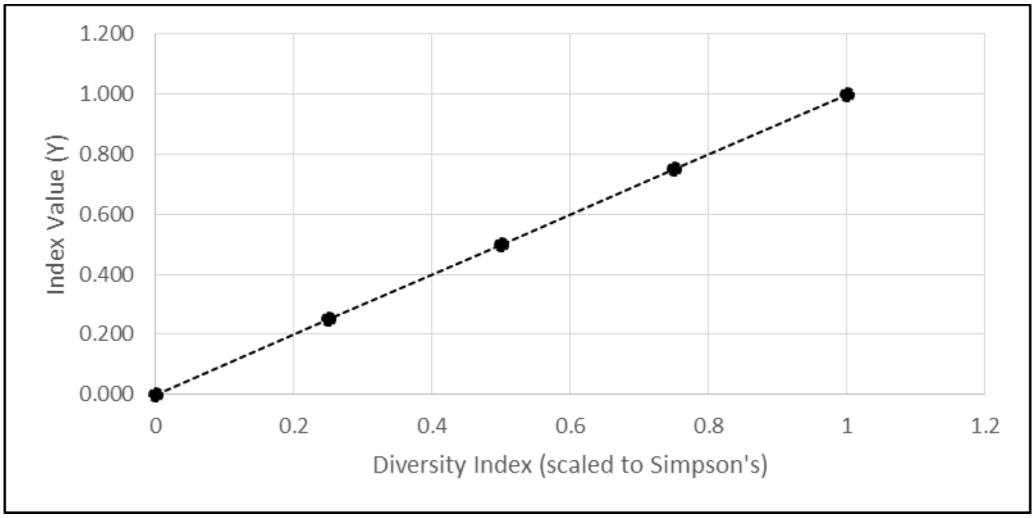


2.3.1.2.1 *Floodplain features (T, W, E) (formerly known as* floodplain*)*

Floodplains provide important habitat features for anadromous fish, especially salmonid species. Floodplain includes the following features: wall-based ponds, oxbows, wetlands, and others. Once floodplain features are destroyed through development or agriculture, they are lost as habitat. As a floodplain is restored, the number of different habitat features available increases, and the quality of habitat increases (figure 6). The group decided that an appropriate measure of this parameter is an index of diversity, such as Shannon's or Simpson's (see channel parameter and Jost [2006]). There is a positive relationship between the diversity of floodplain features and suitability of habitat. The group also decided that the type, number, and evenness of floodplain features differ between landscape units. Mainstem floodplain features include small intermittent tributaries, ponds, lakes, various wetlands, natural levees, and natural upland edges. Tributaries contain oxbows, wall-based ponds, various wetlands, and natural upland ridges. Estuaries contain different various wetlands, tidal channels, panes, natural upland ridges, and tributaries. The group also decided that, depending on the project, one or more of the landscape units may be modeled (for example, mainstem), while the mathematical relationship of the parameter would remain the same for each landscape unit.

References: Branton and Richardson (2014), Beechie, et al. (2012), Roni et al. (2006), and Smokorowski and Pratt (2007).

Figure 5. Draft floodplain features.



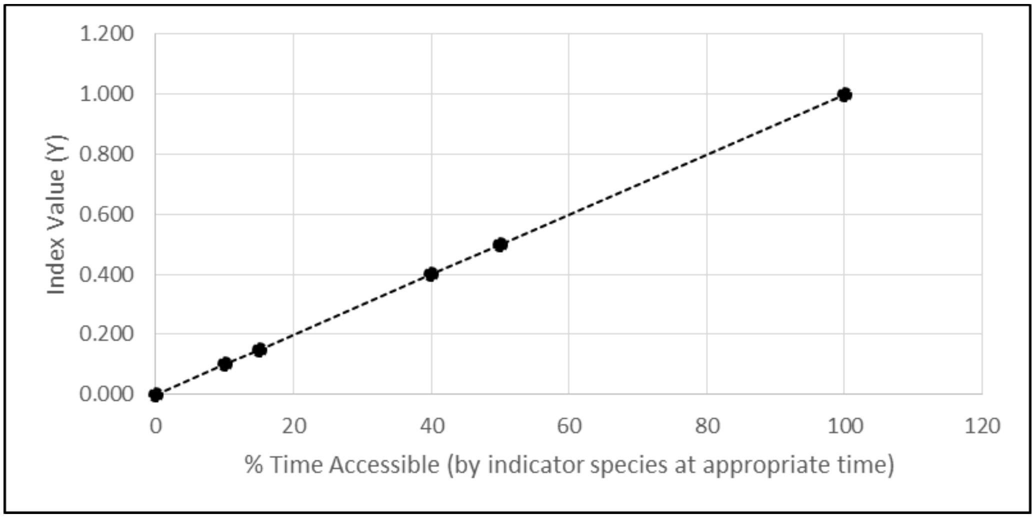
2.3.2 Connectivity

2.3.2.1 Longitudinal connectivity (T, W, E)

Longitudinal connectivity is the ability of an organism to access areas within a stream or river network (for example, watershed). Barriers to movement create disconnected habitat. Barriers to movement may manifest during different times (for example summer low flow) of the year. Longitudinal connectivity is a critical ecosystem component for anadromous species that need to access different habitat types within an aquatic network during different life stages and during different times of the year. As the percent of time increases for the ability of a species to access formerly disconnected habitat, the suitability of the aquatic network or system as a whole increases. The group added a word of caution when calculating baseline and future with project conditions for this parameter because overestimating percent-time accessible is possible. For example, the removal of one barrier may not provide access to all potential habitats above barrier during different times of the year or for different life stages of a species.

