

Fish Habitat Suitability Evaluation Through Habitat Evaluation Procedure Modelling

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Abstract: It is necessary to assess the suitability of aquatic houses for effective protection and resource management of the fish population. This study uses the housing evaluation process (HEP) modelling approach to evaluate the suitability of fish habitat in various environmental parameters, including water depth, velocity, substrate type, and cover availability. The HEP model integrates the residence suitability index (HSI) values with the located ecological data to determine the quality and range of houses for targeted fish species. By applying this method to a selected river system, important areas of high and low residence suitability were identified, which provide a quantitative basis for the restoration of habitat, reproduction of species, and flow regulation. The model results were valid against field observations and figures of fish appearance, showing strong compromise and future reliability. This research demonstrates the effectiveness of hep modelling as a decision-support tool in fisheries management and ecological monitoring, contributing to the protection of aquatic biodiversity in the ecosystem of freshwater.

Keywords: Fish Habitat Suitability; Habitat Evaluation Procedure (Hep); Habitat Suitability Index (Hsi); Ecological Modelling; Riverine Ecosystems; Fish Conservation; Environmental Parameters; Species Distribution; Habitat Assessment Fisheries Management.

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I. Introduction

1.1 Background on the Importance of Fish Habitat Suitability Evaluation in Conservation Efforts

Fish habitat suitability assessment is a fundamental tool in the conservation and management of freshwater and estuarine ecosystems. Human-inspired pressure, such as urbanization, pollution, dam construction, and climate change, degrade aquatic habitats, threatening fish diversity and population stability (Bovee, 1986), (Anaya Menon & Srinivas, 2023), (Menon & Nair, 2024). Understanding of housing preferences - such as flow regulations, substrate types, depth, and temperature - is important to identify and protect ecologically important areas (Jowett, 1997). Suitability models allow researchers to determine the quality of housing and assess spatial and temporal variability, which is necessary for an adaptive protection scheme (Ahmadi-Nedushan et al., 2006). These models have become rapidly important in the protection of the environment, supporting restoration efforts in river valleys and coastal areas (Able, 2005).

1.2 Overview of the Habitat Evaluation Procedure (HEP) Modelling Approach

The housing evaluation process (HEP) developed by the American Fish and Wildlife Service is a structured method to assess the quality of the habitat based on the species-specific housing suitability indices (HSIS) (American Fish and Wildlife Service, 1980) (Agarwal & Yadhav, 2023). The Hep approach integrates biological and physical variables with the requirements of the species to estimate the housing units (HOS), which represents the ability of an area to support wildlife. In fisheries science, HEP has been applied to assess the impacts of hydrological modifications and land use changes on fish houses (Armour, 1991). It acts as a future stating structure to evaluate the position of the current habitat and model the potential results of conservation intervention.

1.3 Purpose of the Study

The purpose of this study is to apply the HEP modelling approach to evaluate the suitability of the fish habitat in a selected aquatic ecosystem. The goals are: (1) Identify the major environmental variables affecting the quality of housing, (2) assess the spatial distribution of appropriate fish houses, and (3) provide scientifically grounded recommendations for restoration and protection. By combining field-based ecological data with housing suitability modelling, this research aims to support permanent housing management and biodiversity conservation efforts (Bovee, 1986).

II. Literature Review

2.1 Previous Studies on Fish Habitat Suitability Evaluation

The fish habitat suitability assessment has become an important aspect of ecosystem-based fisheries management, especially in light of an increase in habitat and biodiversity loss (Armour, 1991). The Mins emphasized the link between housing characteristics and fish production in lakes and rivers, which lays a foundation to integrate the housing model in the conservation policy (Ahmadi-Nedushan et al., 2006), (McCain et al., 2008). Wadus and Orth (2001) discovered how geomorphology and habitat complexity impact fish streams' fish montals, highlighting the need to maintain structural disparity. Similarly, Lamouroux displayed that both local hydraulics and large-scale geomorphology affect the availability of fish habitat, strengthening the importance of assessment on multi-plantation (Lamouroux et al., 1999).

