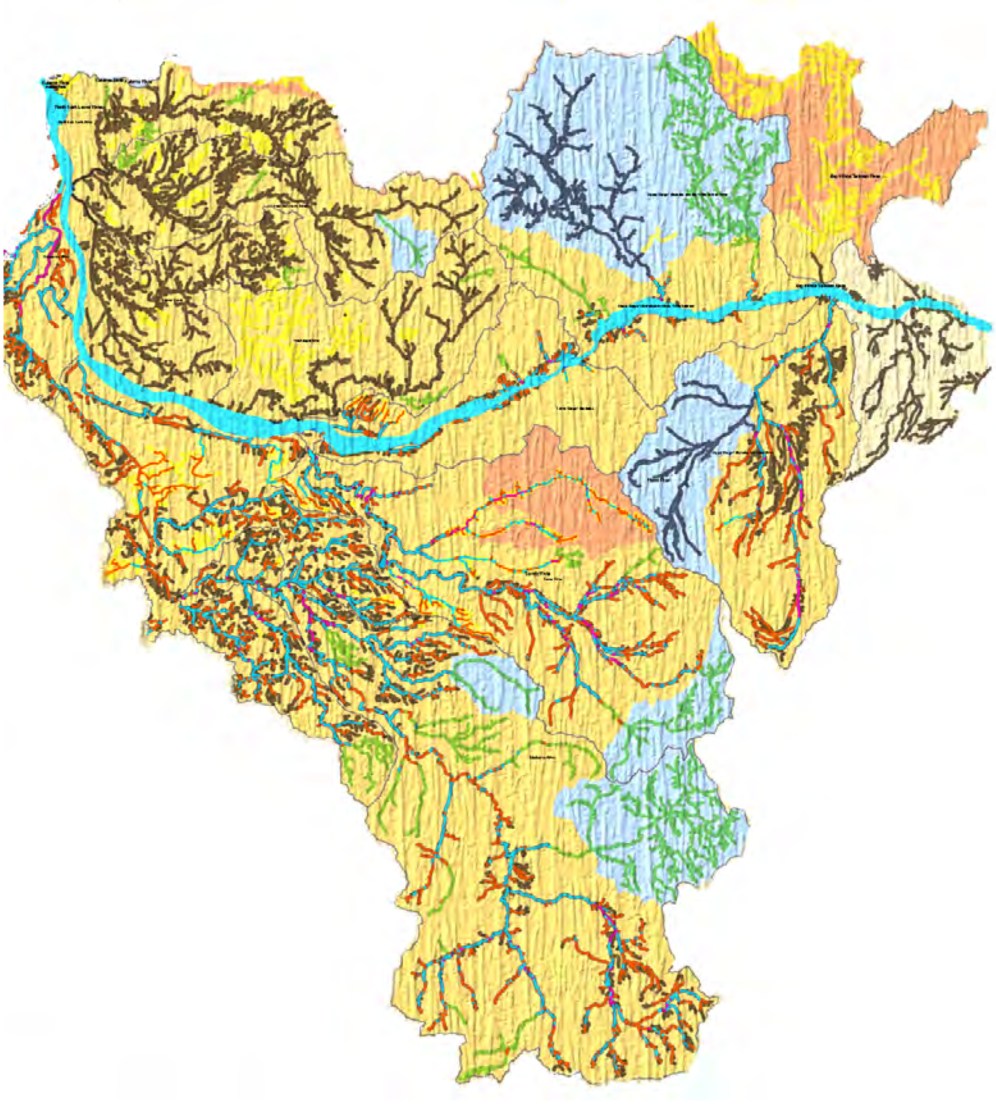
Development and Management of Fish Intrinsic Potential Data and Methodologies:

State of the IP 2008 Summary Report



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Development and Management of Fish Intrinsic Potential Data and Methods: State of the IP 2008 Summary Report

By Mindi B. Sheer[1], D. Shallin Busch[1], Erin Gilbert[2], Jennifer M. Bayer[3], Steve Lanigan[4], Jacquelyn L. Schei[3], Kelly Burnett[4,] Dan Miller[5]

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Development and Management of Fish Intrinsic Potential Data and Methodologies—State of the IP 2008 Summary Report

By Mindi B. Sheer[1], D. Shallin Busch[1], Erin Gilbert[2], Jennifer M. Bayer[3], Steve Lanigan[4], Jacquelyn L. Schei[3], Kelly Burnett[4], Dan Miller[5]

Executive Summary

The Pacific Northwest Aquatic Monitoring Partnership (PNAMP) and National Oceanic and Atmospheric Administration (NOAA) Fisheries Service hosted a workshop in Portland, Oregon, November 19–20, 2008, on Intrinsic Potential (IP) analyses. The purpose of the workshop was to improve the state of the knowledge and consistency of IP analyses and methodologies for anadromous and resident salmonids in the Pacific Northwest and California. This is a summary report from that workshop; it contains background reference material compiled in advance of the workshop, summaries of the sessions held, contributions from participants, and a synthesis of this input in the form of guidelines for conducting IP analyses. This report is intended to provide general guidance and scientific and technical perspectives for reach-based habitat potential analyses.

The first day was devoted to discussion of the development and maintenance of spatial datasets. The second day was devoted to biological considerations of IP models. Sixty-two participants attended the workshop, from six Federal agencies, two State agencies, three Tribal entities, six nongovernmental organizations, and seven private firms. Prior to the workshop, approximately 15 individuals provided information about their research relevant to IP analyses; some of this information is summarized and synthesized in this report.

The workshop resulted in an increase in regional knowledge, awareness, and input on this new paradigm for describing habitat potential for aquatic organisms. It brought together scientists, GIS analysts, and resource managers to facilitate a greater understanding of the importance of data quality, scale, sources, and gaps in the context of designing biological models. Specifically, spatial analysts and biologists gained perspective on both the accuracy and precision of hydrogeomorphic variables and the accuracy and precision of species-specific preference curves and thresholds based on the same variables.

Workshop accomplishments include the following:

- Improved state of the knowledge and consistency of approach for IP analyses on anadromous and resident salmonids in the Pacific Northwest (Oregon, Washington, Idaho, and northern California);
- Enhanced working relationships among State,Tribal, private and Federal fisheries biologists, spatial analysts, and resource managers who develop IP-type models or utilize their results;
- Shared IP-related habitat data and species preference curves; and
- Gained consensus on the need for coordination regarding IP-related research and application.

Photograph by U.S. Forest Service.

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This report is a summary of the workshop proceedings, input received in advance of the workshop, and expert opinion of the workshop leaders. It is not a traditional workshop summary. Our goal for this report is to provide the reader with background information (much of it refereed), general guidance and common perspectives (from attendees), an overall synthesis, and suggested guidelines from the authors and their combined expertise in IP analyses.

There was a large volume of information offered and referenced by participants in advance of and during the workshop; this report is our attempt to share that information in an outlet that can be referenced in the future. The report emphasizes the current state of knowledge and use of IP models; however, we also attempted to capture discussion about needs for development of additional tools, resources, and guidelines. These perspectives will be incorporated into upcoming peer-reviewed manuscripts that will include a guidance framework to help researchers develop IP models.

Introduction

Landscape features that are not easily modified by anthropogenic influences (e.g., channel gradient, geology) can be helpful in evaluating the suitability of habitat for aquatic vertebrates. Datasets on such spatial features are broadly available or relatively easy to estimate using GIS tools. Analyses based on the relationship between these spatial features and species' habitat preferences could form the foundation of a consistent approach to measure a habitat's potential to host populations of aquatic species (e.g., resident and anadromous fishes or amphibians). Such information can inform species conservation and habitat restoration activities.

Intrinsic Potential (IP) models are one type of habitat-potential model that use geospatial data to identify stream reaches with high, low, or no potential to host a particular species. IP models rate habitat potential at the level of a stream reach but provide a method for estimating habitat quantity and quality across local or regional scales. Typically, IP models use a set of species preference curves (index curves) to relate each habitat variable to species preferences, and then combine the scores from each preference curve to estimate a single score for a particular river reach. IP models have been developed for some salmon and steelhead groups listed under the Endangered Species Act, and model results have been incorporated into recovery planning activities. However, currently, there is no standard methodology for developing geospatial datasets needed for IP models nor are there peer-reviewed species preference curves for many resident and anadromous species in the Pacific Northwest.

An important result of this workshop is the formalization of draft general guidance for developing IP models (table 1) (K.M. Burnett, oral commun., January 2009; a separate manuscript is in preparation, tentative title, "Describing the intrinsic potential of streams to provide habitat for salmonids"). Another product is the compilation of current habitat suitability models for coho salmon, Chinook salmon, and steelhead (p. 8–21). A variety of other information also is incorporated in this report, including: IP model background, hydrography as the 'building block' of IP models, selection of physical variables to utilize in IP models, methodologies for developing habitat suitability curves, examples of applied IP models (appendix A), and reporting of workshop participant input (appendixes B, C, D, and E). Information in this report related to geospatial data will also be synthesized in a separate manuscript (M. Sheer, oral commun., July 2009; tentative manuscript title "Integrating aquatic biological thresholds with spatial data models to identify intrinsic fish habitat in stream networks").

Table 1. Draft decision tree to use as a guide when developing an Intrinsic Potential model.

This guidance is offered to help researchers consider and prioritize issues relevant to IP models (K.M. Burnett, oral commun., January 2009. A separate manuscript is in preparation. Tentative title, “Describing the intrinsic potential of streams to provide habitat for salmonids.”)

1. Have ESUs or populations been mapped for the species?
   Yes, select and justify which ESU or population to model, document, then go to #3.
   No, go to #2.

2. Select which geographic area and, if appropriate, life history (based on run timing of adults, timing of out-migrating juveniles, etc.) to model.
   Justify and document, then go to #4.

3. Was the ESU designated to include different life histories of the species (based on run timing of adults, timing of out-migrating juveniles, etc)?
   Yes, go to #3a.
   No, go to #4.

   3a. Do the various life histories use different habitats or use similar habitats differently?
       Yes, select a life history to model, justify, document, and then go to #4.
       No, justify and document that various life histories will be modeled together, go to #4.

4. Select which life stage to model (e.g., limiting life stage or life stage about which most knowledge exists).
   Justify and document then go to #5.

5. Does available information suggest that fish-habitat relationships for the selected life stage differ among bio-physical regions (e.g., geology, EPA Level III Ecoregions, natural disturbance regimes, other)?
   Yes, document then go to #6.
   No, go to #8.

6. Is sufficient knowledge available for the selected life stage to model how fish-habitat relationships differ among bio-physical regions?
   Yes, document then go to #7.
   No, go to #8.

7. Does an appropriate model exist for the selected life stage in the specific bio-physical region of interest?
   Yes, apply the model.
   No, go to #7a.

   7a. Is a model for the life-stage in any bio-physical region available and adaptable?
       Yes, adapt and apply it.
       No, go to #7b.

   7b. Build and apply model.

8. Does an appropriate model exist for the selected life stage?
   Yes, apply the model.
   No, go to #8a.

   8a. Is a model for another life history, life stage, population, ESU, etc. available and adaptable?
       Yes, adapt and apply it.
       No, go to #8b.

   8b. Build and apply model.

Workshop Overview

Day 1 – Habitat Variables, Spatial Datasets and GIS Methods

On the first day of the workshop, participants (appendix F) focused on habitat variables, spatial datasets, and GIS methods related to IP analyses. The day began with presentations providing general information about IP models, including background, methods used, and data requirements. Two sessions followed the presentations. In the first session, participants split into two groups to discuss applications of IP models. The groups collected information about ongoing projects from participants, discussed caveats to consider when using output from IP models in research and management, and weighed in on appropriate application for this type of analysis. One group focused more on the technical aspects, while the other focused more on the management perspective. In the second session, workshop participants again split into two groups. One group focused on estimating physical stream habitat variables, caveats regarding these variables, the type of output that is generated by IP models, and how regional differences should be incorporated in IP models. The second group focused on hydrography, which is the building block of IP models. Specifically, the group discussed technical hydrographic considerations independent of source, reviewed source hydrographic data used in IP models, and collected feedback on issues that can affect the interpretation of output from IP models.

Day 2 – Biological Considerations of IP Analyses

The second day of the workshop was devoted to the biological considerations of IP analyses. The day started with presentations describing specific applications of the IP model and discussing existing and potential geomorphic measures used in creating habitat suitability curves. A follow-up discussion covered management and recovery-based uses of IP models, steps needed to develop or improve existing species preferences curves utilized in IP models, and possibilities for validating model results with field data on fish use. The afternoon session emphasized species-specific biology. A short presentation outlined the session's goals to assess if there was agreement among experts on appropriate habitat preferences curves for Chinook salmon, coho salmon, and steelhead and if not, develop a working plan to finalize species-specific curves. In addition, groups also touched on appropriate uses of the models and the necessity to evaluate the limits of IP models, e.g., identify where a model may "underperform" and provide some guidelines for how to remedy this. The species-level workgroups made great progress in designing and contributing to IP models, and provided valuable expert opinion on habitat preference curves for salmonid species and how to incorporate regional, ecological, and life history differences.

Photograph by U.S. Forest Service.

IP Background and General Discussion Summaries

Applying Intrinsic Potential Models

Intrinsic potential (IP) models use geospatial data to rank stream reaches in terms of their potential to provide habitat that can support high or low potential for fish or other species. These data typically do not resolve habitat features directly, so IP models identify landscape attributes conducive to habitat development and provide a method for estimating potential habitat quantity and quality across local or regional scales (fig. 1). IP analyses currently inform prioritization of sites for restoration or conservation, recovery planning, and the historic distribution of fish. General background and applications of IP can be found in Burnett et al. (2003, 2007) and Agrawal et al. (2005). Invitees provided information pertaining to IP-related studies prior to the workshop, which formed the basis of workshop discussions.

During the workshop, participants discussed Federal, State, Tribal, and non-profit sector efforts underway to develop new IP models and efforts that use results from existing IP models to inform management decisions.

Examples of applications of IP analyses included incorporation into population viability analyses, restoration scenarios and watershed planning, land-use decisions, and an evaluation of habitat diversity. For instance, results from an IP model were used to examine population structure in conjunction with critical habitat on the Oregon coast (Dent et al., 2005). To date, IP models have focused on anadromous fish species. Participants also discussed models that use a similar framework as IP. Specific comments by participants on applications of IP analyses are provided in appendix B. A draft synthesis of biological and ecological factors to consider when developing an IP model is presented as a decision tree in table 1.

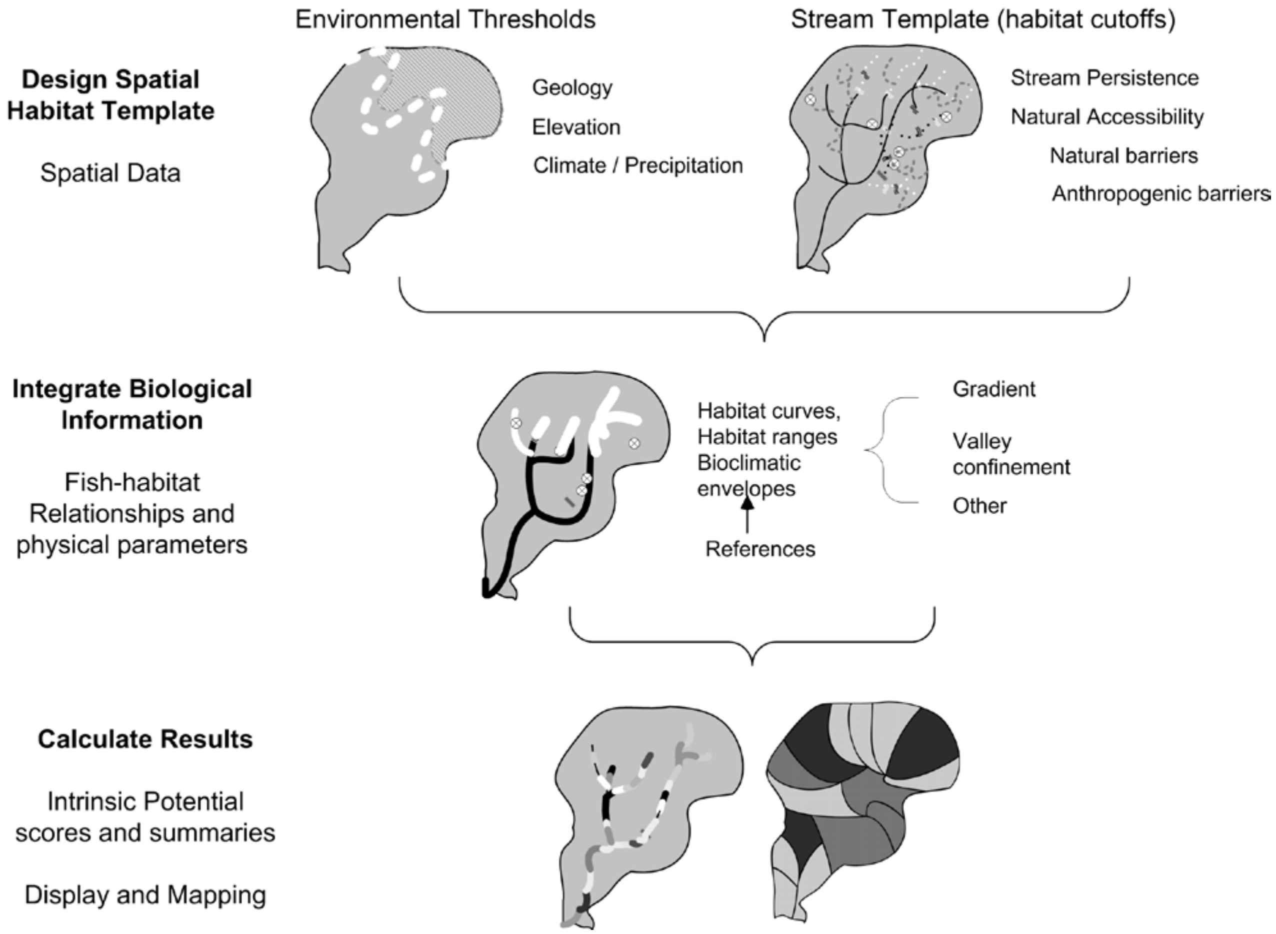


Figure 1. Diagram illustrating the flow of spatial data and biological information (habitat curves) into components of intrinsic potential analyses (M. Sheer, oral commun., July 2009; manuscript in preparation, tentative title, “Integrating aquatic biological thresholds with spatial data models to identify intrinsic fish habitat in stream networks”).