References: Beechie, Beamer, and Wasserman (1994), Cote et al. (2009), and Buddendorf et al. (2017).

Figure 6. Draft longitudinal connectivity.

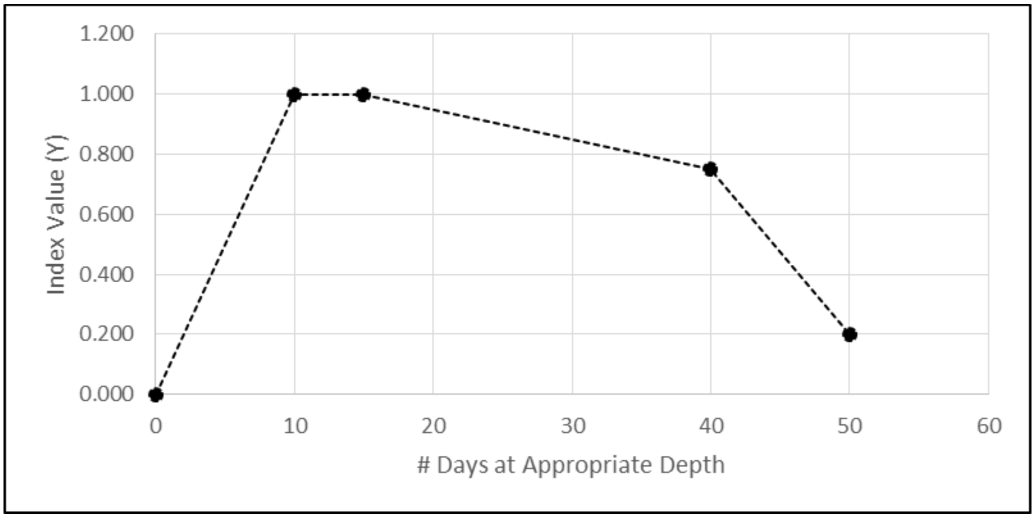


2.3.2.2 Lateral connectivity (T)

Lateral connectivity is the ability of organisms to access habitat adjacent to stream and river reaches within floodplain and surge plain areas. Lateral connectivity is driven by river fluctuations that allow access to floodplain habitat during portions of the year. Lateral connectivity is impacted when barriers (for example, levees) no longer allow species to access floodplain habitat. Another aspect of hydrological connectivity the group identified as an important component in the system of interest was vertical connectivity. Vertical connectivity is the interface of groundwater and surface water in the zones found along the alluvial (hyporeic zone) and hillslope aquifers (phreatic zone). Generally, as lateral connectivity increases, so does vertical connectivity. The group decided that even though a measure of changes in lateral connectivity would account for most changes in vertical connectivity, vertical connectivity should be assessed during site selection in the planning phase. Measurement of lateral connectivity is the combination of time accessible (number of days) and at appropriate depth of flood water (figure 8). As the time a floodplain feature is accessible and the depth of water over the feature increases, so does the suitability of habitat. However, after a 15-day inundation, the suitability of habitat declines, which is outside the normal range of time of inundation for salmonid species specifically. Greater than 50 days of inundation doesn’t destroy the habitat, but it is very poor quality.

References: Merenlender and Matella (2013), Pringle (2003), Sommer et al. (2001), and Sellheim et al. (2015)

Figure 7. Draft lateral connectivity.



2.3.1 Edge-type landscape cover (T, W, E)

The type and amount of vegetation that occur along the network of streams and rivers within a watershed is an important indicator of suitable habitat. As riparian vegetation is converted or lost due to human activities, there is an overall decrease in the quality of habitat (figure 9 and 10). Additionally, in some areas non-native plant species have replaced native plant species. In some cases the non-native plant species provide similar functions as native plant species. However, non-native species largely negatively impact the ecosystem function and structure that support suitable habitat. In order to capture the changes from loss of overall edge cover and conversion of native species to non-native species, the group developed two measures of edge cover and decided that the percent vegetated cover within the riparian buffer (for example, can be both native and non-native or a mix) is positively correlated with suitable salmonid habitat. Edge cover 1 (figure 9) is a response curve exhibiting a mostly linear relationship with percent cover in the riparian buffer area and a plateau of suitability around 75% cover. Additionally, the percent of the riparian buffer area covered by native species was positively correlated with suitable habitat (figure 10). Edge cover 2 (figure 10) exhibits the same response curve as edge cover 1. The group also decided that the buffer area will be measured from toe of bank to the high water level, which allows the measurement of the high water level to accommodate specifics of a project area.

References (edge cover 1 and 2): Burnett et al. (2007), Pess et al. (2012), Klimas and Yuill (2013), del Tanago and de Jalon (2006), Battin et al. (2007), Mellina and Hinch (2009), Wootton (2012).

Figure 8. Draft edge cover (1).