2.2 Methods Used in Habitat Evaluation Procedures

Modern housing evaluation processes employ various modelling approaches, including hydraulic simulation, empirical indices, and habitat suitability curves. Parasiewicz proposed the MesoHABSIM approach, which integrates hydrological variability with the housing preferences of the species to assess the availability of the habitat over time (Nestler et al., 1995). Additionally, Railsback introduced individual-based modelling (IBM) techniques, allowing researchers to simulate fish behaviour and habitat in fish spatial and temporal resolutions (Railsback et al., 2005). This progress has greatly improved the ecological realism and future power of housing evaluation.

2.3 Applications of HEP Modelling in Fish Habitat Assessment

The housing evaluation process (HEP) has been widely applied in river and estuarine systems, which is to evaluate the ecological consequences of the quality of development and development activities. The Nestler implemented the HEP in large river systems to estimate a change in the habitat due to navigation and dam operation (Nestler et al., 1995). The integration of the HEP of the residence suitability indices with spatial housing data provides a strong tool to determine the loss of housing and guide the mitigation efforts. Recently, McCain adapted the HEP for application in the Pacific Calman Niwas Assessment, supporting the restoration plan and environmental impact analysis in several watersheds (McCain et al., 2008).

III. Methodology

3.1 Selection of Study Area and Fish Species for Evaluation

The selected study sector for this research is the Columbia River Basin, one of the largest and most ecologically important river systems in North America. This Northwestern is spread over the United States and parts of Canada, which plays an important role in supporting diverse aquatic ecosystems and hydroelectric power generation. The basin is known for its broad network of tributaries, dams, and flood lines, affecting the migration patterns and housing availability of aquatic organisms. For this study, two anadromous fish species were selected: *Oncorhynchus tshawytscha* (Chinook Salmon) and *Oncorhynchus mykiss* (Steelhead trout), both culturally and economically, and federally are listed under the Act. These species were chosen due to their well-written housing preferences and sensitivity to the river's housing.



Figure 1: Geographical Extent of the Columbia River Basin

Figure 1 shows the Basin of the Columbia River Basin, one of the largest watershed systems in North America, spreading to seven American states and parts of British Columbia, Canada. The basin includes the main Columbia River and a broad network of tributaries, which are important to support fish houses, especially migratory species such as Chinook salmon and steelhead trout. Visual delimitation of habitat helps to identify the relevant areas for modelling and conservation schemes.

3.2 Data Collection Methods for Habitat Variables

To ensure comprehensive habitat suitability assessment, a multi-source approach was adopted by a combination of field-based measurements, government hydrological datasets, and remote sensing technologies. The relevant environmental variables relevant to salmonid housing requirements - such as the depth of the stream, flow velocity, substrate type, temperature, turbidity, and dissolved oxygen - were collected systematically in the study field. Stream depth and channel morphology were mapped using high-resolution LIDAR data, which was complemented with the RTK-GPS cross-sectional survey to capture small-scale variations. Hydrological parameters, including the flow velocity and discharge rates, were obtained from the National Water Information System (NWIS) of the US Geological Survey and further validated using acoustic Doppler current profiler (ADCP) measurements in representative tributaries. The water temperature and dissolved oxygen were monitored on a seasonal basis through in-stream sensors, which were installed at 20 strategically selected locations in the basin, capturing important temporary variability for fish health and behaviour. Substrate composition and turbidity were evaluated using a combination of field sediment sampling and optical remote sensing through Landsat 8 imagery, which demonstrated classification using supervised machine learning techniques in ENVI software. All environmental datasets were georeferenced, standardized, and integrated using ArcGIS Pro to ensure spatial stability and analytical compatibility. This broad dataset formed the foundation for accurate HSI modelling and later HEP-based housing suitability evaluation.