There is general agreement that results from IP models have much to offer scientists and managers, if applied appropriately. Intrinsic potential models are thought to define general conditions for species suitability and are most informative as a screen for identifying areas with a low likelihood of species utilization. Results of IP models cannot predict current species distribution and may not be appropriate to use as a predictor of population size, but may be useful for predicting current species absence. Participants recognized the benefits of utilizing simple habitat preference models (in fact, the group expressed that the simplicity of IP models is one of the major strengths) and recommended that model developers not increase model complexity.

Developing Habitat Suitability Curves

A draft decision tree to guide IP model development and an associated figure to explain IP modeling were generated from the discussions of workshop participants (table 1; fig. 1). The process of IP model development begins with determining the species and life stage of interest, identifying the geographic region for the model, and modifying or developing appropriate habitat suitability curves (table 1). Current distribution data for the focal species can sometimes help guide habitat suitability curves by indicating whether certain variables are a good predictor of the distribution over the landscape. Because the relationship among variables often does not stay constant, interactive effects and covariation among variables should be considered during model development (table 2). Better documentation of some IP models is needed to clarify where, when, and how the models' habitat suitability curves were developed, including if the model curves were developed from empirical data.

Historic Conditions

IP models are based on intrinsic topographic and climatic features that influence habitat development. Under most circumstances, intrinsic potential is a surrogate for historic potential and is assumed to reflect current potential in the absence of human disturbance. In other words,

Current potential = Intrinsic potential – human disturbance.

Table 2. Examples of some hydrogeomorphic and climatic variables related to habitat quality that can be obtained from a modeled stream network and digital elevation models (DEM) (M. Sheer, oral commun., July 2009; manuscript in preparation, tentative title "Integrating aquatic thresholds with spatial data models to identify intrinsic fish habitat in stream networks").

Variable	Source
Channel gradient[1,2]	From DEM[3,4]
Mean annual flow[1,2]	Regression of gauge data to drainage area (DEM) and mean annual precipitation[3]
Channel constraint[1,2]	Valley-width index (ratio of valley to channel width, with channel width based on regional regression to mean annual flow) correlated with field inventoried constraint categories. Valley width estimated from DEM[3,6]
Mean Summer (August) Low Air Temperature[1]	Parameter-elevation Regressions on Independent Slopes Model (PRISM)[1]
Valley-width transitions (e.g., from confined to unconfined channels)[5]	From DEM[5]
Tributary confluences[5]	From DEM[5]

[1] Agrawal et al. (2005).

[2] Burnett et al. (2003, 2007).

[3] Clarke et al. (2008).

[4] Davies et al. (2007).

[5] Benda et al. (2004, 2007).

[6] Hall et al. (2007).

Thus, IP models reflect historic conditions prior to anthropogenic modification of the landscape and habitat (e.g., forestry, pollution, construction of in-stream barriers). However, under certain circumstances, human disturbance can alter a system to the point that current potential no longer reflects historic potential. And thus, historic potential can no longer reasonably be considered a baseline for evaluating or planning recovery actions. For example, streamflow and stream location figure prominently in IP analyses; human-induced changes to flow regimes (e.g., irrigation withdrawals, diversions, damming) can result in an inaccurate representation of "intrinsic" stream location and streamflow estimates. Reporting results of IP models to managers should point out model limitations.

Non-Intrinsic Variables

Examples of intrinsic habitat features included in an IP model are reach-averaged channel width, gradient, and erosion susceptibility (table 2 and appendix B, table B9). Many variables commonly used to assess watershed/stream health and habitat potential (e.g., riparian quality, percent fines, erosion indices, road density, population density) are not part of the IP model framework because they can be highly modified by humans. However, they can be used in conjunction with intrinsic variables or the IP model results to identify high potential areas that may be compromised by anthropogenic impacts.

Species-Specific Habitat Suitability Models

Prior to the workshop, we asked participants to complete a worksheet on the key components of the habitat suitability models that they, or their institution, have developed or used. A workshop organizer summarized the information from most of these worksheets and from other select sources into short, species-specific documents (see below). These species summaries were distributed to participants prior to the workshop to help them prepare for planned meeting discussions. At the workshop, the species summaries were used as references during discussions and to assist the species-specific focal groups in their discussions about relevant IP models (appendixes C, D, and E). In addition, workshop organizers thought that these species summaries would be a valuable outcome of the workshop for scientists and managers who engage in developing and utilizing habitat suitability models.

Summaries follow as separate sections for coho, Chinook, and steelhead. Each section summarizes some of the information sent to workshop organizers by workshop participants engaged in exercises to quantify the suitability of habitat for salmon or steelhead, as well as information from other sources. Both intrinsic and extrinsic features are included. Intrinsic features are those that cannot be changed by humans on a small time scale. Extrinsic features are those that can be changed by humans on a small time scale. Names after each listed variable indicate the people/organization(s) that used models containing that variable.

These summaries are in no way intended as a complete description of the included models or as an exhaustive survey of all habitat models from the Pacific Northwest that focus on coho, Chinook, or steelhead. They are an attempt to survey many pertinent write-ups submitted, to illustrate the variety of methods, sources, and habitat curves being used for IP analyses. We hope this is useful to the readers in tracking down data, results, or publications. Full descriptions of the models discussed in each section can be found in the primary literature documents cited.

Summary of Coho Salmon Models

This summary includes responses from:

- Shallin Busch et al., NOAA Northwest Fisheries Science Center
- Brian Spence, NOAA Southwest Fisheries Science Center (Agrawal et al., 2005)
- Nikki Moore, Bureau of Land Management (BLM, 2008)
- Porter et al. (2008), ESSA Technologies, Ltd.
- Jody Lando and A.J. Keith, Stillwater Sciences (1998; 2006; 2007a; 2007b), Ripple model
- Andy Weiss, Washington Department of Fish and Wildlife (some info referenced as Herger et al., 2003)

This summary includes data from documents by:

- Burnett et al. (2007), USDA Forest Service
- Dent et al. (2005), Oregon Department of Fisheries.*
- Lawson et al. (2004), NOAA Northwest Fisheries Science Center

*Note that Lawson, Dent, BLM used same data and model as Burnett et al. (2007)

Intrinsic habitat features used or considered:

- Valley constraint (Spence/Agrawal, Burnett, BLM, Dent, Lawson)
- Gradient (Spence/Agrawal, Burnett, BLM, Dent, Lawson, Porter, Lando and Keith, Weiss)
- Temperature (Spence/Agrawal, Weiss [mean January minimum temperature, mean July maximum temperature, 30-year air temperature mean])
- Mean annual flow (Spence/Agrawal, Burnett, BLM, Dent, Lawson)
- Bankfull width (Porter, Lando and Keith)
- Bankfull depth (Lando and Keith)
- Elevation (Weiss)
- Mean annual precipitation (Weiss)

Extrinsic habitat features used or considered:

- Lifestage and habitat specific carrying capacities (Lando and Keith)
- Lifestage specific density independent mortality (Lando and Keith)
- Multistage stock production relationship with four different functional forms—Linear, Hockey-stick, Beverton-Holt, individually based superimposition model (Lando and Keith)
- Width (summer low, winter base, min and max) (Lando and Keith)
- Depth (summer low, winter base, min and max) (Lando and Keith)
- Grain size (min and max) (Lando and Keith, Weiss)
- Percent of channel habitat type (pool, riffle, glide, cascade) by slope (Lando and Keith)
- Riparian condition (Weiss)
- Water chemistry (Weiss)
- Land ownership (Weiss)
- Land cover (Weiss)

Available IP models and where these have been applied:

- Burnett et al. (2007) (Oregon Coastal ESU, Lower Columbia ESU in Oregon)
- Agrawal et al. (2005)/Spence (Southern Oregon Northern California ESU)

Available non-IP models and where these have been applied:

- British Columbia, Thompson River Basin (Porter)
- PNW west of the Cascades, Alaska, California (Lando and Keith)
- Pacific Northwest Coast Range (Weiss)

What time frame do models apply:

- Historical (Spence/Agrawal, Burnett, Dent, Lando and Keith)
- Current (BLM, Porter, Lando and Keith, Weiss)
- Future (Lando and Keith)

Life-stages for which models have been developed:

- Rearing habitat (Burnett, Spence/Agrawal, Porter, Weiss)
- Full life cycle (Lando and Keith)

Unit of habitat quantified:

- Reach (Spence/Agrawal, Burnett, Porter, Lando and Keith, Weiss)

Specified natural barriers:

- *Busch et al.*: Reaches above a natural barrier to fish passage were excluded. Natural barriers were as follows: gradient ≥ 16% , documented waterfalls >3.7 m, bankfull width < 1.2 m.
- *Spence/Agrawal*: Maximum gradient = 7%, but very low IP value >5%; minimum mean annual discharge = 0.01 m^3/s; maximum air temp = 21.5 ºC.
- *Dent*: Maximum gradient = 7%
- *Burnett et al.*: Assumes no use upstream of reaches with gradients exceeding 7% and reports IP only for reaches beneath naturally occurring barriers to adults. Barriers were identified based on information from ODFW that included a field determination of passability, barrier type, barrier height, and 1:100,000-scale maps of fish distribution.

Techniques for validation:

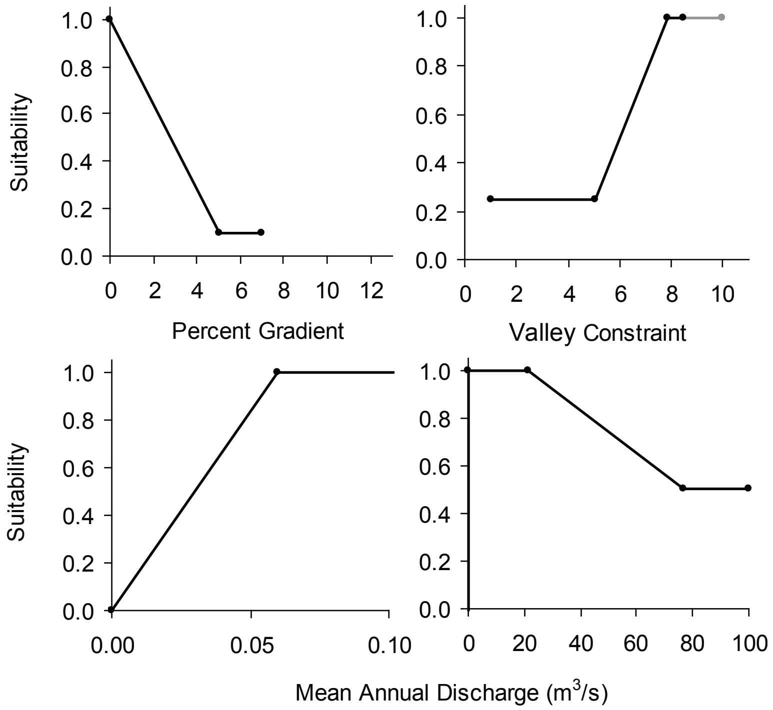
- *Burnett et al.*: Reach-level IP scores were binned into three categories: high, moderate, and low. For select populations with data on fish density, reaches were binned into density categories: high, moderate, and low. Correspondence between reach density score and reach IP score was assessed.
- *BLM:* Current fish distribution GIS data were compared to the IP model output to determine how well current distribution matched with IP >0.75. In this case, the terminology used for IP was Habitat Intrinsic Potential (HIP).
- *Porter:* Attempted to derive relationships empirically, from provincial fish datasets in relation to macrohabitat features, and did not use suitability curves.
- *Dent:* Conducted sensitivity analyses on the degree to which the maximum gradient threshold selected to represent the upper extent of coho distribution influenced estimated habitat length.
- *Lando and Keith:* Two methods dependent on data availability – (1) Field studies of current fish distribution to determine the extent of currently available habitat and (2) field studies to validate model predictions.
- *Weiss:* Explored how fish assemblages are structured by species composition, and by the interaction of species with natural and anthropomorphic environmental variables (EVs). Used multivariate statistical ordination techniques to extract the major environmental gradients shaping / governing the distribution of fish species and determine the most important EVs forming these gradients. Identified a subset of environmental metrics out of hundreds of potential metrics that can measure these EVs.

Candidate curves:

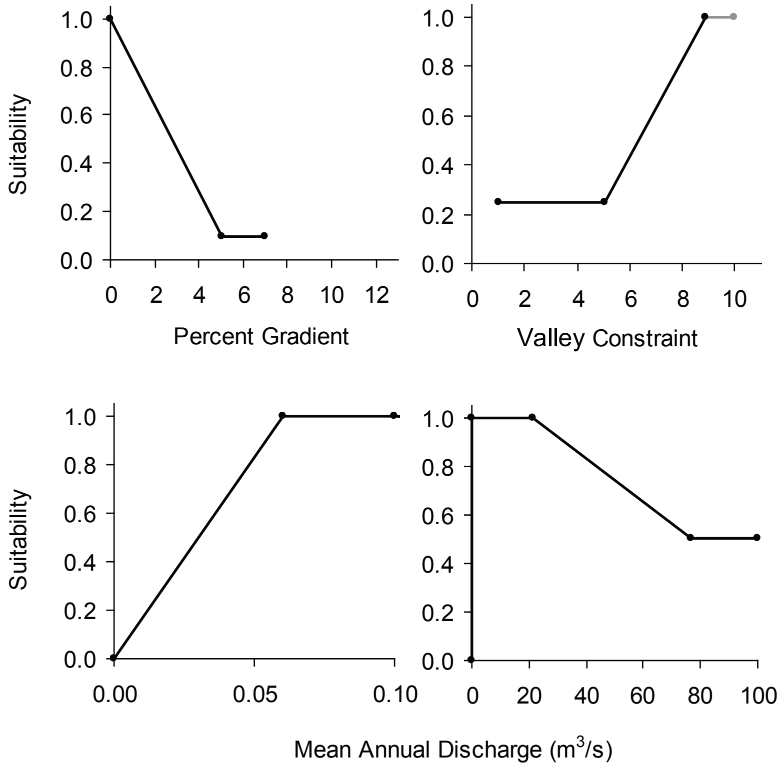
All curves, images, or numbers in this section are copied from the reference documents, or are unpublished data from the authors. Some modifications have been made to the curve axes or format for comparability between sources. Refer to original documents or contact authors directly for full descriptions, captions, and copies of the original curves. The terms valley width index, valley constraint, and valley width to bankfull width ratio are used interchangeably.

Agrawal et al. (2005):

Maximum gradient = 7%, but very low IP value >5%; minimum mean annual discharge = 0.01 m^3/s; maximum air temp = 21.5 ºC. The portion of the valley constraint curve in gray indicates an extension of Agrawal et al. (2005) curve that was implied, but not depicted, in their document.



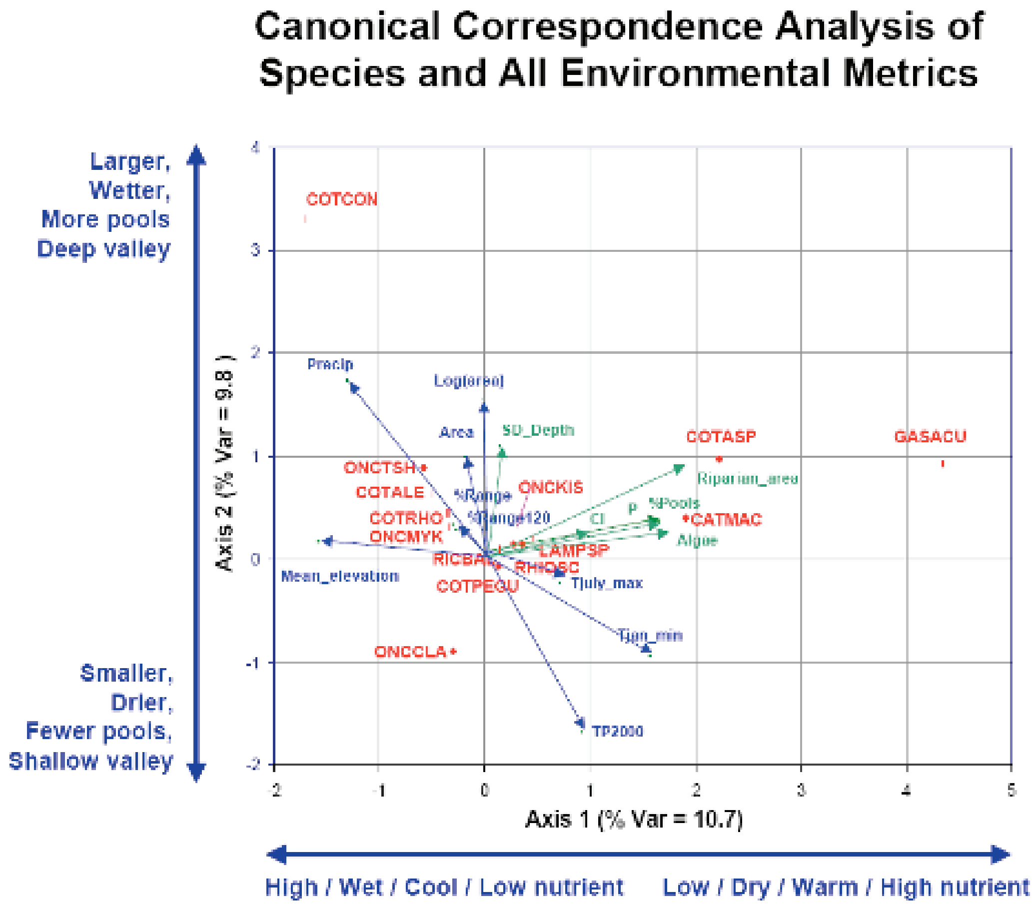
Burnett et al. (2007):



Porter (2008):

1. If Gradient ≥ 3.25% then LOW
2. If Gradient < 3.25% and Gradient > 2.45% then HIGH
3. If Gradient ≤ 2.45% and Bankfull Width < 1.75 m then LOW
4. If Gradient ≤ 2.45% and Bankfull Width ≥ 1.75 m then MEDIUM
5. If Channel Type = Lake then LAKE
6.