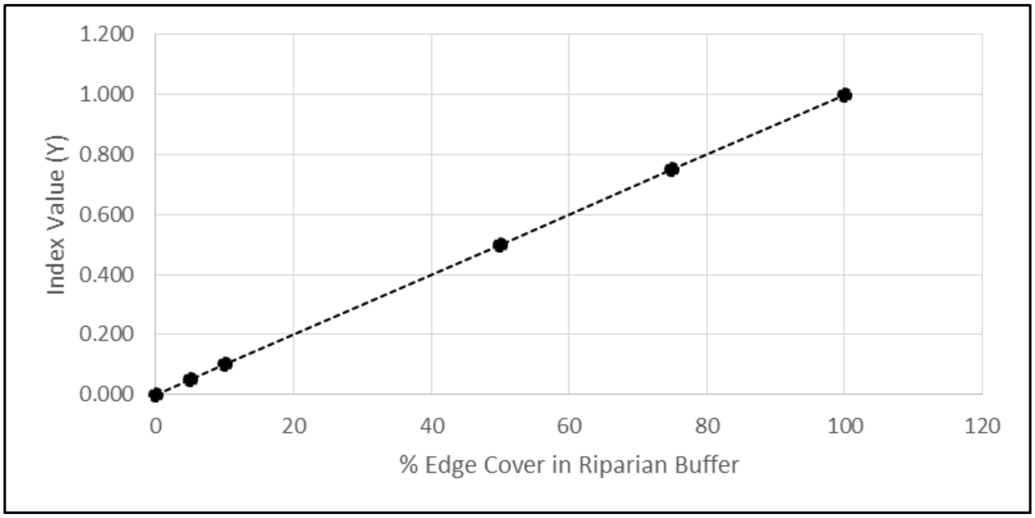
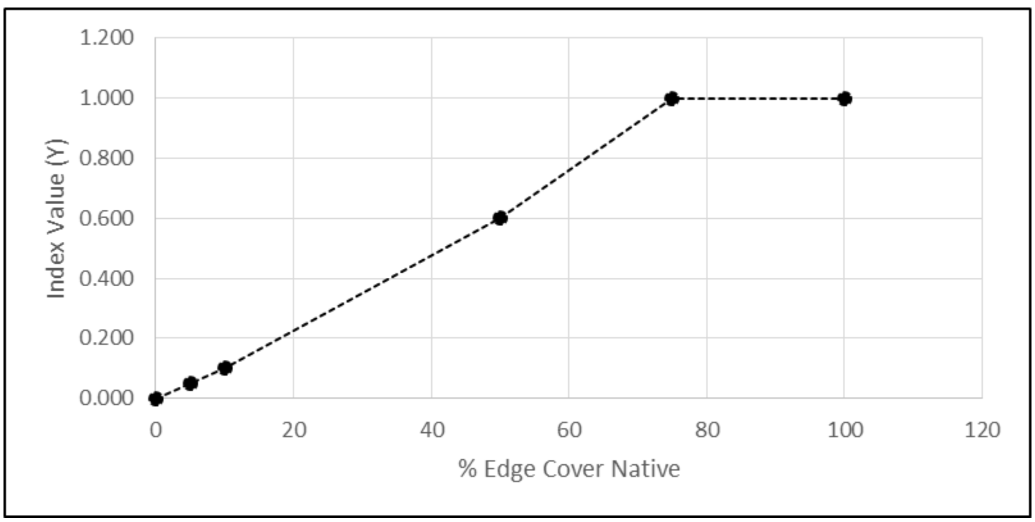


Figure 9. Draft edge cover (2).



2.3.1 Refuge cover

2.3.1.1 Woody Debris (T, E)

Woody debris that falls or is washed into an aquatic system forms critical structures for anadromous fish species at different life stages and during different seasons. As the number of woody debris pieces or multiple piece jams are found within a reach, the quality of habitat for fish species increases (figure 11–13). The group decided this parameter should be measured by the number of pieces found within the bankful width of a reach at the scale of concern (tributary, mainstem, and estuary). There are different optimum number of pieces found within different landscape units (for example, tributary vs. mainstem), and they may differ between watersheds, according to research in Fox and Bolton (2007). After the optimal number of pieces are present within a reach at the scale of concern, any increase in the number of pieces does not increase suitability of habitat. The tributaries are measured as the average number of pieces of woody debris per square meter within the bankful width of the reach (figure 11). Mainstem is measured as the number of pieces within the bankful width along a kilometer of a reach (figure 12). The estuary is measured as the number of pieces found within a drainage area (figure 13). An important note about this parameter is that the reasoning behind the structure of the curve is not necessarily total number of static pieces of woody debris; rather, the curve reflects the restoration of a process that will systematically replenish woody debris over time (for example, upstream woody resources). The direct placement or installation of woody debris as a restoration technique will not necessarily replace this natural mechanism.

References (woody debris 1–3): House and Boehne (1985), Smokorowski and Pratt (2007), Louhi et al. (2016), Beechie et al. (2012), Roni et al. (2010), Fox and Bolton (2007), and Mellina and Hinch (2009).

Figure 10. Draft woody debris tributary (1).