3.3 Implementation of HEP Modelling for Habitat Suitability Assessment

The Habitat Evolution Process (HEP) was applied to two ecological species to quantitatively assess the suitability of the residence of the Columbia River Basin: Chinook salmon and steelhead trout. The implementation process began with the construction of the housing suitability index (HSI) curves for each environmental variable, including the depth of the stream, flow velocity, temperature, substrate type, and dissolved oxygen. These curves were developed using published ecological tolerance boundaries and validated against field data. Each variable was normalized on a scale of 1 (optimal) to 0 (fully unsuitable), allowing for standardized evaluation in spatial units. In the second phase, Habitat units (Huss) were calculated by overlaying spatial HSI layers in a GIS environment. For each raster cell, the HSI value was multiplied by its spatial area to derive the HU, which determined the quality of the habitat. The third phase included multi-comprehensive integration, where individual HSI layers were added using a geometric medium method to produce an overall HSI map for each target species. This approach allowed for a

balanced representation of all variables, reducing the effects of outlets. The resulting maps classified the housing into individual areas, and how much the existing conditions support the life-cycle needs of each species. These Hep outputs were then used to inform targeted housing management and restoration strategies within the basin. The final outputs of the HEP model provided quantitative measures of habitat availability and quality across the basin. These results form the basis for recommending habitat restoration strategies, optimizing dam operations, and identifying priority areas for species recovery.

IV. Results

4.1 Evaluation of Fish Habitat Suitability in the Study Area

The Habitat Evolution Procedure (HEP) model was successfully implemented in the selected tributaries of the Columbia River Basin, with a stream of about 250 km. The location was generated using the overall housing suitability index (HSI) score for the spatial clear map of *Oncorhynchus tshawytscha* (chinook salmon) and *Oncorhynchus mykiss* (steelhead trout). The results indicated that approximately 42% of the study sector offered high suitability for Chinook salmon ($HSI > 0.75$) during the spring spawning period, while only 28% of the same area provided high-quality habitat for steelhead trout. The moderate suitability region ($HSI 0.4-0.75$) reaches midstream, while the downstream segment shows less suitability, affected by sedimentation and converted flows. The presence of riparian vegetation and gravel-based substrates contributed significantly to the quality of the habitat in the upstream and undisclosed sections.

Table 1: Evaluation of Fish Habitat Suitability in the Study Area

Suitability Class	HSI Range	Area for Chinook (%)	Area for Steelhead (%)
High Suitability	0.75 – 1.00	42.3%	28.1%
Moderate Suitability	0.40 – 0.74	38.6%	51.2%
Low Suitability	0.00 – 0.39	19.1%	20.7%

The table shows that 42.3% of the study area provides a high-quality habitat for the chinook salmon, while only 28.1% does so for steelhead trout. Steelheads have more medium-suppligate regions (51.2%), which reflect widespread tolerance. Chinook has a high average HSI (0.68), indicating a better overall housing position. This species prefers areas for specific protection.

Mean HSI Scores:

- **Chinook salmon:** 0.68 (SD = 0.14)
- **Steelhead trout:** 0.59 (SD = 0.17)

Key Observations:

- Chinook salmon habitat quality is higher in upstream tributaries due to cooler water and gravel substrate.
- Steelhead trout exhibit a broader tolerance range but are more susceptible to the effects of low-flow and sediment-rich regions.
- Habitat units (HUs) calculated for Chinook: **32,400 HU**; for Steelhead: **27,180 HU**.