Herger et al. (2003), reported by A. Weiss



Summary of Chinook Salmon Models

This summary includes responses from:

- Sean Gallagher (2008), California Department of Fish and Game
- Tom Miewald, (oral commun., November 19, 2008), Wild Salmon Center
- Charles Paulsen (2001; 2005), Paulsen Environmental Research, Ltd.
- Shallin Busch et al., NOAA Northwest Fisheries Science Center
- Nikki Moore, Bureau of Land Management (BLM, 2008)
- Marc Porter (2008), ESSA Technologies, Ltd.
- Brian Spence, NOAA Southwest Fisheries Science Center (Agrawal et al., 2005)
- Jody Lando and A.J. Keith, Stillwater Sciences (1998; 2006; 2007a; 2007b), Ripple model
- Krista Bartz, NOAA Northwest Fisheries Science Center (Bartz et al., 2006)
- Andy Weiss, Washington Department of Fish and Wildlife (some information referenced as Herger et al., 2003)

This summary includes data from documents by:

- Tom Cooney and Damon Holzer (2006), NOAA Northwest Fisheries Science Center

Intrinsic habitat features used or considered:

- Valley constraint (Busch, Spence/Agrawal, BLM, Miewald, Cooney and Holzer)
- Gradient (Busch, Spence/Agrawal, BLM, Miewald, Cooney and Holzer, Porter, Lando and Keith, Bartz, Weiss)
- Mean annual flow/velocity (Spence/Agrawal, Gallagher, BLM, Miewald, Cooney and Holzer)
- Bankfull width (Busch, Cooney and Holzer, Porter, Lando and Keith, Bartz)
- Elevation (Busch, Miewald, Weiss)
- Precipitation (Weiss)
- Prism precipitation (Paulsen and Fisher)
- Glacial influence (Miewald)
- Lake effects (Miewald)
- Drainage density (km stream/km^2) (Paulsen and Fisher)
- Number of 6th field hydrological units upstream (Paulsen and Fisher)
- Total 1:100,000-scale streams upstream (Paulsen and Fisher)
- Solar radiation (W/m^2) (Paulsen and Fisher)
- Channel planform (Bartz)

Extrinsic habitat features used or considered:

- Width (summer low, winter base, min and max) (Lando and Keith)
- Temperature (Busch, Cooney and Holzer, Weiss [mean January min, mean July max])
- Sediment (Cooney and Holzer)
- Depth (summer low, winter base, min and max) (Lando and Keith, Gallagher)
- Substrate (Gallagher, Cooney and Holzer, Lando and Keith, Weiss)
- Percent of channel habitat type (pool, riffle, glide, cascade) (Lando and Keith, Bartz)
- Land use (Paulsen and Fisher)
- Vegetation cover (Gallagher, Paulsen and Fisher, Cooney and Holzer)
- Road density (Paulsen and Fisher)
- Lifestage and habitat specific carrying capacities (Lando and Keith)
- Lifestage specific density independent mortality (Lando and Keith)
- Multistage stock production relationship with four different functional forms—Linear, Hockey-stick, Beverton-Holt, individually based superimposition model (Lando and Keith)
- Riparian condition (Weiss)
- Water chemistry (Weiss)
- Land ownership (Weiss)
- Land cover (Weiss)

Available IP models and where these have been applied:

- Burnett et al. (2007) (Oregon Coastal ESU, Lower Columbia ESU in Oregon, Western Oregon (BLM))
- Agrawal et al. (2005)/Spence (Southern Oregon Northern California ESU)
- SE Alaska (Miewald)
- Western Oregon, all 5th field watersheds (BLM)

Available non-IP models and where these have been applied:

- Lower Snake River (Paulsen and Fisher)
- Interior Columbia domain (Cooney and Holzer)
- British Columbia, Thompson River Basin (Porter)
- Pacific Northwest, west of the Cascades, Alaska, California (Lando and Keith)
- Snohomish Basin (Bartz)
- Puget Sound (Bartz)
- Pacific Northwest Coast Range (Weiss)

What time frame do models apply:

- Historical (Busch, Spence/Agrawal, Cooney and Holzer, Lando and Keith, Bartz)
- Current (Meiwald, BLM, Porter, Lando and Keith, Bartz, Weiss)
- Current land use (Paulsen and Fisher)
- Seasonal (depending on flow, Gallagher)
- Future (Lando and Keith)

Life stages for which models have been developed:

- Spawning and rearing habitat (Miewald, Gallagher, Busch, Cooney and Holzer)
- Rearing (Spence/Agrawal, BLM, Porter, Bartz, Weiss)
- Parr to smolt survival (Paulsen and Fisher)
- Full life cycle (Lando and Keith)

Unit of habitat quantified:

- Reach (Spence/Agrawal, Busch, BLM, Cooney and Holzer, Porter, Lando and Keith, Bartz, Weiss)
- Subbasin (Paulsen and Fisher)

Specified natural barriers:

- *Cooney and Holzer:* gradients > 20% for > 200 m and waterfalls deemed impassable by observation and expert opinion. Reach level data also was limited to reaches wider than 5.7 m.
- *Busch et al.*: gradient > 16%, documented waterfalls >3.7 m, and bankfull width <2 m. For Lower Columbia fall Chinook, used a threshold of 350 m elevation to limit IP scores to streams low enough in the watershed to reasonably represent spawning / rearing for fall Chinook.
- *Spence/Agrawal*: Maximum gradient = 8%, but very low IP value > 3.5%; minimum mean annual discharge = 0.28 m^3/s.

Techniques for validation:

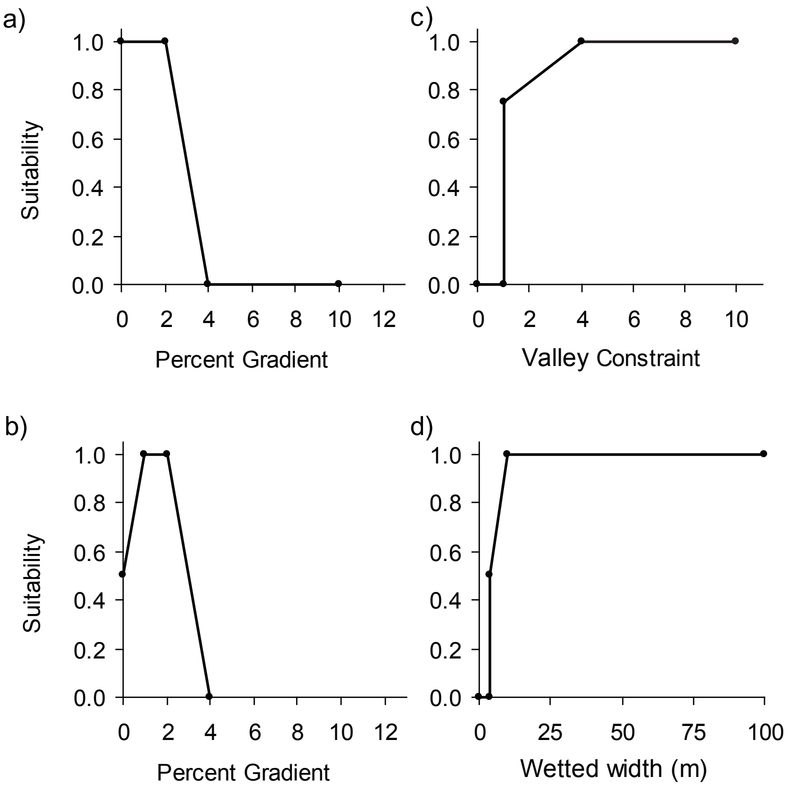
- *Busch:* Assessed against data on population size generated by Willamette/Lower Columbia TRT.
- *Cooney and Holzer*: Utilized established relationships between habitat type, stream structure, landscape processes, and spawning use, build a locally adapted GIS-based model incorporating regional spatial data, fisheries surveys, and professional knowledge. The GIS was used for the development, presentation, management and modeling of spatially referenced data. Modeled geomorphological characteristics were assigned to unique categories consisting of gradient, width, and valley confinement, from which additional stream and landform modifiers were incorporated to adjust intrinsic potential. These classes were then evaluated against known distributional densities to test modeled habitat quality. Results from these comparisons were used to weight and summarize reach areas for the entire stream network within the Interior Columbia Basin based on relative Chinook salmon and steelhead habitat preferences.
- *BLM*: Current fish distribution GIS data were compared to the IP model output to determine how well current distribution matched with IP >0.75.
- *Porter:* Attempted to derive relationships empirically, from provincial fish datasets in relation to macrohabitat features, and did not use suitability curves.
- *Lando and Keith*: Two different methods dependent on data availability—(1) Field studies of current fish distribution to determine the extent of currently available habitat and (2) field studies to validate model predictions.
- *Weiss:* Explored how fish assemblages are structured by species composition, and by the interaction of species with both natural and anthropomorphic environmental variables (EVs). Used multivariate statistical ordination techniques to extract the major environmental gradients shaping / governing the distribution of fish species and determine the most important EVs forming these gradients. Identified a subset of environmental metrics out of hundreds of potential metrics that can measure these EVs.

Candidate curves:

All curves, images, or numbers in this section are copied from the reference documents, or are unpublished data from the authors. Some modifications have been made to the curve axes or format for comparability between sources. Refer to original documents or contact authors directly for full descriptions, captions, and copies of the original curves. The terms valley width index, valley constraint, and valley width to bankfull width ratio are used interchangeably.

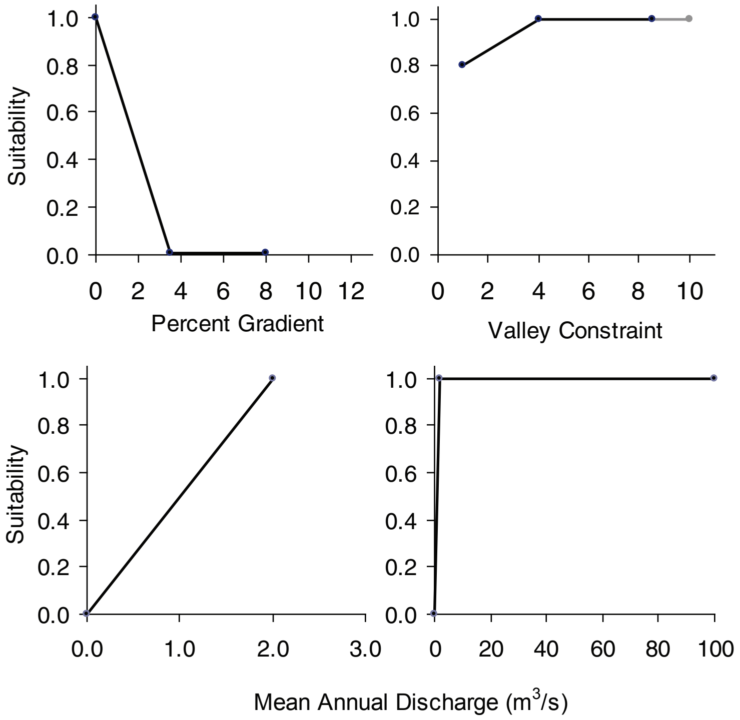
Busch et al.(unpublished data):

Figures a) Gradient when reach width is > 25 m;
b) gradient when reach width is between 2 and 25 m;
c) ratio of valley width to bankfull width;
d) bankfull width.



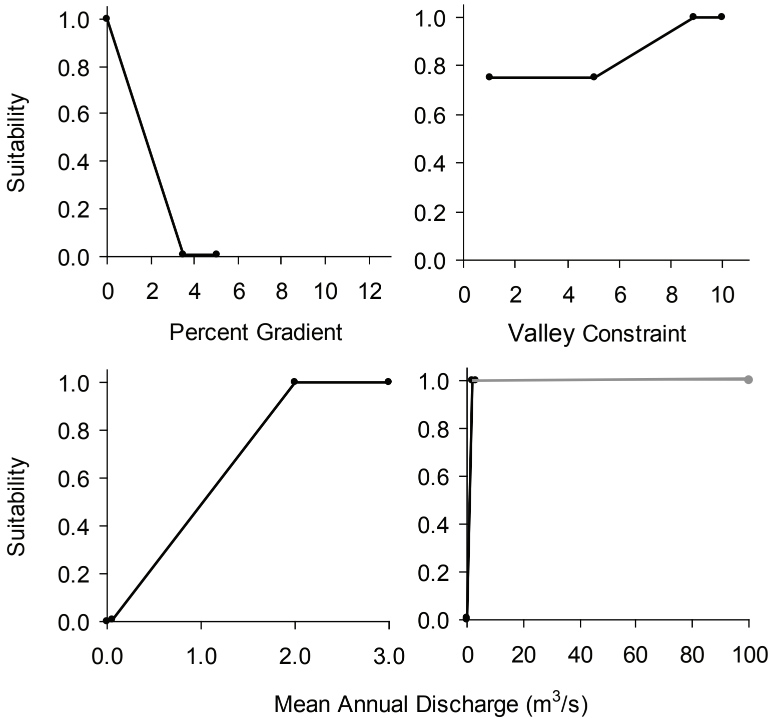
Spence/Agrawal et al. (2005):

Maximum gradient = 8%, but very low IP value > 3.5%; minimum mean annual discharge = 0.28 m³/s. The portion of the valley constraint curve in gray indicates an extension of Agrawal et al. (2005) curve that was implied, but not depicted, in their document.



BLM (2008):

The portion of the mean annual discharge graph in gray indicates an extension of the BLM (2008) graph that was implied, but not depicted, in their document.



Cooney and Holzer (2006) (table 3):

Used two screens when generating IP scores.
1) Sediment screen
When the following conditions are met, IP for a reach is scored 0.

a. Gradient <0.5% intersected with K>0.4
b. Subwatershed having at least 50% of their area with K>0.4
c. Area above reach has a mean K value > 0.4

2) Temperature screen.
IP score = 0 if weekly mean annual air temperature in July ≥ 22°C

Table 3. Relative potential for Interior Columbia basin Spring and Spring/Summer Chinook salmon spawning and initial rearing as a function of stream reach physical characteristics.

[BF: Bankfull stream width; Gradient: percent change over 200 m reach; and relative confinement: valley width expressed as ration to BF stream width]

Stream Width/ Gradient Categories		**Valley Width Ratio (Ration of valley width to bankfull stream width)**		
Bankfull Width (BF)	**Gradient**	**Confined (≤ 4 × BF width)**	**Moderate (4–20 × BF width)**	**Wide (> 20 × BF width)**
BF < 3.7 m	≥ 0	None	None	None
BF 3.7 m to 25 m	0–0.5	*Medium*	*High*	*High*
	0.5–1.5	*Low*	*Medium*	*High*
	1.5–4.0	*Low*	*Low*	*Medium*
	4.0–7.0	Negligible	*Low*	*Low*
	> 7.0	None	None	None
BF 25 m to 50 m	0 – 0.5	None	*Medium*	*Medium*
	0.5–10	None	None	None
	≥ 10	None	None	None
BF > 50 m	≥ 0	None	None	None

Porter (2008):

1. If Gradient <3.25% and Bankfull Width ≥ 15 m then LOW
2. If Gradient <3.25% and Bankfull Width < 15 m then MODERATE
3. If Gradient ≥3.25% and Bankfull Width ≥ 2.6 m then MODERATE
4. If Gradient ≥3.25% and Bankfull Width < 2.6 m then HIGH
5. If Channel Type = Lake then LAKE

Bartz et al. (2006) (tables 4 and 5):

Table 4. Equations used to estimate juvenile rearing in certain habitat types under the current path and test case scenarios.