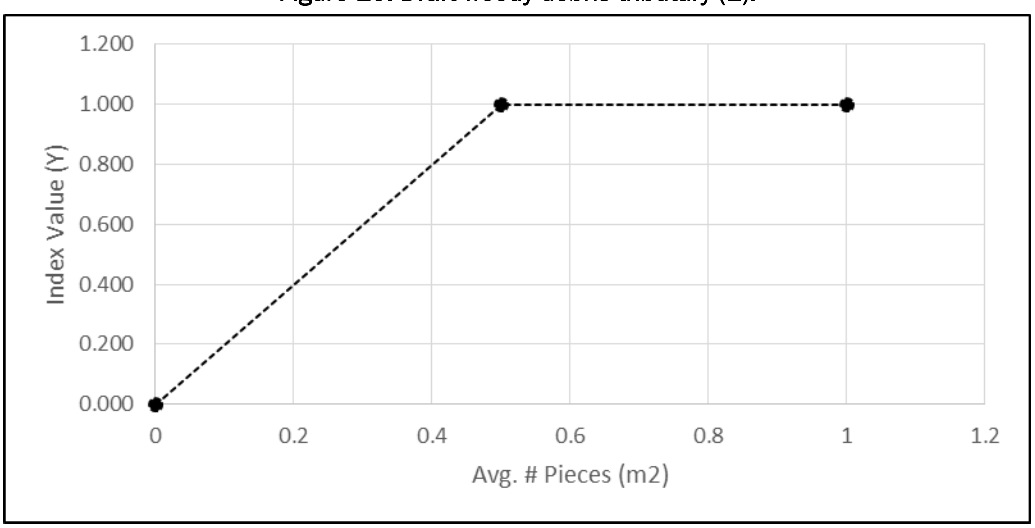


Figure 11. Draft woody debris (2).

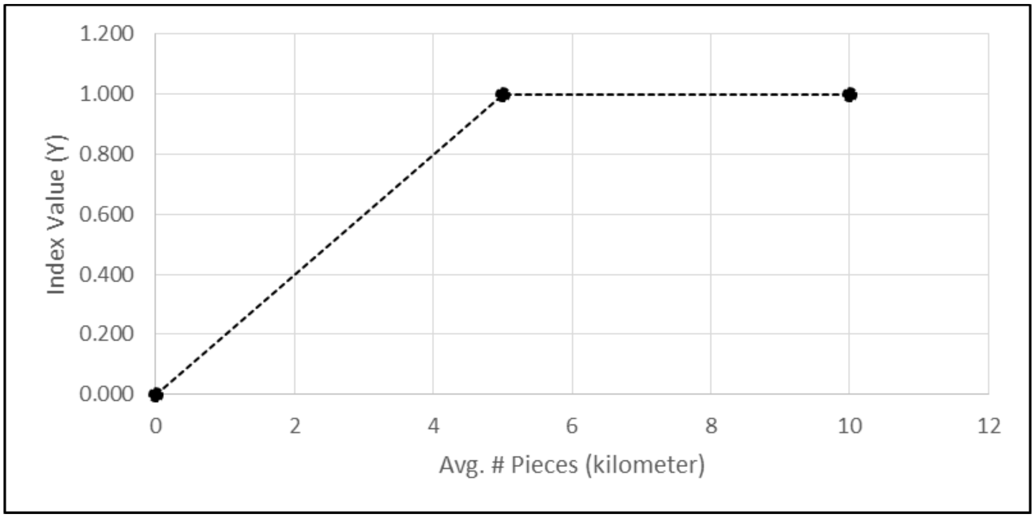
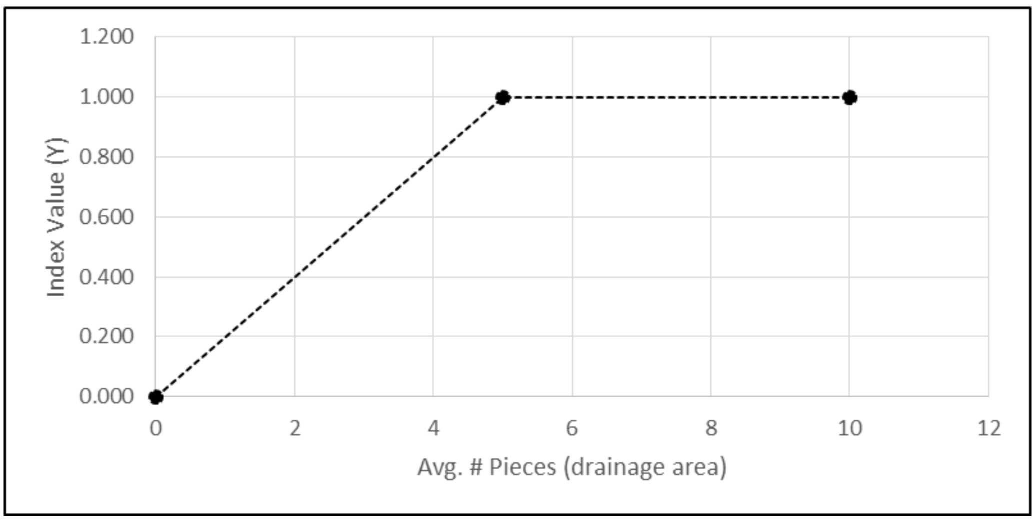


Figure 12. Draft woody debris estuary (3).