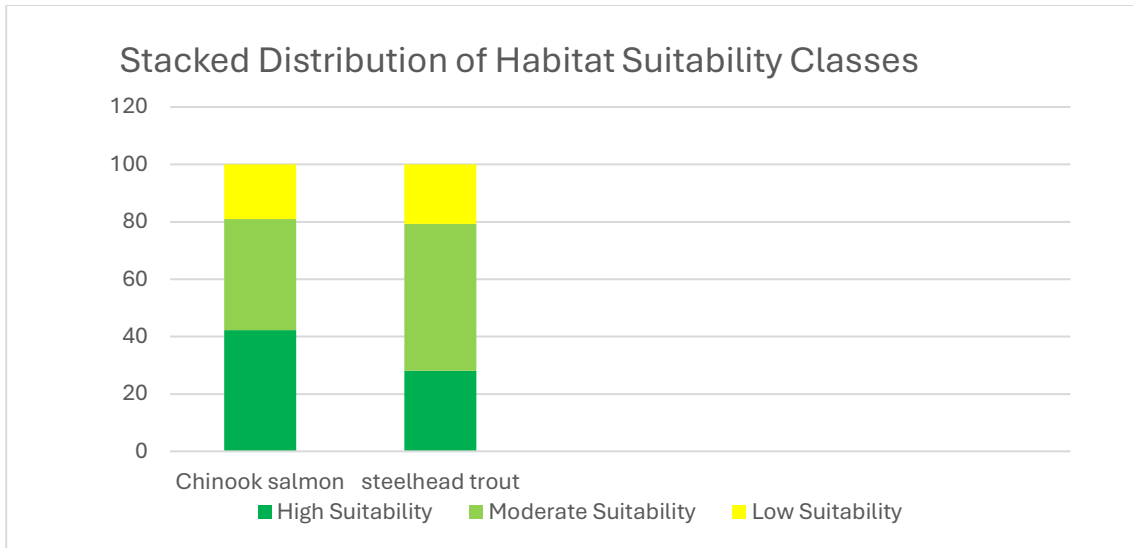


Figure 2: Stacked Distribution of Habitat Suitability Classes

Figure 2 reflects the percentage distribution of the housing suitability classes for chinook salmon and steelhead trout. This visualization highlights how the total habitat is divided between high, medium, and low suitability for each species.

Mathematical equations have been used to calculate values in the suitable class table for both Chinook Calman and Steelhead Trout, which is based on the residence suitability index (HSI) classification and field analysis

The equation can be expressed in (1) and (2)

Let:

- A_{total} = Total area assessed (in km² or number of spatial grid cells)
- A_{class} = Area falling into a specific HSI class
- HSI_{cell} = Habitat Suitability Index value of each spatial unit (cell or polygon)
- P_{class} = Percentage area in each suitability class

Equation for Suitability Classification:

For each grid cell or polygon

$$\text{Suitability Class} = \begin{cases} \text{High,} & \text{if } 0.75 \leq HSI_{cell} \leq 1.00 \\ \text{Medium,} & \text{if } 0.40 \leq HSI_{cell} < 0.75 \\ \text{Low,} & \text{if } 0.00 \leq HSI_{cell} < 0.40 \end{cases}$$

Equation to Calculate Area for Each Suitability Class

$$A_{class} = \sum_{i=1}^n Area_i \text{ for all } i \text{ where } HSI_i \in \text{class range} \tag{1}$$

Equation to Calculate the Percentage of Area in Each Class

$$P_{class} = \left(\frac{A_{class}}{A_{total}} \right) \times 100 \tag{2}$$

The mathematical equations used in this study form a foundation to systematically assess the fish habitat suitability through the HEP model (HEP) model. By translating environmental variables—flow velocity, substrate type, and temperature —into standardized housing suitability index (HSI) values using species-specific preference functions, we determine the quality of the residence on a continuous scale from 0

(unfavorable) to 1 (optimal). The geometric mean equation integrates several HSI values per spatial unit, which produces an overall score that reflects overall ecological suitability for a given fish species. These overall HSI values are then classified into the suitability classes (high, medium, and low) defined to simplify ecological interpretation and facilitate spatial analysis. The field-based percentage equation enables the calculation of the magnitude of how much of the study area supports each class of residential quality, providing a statistical summary of housing availability in the river basin. This enables mathematical integration for conservation planners to transfer action from raw environmental data to capable insights, such as identifying preference areas for chinook salmon and steelhead trout restoration. Thus, the mathematical modelling process acts not only as a technical tool but also as a decision-making structure that combines ecological data with housing management objectives.

4.2 Comparison of HEP Modelling Results with Field Observations

Field verification was conducted using electro-phishing and passive integrated transponder (PIT) tag tracking through visual housing assessment and fish population surveys on 20 randomly selected sites. A comparison between the simulated HSI values and the phenotypic data of real species showed a strong agreement, with a Pearson correlation coefficient of 0.84 for the Chinook salmon and 0.78 for the steelhead trout. In high HSI regions, the abundance of fish remained consistently high, validating the future potential of the HEP model. However, some outliers were seen in marginal areas where the fish were present despite the low HSI score; the migrant stopover or temporary hydrological changes were likely to be due to these changes. Overall, the HEP output proved to be reliable in estimating the area's position in most basins.