[CA, channel area; BA, bank area; OA, off-channel area; EA, estuarine area. Subscripts: a, above culvert; c, current; f, future scenario, either current path or test case; h, historical; m, modified; n, natural; t, total (i.e., natural + modified). The estuarine area equation assumes that 80 percent of the historical area is currently inaccessible (Hass and Collins, 2001)]

Habitat type	Potential juvenile rearing area equation
Freshwater, tributaries	$CA_f = CA_c$ + [CA_a (anthropogenic barrier target$_f$/100)]
Freshwater, large mainstems	$BA_{n,f} = BA_{t,c}$ (edge habitat target$_f$/100)
Freshwater, large mainstems	$BA_{m,f} = BA_{t,c} - BA_{n,f}$
Freshwater, off-channel	$OA_f = OA_h$ (off-channel habitat target$_f$/100)
Estuary	EA_f = [0.8EA_h(off-channel habitat target$_f$/100)] + (0.2EA_h)

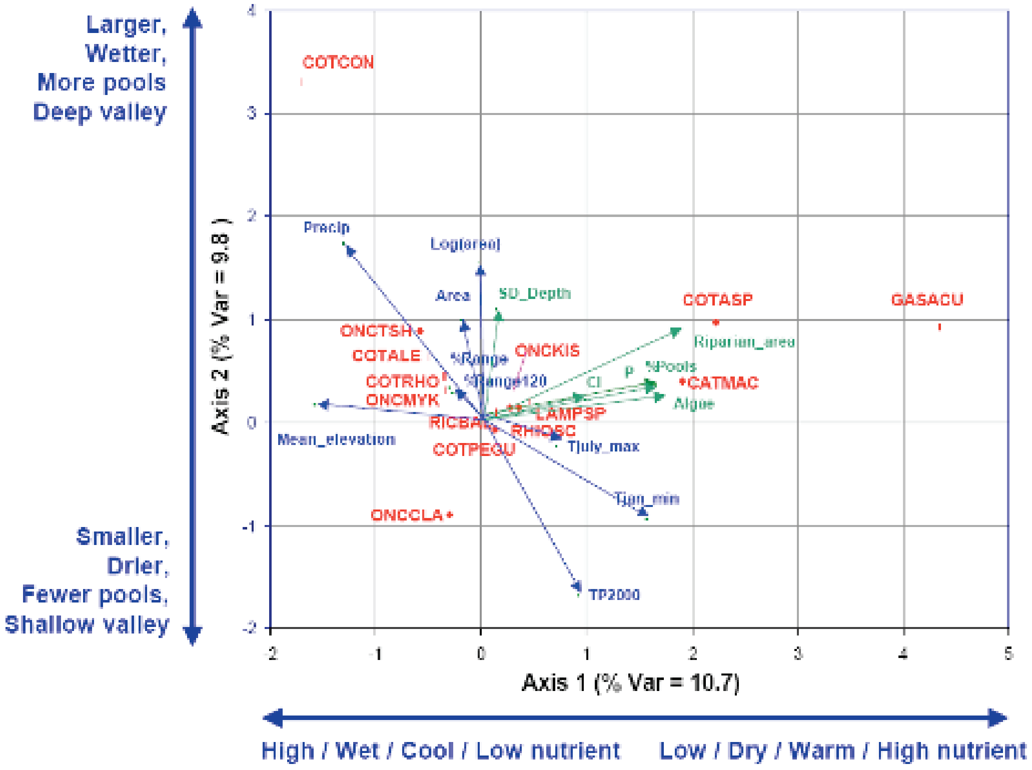
Table 5. Equations used to estimate potential adult capacity under current conditions for three stream width-gradient classes.

[Units for stream area and stream length are square miles and kilometers, respectively. OA, off-channel area; EA, estuarine area. Subscripts: f, future scenario, either current path or test case. The estuarine area equation assumes that 80 percent of the historical area is currently inaccessible (Hass and Collins, 2001)]

Bankfull width, gradient	Potential adult capacity equation
>25 m, ≤4%	Capacity = [(stream area) × (% spawnable area/100) × (adults•redd^{-1})] × (m^2•redd^{-1})$^{-1}$
5-25 m, <1%	Capacity = (stream length) × (adults•redd^{-1}) × (redds•km^{-1})
5-25 m, 1–4%	Capacity = (stream length) × (% forced pool-riffle/100) × (adults•redd^{-1}) × (redds•km^{-1})
Freshwater, off-channel	$OA_f = OA_h$ (off-channel habitat target$_f$/100)
Estuary	EA_f = [0.8EA_h(off-channel habitat target$_f$/100)] + (0.2EA_h)

Herger et al. (2003), reported by Weiss

Canonical Correspondence Analysis of Species and All Environmental Metrics



Summary of Steelhead Models

This summary includes responses from:

- Sean Gallagher (2008), California Department of Fish and Game
- Jason Dunham, U.S. Geological Survey
- Eric Anderson, Master's thesis, Oregon State University
- Nikki Moore (2008), Bureau of Land Management (BLM, 2008)
- Brian Spence, NOAA Southwest Fisheries Science Center (Agrawal et al., 2005)

This summary includes data from documents by:

- Tom Cooney and Damon Holzer (2006), NOAA Northwest Fisheries Science Center
- Burnett et al. (2007), USDA Forest Service
- Zimmerman and Reeves (2000), Oregon State University and USDA Forest Service
- Boughton and Goslin (2006), NOAA Southwest Fisheries Science Center

Intrinsic habitat features used or considered:

- Valley constraint (Spence/Agrawal, Burnett, BLM, Cooney and Holzer)
- Gradient (Spence/Agrawal, Burnett, BLM, Cooney and Holzer, Boughton and Goslin)
- Temperature (Cooney and Holzer, Boughton and Goslin)
- Mean annual flow/velocity (Spence/Agrawal, Burnett, BLM, Gallagher, Zimmerman and Reeves, Boughton and Goslin [just for summer])
- Bankfull width (Cooney and Holzer)
- Valley width relative to mean discharge (Boughton and Goslin)

Extrinsic habitat features used or considered:

- Vegetation cover (Gallagher, Cooney, and Holzer)
- Sediment (Cooney and Holzer)
- Depth (Gallagher, Zimmerman, and Reeves)
- Substrate (Gallagher, Cooney and Holzer, Zimmerman and Reeves)
- Soil type (Boughton and Goslin)

Available IP models and where these have been applied:

- Burnett et al. (2007) (Oregon Coastal ESU, Lower Columbia ESU in Oregon)
- Agrawal et al. (2005)/Spence (Southern Oregon Northern California ESU)
- Pacific Northwest, west of Cascades (Anderson)
- Western Oregon, All 5th field watersheds (BLM)

Available non-IP models and where these have been applied:

- Interior Columbia domain (Cooney and Holzer)
- Deschutes River (Zimmerman and Reeves)
- Mid-Columbia Basin (Dunham)
- South-Central, Southern California Coast (Boughton and Goslin)

What time frame do models apply:

- Historical (Spence/Agrawal, Burnett, Cooney and Holzer, Boughton and Goslin)
- Current (BLM, Zimmerman and Reeves)
- Seasonal (depending on flow, Gallagher)

Life-stages for which models have been developed:

- Spawning and rearing habitat (Gallagher, Cooney and Holzer)
- Rearing habitat (Burnett, Spence/Agrawal, Boughton and Goslin)
- Spawning habitat (Zimmerman and Reeves)

Unit of habitat quantified:

- Reach (Spence/Agrawal, Burnett, BLM, Cooney and Holzer, Boughton and Goslin)
- Redd (Zimmerman and Reeves)

Specified natural barriers:

- *Cooney and Holzer*: gradients > 20% for > 200 m and waterfalls deemed impassable by observation and expert opinion. Reach level data also were limited to reaches wider than 5.7 m.
- *Spence/Agrawal*: Maximum gradient = 12%.
- *Burnett et al.*: Assumes no use upstream of reaches with gradients exceeding 10% and reports IP only for reaches below naturally occurring barriers to

adults. Barriers were identified based on information from ODFW that included a field determination of passability, barrier type, barrier height, and 1:100,000-scale maps of fish distribution.

Techniques for validation:

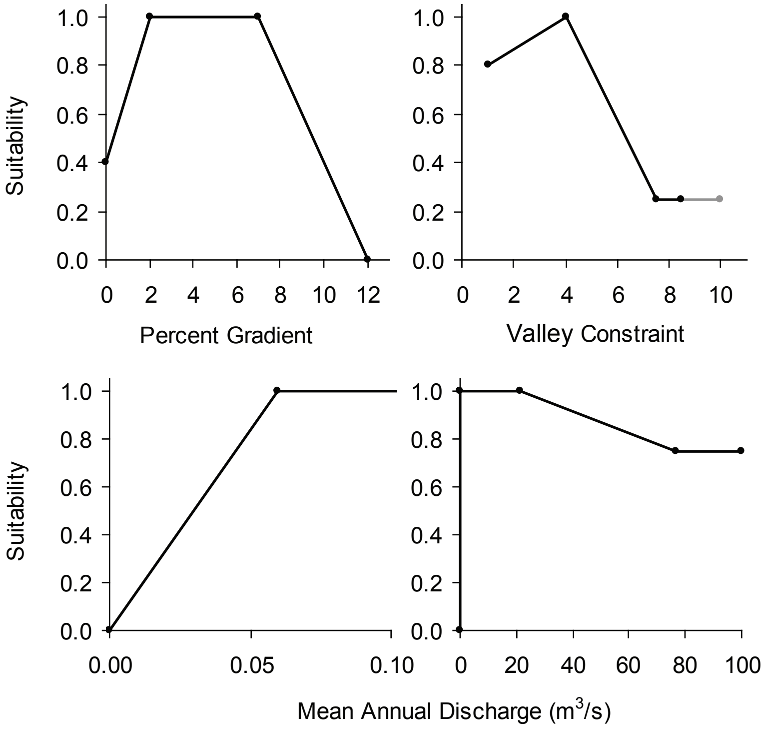
- *Cooney and Holzer*: Utilized established relationships between habitat type, stream structure, landscape processes, and spawning use to build a locally adapted GIS-based model incorporating regional spatial data, fisheries surveys, and professional knowledge. The GIS was used for the development, presentation, and management and modeling of spatially referenced data. Modeled geomorphological characteristics were assigned to unique categories comprised of gradient, width, and valley confinement, from which additional stream and landform modifiers were incorporated to adjust intrinsic potential. These classes were evaluated against known distributional densities to test modeled habitat quality. Results from these comparisons were used to weight and summarize reach areas for the entire stream network within the Interior Columbia Basin based on relative Chinook salmon and steelhead habitat preferences.
- *Burnett et al.*: Reach-level IP scores were binned into three categories: high, moderate, and low. For select populations with data on fish density, reaches were binned into density categories: high, moderate, and low. Assessed the correspondence between reach density score and reach IP score.
- *BLM*: Current fish distribution GIS data were compared to the IP model output to determine how well current distribution matched with IP >0.75 (HIP).
- *Boughton and Goslin*: Built environmental envelope models from historical data. Tested models predictive ability using bootstrapping.

Candidate Curves:

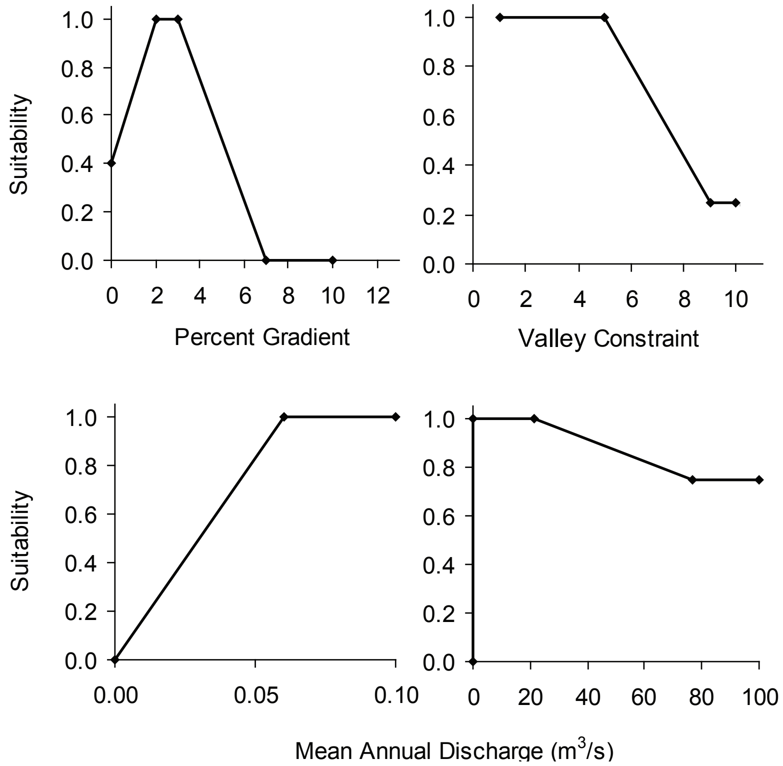
All curves, images, or numbers in this section are copied from the reference documents, or are unpublished data from the authors. Some modifications have been made to the curve axes or format for comparability between sources. Refer to original documents or contact authors directly for full descriptions, captions, and copies of the original curves. The terms valley width index, valley constraint, and valley width to bankfull width ratio are used interchangeably.

Spence/Agrawal et al. (2005):

Maximum gradient = 12%. The portion of the valley constraint curve in gray indicates an extension of Agrawal et al. (2005) curve that was implied, but not depicted, in their document.



Burnett et al. (2007), BLM:



Zimmerman and Reeves (2000) (table 6):

Table 6. Characteristics (mean ± SE) and one-way analysis of variance of 28 steelhead and 52 rainbow trout redds, Deschutes River, Oregon.

[cm, centimeter; cm/s, centimeter per second]

Variable	Steelhead	Rainbow trout	F ratio	P
Water depth (cm) adjacent to pit	54.07 ± 2.74	42.58 ± 1.89	3.51	0.0007
Mean water velocity (cm•s^{-1}) adjacent to pit	71.43 ± 3.41	63.35 ± 2.51	1.43	ns
Gravel size (mm) in tailspin	32.50 ± 1.98	25.10 ± 1.11	3.53	0.0007
Redd length (m)	2.08 ± 0.14	1.50 ± 0.05	4.77	0.00001
Redd width (m)	1.18 ± 0.11	0.83 ± 0.03	3.81	0.0003

Cooney and Holzer (2006) (table 7):

Used two screens when generating IP scores
(1) Sediment screen.
When the following conditions are met, IP for a reach is scored 0.
  a. Gradient <0.5% intersected with K>0.4.
  b. Subwatershed having at least 50% of their area with K>0.4.
  c. Area above reach has a mean K value > 0.4.
(2) Temperature screen.
IP score = 0 if weekly mean annual air temperature in July ≥ 22°C

Table 7. Relative potential for Interior Columbia basin steelhead spawning and initial rearing as a function of stream reach physical characteristics.

[BF: Bankfull stream width; Gradient: percent change over 200 m reach; and relative confinement: valley width expressed as ratio to BF stream width]

Stream Width/ Gradient Categories		**Valley Width Ratio (Ratio of valley width to bankfull stream width)**		
Bankfull Width (BF)	**Gradient**	**Confined (≤ 4 × BF width)**	**Moderate (4–20 × BF width)**	**Wide (> 20 × BF width)**
BF < 3.8 m	≥ 0	None	None	None
BF 3.8 m to 25 m	0–0.5	None	*Medium*	*Medium*
	0.5–4.0	*Low*	*High*	*High*
	4.0–7.0	None	*Low*	*Low*
	>7.0	None	None	None
BF 25 m to 50 m	0–4.0	*Low*	*Medium*	*Medium*
	>4.0	None	None	None
BF > 50 m	≥ 0	None	*Low*	*Low*

Boughton and Goslin (2006) (table 8):

Reach is disqualified if it occurred in alluvial soils.

Table 8. Environmental envelopes estimated from observations of juvenile *O. mykiss* during the summers of 1961–2003.

[A complete envelope is the interval defined by the maximum and minimum predictor values that are present in the steelhead observations (i.e., the range on that predictor). The steelhead data were resampled (with replacement) 50,000 times, and complete envelopes were computed for each resample, then sorted from most conservative (most restrictive) to most inclusive. Bootstrapped envelopes are as follows: A 95% envelope is the interval spanned by the 95% most conservative resamples. Majority-rule envelopes are the interval spanned by the 50% + 1 most conservative resamples; consensus envelopes are the interval spanned by all 50,000 resamples]

Environmental envelopes	**Lower boundary of envelope**			**Upper boundary of envelope**		
	Complete[1]	**95%**	**Consensus**	**Consensus**	**95%**	**Complete[1]**
South-central California Coast ESU						
Summer Discharge (m^{3}s^{-1})	0.000763	0.002	0.0061	0.09257	0.26984	0.280266
Gradient (%)	0.03	0.03	0.23	6.2	9.31	10.72
Valley Width Index	2.8	3.44	5.84	26.28	37.53	64.96
Mean August Temp. (ºC)	–	–	–	20.4	22	24.1
Mean Annual Temp. (ºC)	–	–	–	15	15.2	16.1
Southern California Coast ESU						
Summer Discharge (m^{3}s^{-1})	0.000254	0.0008	0.00229	0.09842	0.15412	0.181588
Gradient (%)	0.03	0.03	0.51	8.26	10.57	16.26
Valley Width Index	2.54	2.69	3.76	18.68	29.56	51.24
Mean August Temp. (ºC)	–	–	–	23.5	24.1	24.6
Mean Annual Temp. (ºC)	–	–	–	16.2	17.4	17.5

[1] Majority-rule and one-plus envelopes were without exception identical to the complete envelopes.

Presenting Results of Intrinsic Potential Analyses

Summarizing IP Scores

IP models produce a score for each stream reach. Thus, it is important to account for differences in reach length when comparing results across reaches with variable lengths. Reach IP scores can be multiplied by the length of the reach to give an IP score-adjusted reach length, referred to as IP kilometers (IPKM). IPKM for all reaches in a river or watershed can be summed to give the amount of suitability habitat in the area of interest. IPKM can be readily compared among areas, such as 4th, 5th, or 6th field hydrologic units, or between spatial datasets, for example to evaluate how different methods for designating stream reach breaks impact the amount of habitat assigned as suitable.

Presenting Results

There seems to be consensus that the accuracy level of IP model output at the reach level is less than the accuracy of IP model results at broader spatial scales. For this reason, care should be taken when presenting results from IP models to express the uncertainty of results or to generalize maps and presentations appropriately. In addition, we suggest that modelers tailor the scale of visual representation (maps) of results to the questions/needs of users, so uncertainties are clear. The subject of visual representation of model output needs more exploration.

Maps of IP model results that present data in blocks or by watershed best match the accuracy of IP models. IP models are not designed for pinpointing individual reaches, and are instead useful for determining areas or patches in the watershed that represent potentially poor, fair, or good habitat. Precision, accuracy, and scale of the input variables can help determine a minimum appropriate mapping unit (e.g., the number of reaches included in a summary).