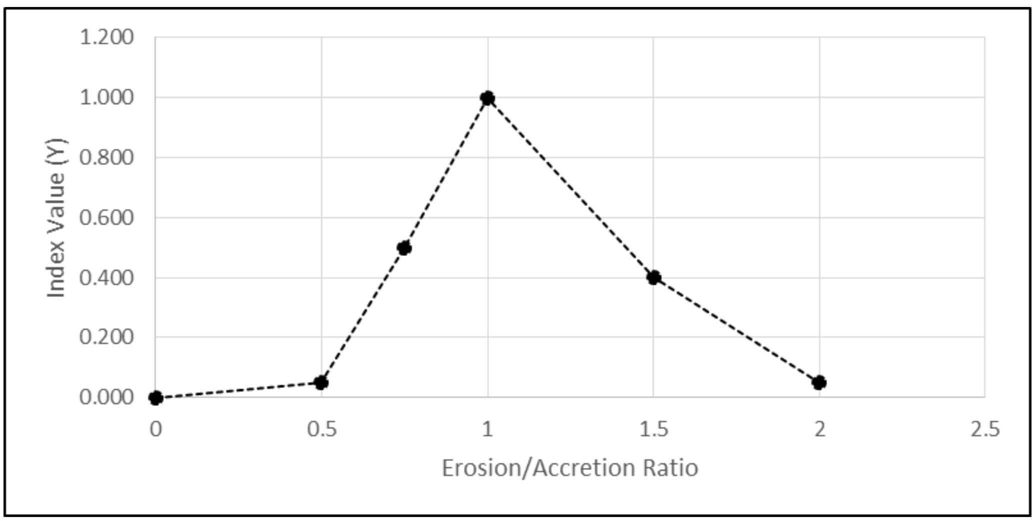
2.3.1 Substrate

2.3.1.1 Sediment (formerly size) (T)

The parameter sediment (formerly size) refers to the sedimentation processes that form critical substrate for a variety of different life stages of anadromous fish species. During discussions, the group realized that trying to measure average size of particles or dominant particle size of any substrate type would not support the model objectives, such that the model objectives emphasize the benefits of restoring processes vs. static features. In order to support model objectives, the group decided to measure a proxy of sediment transport processes that indicates suitable habitat. The ratio of accretion to erosion is indicative of a process that forms and maintains critical substrate for different life stages of anadromous fish species. As the rate of accretion exceeds erosion, or erosion exceeds accretion, habitat suitability decreases (figure 14). The goal of restoration is to assist these dynamic forces into a more normalized pattern where the rates of accretion and erosion are similar. The measurement of this parameter would be an average visual assessment of the area of concern to decide whether a project along a tributary or main stem is more or less accreting or eroding. The reason for visual assessment, instead of a more robust quantitative measurement, is that the cost of quantitative measurement does not provide any further information that would be needed to determine habitat suitability.

References: Reiser and White (1988), Collins et al. (2014), and the National Oceanic and Atmospheric Administration (NOAA) Fisheries (2004).

Figure 13. Draft sediment.



2.3.1 Water

2.3.1.1 Temperature (T, W, E)

High water temperatures (>25°C) within the summer months are known to have adverse impacts on anadromous fish species, particularly salmonids. Water temperature is measured as a function of habitat suitability (figure 15–19). The group expressed concern that just one measure of temperature, such as mean daily summer temperature, would not capture all the possible scenarios of restoring water temperature to a more suitable range. Different life stages of fish species have different tolerances related to time of exposure, seasonality, and landscape unit type. In order to accommodate potential future restoration scenarios, the group developed three different mathematical relationships for representing different aspects of how temperature is a function of habitat. In addition, each of the three curves was calibrated for west coast (WC) and east coast (EC) anadromous fish species.

The first (1) relationship (general temperature) describes the general range of water temperature and its associated habitat suitability. As temperature increases for the WC, from the expected low of 15°C to greater than 25°C, the suitability of habitat decreases. The EC is calibrated for colder and hotter temperatures, ranging from 8°C to 32°C. The second (2) relationship (bioenergetics) describes the predicted performance of individuals in terms of successful migration, breeding, and rearing. The bioenergetics curve is shared by both EC and WC anadromous species. There is an optimum range of bioenergetics that sits around 15°C, and anything lower or higher is not as suitable. The third (3) relationship describes predictive survival ranges. WC anadromous fish are expected to survive temperatures between 0°C to 25°C; anything greater than 25° is considered lethal to most life stages and in most landscape units. EC anadromous fish share a similar relationship but can withstand higher summer temperatures, 0°C to 34°C. The way in which temperature is measured for each relationship (for example, mean annual temperature, mean daily temperature) is intentionally left open for future project needs. For example, if a project planned to restore optimum performance temperatures within an estuary, the measurement and range of optimum temperatures would be different than for a tributary. Note that while the *x* axis is a placeholder for some measurement of temperature to be determined according to project objectives, the response curve remains the same.

References (temperature 1–3 WC): Branton and Richardson (2014), Geist et al. (2006), Groves and Chandler (1999), Mellina and Hinch (2009), Honea et al. (2009), and Wootton (2012).

References (temperature 1–3 EC): Bigelow et al. (1963), Peterson, Spinney, and Sreedharan (1977), Jordan and Beland (1981), Kynard et al. (2009), and Dadswell et al. (1984).

Figure 14. Draft general temperature (1) WC.