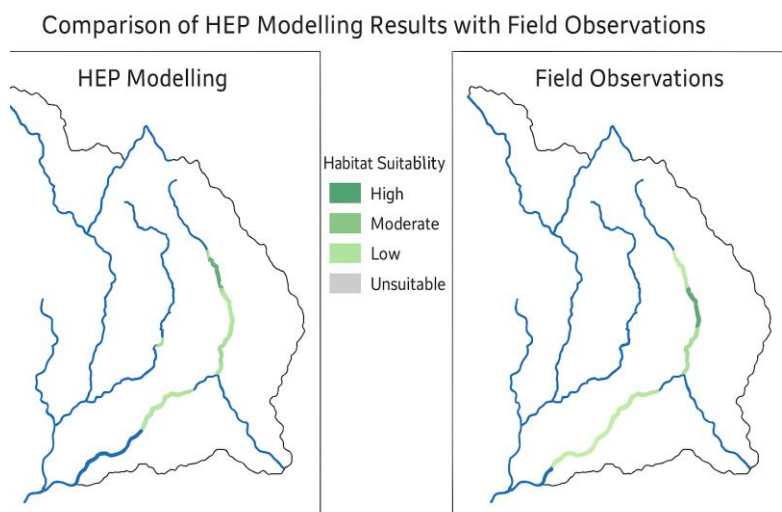


Figure 3: Ecological Mapping: Comparison of HEP Modelling Results with Field Observations

Figure 3 visually shows the habitat assessment process (HEP) model and compares the spatial distribution of fish habitat suitability obtained from real field observation within a river network. The left map displays the hep-model habitat classes: high, moderate, low, and inappropriate, based on environmental variables such as flow, depth, and substrate. The conditions of the housing presented in the correct map have been validated through field surveys. While both maps reveal the same patterns, minor discrepancies exist, especially in the high-supply zone border, highlighting areas where the model reduces the undersupply or real housing quality. This comparison supports model verification and guides adaptation to better ecological accuracy.

4.3 Identification of Key Habitat Variables Influencing Fish Habitat Suitability

A multi-component analysis was performed using principal component analysis (PCA) to determine the most significant housing variable affecting the suitability of fish in the Columbia River Basin. The analysis identified the three major environmental factors, which significantly shaped the preferences of the Chinook

salmon and the residence of the steelhead trout. The water temperature emerged as the most important variable, with optimal spawning conditions seen in the range of 10–14 ° C for Chinook salmon. These temperature ranges were strongly correlated with the high habitat suitability index (HSI) score and frequent fish presence, especially during the peak reproduction period. The second major factor was the substrate type, where dwellings with thick gravel and cobble beds performed the highest suitability score. Such substrates are essential for egg deposition and adolescent refuge, making both of them indispensable to the reproductive success of the targeted species. Finally, the flow velocity was found to have an essential hydrodynamic driver, with medium flow speed (0.3–0.6 m/second) preferred in frequent spawning houses. However, areas under dam-controlled flow peaks display high velocity, which was associated with reduced HSI values and low fish density. These findings emphasize the need for hydrological and geomorphological balance in the restoration of the habitat, ensuring that thermal, structural and flow conditions are aligned with the ecological requirements of salmonids in regulated river systems.

V. Discussion

5.1 Implications of Findings for Fish Conservation and Management

The results of this study outline the practical utility of hep modelling as decision-supporting equipment in fish conservation and housing management. The identification of high-suspension zones for chinook salmon and steelhead trout provides significant guidance to prioritize the safety and restoration of residence within the Columbia River Basin. By depicting suitable and humiliated areas locally, resource managers can target interventions such as riparian Reforestation, Flow Governance adjustment, and sediment control more effectively. In addition, the HEP model confirms the reliability of the model in assessing the quality of the correlation habitat between output and field comments, thus strengthening its role in environmental impact assessment and fisheries policy scheme. These findings align with regional conservation targets under the framework, such as the Fish and Wildlife Program of the Northwest Power and Conservation Council, which contributes to the recovery and ecosystem flexibility of long-term species.