IP scores are often represented at four scales: reach (30–100 m), reach clusters (patches of reaches, 500 m–3 km), and tributary, and watershed scale. Tools that help generalize the IP scores to patches or core habitat types within the watershed (e.g., core tool in NetMap) are a helpful way to summarize results from IP models. Results from IP models also can be binned and compared to identify clusters of high, medium, or low potential habitat. Spatial proximity of one habitat type to another is an important factor that may influence habitat use. For example, a small tributary near a mainstem can provide key habitat for some anadromous fishes. Participants recommended summarizing IP results at units that capture the spatial proximity of habitat types to one another (e.g., data presented at the 6th-field Hydrologic Unit may be too coarse). Small-scale maps can be used to focus attention on certain key spots in large watersheds (e.g., to guide restoration, or to communicate the location of potentially good habitat).

Validating and Calibrating Intrinsic Potential Scores

There is a recognized need for ground-truthing IP models prior to using results for field work, such as restoration. Group discussions indicated that IP may over predict the amount of high-quality habitat, a phenomenon that should be considered when interpreting results. Model results should be tested against fish distributions, redd surveys, and/or snorkel surveys (depending on life stage) whenever possible.

Few studies have attempted to do a quantitative calibration and/or validation of IP models. [Refer to the habitat curve section on pages 8-21 of this report for information on studies that have done this.] Participants were interested in understanding how, in each model, the strength of the correlation between results of IP models and fish distribution changes with alterations to parameter thresholds and thought that work should be done on curve sensitivity to develop confidence in curves. However, because the IP score for a reach represents the geometric mean (geomean) of three or more variables, this combined output is what should be validated seriously, rather than individual habitat suitability curve scores.

Model validation is currently limited by data availability on current and historic fish distribution, the depression of populations compared to their historic size, and changes in species distribution due to anthropogenic activities. When abundance is low, the habitat will not be fully seeded and individuals will likely not occupy all suitable habitat types: we would expect that only the most suitable habitat (highest IP scores) will be occupied when population abundance is low. In addition, the influence of anthropogenic habitat modification on the current distribution of species in the landscape is not incorporated in IP models and could add noise to the correlation between IP models and species density. Using data from areas with “pristine” conditions could increase the likelihood of accurately predicting species presence/absence with IP scores.

Given the comparatively lower variability in populations of resident fish compared to anadromous fish, it may be useful to look at resident fish abundance to validate IP curves.

Impact of Climate Change on Intrinsic Potential Metrics

Results of IP models represent a historical baseline before the current era of human-induced climate change. To incorporate the impact of future climate conditions on habitat suitability, one could use downscaled climate models (e.g., from the University of Washington’s Climate Impacts Group) to develop datasets that reflect future landscape features (e.g., estimated future flow levels) and use these data to estimate habitat suitability in a projected future environment. These results could be compared to results when current data are used. For example, groundwater can affect flow and can be an important component driving fish distributions under changing climate conditions. Grant, Taugue, and others have worked (and are currently working) on modeling groundwater and summer low flows in the McKenzie River (Oregon), including estimating the effects of vegetation growth under different CO_2 regimes (Tague and Grant, in press; Tague and Grant, 2004; G. Grant, oral commun., November 19, 2008). Other work could focus on predicting conversion of snow melt-dominated systems into rain-dominated systems, changes in the hydrograph, and areas with high IP score that may be resilient to predicted climate change scenarios.

Examples of Software and Programs Used to Calculate Intrinsic Potential

NetMap

Earth Systems Institute, specifically Lee Benda and Dan Miller, have designed a publicly available tool named NetMap (Benda et al., 2007). NetMap provides an ArcGIS toolkit to calculate a variety of topographic and watershed attributes over a DEM-traced channel network. It has a model-design tool for using these attributes to build IP models, with published models provided as options. NetMap includes analysis tools to address a suite of watershed processes (sediment production, wood production, water temperature) and habitat attributes (IP, core habitat areas, habitat diversity) to aid in development of empirical models, in watershed assessments, and in management, conservation, and restoration planning.

Shallin Busch and Paul McElhany (NOAA) developed a JAVA program to run IP models based on the habitat variables used in their work. The program takes properly formatted data input tables and habitat suitability curves and calculates reach-specific IP scores and IPKM. It also calculates summary statistics for each dataset run through the model.

Earlier IP work was done in ArcInfo, using Arc Macro Language (AML) (K.M. Burnett, oral commun., November 19, 2008).

Hydrography—The Building Block of Intrinsic Potential Analyses

Hydrography is a primary building block of IP. Many attributes used in IP analyses are based on physical stream features, such as gradient, valley form, channel width, and basin size, linked to specified reaches in a channel network. We define hydrography as the spatial location and connections between all channel reaches of a stream network. The scale of the hydrographic network (e.g., 1:100,000 versus 1:24,000), the resolution of the elevation data used to infer physical features (and in some cases, to trace channel networks), the method used to delineate reach breaks (e.g., equal versus variable length), and the length of delineated reaches all affect the estimated value of physical stream features and, in turn, reach- and basin-scale IP scores.

There are various sources of hydrography and methods for incorporating hydrography into a GIS. Hydrography may be created directly from spatially explicit field data, digitized from existing maps, or generated using digital elevation models (DEMs). Current sources for non DEM-derived hydrography data include the National Hydrography Dataset (NHD) (http://nhd.usgs.gov/) and the Pacific Northwest Hydrography Framework (http://hydro.reo.gov/). While non DEM-derived stream networks can be more spatially accurate, only DEM-derived streams provide the physical habitat attributes needed to calculate IP scores (table 2). Ten-meter resolution DEMs are widely available across the continental United States (National Elevation Dataset, http://ned.usgs.gov/), allowing for the possibility of regional standardization of DEM-derived hydrography.

Stream Networks

Stream networks can be generated using one of many products (ArcHydro; NetStream (www.netmaptools.org); Arc GRID; TauDEM (http://hydrology.neng.usu.edu/taudem/)). DEM-derived streams simplify delineating catchment basins—catchments sometimes are required for determining relationship of upslope and in-channel attributes. Ancillary data can be linked to these streams and routed to the streams where necessary. This technique is especially useful for analyses where researchers want to start with intrinsic features and then add anthropogenic ‘extrinsic’ factors (land use, riparian vegetation, runoff, roads and erosion indices). Participants agreed it is best to use drainage-enforced DEMs (DE-DEMs) for generating stream networks. DE-DEMs are corrected to enforce the flow pathways of generated stream networks to correspond with channel locations in existing hydrographic data by altering elevation values of DEM cells. Alternately, DE-DEMs also have the potential to reduce accuracy of ancillary attributes, because alteration of elevation values affect the calculation of topographic attributes.
An alternate method is using a vector stream layer to modify DEM-derived flow directions on the fly. Using a DEM with a corresponding stream network can simplify referencing ability between other datasets.

Inaccuracies in elevation values can result in missed stream channels, incorrect channel locations, and unresolved topographic features (e.g., channel-confining terraces). Horizontal resolution may be insufficient to resolve pertinent topographic features such as incised channels. Channels may not line up with other georeferenced channel data (e.g., with stream layers derived with other techniques). Joining DEM-derived data with other attribute sources (i.e., NHD) or stream layers can result in miscorrelated channel segments. Improved algorithms use a combination of routing, topology, proximity, and stream attributes (e.g., drainage area) to match stream segments between datasets. Such a tool is currently being added to NetMap (Benda et al., 2007).

Identifying ephemeral and perennial streams and streams with minimum flows for fish is an important step in IP or fish potential analyses. Ascertaining an appropriate channel initiation threshold for DEM-derived streams will minimize the number of ephemeral streams (or drainage lines misidentified as streams) in a generated stream network. Ephemeral streams may be identified in the stream network using attributes such as flow, gradient, and channel width. Clarke et al. (2008), for example, used data from field-surveyed points of initial perennial flow to estimate the probability for perennial flow based on drainage area. Another strategy is to generate the densest coverage that can be resolved from DEMs and use other data sources to delineate dry from intermittent from perennial channels (Clarke et al., 2008).

A regionally standardized DEM-derived stream network used by everyone could allow for comparisons of watershed attributes between watersheds using comparable methods and base datasets (e.g., the same DEM that generated the stream is used as a base for other attributes). DEM-derived streams could be generated at the same resolution (e.g., 1:24,000) as the ancillary topographic data used in an analysis. Channel density could be consistent across administrative units (with some exceptions crossing 24K quad boundaries, i.e., crenulation changes), as would methods of calculating attributes (improving comparability of attributes).

LiDAR-Derived Stream Networks

Light Detection and Ranging (LiDAR) is a remote sensing system used to collect topographic data. LiDAR can potentially provide elevation data of sufficient resolution and accuracy to directly resolve most or all stream channels (Mouton, 2005) as well as topographic attributes pertinent for calculations of IP scores. It may be possible, for example, to measure channel width and terrace extent directly from LiDAR data, rather than relying on regional regressions to drainage area and precipitation. LiDAR also may allow the measurement of floodplain attributes, such as the number and area of side channels, features not captured by 10-m DEMs.

In addition to the potential advantages mentioned above, the high resolution of LiDAR data also may present challenges when applied to IP analyses. LiDAR data are often able to resolve road prisms, but not culverts and cross drains. Hence, flow routing from LiDAR-derived DEMs can result in rerouting of flow paths by roads. LiDAR also may have horizontal point spacing less than the width of the stream channel resulting in multiple parallel flow paths being traced within a single channel. Issues such as these will require the development of new algorithms, e.g., channel delineation may be done with data subsampled to a lower resolution and then reach attributes calculated using the original high-resolution DEM. In general, LiDAR-based analyses will have to address issues with managing large datasets, slower processing speeds, limited availability of data, and data quality variability.

Stream Reach Delineation

The tools used to generate DEM-derived streams break the stream network into reaches of equal or varying length. Reaches may be broken at tributary junctions, at natural geomorphic breaks (e.g., transitions in valley width or channel gradient, Clarke et al., 2008), or based on the horizontal resolution of elevation data (Clarke and Burnett, 2003). Physical stream parameters such as gradient and confinement are summarized at the scale of reach lengths. Thus, the length of a reach and the method used for determining reach breaks will influence the IP scores generated from it. Reach length can be designated either prior to stream generation by setting tool parameters or following stream generation using routing and dynamic segmentation methods (as links between tributary confluences, ESRI, 2002). The equal reach-length method is the easiest for summarizing results, as it allows a relatively easy conflation to different lengths if necessary.

Large Rivers and Reservoirs

IP models for anadromous species typically do not incorporate a special classification for lakes, reservoirs, and ponds (GIS terminology: double-banked streams). Values for bankfull width typically are developed for lotic systems and are linked to river size. In run-of-the-river lakes or reservoirs, stream reaches that go through the midline of a lake or reservoir are considered the same as other stream reaches, with the exception that they have a very large bankfull width. We argue that reservoirs or lakes should be considered separately when developing habitat suitability curves. Netstream and NetMap include an optional field in the channel coverage to flag channel reaches traversing lakes or reservoirs (which must be identified from another data source, e.g., a polygon file of water bodies). These reaches are then excluded from summary statistics of channel attributes or treated as sinks (e.g., for sediment routing).

Calculated measurements of gradient, valley width index, flow and bankfull width can be problematic or inaccurate in reservoirs or lakes due to DEM representation of these features. Dams at the outlet of reservoirs also can cause inaccuracies in DEM-generated stream network flow accumulation because of dam elevations. Raw variables for IP should be checked for accuracy in double-banked streams. Lake and reservoir systems are more effectively represented by lateral rather than linear representation. If these features are to be included in IP model, they would need specific habitat suitability curves.

Photograph by U.S. Geological Survey.

Physical Variables and Biological Thresholds

IP models use geospatial data on physical aquatic habitat features to identify stream reaches with high or low potential to host fish or other species, and provide a method for estimating potential habitat quantity and quality across local to regional scales. Reach-level hydrogeomorphic and other physical features used in IP analyses are estimated using hydrologic, GIS, and remote sensing methods. Many of these variables are correlated. For example, valley confinement and flow are both based on regressions using drainage areas. Gradient and valley confinement also may be correlated. Correlations among variables should be considered when choosing variables to use in IP models.

A summary of how the features in this section are used within IP models is described briefly in section, "Applying Intrinsic Potential Models" (p. 5-6) and also in Burnett et al. (2003, 2007) and Agrawal et al. (2005). Specifics on the intersection of geospatial data and biological thresholds will be detailed in a separate manuscript (M. Sheer, oral commun., July 2009; tentative manuscript title, "Integrating aquatic biological thresholds with spatial data models to identify intrinsic fish habitat in stream networks").

Impassable Barriers

Blockages and Barriers

Fish passage is limited by both natural blockages (e.g., cascades, waterfalls, and limits to flow) and anthropogenic barriers (e.g., culverts and dams). Distinguishing between natural and anthropogenic barriers is an important initial step in IP analyses. Much discussion at the workshop centered on identifying and incorporating both anthropogenic and natural barriers in IP analyses (appendix B, table B10). Some IP analyses require an estimate of the reach-based potential upstream of anthropogenic barriers and include an attribute in the results database to identify reaches upstream of those barriers. Summaries of IPKM or average reach IP score can be done with or without these values.

IP analyses incorporate information on natural blockages to fish passage (e.g., State fish and barrier databases and data layers, National Inventory of Dams) by either snapping the barrier points to the stream and cropping the streams at these locations or identifying the upstream reaches with an attribute. Calculating IP scores above barriers and then attributing those reaches as such allows for the greatest flexibility in analyses.

State-identified natural barriers differ from general species-gradient barriers because DEM-derived stream networks provide higher resolution of gradients than can be found in the point datasets (which typically were obtained through field visits and linked to 100K streams; table 9). In addition, a natural barrier may have suitable habitat above it that cannot be accessed while a general gradient barrier typically will be at the end of suitable habitat. A natural fish barrier is described by Washington Department of Fish and Wildlife (2000) as a waterfall greater than 12.14 ft in vertical height. Consulting with persons that have regional expertise is recommended when trying to accurately identify natural barriers for anadromous fish species.

Gradient

Gradient thresholds are used to limit the stream dataset to those reaches fish can access. Gradient is a useful parameter even when defining resident fish distributions, is easily measured in the field or from digital data, and is related to many other commonly used habitat features (table 9).

Gradient thresholds are applied as a filter or envelope. In the Pacific Northwest, the most accepted gradient cutoffs are 20% for steelhead, 16% for coho, 16% for Chinook, and 5% for chum (table 9). Oregon coast studies have indicated that a 10% gradient break is more appropriate for steelhead, and 7% is more appropriate for coho (Burnett et al., 2007). Gradient may not be the most helpful variable in identifying base habitat for steelhead—flow and drainage may be more useful parameters (D. Rawding, oral commun., November 19, 2008).

It is important to distinguish between using gradient to define the limit of a species distribution (thresholds) and using gradient to assess habitat potential. Both are important uses of gradient data, and the distinction between the two uses is sometimes unclear. One is an absolute break and the other informs a continuous curve of low, medium, and high habitat preferences.

Habitat Curve Variable Estimates

Flow

The predominant flow-related parameter used in IP models for various fish species is mean annual discharge. A common approach for estimating this parameter is by regression, using log-transformed variables for drainage area and precipitation (Leopold et al., 1964; Sumioka et al., 1988). Species and region-specific considerations may require using a flow-related parameter other than mean annual discharge. Factors to consider when selecting a flow parameter include run-timing and seasonal variability in habitat use of the species of interest, regional variability in flow, historic changes in flow regime, and the hydrologic regime of the area of interest (whether snowmelt or rain dominated). The flow parameter selected should reflect the closest match to the run-timing and seasonal variability important for the species of interest. If the area has undergone major anthropogenic alterations, to truly represent “intrinsic” flow, it may be necessary to use different regression models to predict flow in areas with major diversions or structures.

An existing source of flow data is the 1:100,000 NHD (http://nhd.usgs.gov/). The NHD estimates flow using the Vogel method or the Unit Runoff method (NHD, 2007). The Unit Runoff Method uses empirical calculations of average cubic feet per second per square mile of drainage area for relatively small basins, then estimates flows for larger basins as area-weighted averages (NHD, 2007). One caveat in using the NHD data is the applicability of 1:100,000 scale flow estimates to 1:24,000 scale stream reaches. Regarding flow estimates in general, there may be inconsistencies in results when combining different methods. In addition, the suitability of applying broader basin-scale regressions to finer reach-scale estimates varies among regions.

Table 9. Species utilization and passability table from WDFW 2000.

[Dark shading indicates usability, light shading indicates passability, and no shading indicates an impassable stream channel]

Species	Gradient strata (percent)						
	0–1	1–3	3–5	5–7	7–12	12–16	16–20
Chum	■	■	▒				
Coho	■	■	■	■	▒	▒	
Sockeye	■	■	■	■	▒	▒	
Chinook	■	■	■	■	▒	▒	
Steelhead	■	■	■	■	■	▒	▒
Cutthroat	■	■	■	■	■	▒	▒
Bull Trout	■	■	■	■	■	■	■
Trout	■	■	■	■	■	■	■

Channel Width

Channel width parameters used in IP models include bankfull width (BFW, also referred to as active channel width) and wetted width. Channel width parameters can be estimated using regression models incorporating field or gauge data (Castro and Jackson, 2001) or by digitizing aerial photographs or maps (Davies et al., 2007). Typically, BFW rather than wetted width is used for IP or habitat potential work because it is a relatively static geomorphic parameter, whereas wetted width varies with discharge. Because of the data distribution used in the local regression model, the width of all stream reaches may not be predictable. Missing data for reaches may be filled in by assigning upstream or downstream estimates or by supplementing with data from digitized measurements from maps or aerial photographs. Channel width values in floodplain areas can be estimated through GIS by manually measuring apparent floodplain and active channel widths using a 1:24,000 Digital Elevation Model (DEM) or by referencing National Hydrography Dataset attributes. Davies et al. (2007) presents options for predicting BFW estimates using aerial photographs.