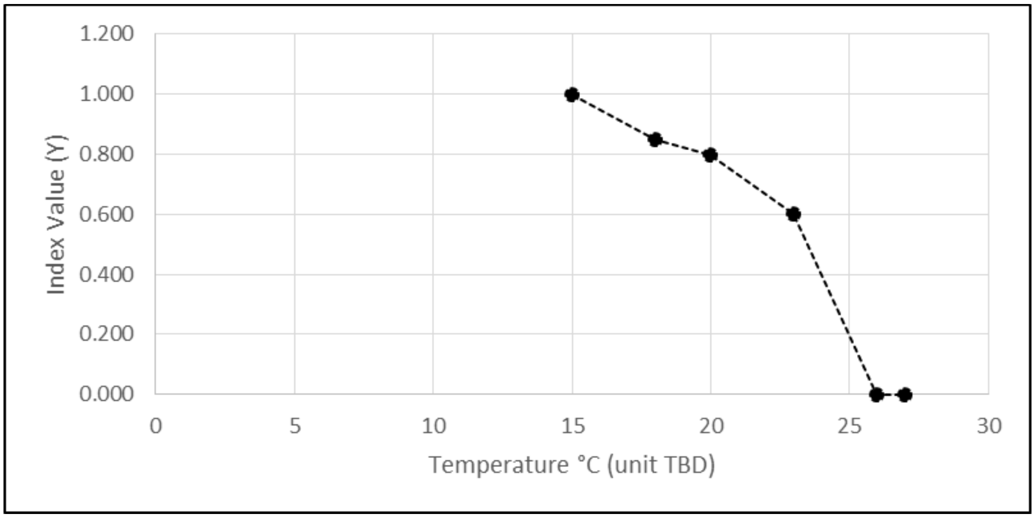


Figure 15. Draft general temperatures (1) EC.

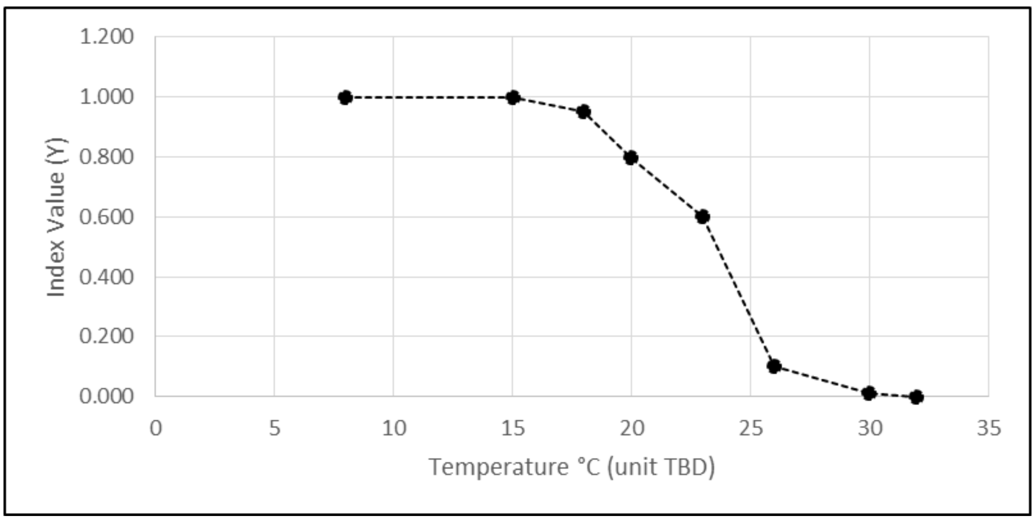


Figure 16. Draft bioenergetics temperature (2).

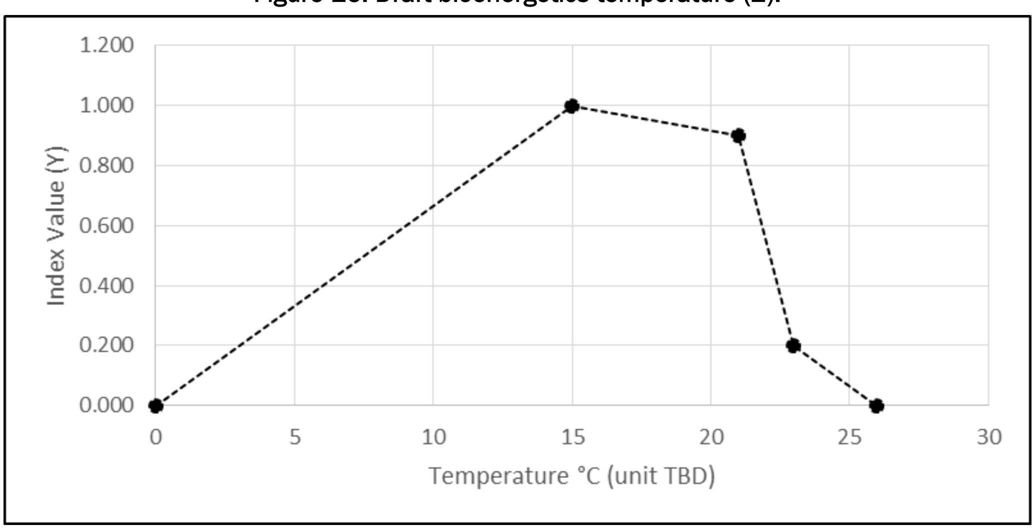


Figure 17. Draft survival temperatures (3) WC.