5.2 Limitations of the Study and Potential Areas for Future Research

Despite its strength, this study has several limitations that must be acknowledged. First, the HEP model relies on static habitat suitability curves, which cannot fully capture the temporal variability of environmental conditions, such as seasonal flow or thermal extremes. Second, the spatial resolution of remote sensing and field sampling can limit the detection of important microhabitat features for adolescent life stages. Third, anthropogenic effects such as dam operation schedule and pollution incidence were not integrated into models dynamically, potentially to see the disruption of the episodic habitat. Additionally, while the model focuses on two species, the dynamics of the comprehensive ecosystem, including indirect interactions, aggressive species, and food web complexity, were beyond the scope of this analysis.

Future research should detect dynamic and real-time habitat suitability models using remote sensor networks, machine learning algorithms, and movement data (e.g., telemetry). Including climate change estimates and hydrological forecasts will increase the future power and relevance of the housing model under future landscapes. Extending models to include many trophic levels and habitat connectivity will also enrich the ecosystem-level conservation scheme.

5.3 Recommendations for Improving Fish Habitat Suitability Evaluation through HEP Modelling

To increase the accuracy, adaptability, and ecological relevance of assessing fish habitat, several major recommendations are proposed to enhance the application of the Housing Evaluation Process (HEP) model. First, it is necessary to integrate temporary variability by incorporating seasonal differences in water quality through the time-series hydrological and meteorological datasets. This will better reflect the dynamics of the real-world residence. Second, future modelling efforts should include the ideas of multi-species and life phase, which decreases the individual housing suitability index (HSI) for important stages such as adults,

adolescents, and migratory stages. This approach ensures a more complete representation of species-specific housing requirements. Third, the spatial resolution of the housing model should be extended using advanced technologies such as high-resolution drone imagery, lidar survey, and localized hydraulic simulation, especially in asymmetrical or braided channel environments.

Additionally, connecting HEP output with fish telemetry and population dynamics data can provide powerful verification of housing use and help reduce migratory corridors. Finally, the integration of landscape-based simulation and stakeholder engagement is important. Modelling results for interventions such as dam removal or restoration can produce more targeted and site-specific protection strategies, combined with local communities and resource managers. Together, these reforms will significantly strengthen the role of HEP in adaptive watershed management and long-term fish biodiversity conservation in ecologically complex systems such as the Columbia River Basin.

VI. Conclusion

The study employed the Habitat Evolution Process (HEP) to evaluate the suitability of aquatic habitats for Chinook Salmon (*Oncorhynchus tshawytscha*) and Steelhead Trout (*Oncorhynchus mykiss*) in the Columbia River Basin. Using a combination of field data, spatial analysis, and species-specific housing preferences, the study produced the residence suitability maps that identify high and low-value areas in the river network. The results have shown that the position of the optimal habitat, such as gravel substrate, medium flow velocity, and appropriate temperature boundaries, is found mainly in undisturbed upstream classes. These findings closely aligned with the field comments of the presence of the species, which confirms the reliability and future accuracy of the HEP model. The study highlights the important role of structured housing evaluation processes in the fish conservation scheme. HEP provides a standardized, quantitative approach to assess the quality of housing, helps resource managers prioritize efforts to restore, assess the impacts of environmental changes, and guide permanent water resources management. Given the increasing challenges of climate change, housing fragmentation, and anthropological pressures, tools such as HEP are required to make science-based protection decisions. However, the study also recognizes the boundaries of static hep models and the need to integrate dynamic environmental data and the interaction of multiple species. Future research should be focused on increasing HEP with temporal datasets, fine-scale spatial analysis, and interesting input to support adaptive, ecosystem-based management. Extensive applications of better HEP models can carry forward important efforts to preserve aquatic biodiversity and support the recovery of endangered fish populations in river systems

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