Valley Width Index

Remote measurements for valley width and valley width index may be calculated using DEM estimates (Miller, 2003; Cooney and Holzer, 2007; Hall et al., 2007; Clarke et al., 2008). As described in Clarke et al. (2008), valley floor width can be estimated as the length of a transect that intersects the valley walls at a specified height above the channel. Because the orientation of the valley is unknown, transect orientation is varied to find that which provides the minimum length. A valley-floor width estimate is obtained for each channel pixel, for each side of the channel. Widths are then averaged over the length of the reach for each side of the reach. The NetMap model (Benda et al., 2007) uses a slightly different approach for estimating valley width. For each reach, it delineates the area within a certain elevation (e.g., three bankfull depths) of the channel edge and estimates the valley width as the area divided by channel length. The Valley Width Index (VWI) is calculated by summing the estimated left and right valley width for the reach and dividing this sum by the estimated bankfull width.

VWI calculated from remote methods may not relate to channel constraint in the same way as field-estimated values. In the Oregon Coast Range, Clarke et al. (2008) interpreted DEM-based VWI < 5.06 as indicative of constrained channels and VWI > 8.87 as indicative of unconstrained channels based on comparisons between field- and DEM-determined values.

The Oregon Department of Fish and Wildlife's Aquatic Inventories Project (AIP) also provides methods for calculating and interpreting the hydrogeomorphic metrics of VWI (ODFW, 2006). In the AIP methodology, a VWI of ≤ 2.5 means a narrow valley type, and >2.5 means a broad valley type. The narrow valleys will be constrained (either by bedrock, hill slope, or alluvial fan), while the broad valleys can have unconstrained or constrained channels. A VWI >2.5 does not guarantee the reach is an unconstrained channel.

There is still considerable uncertainty in the accuracy and interpretation of VWI values. Use of high-resolution LiDAR data may provide more accurate estimates of VWI, but these will still need to be empirically related to habitat potential.

Photograph by U.S. Forest Service.

Floodplain, Channel Type, and Channel Form

Variables that describe floodplain characteristics, channel complexity, and channel type may be useful, but are not included in any available IP models. There are strong links between these features and habitat potential. For example, channel type could be used to better identify elements of both channel width and valley confinement that are pertinent for fish, such as meandering or braided channels (Beechie et al., 2006). A simple model to predict channel complexity and type is currently being developed (T. Beechie and H. Imaki, oral commun., January 30, 2009).

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Appendix A. Examples of Applications of Habitat Suitability Models

Viability Analyses – Population Structure and Extinction Risk Estimates

- Describe historical population structures of steelhead, coho salmon, and Chinook (e.g., Lindley et al., 2006).
- Historical population structure of Central Valley steelhead and its alteration by dams. San Francisco Estuary and Watershed Science 4(3):1–19.; Bjorkstedt, E. P., B.C. Spence, J.C. Garza, D. Hankin, D. Fuller, W. Jones, J. Smith, and R. Macedo, 2005.
- An analysis of historical population structure for Evolutionarily Significant Units of Chinook salmon, coho salmon, and steelhead in the North-Central California Coast Recovery Domain. (NOAA Technical Memorandum NMFS-SWFSC-382. National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, California, USA.)
- Recovery planning (e.g., Interior Columbia Technical Recovery Team, Coastal Coho Technical Recovery Team).
- Applied intrinsic potential methods to calculate the amount of habitat available to coho and Chinook salmon and steelhead populations in the Willamette/Lower Columbia domain (Busch et al., personal commun., January 22, 2008). They used results from the IP models to help set Quasi-Extinction Thresholds (QET) used by the Technical Recovery Teams.

Restoration Scenarios and Watershed Planning

- Sheer et al. (2007) used habitat suitability analyses in their study in the Lewis River in southwest Washington. They developed a fish potential model called “FishEye,” a ranking model that uses intrinsic and extrinsic parameters separately. Extrinsic factors (riparian habitat, percent fines, bed scour) were varied to assess simulated restoration scenarios on high potential fish habitats. The intrinsic potential was one piece of an analysis of restoration potential (Steel et al., 2008). Factors used in FishEye differed slightly from those indicated in Burnett et al. (2007) and Clarke et al. (2008) (hydrologic scour was included) and not all were species-specific variables.
- Miewald et al. (personal commun., November 19, 2008) used intrinsic potential analyses for a number of projects across the Pacific Rim. Their analyses integrated current watershed conditions with intrinsic potential data to support conservation planning on the Oregon North Coast, validation of IP models using multiple years of survey data on the Hoh River, development of IP models to inform monitoring on the island of Sakhalin, Russia, and development of IP models for sockeye and Chinook in the Copper River basin.
- Benda et al. (2007) developed tools to help implement IP models and integrate them with watershed and land-use attributes (NetMap). NetMap provides an ArcGIS toolkit to calculate a variety of topographic and watershed attributes over a DEM-traced channel network. It has a model-design tool for using these attributes to build IP models, with published models provided as options. It also includes analysis tools to address a suite of watershed processes (sediment production, wood production, water temperature) and habitat attributes (IP, core habitat areas, habitat diversity) to aid in development of empirical models, in watershed assessments, management, conservation, and restoration planning.
- Development of maps designed to guide habitat restoration and resource management for Oregon coastal coho (Erin Gilbert, personal commun., November 19, 2008). Poster-sized maps displaying IP data for juvenile coho have been distributed to district offices and watershed councils as a tool to help strategically implement habitat restoration projects.

Forestry/Land Use-Related Analyses

- Burnett et al. (2003) applied Intrinsic Potential methods for steelhead (*O. mykiss*) and coho salmon (*O. kisutch*) to describe the likelihood of finding unimpaired habitat in high-Intrinsic Potential reaches, and to assess conservation options. The study suggests using this method to improve efficiency of broad-scale conservation strategies. Burnett et al. (2007) also used Intrinsic Potential with these species to assess the high potential habitat with respect to landscape characteristics (land ownership, land use, and land cover) under current and future conditions. This study found that almost one-half the high potential reaches for coho were co-located with watershed areas that were non-forested or recently logged. This percentage was lower for high steelhead Intrinsic Potential reaches.

- Riparian restoration (Lauren A. Mollot, Robert E. Bilby, 2008) The Use of Geographic Information Systems, Remote Sensing, and Suitability Modeling to Identify Conifer Restoration Sites with High Biological Potential for Anadromous Fish at the Cedar River Municipal Watershed in Western Washington, U.S.A.. Restoration Ecology 16:2, 336-347 Online publication date: July 1, 2008.)
- Evaluating forest management alternatives (BLM 2008 Western Oregon Plan Revision—e.g., Part H and Appendix J)
- Prioritizing lands for restoration (Oregon Water Resources Division Private Lands Restoration Initiative)
- Identifying salmon strongholds for Oregon State Forest lands (Wild Salmon Center)

Habitat Diversity and Spatial Structure

- Researchers are considering using IP scores to look at structural connectivity in watersheds (A. Fullerton, personal commun., November 19, 2008). Do relationships exist between structural connectivity (i.e., size and distance between suitable habitat patches) and population viability? If so, then conservation/restoration prioritization schemes that include connectivity metrics should perform better than those including only classic metrics (i.e., percent of watershed considered suitable). To answer this, we will use intrinsic potential scores as a way to assess suitability of habitat patches. We will then conduct broad-scale correlations sensu (Sheer and Steel, 2006) to see if viability of Willamette and Lower Columbia salmon populations are related to these habitat connectivity metrics.
- Researchers are considering using IP scores to help look at spatial structure of Willamette-Lower Columbia salmon populations (A. Fullerton, personal commun., November 19, 2008). How has the spatial structure of salmon populations in the Willamette/Lower Columbia changed since addition of passage barriers (i.e., large dams)? And, assuming a metapopulation structure (Schtickzelle and Quinn, 2007), what source-sink dynamics might we expect under possible alternative future scenarios? We will replicate work by Schick and Lindley (2007) using graph theory to evaluate spatial structure of WLC populations. We are evaluating the best metric to use to represent population size that is available for both historical and current estimates, and intrinsic potential scores are one possible index we are considering.

General Fisheries Management

- Intrinsic Potential was used to evaluate the quality of habitat made available by past fish passage improvements and to help plan future culvert repair and replacement (e.g., Dent et al., 2005)
- Identifying key watersheds on U.S. Forest Service lands covered by the Northwest Forest Plan, PACFISH and INFISH. (*The land management plan, known as "Pacfish," was produced by the U.S. Forest Service and the Bureau of Land Management. It establishes habitat conservation areas for salmon in and along rivers and streams, and sets goals and standards to protect salmon within that habitat. INFISH is the inland native fish strategy: Interim strategies for managing fish-producing watersheds in eastern Oregon and Washington, Idaho, western Montana, and portions of Nevada*).
- Determined landscape-wide intrinsic potential for general planning purposes for the Western Oregon Plan Revisions Areas (Columbia to California, plus Klamath Falls resource area) (BLM).
- Smolt Capacity Estimates for Coho Salmon in the Oregon Portion of the Southern Oregon North California Coast ESU (Tom Nickelson - Consultant, Erin Gilbert – ODFW). Intrinsic potential (incorporating stream temperature) was used along with the Habitat Limiting Factors Model to make reach-specific smolt capacity estimates.
- Intrinsic Potential scores were used to assess habitat upstream of fish passage barriers in coastal California (Holycross, Koller, Mora).

Table A1. Brief, general summary of IP analysis projects, as collected from IP workshop participants and select other references.

[Refer to the species-level summaries in this report or contact the researchers directly for more information on each model. **Models used**: IP style, indicates that the analysis used an approach similar to the one described in Burnett et al. (2007). **Contacts:** A key for people and their contact information given in the Participant List. **Abbreviations:** SHD, steelhead; COH, coho salmon; CHM, chum salmon; CHN, Chinook salmon; w, winter; s, spring; su, summer, f, fall]

Group	Project Name	Species/run	Project Area	Models used	Date	Contact	Published or in report (incomplete)?
NOAA	Lower Columbia-IP	SHD (w/su), COH	ESU Populations	IP style	Sept. 2008	SB,MS	No
NOAA	Lower Columbia-IP	CHN(s/f)	ESU Populations	IP style	Sept. 2008	SB,MS	In progress (fall)
NOAA	Lower Columbia-IP	CHM (f)	ESU Populations	Mainstem, Dauble	Sept. 2008	SB,MS	In progress
NOAA	Oregon Coast - IP	COH	ESU Populations	IP style	Sept. 2008	SB,MS	No
NOAA	Willamette-IP	CHN (s), SHD (w)	ESU Populations	IP style	Oct. 2008	SB,MS	No
NOAA	Puget Sound-IP	CHN	ESU Populations	IP style	2007	SB,MS	No
NOAA	Interior Columbia - Historical Production Potential	CHN, SHD	ESU Populations, Interior Columbia	Physical habitat potential	2006	TC,DH	Cooney and Holzer, 2006
USFS	Gifford Pinchot National Forest	Unknown	Various large rivers	Unknown		KM	Unknown
WDFW	Lower Columbia	Various	Various large rivers	WDFW		DR,SV	Unknown
CLAMs	CLAMs - Protected areas	SHD, COH	Tillamook Bay, Nestucca River (Oregon)	IP style	2002	KB,GR	Burnett and others, 2003
CLAMs	CLAMs - Landscape characteristics	SHD, COH	Coastal Province (Oregon), 6 subprovinces	IP style	2007	KB,GR	Burnett and others, 2007
ODFW	Coastal Coho Assessment	COH	Coast Coho ESU	IP style	2005	EG,JR	E. Gilbert, oral commun.
ODFW	Lower Columbia Recovery Planning	COH, SHD	Lower Columbia ESU	IP style	2007	EG,JR	E. Gilbert, oral commun.
NOAA	Predicting potential for historical habitat: Southern Oregon Northern California	COH, SHD, CHN	Populations from Cape Blanco, OR to Punta Gorda, CA	IP style	2005	ED, BS	Agrawal et al., 2005
NOAA	Predicting potential for historical habitat: North-Central California Coast	COH,CHN, SHD	Populations from Punta Gorda, CA to Monterey Bay, CA	IP style	2005	ED, BS	Agrawal et al., 2005
BLM	Final Environmental Impact Statement	CHN	Western Oregon	IP style	2008	JN	BLM, 2008

Table A1. Brief, general summary of IP analysis projects, as collected from IP workshop participants and select other references.—Continued

[Refer to the species-level summaries in this report or contact the researchers directly for more information on each model. **Models used**: IP style, indicates that the analysis used an approach similar to the one described in Burnett et al (2007). **Contacts:** A key for people and their contact information given in the Participant List. **Abbreviations:** SHD, steelhead; COH, coho salmon; CHM, chum salmon; CHN, Chinook salmon; w, winter; s, spring; su, summer, f, fall]

Group	Project Name	Species/run	Project Area	Models used	Date	Contact	Published or in report (incomplete)?
Ecotrust/Wild Salmon Center/PNW Research	Copper River, conservation planning	CHN, Sockeye	SE Alaska	IP style		GR,MG, TM	In progress. T. Miewald, oral commun., March 20, 2009
Wild Salmon Center	Oregon North Coast Salmon Conservation Assessment	Chum	Tillamook, Nehalem	IP style	2008	TM	In progress. T. Miewald, oral commun., March 20, 2009
USGS	Anadromy vs residency	SHD	John Day Basin	IP-like model	2008	JM	Mills, 2008
Wild Salmon Center	Sarufutsu Basin Conservation Plan	Sakhalin Taimen	Sarufutsu River Basin, Japan	IP style	2009	TM	In progress. T. Miewald, oral commun., March 20, 2009
OSU	Population structure	SHD	Deschutes River	IP-like model	2000	CZ,GR	Zimmerman and Reeves, 2000
NOAA	Summer habitat	SHD	South-Central,Southern California Coast	IP-like model	2006	DB,MG	Boughton and Goslin, 2006

Contacts:

AA	Aditya Agrawal	ED	Eric Danner	KM	Ken Meyer
BS	Brian Spence	EG	Erin Gilbert	MG	Matt Goslin
CP	Charlie Paulsen	GR	Gordie Reeves	MS	Mindi Sheer
CZ	Christian Zimmerman	JN	Jeff Nighbert	SB	Shallin Busch
DB	David Boughton	JD	Jason Dunham	SV	Steve VanDerPloeg
DH	Damon Holzer	JM	Justin Mills	TC	Tom Cooney
DR	Dan Rawding	JR	Jeff Rodgers	TF	Tim Fisher
		KB	Kelly Burnett	TM	Tom Miewald

Appendix B. Input from Workshop Participants.

Table B.1. Input from workshop participants regarding appropriate uses of IP data and considerations when using an Intrinsic Potential approach.

Results from IP analyses can be used to:

- Give general idea of habitat potential and /or condition, especially to help direct site visits.
- Rank possibilities for dam removal—ok to use IP to prioritize (obviously, no actions again would be taken without some kind of site visits).
- Determining recovery potential—What is the response of high, moderate, low disturbances with respect to species?
- Lay IP out as a hypothesis then test it. Develop parameters (GIS scenario) and select which you want to use based on the habitat you are looking at.
- Estimate probability of species use and spatial distribution (can be improved with ground-truthing).
- Designate reach-level habitat classification by geomorphology or other features.
- Estimate subwatershed scale features; to compare potential among areas.
- Standardized approach for identification of population segments based on contiguous habitats.
- Organize assessments of fish use and habitat potential.
- Determine juvenile rearing potential, filtered with spawning potential.

IP scores – Inappropriate uses or special caution:

- Inappropriate use as opposed to what? Managers need to make decision whether data are there or not. Is there something besides IP that will improve decision-making capabilities? If so, that can be used – sometimes it is the best available though.
- Assessment of low gradient habitat to evaluate current conditions.
- Estimating fish density/productivity.
- Estimating historic abundance (proceed with caution because not able to validate results).
- Applying models developed for one locale or species to a different locale or species.
- IP used to predict amount of habitat—it can over-predict habitat though.
- Consider scale and accuracy of data layers in context of results and inference.
- Make conclusions on specific reaches based on broad scale assessments (especially for low gradient habitat).
- Cautioned use at the reach scale due to lack of geomorphological data.
- Cautioned use of extrinsic attributes at the reach scale for alteration of geomorphological features over time.

Table B2. Input from workshop participants regarding data and general model considerations.

- Need identified for ground truthing of GIS data; snap IP data to 1:24K hydro layers.
- Validation of DEM drainage enforcement.
- Consider adding wood recruitment models to IP models.
- Validation of IP models are coarse, but they tend to line up with predictions for fish.
- The major benefit of IP is that it is simple.
- Clearly identify species and life stage before applying a particular model:
    - What life stage is the limiting factor life stage?
    - Which habitat metric measures that stage?
    - What remotely sensed variables can be used to measure that metric?
- At what point does an IP model become simply a fish distribution model?
    - If you consider spawners in different habitats in different years and summarize this somehow—does this move away from IP and become more of a steelhead distribution model?
- IP users and managers using IP need to consider and incorporate the temporal domain as well as the spatial.
    - IP models do not typically do this, and this can be confusing or limited when presenting results.
- Is it appropriate to think the past can be in the future (i.e., is IP useful in highly modified areas, or areas that have undergone climate shifts)?
- What about cases where the future potential is vastly different than past (historical) situations—e.g., climate change?
    - The concept of IP highlights historic potential, but in some cases the environment has changed so substantially (temperature, flow regimes, etc., such as in southern California), that the concept of identifying what could habitat could support fish from a historic perspective may not be pertinent, so it may need redefining.
- With changing climate, even if mean annual flow has changed over time, drainage area probably has not (i.e., this might be a better intrinsic variable than mean annual flow, which is more sensitive to human interactions or changes in climate).
    - What about extreme events?
- Precipitation and mean annual flow may be shifting with climate changes, mainly in the seasonal timing. Seasonal changes in timing of precipitation and peak flows may be changing, which impacts IP for fish.
- Models do not deal well with ephemeral streams, some models do not deal well with wide streams (for example > 50 m wide streams)

Table B3. Input from workshop participants regarding considerations for display and scale of intrinsic potential results.