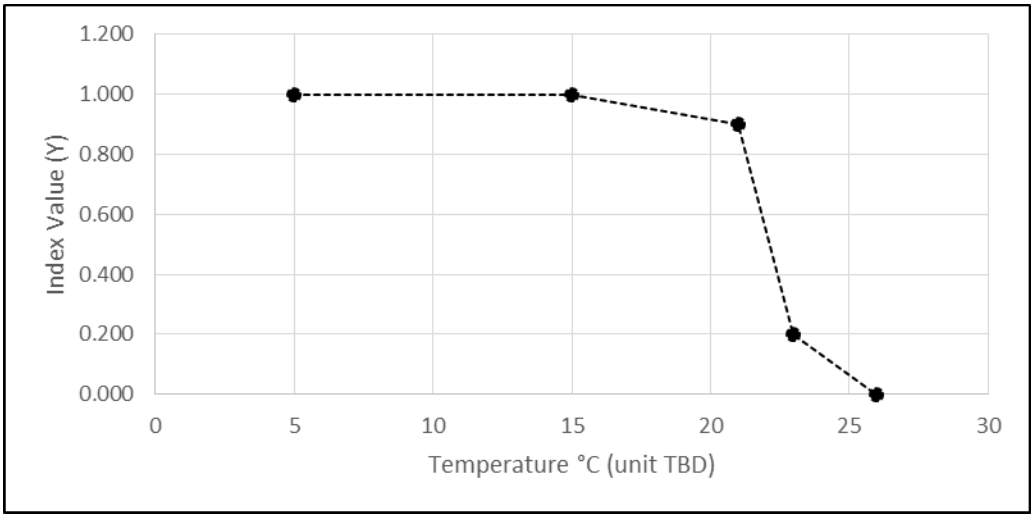
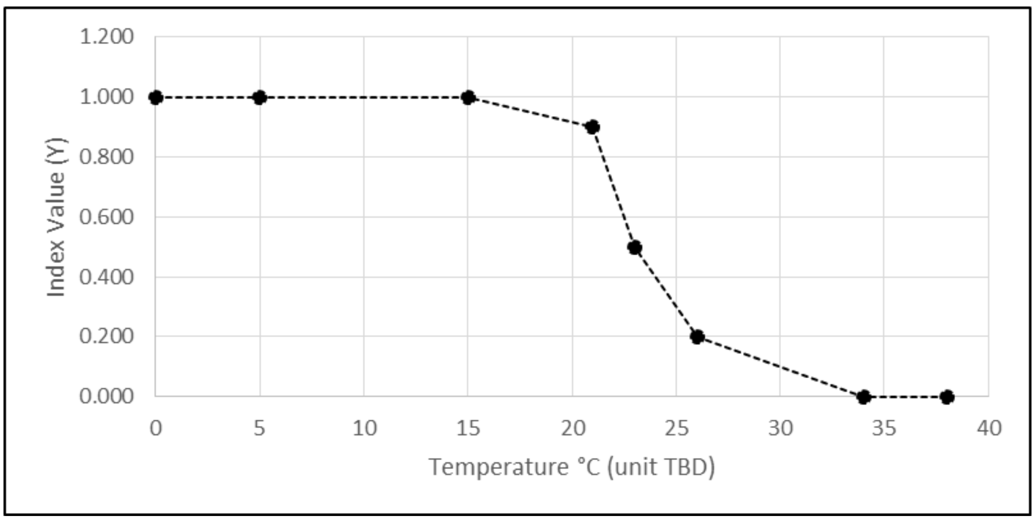