General comments:

- For displaying and presenting data to managers, we need to answer—“What is the management question you are trying to answer with IP score”? and “Who are you presenting information to”?
- Management questions being asked now are different than the questions asked for historic IP scores. Is this for restoration or protection?
- Display by 6th field HUC (hydrologic unit code).
- For display or further analysis, use the Clustering Tool in NetMap (Core Area Tool), which allows you to set clusters (cluster tolerance factor).
- It would be useful to display estimated IP versus actual spawning ground aggregations (potential versus actual).
- It would be useful to come up with a probability index for a certain percent of an index (suite of probabilities that give insight into particular parameters).
- IP take home message is “where is the ‘high’ score”? and “How much of the network does that high score cover”?

Scale of analysis comments:

- The smaller the spatial extent, the higher resolution data are needed.
- NetMap Geomorphic reach length is limited by resolution of data used to calculate reach gradients; use variable reach lengths and set reach breaks at geomorphically relevant reach gradients.
- IP scores based on reach length used.
- Another approach is to make all reach lengths the same—consensus was that this makes analysis easier. Reaches can be grouped later.
- How long of a reach do you need to get an accurate gradient?
  - Rely on contours
    - Calculate where the contour crosses the stream. The gradient is then assigned to the local reach, even if the reach length does not match the length between contour crossings.
- Lengths over which gradients are calculated change based on slope (in NetTrace).
- Has anyone looked at IP scores at 100 m, 200 m, 400 m—to look for opportunities at smaller scale?

Table B4. Input from workshop participants regarding concerns about the underlying hydrography used to develop IP, including:

- We need to improve documentation of technical considerations related to generating streams from DEMs and for calculating IP scores by reach.
- Software (and version) used to generate stream networks must be documented (because settings may change depending on version).
- Lakes, reservoirs, and ponds should be treated differently than linear stream reaches; preferably at the level of the IP model or possibly using input parameters that would account for this difference.
- The question of historical versus current (conditions) was raised. For example, ephemeral oxbow lakes and flooded floodplains are conditions more prevalent historically and provide important over-wintering habitat. These could be more effectively included in IP analyses in the future.
- How to measure connectivity of high quality patches of habitat, and which attributes would be appropriate for converting a historical IP to a more current-focused IP.

Table B5. Input from workshop participants regarding considerations for the use of NHD and other stream networks.

- Tracing / burning in the stream line will give you more positional accuracy than DEM derived (alone).
- USGS is building NHD+ tools for users to provide some DEM-derived summaries that attach to the NHD layers. Currently, NHD is just for 100K.
- Generally, the NHD 100K streams are burned into 30-m DEM.
- NHD+— had land-use data (from mid-1990s?).
- Issue with NHD reaches. Confusion over the mean reach length and the rules that standardize reach length in NHD. NHD is currently confluence to confluence.
- Many researchers doing small-scale, process-based models that require shorter or variable-length stream reaches. NHD is problematic for this, as process-based models need finer resolution (longitudinally), and need to be able to link to DEM-originating features (hillslopes, etc.).
- Participant gave indication that the NHD linework may change someday to match LiDAR channels, once this becomes available.
- NHD is good for managing stream based data; biologists in field use NHD.
- Need to have easy method to link different stream layers.

Table B6. Input from workshop participants regarding benefits of using LiDAR (focus on green LiDAR) for generating streams and intrinsic potential variables.

- LIDAR measures at least three levels more of detail with its density of data.
- LIDAR will make interpreting from 10-m DEM obsolete.
- From LiDAR, we can calculate: extent of terraces, measure floodplain directly, measure channel geography, can detect multiple channels.
- Difficult to get people to think in a way that is not reach by reach, cross-section to cross-section. All pools and riffles could be identified in a continuous dataset, not by reach.
- Accesses thalweg profile—allows us to see new patterns (emerging).
- System operates in up to 25 m water depth. Hard to use LIDAR during high flows due to turbidity, etc.
- LIDAR will not work through ice. When water < 10 cm, hard to measure the channel depth. See reflection of surface and bed, but not in between.
- In the near future, could do local analyses (within 5 years).
- About 10–15 months for it to be very readily available everywhere.
- Resolution of bathymetric LIDAR is currently about every 2 m. New system will be six orders of magnitude better. New instrument does bed elevation better than bank estimation.
- Some data already available. Puget Sound (data are free, can be downloaded).
- Dan Miller working with LIDAR data in Alberta, Puget Sound, Oregon.
- We need new tools to deal with density of data—wavelet analyses to pull out signals from data.
- Measuring channel attributes directly instead of via models.
- Toolkit that is related to IP but using LIDAR (for interpreting raw data, to map appropriate stream parameters). Available in 12–18 months (late 2009 to early 2010), will have a system available to everyone.
- Recommend using existing LIDAR data to move IP forward.

Table B7. Input from workshop participants regarding characteristics of stream hydrography important for Intrinsic Potential and habitat suitability models.

Stream persistence:

- Need to define where perennial streams begin/end (information is not consistent).
- Use channel width (bankfull width; Net Trace approach) to create a threshold.
- Original USGS criteria—perennial was 9 months of the year, then changed to year round. Intermittent was defined as some subset of year. Classification took place at one point in time, other factors subjective.
- Bring precipitation and geologic data into the mix to help determine channel cutoffs.
    - These are especially important because they are used to define lack of fish.
- Need a description of the difference between dry and intermittent streams.
- Difference between ephemeral and intermittent? Intermittent – some sort of flow seasonally; ephemeral is based upon specific flow events and will not have flow every year.

Ephemeral features and fish:

- Ephemeral streams should be dealt with in an IP model, but in a more general way than permanent features.
- Spatial configuration of ephemeral streams makes a big difference to fish—they are non-intuitive to predict.
- Ephemeral oxbow lakes, flooded floodplains, etc, also are important for overwintering.
- Determine what processes lead to the development of these ephemeral features.
- Long-term processes likely involved (and how this influences modeling in IP).
- Bars that form near channel mouths are a big issue to steelhead in California; also lagoons impact both production and access.
- Life-history stage modeled impacts impact of ephemeral streams on species and IP estimates.

Stream reaches—solutions for breaking reaches and matching reaches in IP

- Segment the NHD and join to reach lengths that are more appropriate.
- NetMap tool allows summary of land use and vegetation information per reach.
- Event tables (i.e., dynamic segmentation) are a good, flexible way of getting/using reach breaks. Both NetTrace and NHD allow dynamic segmentation. Breaking reach lengths—dynamic segmentation approach, break where you want depending on analyses.
- NHD—is supposed have reaches that break at each confluence; the 24K NHD is more detailed (but it was not clear or discussed what the reach break strategy was for 24K).
- COM ID segments or reach code segment. COM ID—is an NHD internal segment identifier—but reaches sometimes span multiple COM IDs. Data should be broken at confluences in NHD. There are insignificant tributaries that do not cause a reach breakthrough.
- Researchers need a length of stream segment that represents a uniform attribute throughout (i.e., geomorphically broken reaches). For DEM-derived streams, the NetTrace program has a setting that limits confluence breaks in upper reaches (so many small streams).
- Other methods to determine reach break—use adult spawning distribution. For example, looked at redd distribution and see how close redds are clustered together (WDFW). STREAM STATs (scale? 30-m DEM?) Mean elevation, mean slope, average impervious surface area. All DEM-derived streams (whichever scale) typically have weighted flow accumulation models

Table B8. Input from workshop participants regarding considerations for lakes, reservoirs, and ponds in intrinsic potential models.

Reservoirs and lakes:

- Cartographically, 40 ft in channel width (USGS definition) is the size at which a mapped stream becomes "double banked" (i.e., polygon available) in the spatial world (24K).
- NetTrace – includes lake mask – code reaches with the lake mask code. Is this or is this not summarized in fish habitat summaries (or do you have to indicate to not include)?
- NHD and other sources typically include water bodies also—are these easy to link to the stream data to indicate it is a double-banked stream?
- Can add lines manually to represent braided channels, but their position may change with major storm events from deposition, etc.
- Could characterize a channel reach as meeting certain requirements, and come up with a factor/ratio or coefficient—i.e., a linear kilometer of this type of channel reach is (or could be equal to) X km of braided channel. Can include this value as the possible reach length with braid. More accurate than the length of the reach, but the value will be stored on the straight line.
- Use mask to identify unconstrained floodplain channels that may become braided channels.
- Is there a State protocol for braided channels? How are these represented in NHD?
- No IP model results calculated in reservoirs; for larger rivers need to appropriately deal with very larger rivers—perhaps as add-on to existing width curve, or another threshold. Currently, IP does not differentiate between mainstem river, reservoir, or pond.
- Reservoirs were historically a different habitat type. If you are calling something "intrinsic" what kind of habitat do you call reservoir? What about if you are trying to look at current habitat?
- Coho on coast range – lake areas are highly productive—but in analyses, researchers typically code out lakes because they are not reflected well in habitat curves.

Reservoirs and waterbodies (variables discussion – data sources):

- Tim Beechie modeling historical channel forms with flow, precipitation, etc. and discriminate function analysis. Working on how to model side channels.
- Lewis River, Mindi Sheer used photographs to reconstruct what channel looked like before damming.
- Beavers have impact on historical stream channels. Model historical dam densities and thus pond area. May want to look into research on the impact of beavers on the stream historically and incorporate that into your model.
- Reservoirs: sediment sinks, are determinant of longitudinal temperature patterns.
- Lakes, side lake, and reservoirs are important for coho high potential (Coho overwinter there).
- Should lake and reservoir IPs be estimated? Yes, but treat them differently than stream reaches (in the model).
- Can we characterize process domains, where stochastic processes happen on different time scales?
- How do we incorporate this understanding into data that feeds into IP models?

Table B9. Intrinsic variables suggested by workshop participants.

(These are in addition to common variables noted in table 2 of the report.)

Intrinsic variables
• Temperature (Agrawal et al., 2005; Cooney and Holzer, 2007)
• Erosion, sediment deposition potential (Benda et al., 2007; Cooney and Holzer, 2007)
• Downstream variation in valley confinement (Benda et al., 2007)
• Downstream variations in channel gradient (e.g., upstream of a fan or earthflow, Benda et al., 2007)
• Tributary confluences (Benda et al., 2007)
• Basin soils, geology (Cooney and Holzer, 2007)
• Patch size, abundance, separation distance between high IP zones (Benda et al., 2007)
• Climatic attributes, such as mean annual snow fall, or 100-year, 24-hour storm intensity
• Hydrologic attributes, such as 100-year peak discharge, mean annual low flow, skew of the flow duration curve
• Proportion of watershed in wetlands
• Elevation
• Downstream variation in confinement
• Tributary confluences
• Patches of habitat surrounding stream reach
• Distance from the ocean
• Measuring connectivity of high quality patches

Table B10. Input from workshop participants regarding barriers to fish migration.

Barrier Data and Sources—Oregon, Washington, California

- Suggestion: develop IP for all reaches (even beyond natural barriers) and then apply the barrier layer. Apply natural and manmade barriers together or separately and/or have the barriers coded into the stream layer.
- In Washington, there is an incomplete barriers dataset—developed when getting permits; captures the "low-hanging fruit" on rivers. Not likely accurate for smaller streams and tributaries WFDW uses the SalmonScape dataset (http://wdfw.wa.gov/mapping/salmonscape/).
- There is no standard barriers dataset, but it would be useful.
- California coast (border with Oregon and to Monterrey Bay) have a barrier layer for Chinook and coho (B. Spence). Spotty barrier dataset farther south.
- Interior Columbia: started with State (Washington, Oregon, Idaho) natural barrier (point) data and added a physical description of a "barrier" (i.e., a percent change over 200 m). (T. Cooney)
- Small waterfalls not picked up in the DEM. Point data (cascade and waterfall locations) may not be picked up by DEM. States do have most major waterfalls and cascades in their point barrier data—can be incorporated into the stream network, or used to limit extent.
- Oregon (ODFW): putting together a barriers GIS standard database
  - Managed by Natural Resources Information Management Program (NRIMP) (still should discuss barriers with district biologist to verify).
  - http://rainbow.dfw.state.or.us/nrimp/default.aspx
- Oregon Coast: Coastal Landscape Analysis and Modeling Study (CLAMS has a natural barriers database used fish distribution maps combined with fish bearing streams at 20% gradient to run IP model, report results up to 10% gradient NetTrace method of max_grad_downstream estimate, helpful in allowing this kind of reporting and summarizing results efficiency.
- Federal lands in Oregon and Washington (Region 6)—D. Heller (USFS) has developed a culvert database that capture 80% of the culvert barriers to anadromous fish, to be released late 2009.
- Uses the software "Stream Crossings" ("Stream Xings"?) from Arcata, CA
- **Recommendation**: Develop a standard definition for what a barrier is. Create a list of available datasets for barriers and culverts with contact information for someone who developed it. Rank certainty of barriers with color (red for uncertain, green for highly certain etc.).

Gradient and fish in IP Analyses

- Is gradient a proxy measure or is other measure more ultimate driver of fish distribution?
- Many variables depend on gradient, so it seems like a good catch-all for them.
- For steelhead, gradient is not the most influential descriptor of steelhead distribution in the Lower Columbia, flow and drainage area seem better predictors.
- Steelhead need a certain flow (and channel width) to reach spawning sites in the spring.
- For some resident fish, gradient is the most important predictor.
- Because gradient is a primary driving/limiting factor in IP analyses, is it possible to come up with a probability-driven cutoff to counteract erroneous gradient estimates?
- Perhaps gradient (?) cutoffs or other curves (?) could be derived using a regression (estimates incorporating geology).
- Perhaps use 'stoplight' method to define barrier threshold; Red—fish cannot get through barriers: Green—fish can get through barriers: Yellow—undetermined.
- Fish gradient especially dependent on width and flow in the reach. The gradient curve (for fish) should reflect this dependency. Key is interaction of gradient and magnitude of high flows.
- Distribution of fish varies by mean flow and flow during 7–10 days prior to spawning. Both the IP curves and how gradient is seen will vary by this (temporal variation).
- Gradient cutoffs (at 20% gradient, as indicated by WDFW suitability cutoffs). Lower Columbia tributaries are not so useful for steelhead.
- Project using regression to look at transition zones for steelhead, chum, and Chinook, assessing attributes for 4–100 m reaches above and below the stopping point (D. Rawding).

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Appendix C. Coho Salmon Species Session Workgroup Notes.

Below are notes from the coho workshop session at the "State of the IP 2008 Workshop" held in Portland, OR, on November 19–20, 2008. Some editing and synthesis was done after the fact for clarity. These notes were compiled from discussions between workshop participants.

Group Participants:

1. Jody Lando – Stillwater Sciences
2. Joe Ebersole - EPA
3. Mark Meleason - USFS
4. Kurt Fesenmyer – Trout Unlimited
5. Kelly Burnett – USFS PNW (Group Lead)
6. Pete Lawson – NOAA NWFSC
7. Brian Spence – NOAA FWFSC
8. Steve Lanigan – USFS/BLM
9. Dan Miller – EarthSystems Institute

Number of regional models and their locations

Geology and climate are basic considerations for this question. Because ecoregions capture much of this information, they are a good place to start for figuring out what appropriate IP models are.

1. Spatial extent determined (Burnett et al., 2007) for OR/WA/CA in rain-dominated coastal systems based on:
    a. Gradient
    b. Flow
    c. Barriers
2. Factors that may influence spatial extent in other regions
    a. Temperature
        i. CA model (technical memo—Agrawal et al., 2005)
    b. Flow seasonality
        i. Snowmelt-dominated systems, e.g., Alaskan and British Columbia river systems include:
            1. rivers are expected to freeze
            2. rivers that are fed by snowmelt
        ii. Rain-dominated coastal systems
        iii. Ground water systems, e.g., arid areas
    c. Geology (ecoregions)
3. Interactions among above variables

Have the models been validated?

1. Burnett et al., 2007: parameters that go into the model were validated (Clark et al., 2008), validation of the model itself is not published yet.
2. Agrawal et al., 2005: no

Best life stage to model for each region

1. Need to first identify the limiting life stage:
    a. Juvenile overwintering was assumed to be limiting for Oregon coastal systems, but because no data were available, summer rearing was used (and assumed to function as a surrogate for overwintering as well).
    b. Need to determine if model is being used to address historical or current conditions.
        i. What time frame you develop a model for depends on your objectives.

Top 5-10 remotely sensed parameters that best assess habitat suitability for coho throughout its range

1. Gradient
2. Valley constraint
3. Flow (mean annual flow) – as a surrogate for stream size
4. Alternative expressions of flow, e.g., summer low flow
5. Bankfull width; depth (from LiDAR)

Best ways to validate models (technique, data, etc)

1. Examine data (e.g., Wild Salmon Center studies on Hoh River)

Steps for moving forward

1. Who wants to work on curve development and validation
    a. Pudget Sound (based on LiDAR data):
        i. K.Burnett
        ii. D.Miller
        iii. B.Bilby (Weyerhauser)
        iv. D.Price (WDFW)
    b. Eastern Oregon and Washington - ?
    c. Snowmelt river systems (British Columbia and Alaska) - ?
2. Plan for getting work done
    a. Determine where IP would help regulatory agencies with recovery plans.
    b. Who is willing to fund work?
        i. Are agencies willing to fund developing IP?
        ii. E.g., State/Federal agencies that want to use IP as a course screen as part of prioritizing restoration efforts.
3. Provide context for interpreting IP
4. Provide conceptual guidance on how to regionalize existing models

3 main points to bring back to main group

1. Desire to have:
    a. Fish and habitat data that can be used to validate curves (e.g., Hoh River)
        i. Guidance on proper way to validate.
2. Unclear what the need for additional curves is in new regions (e.g., eastern OR/WA)
3. Need to provide conceptual guidance on how to regionalize existing models (taking into account biological and physical relationships).

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Appendix D. Chinook Salmon Species Session Workgroup Notes.

Below are notes from the chinook workshop session at the "State of the IP 2008 Workshop" held in Portland, OR, on November 19–20, 2008. These notes were compiled from discussions between workshop participants. Some editing and synthesis was done after the fact for clarity.

Group Participants:

1. Krista Bartz, NOAA- NWFSC
2. Shallin Busch, NOAA – NWFSC
3. Tom Cooney, NOAA- NWFSC (Group Lead)
4. Matthew Goslin, EcoTrust
5. A.J. Keith, Stillwater Sciences
6. Dale McCullough, Columbia River Inter-Tribal Fish Commission
7. Charlie Paulsen, Paulsen Environmental Research

Introduction discussion:

- How do models perform over space?
    - This understanding is required if thinking about evaluating management or status of species over large geographic scale
- Intersection between habitat use and land use change
    - How this intersection changes over space
    - River History Project, Brian Collins (http://riverhistory.ess.washington.edu/index.html) has developed a map of historical channels in Puget Sound
    - Looking for funding to do similar studies
- Do we need different IP models for spawning and rearing?
    - Can we capture both types of habitat in one model?
- Develop guidance for if/how generic IP models can be used for specific areas

Number of models needed for Chinook

Geology and climate are basic considerations for this question. Because ecoregions capture much of this information, they are a good place to start for figuring out what appropriate IP models are.

1. Variables to consider when evaluating number of models needed:
    a. Life history
        i. Juvenile life history (Myers et al., 1998, fig. 11)
    b. Climate
    c. Elevation
    d. Geology
    e. Overwinter flood events
    f. Other local issues
        i. Summer high temps in CA
        ii. Overwinter low temps in interior systems
        iii. Groundwater
    g. What information is available across regional scales
2. The number of models that you need will depend on the interaction of climate and life history
    a. Define climate using EPA ecoregions IV (see figures below)
        i. Ecoregions - Vegetation as an expression of geology and climate
        ii. Use ecoregions as a surrogate for temperature and precipitation
        iii. Geologic regions
            1. Classification considerations
                a. Elevation
                b. Temperature
                c. Precipitation - hydrologic response
                d. Drainage characteristics
    b. Determine number of models needed for each ecoregion by looking at life history
        i. Could have multiple models for one region
    c. Life histories that need to be captured (depending on life history of population)
        i. Spawning
        ii. Summer rearing
        iii. Overwintering

Developing new models

1. Look at published curves
    a. Is process you are trying to model that different for the new life stage/species?
        i. e.g. look at coho and Chinook curves for Oregon Coast when developing models for Chinook in other locales
        ii. How different should the new model be from the OR coast model?
2. IP seems designed for rearing, do you need different model for spawning?
    a. Hypothesize that spawning and rearing can use similar models

Summary of life-histories coastwide

1. Puget Sound
    a. Dominant form is subyearling stocks
    b. Bulk of production is in estuary or marine waters in summer
2. PNW, west of Cascades
    a. Juveniles are in low gradient, large rivers
    b. Juveniles primarily in 10 m strips along edges
3. Interior Columbia
    a. Productive Chinook areas have two habitat types:
        i. Typical OR coast habitat
        ii. Valley floor habitat
    b. Limited for fish:
        i. Low temperatures
        ii. Streams freezing
        iii. Consider adding a minimum temperature threshold to IP model

  c. Idaho Chinook stocks (spring and summer)
    i. Overwinter one year before migrating out to sea
    ii. Small component go to sea as subyearlings
  d. Large mainstem rivers
    i. All historically subyearling stocks
    ii. e.g. Hanford Reach, Snake River mainstem, Deschutes River mainstem, Yakima River mainstem;
  e. Some stocks migrate from tributaries and overwinter in mainstem Columbia
    i. Juveniles from high mountain tributaries overwinter in mainstems
4. California Central Valley, spring run
  a. Most leave as subyearlings
  b. Fraction leave as subadults
  c. Historically spring run had opportunity to ascend to places that are now blocked by dams
    i. Would be valuable to look at IP of what is lost upstream of dams
5. North Central CA coast, fall run
  a. Largely subyearling stocks
  b. Ocean type life history
  c. Temperature constraints
  d. Small coastal basins
  e. Narrower gradient range
  f. Habitat usage in <50 m bankfull width

Modeling different life history stages

1. Spawning
  a. Highly dependent on depth and velocity
  b. Finding measures that can indicate pools and riffles
    i. Fish like to spawn at (best spawning habitat is at):
      1. The heads of riffles in low gradient streams
      2. Ridges at lower end of pools in mountain streams
  c. Redd formation associated with sinousity
  d. Measure to use for modeling spawning:
    i. Fish like to spawn at (best spawning habitat is at):
      1. Rise over run
      2. Done over 200 m step
      3. Depends on resolution of data
      4. USGS blue line stream network onto DEM
        a. Mark intersection of stream network with blue line to define reach
      5. Combine with natural and anthropogenic barriers
    ii. Bankfull width/flow
      1. Drainage area
      2. Precipitation
    iii. Valley width

Rearing (summer)

  e. Defining attributes that can indicate:
    i. Pools and riffles
    ii. Edge habitats
      1. Especially in larger streams
    iii. Backwater habitat
2. Overwintering
  a. Areas need to model
    i. Mountain reaches
    ii. Valley floor reaches
  b. Elevation
  c. Temperature
    i. Likelihood of freezing
    ii. Stream size threshold
  d. Possible that could used same combination of gradient, bankfull width, valley width as used for other areas

Top parameters to consider

1. Consider each parameter in light of the 3 life history stages
2. Gradient
3. Steam width
   a. Bankfull width is an assumption of flow
      i. Number represents what the conditions would be in the stream during spawning (low flow)
      ii. Develop different curves for different reaches of different widths
         1. Small width
         2. Large width (when large, split into two sections?)
4. Flow
5. Valley width
6. ID other variables that might be considered in other situations
7. Other screens that might be developed separate from the strictly IP analysis
   a. Elevation
   b. Temperature
   c. Sediment

Current curves

1. 3-4 attempts to develop IP relationships, but we didn't fully discuss all
2. Reviewed settings that Chinook utilize and basic life history ranges
   a. Wide range of life history in species
   b. Range of stream sizes utilized
3. Interior Columbia curve relates gradient, bankfull width, valley width to physical features of stream related to Chinook production
   a. Model is for low gradient, small to medium streams, primarily in pool/riffle habitat
   b. Other models have been developed for patchy spawning habitat
      i. Could be integrated into IP models?

Steps for moving forward

1. Continue to develop relationships between gradient, surrogate of flow (stream structure in a given place), valley width
2. How to combine information to rate IP
   a. Look at two different ways to bring information together
      i. Matrix (Interior Columbia style model)
      ii. Weighting (combining parameters with geomean or other calculation)
3. Develop a suite of models
   a. Bifurcation nodes depending on ecoregion and life history stage
   b. End of nodes is a model with specific settings
4. Need to consider physical characteristics
   a. What allowed life history strategies to evolve/persist

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Appendix E. Steelhead Species Session Workgroup Notes.

Below are notes from the steelhead workshop session at the "State of the IP 2008 Workshop" held in Portland, OR, on November 19–20, 2008. These notes were compiled from discussions between workshop participants. Some editing and synthesis was done for clarity.

Group Participants:

1. Charmane Ashbrook, WDFW
2. David Boughton, NOAA-SWFSC
3. Damon Holzer, NOAA-NWFSCMatthew Goslin, EcoTrust
4. Paul McElheney, NOAA-NWFSC
5. Dan Rawding, WDFW (Group Lead)
6. Mindi Sheer, NOAA-NWFSC

Number of regional models and their locations

About half of the group preferred many of the regional models at the ESU level, the other half were comfortable at one of the regional levels (above the ESU). Summary of the discussion we had on this:

1. Might be able to get by with similar/same model for many areas—if you could accurately indicate a regional template to go along with this.
2. An example of where it is more complicated is in Southern California, where air temperature did not reflect water temperature. In this region, fish are targeting more groundwater in the warmer areas, and moving towards cooler water (i.e., the relationship between air and water temperatures is not great). Using air temperature here as a surrogate for water temperature does not work well. Threshold differences are not attributed to adaptation, but driven by environmental differences.
3. But, if a curve is off (or threshold, as in temperature), it would cause prediction problems across the ranges (of the ESU) – in California. In this area (i.e., referenced in Brian Spence's presentation), a particular temperature threshold could screen out the entire extent of a population. Local regional factors (climatic in this case) cause departures from the IP.

EDGE of RANGE:

1. In the Pacific Northwest, we have local factor issues. For chum, we are towards the edge of the chum zone, at the edge of their range. The edge of the range means that the curves in the middle of the range may not be appropriate, as habitat edges may have additional factors that impact the general curves or thresholds.
2. The Columbia River is NOT the edge for steelhead (SHD) – it is considered the "meat" of the steelhead range, unlike SHD in southern California or Chum on the Oregon coast.
3. In the Willamette Lower Columbia, the main contributing physical factors aggregate well (i.e., so perhaps the same models can be used within this area).
4. Interior vs. coast *O. mykiss*
   a. Resident SHD may be more tolerant to warmer temperatures (Benke's book). Is this true – is there local adaptation?
   b. Residents – there may be a greater use of different habitats (than the anadromous form).

EAST of the CASCADES:

1. In the Upper Columbia, they used GPS positions of steelhead redds, to help them tailor their models. Their IP model is based on steelhead spawning habitat. The Technical Recovery Team originally used a rearing model and then changed to a spawning model. They recognized that this was a first step, and that they should work on a model for IP for other life stages.
2. The east side of the Cascades has a higher degree of variability in the physical environment that can affect IP model results (i.e., John Day). There are big changes between ecoregions. On the east side of the cascades, there are sections of populations with completely limited habitat because of low winter temperatures, but the IP model originally would have shown this as good habitat.
3. Changes in amount of forest cover relates differently to habitat quality on the east side than the west side. With sufficient (or some amount of) large woody debris, fish can handle steeper gradients then where there is limited large woody debris. Tree vs. no trees causes changes in suitability that have nothing to do with extrinsic habitat (i.e., there are physical limitations to vegetation that interact with IP-type physical variables). Some populations go from shrub-steppe to alpine.
4. There is a similar issue with vegetation in California (Vegetation vs. Stream temperature)

GENERAL CONSIDERATIONS:

1. There should be additional steps (in any region?) to include over summer and over winter rearing habitat (where appropriate).
2. In southern California, the SHD model came about by starting with the Burnett et al. model, then tweaking the model until it made sense for that region. The temperature mask was used to help the results match the expert ideas of distribution (i.e., leaving out the Russian River).

3. We discussed naming conventions – there is some confusion and inconsistency between if curve differences mean it is a different model, OR if it is a new model if there is a new parameter included. When is it considered a different model? Given differences in thresholds (bioclimatic envelope) – need to make these binary differences (0s1s, mask, thresholds)
4. Used the egg analogy for applicability of models to different regions. If the model was developed in the "yolk" of the distribution for the species - IP models work well because they capture watershed areas. As you get into the "egg whites" (edge) of the range, other factors come into play. The Burnett et al. model for steelhead was close to the "yolk" of the SHD range.
5. Thresholds, Screens, or bioclimatic envelopes can help to address those additional factors to reflect extreme environmental variability (for example, in the Interior Columbia).

Best life stage to model for each region

- The best life stage to model is likely the most limited life stage
- Here are the stages to consider: Generally, California considers summer rearing, Interior Columbia considered spawning.
  - Spawner
  - Fry
  - Summer parr
  - Winter parr
- SHD may repeat the winter/summer stage a few times (3-5 times) depending on where you are
- Smolt stage
- The "run to the stream for fish exercise." You would run to see riffles, braids, island, hyphoreic flow if you wanted to find a spawning SHD. Think of it as what factors you would see if you had to pick the best spot in the river.
  - Bigger fish like greater depth
  - Velocity

SUMMER VERSUS WINTER

- Is it possible to do both summer and winter rearing using the same IP curves/approach? Not so in the Interior Columbia, where entire swaths are not useable in the winter, and rearing is not possible in the tributaries. A temperature or elevation threshold may be able to take care of this though.
- The model for southern California reflects summer parr. Density dependence is an issue – as streams dry up, fish get concentrated. In the Interior Columbia, originally a summer parr model was put together, and then it was modified to reflect spawning. A temperature screen was added in later. Temperature is the most important rearing screen. Winter parr, in some cases are limiting.
- Temperature refugia—Coastal summer steelhead come in as early as March, spawning the following April (in for 13 months). Need refugia to make it through summer flows. Interior has this issue as well (i.e., lower 250 miles)—these fish need to move upstream for temperature refugia.
- Some areas useful for winter steelhead, but not summer. Some streams dry up, so fish need to be out by July (Interior Columbia), so connectivity comes into play.
- In southern California, some systems have good summer habitat, but have small/short migration windows (where there is actually flow).
- Question: are adult stages limited for resident *O. mykiss* a helpful surrogate for looking at summer parr survival? Consensus was that this could be helpful.
- There are different growing periods for juveniles in different regions, this need to be considered in models. In the Pacific Northwest, the growth season is spring—in southern California it's in the winter.

Top 5-10 remotely sensed parameters that best assess habitat suitability for the species throughout its range

- Here is a process / order approach to think about choosing IP model variables:
  a. What are the geomorphic processes for the life stage that we are talking about?
  b. Pick these
  c. Determine if there are suitable GIS attributes or surrogates resolvable by remote sensing to reflect these geomorphic processes.
- Need for sufficient flows, and low enough gradient for spawner distribution.

Summer parr

Attributes to help with scoring suitability:

- Gradient
- Confinement (related to velocity)
- Velocity – measures gradient and confinement together (independence of velocity?) Some areas gradient and confinement not good enough – so we added in velocity and
  It made a better match with expert opinion
- Summer low flow = different regression than mean annual discharge
- Temperature (air) – southern California – August mean air temperature. Interior Columbia regression using forest cover air temperature and elevation to create their screen (binary to represent water temperature). Ex. John Day historically did not have major riparian vegetation, but as you move upstream you move into forested areas.

Spawners

- Gradient
- Substrate or Stream competency/stream power (gradient and depth of peak flows)
- Interior Columbia used a screen for where there were sediment problems
- Precipitation

TOP FEATURES:

- Flow (also, continuity of flow through dry season)
- Gradient
- Temperature (Southern California – may be more important than gradient)
- Valley Width index

Top 3-4 parameters for each

"Wish list" of parameters:

- riffles
- deep riffles
- channel stability (spawning)
- high concentrations of gravel
- low sediment loads
- habitat complexity
- water temperatures.

Breakpoints (1-5) for suitability curves for top parameters throughout range

Group did not come up with new breakpoints, but discussed a couple details about curves.

If IP reflects the abundance within the reach, then we may need to do this differently (i.e., curves). Lateral habitat (12 m) in smaller streams vs. lateral habitat in larger rivers – how to reflect this with curves? This is difficult in the largest mainstems – there are areas in largest rivers where spawning is happening, in certain areas. How to incorporate this into IP scores without swamping summaries?

Steps for moving forward

1. **<u>New Project Ideas:</u>**
   a. A first step for validating the IP models with expert opinion might involve what the group discussed as first "passing the laugh test". This would involve taking the maps to field biologists to review the scoring (WDFW). For the Washington side of the Columbia River, group the scores and see if they make sense. Also, there is a need to finalize the redd layers (WDFW) (~8000 GPS points). Steve V. is the data steward for these GPS points.
   b. Might need to do a sensitivity analysis based on the curves. Who?
      i. How different of a result if you used one set of curves vs. the others? How sensitive are the results to changes? How does reach length influence curves?
   c. Work on perfecting IP for Puget Sound
   d. What is an ideal patch /cluster of IP scores that are useable/meaningful? Holzer worked on this for the Interior Columbia Technical Recovery Team (IC TRT). Possibly use the NetMap Core too. IC used 200 m segments (1,500 m downstream and upstream give a mean IP per reach – to reflect uncertainty and to define best habitat patches). The IC TRT used 0, Low, Med, High spatial relationship to define spawning areas. Perhaps some elements of this approach can be used to help work with IP scores for steelhead.
   e. River size vs. lateral habitat work – refining using IP scores for lateral habitat (i.e., shorelines, island complexes, complexity, linear vs. polygon).
   f. Need to understand intermittent streams and lagoons better. They are key habitat areas.
2. **<u>Ongoing Projects:</u>**
   a. Working on logistic model predicting upper extent of chum SHD and chin distribution. Represents historical distribution (intent). Also get redd data squared away. Look at GIS factors that influence redd distributions.
   b. Southern California group is developing a fine scale water temp model based on NASA ecosystem modeling. Regional office needs tools that allow them to use IP maps in their ESA consultations. Need to take maps and play what if games when at meetings – helping them to connect recommendations to on the ground actions.
   c. Redband historic maps in Washington State – build IP model to look at this, and compare to historic data. Determine orderly method for surveying streams.

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Appendix F. Workshop Participant List.

First Name	Last Name	Affiliation
Eric	Andersen	Oregon State University
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Tom	Cooney	NOAA-NWFSC
Bob	Danehy	Weyerhauser
Joe	Ebersole	Environmental Protection Agency
Peter	Eldred	U.S. Forest Service
John	Faustini	Oregon State University
Kurt	Fesenmyer	Trout Unlimited
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Jamie	Glasgow	Wild Fish Conservancy
Matthew	Goslin	Ecotrust
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