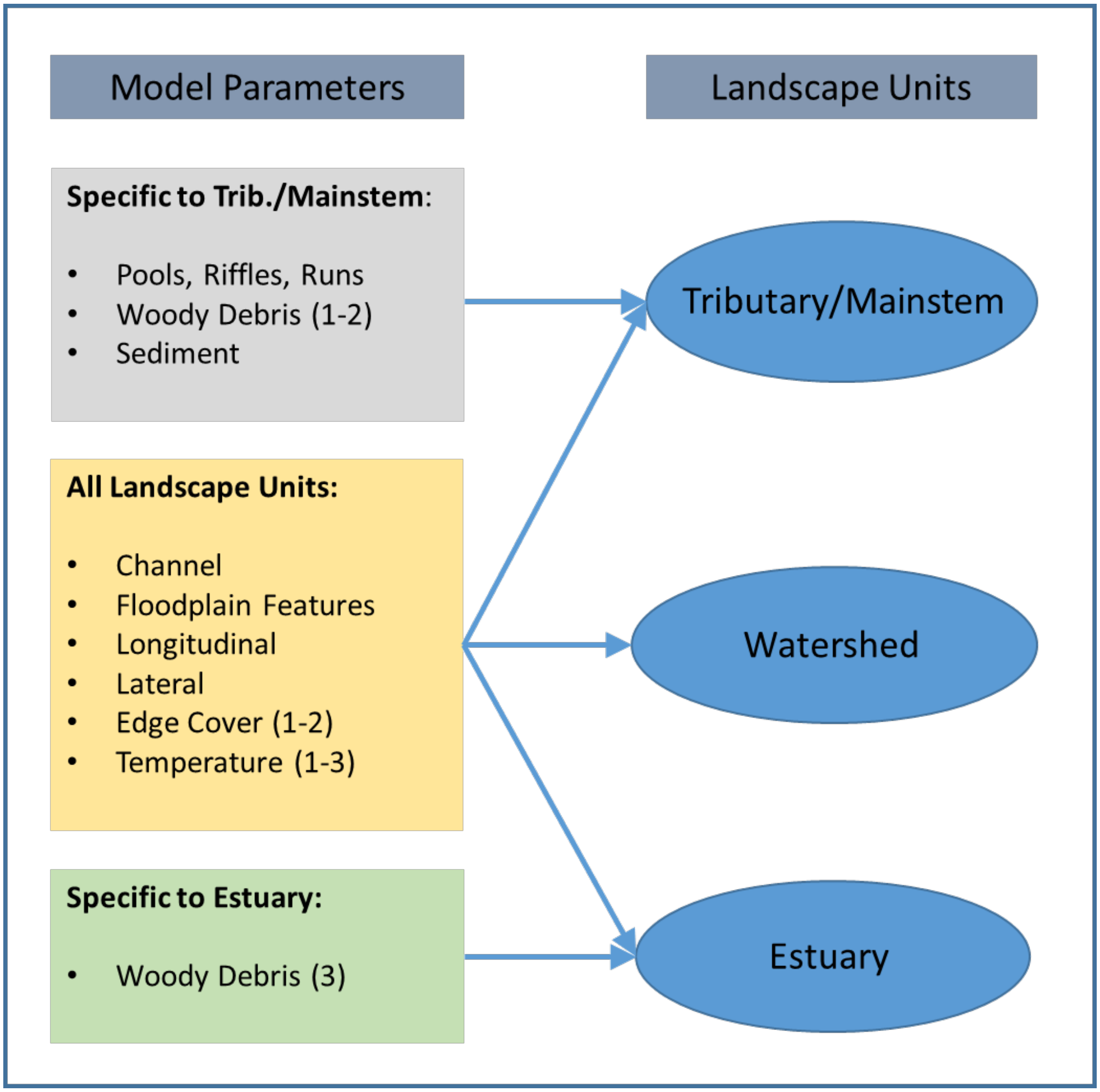
Figure 18. Draft survival temperature (3) EC.



2.4 Model structure

Figure 20 presents how the parameters are grouped by landscape unit, and the model has an output for each landscape unit. If a study has a project area encompassing a reach along a main stem and within an estuary, a separate model output exists for each landscape unit.

Figure 19. Draft model structure.



3 Discussion

The General Anadromous Fish Habitat Model (now the General Salmon Habitat Model) was developed to assist in the plan formulation process for ecosystem restoration and mitigation projects. The model will generate relative differences in habitat quality between proposed alternative future scenarios. The current draft model is scalable, meaning various parameters are measurable at different landscape scales (for example, reach vs. watershed). The model can be applied (model domain) in watersheds that currently or previously supported salmonid fish species along the West Coast. Application outside of the model domain requires further evaluation to ensure appropriate sensitivity to the new system of interest. Although the model is being developed to explicitly capture changes in fish habitat in response to restoration actions, this model is applicable to any planning project focused on the restoration of streams, rivers, and estuaries (for example, dam removals, in-stream habitat enhancement), because the parameters measure ecosystem level structure, function, and process.

4 Conclusion

Overall, the project team has successfully met the goals and objectives of the original model development process through mediated group modeling. This model development effort resulted in a well-defined ecological model with a wide-range of possible uses for USACE. Future steps in model development will include refining the current suitability curves, evaluation (for example, ensuring model outputs reasonably reflect observed patterns) and sensitivity analyses (for example, each parameter's level of influence). The results of model evaluation and sensitivity analyses will be compiled with the reports of model development. The compiled model documentation will then be independently reviewed and certified for use in USACE planning processes.

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Acronyms and Abbreviations

Acronym	Meaning
DoD	Department of Defense
EC	East Coast
EL	Environmental Laboratory
EMRRP	Ecosystem Management and Restoration Research
ERDC	Engineer Research and Development Center
NOAA	National Oceanic and Atmospheric Administration
USACE	U.S. Army Corps of Engineers
WC	West Coast

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14. ABSTRACT

The General Anadromous Fish Habitat Model (now the General Salmonid Habitat Model) was developed to assist in the plan formulation process for ecosystem restoration and mitigation projects. The model generates relative differences in habitat quality between proposed alternative future scenarios. In order to provide model development transparency, this report presents the initial quantification phase of the model development process. The draft model depicted in this report is scalable, meaning various parameters may be measured at different landscape scales (for example, reach vs. watershed). The model can be applied (model domain) in watersheds that currently or previously supported salmonid fish species. Application outside of the model domain would need further evaluation to ensure appropriate sensitivity to the new system of interest. Although the model is being developed to explicitly capture changes in fish habitat in response to restoration actions, this model would be appropriate for use in any planning project focused on the restoration of streams, rivers and, estuaries (for example, dam removals, in-stream habitat enhancement), because the parameters are measures of ecosystem level structure, function, and process.

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