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Ecological Management Decision Support (EMDS)-Based Analysis

I. The Ecological Management Decision Support (EMDS) Model

Introduction

The North Coast Watershed Assessment Program (NCWAP, now known as the Coastal Watershed Planning and Assessment Program (CWPAP)), selected the Ecological Management Decision Support (EMDS) (Reynolds 1999) analysis framework to evaluate and synthesize information on selected watershed and stream conditions that are important to salmonids during the freshwater phases of their life history. Only freshwater factors were considered; factors related to marine habitat and fishing were excluded from the analysis. EMDS uses linguistically based models, which are frequently employed in engineering and the applied sciences to validate expert opinion. This type of approach is one of several that CWPAP used to aid in identifying habitat factors that affect the production of salmonids in California's North Coast Watersheds (see limiting factors discussion in the Assessment Report). This appendix describes the general workings of EMDS, how EMDS relates to the analysis used in current CWPAP watershed assessments, and details of other factors being developed by CWPAP. For additional information on EMDS and its use in previous assessments, see the EMDS Appendix, available at: http://coastalwatersheds.ca.gov/AboutAssessment/AssessmentTools/tabid/259/Default.aspx.

NCWAP scientists constructed "knowledge base" models to identify and evaluate environmental factors (e.g., watershed geology, stream sediment loading, stream temperature, land use activities, etc.) which taken together shape anadromous salmonid habitat. Based upon these models, our analysis evaluated available data to provide insight into the conditions of streams and watersheds for salmonids in the region. The synthesis provided was then compared to more direct measures of salmonid production - i.e., the number of salmonids recently found in streams. The EMDS based analysis offers a number of benefits for the assessment work that CWPAP is conducting, and also has some known limitations. Both the advantages and drawbacks of the EMDS model are presented in this appendix.

Our use of the EMDS based model outputs is tentative. A scientific peer review process conducted in April of 2002 indicated that substantial changes to NCWAP's EMDS modeling approach were needed. At the time of the production of this report, CWPAP staff had implemented some, but not all of these recommendations. Therefore, we used model outputs with caution. CWPAP will continue to work to refine and improve the model and subsequent analysis, based on peer review.

Background

Details of the EMDS Software

EMDS (Reynolds 1999), was developed by Dr. Keith Reynolds at the USDA-Forest Service, Pacific Northwest Research Station. It employs a linked set of software that includes MS Excel, NetWeaver, the EMDS ArcView Add-in, and ArcView™. Microsoft Excel is a commonly used program for data storage and analysis. NetWeaver (http://rules-of-thumb.com/), developed at Pennsylvania State University, helps scientists build graphics of models (knowledge base networks) that specify how various environmental factors will be incorporated into an overall stream or watershed assessment. These networks resemble branching tree-like flow charts, graphically show the logic and assumptions used in the assessment, and are used in conjunction with environmental data stored in a Geographic Information System (ArcView™) to perform the assessments and display the results on maps. This combination of Excel/NetWeaver/EMDS/ArcView software is currently being used for watershed and stream reach assessment within the federal lands included in the Northwest Forest Plan

(NWFP) (Lanigan et al. 2012). Because EMDS version 4.2 was not compatible with current ArcMap 10 (ArcView) software, CWPAP staff created a program in Visual Basic to analyze specific instream habitat data for 4 factors: canopy density, pool depth, pool shelter, and cobble embeddedness. Our analysis used similar logic, factors, and assumptions, but a more simplified model framework compared to the EMDS analysis used in previous NCWAP and CWPAP watershed assessments. Habitat suitability maps were designed by importing model output data into ArcMap 10, and the analysis was referred to throughout the assessment report as an "EMDS based analysis".

NCWAP staff began developing EMDS knowledge base models at a three-day workshop in June of 2001, organized by the University of California, Berkeley. In addition to the NCWAP staff, model developer Dr. Keith Reynolds and several outside scientists also participated. As a starting point, NCWAP used an EMDS knowledge base model developed by the NWFP for use in coastal Oregon. Based upon the workshop, subsequent discussions among NCWAP staff and scientists, examination of the literature, and consideration of California conditions, NCWAP scientists then developed preliminary versions of the EMDS models.

The initial NCWAP models were reviewed over 2 days in April 2002 by an independent nine-member science panel, which provided a number of suggestions for model improvements. According to these suggestions, NCWAP scientists revised their EMDS models, and a description of these models is presented below.

The Knowledge Base Networks

For California's north coast watersheds, the NCWAP team constructed five knowledge base networks reflecting the best available scientific studies and information on how various environmental factors combine to affect anadromous fish on the north coast. All five models were designed to address current conditions (in-stream and watershed) for salmonids, and to reflect a fish's perspective of overall habitat conditions:

1) The Stream Reach model (*Figure 1* and *Table 1*) addresses conditions for salmon on individual stream reaches and is based largely on data collected under the Department of Fish and Wildlife's stream survey protocols;
2) The Sediment Production model evaluates the magnitude of various sediment sources in the basin according to whether they are natural or management related;
3) The Water Quality model offers a means of assessing characteristics of the in-stream water (flow and temperature) in relation to fish;
4) The Fish Habitat Quality model incorporates the Stream Reach model results in combination with data on accessibility to spawning fish and a synoptic view of the condition of riparian vegetation for shade and large woody debris;
5) The Fish Food Availability model has not yet been constructed, but will evaluate the watershed based upon conditions for producing food sources for anadromous salmonids.

The only model currently used in CWPAP assessments is the Stream Reach Condition model, and discussion in this appendix will be limited to this model. For a complete description of the other models, and a discussion of their development, limitations, and applications, see the EMDS Appendix (http://coastalwatersheds.ca.gov/AboutAssessment/AssessmentTools/tabid/259/Default.aspx).

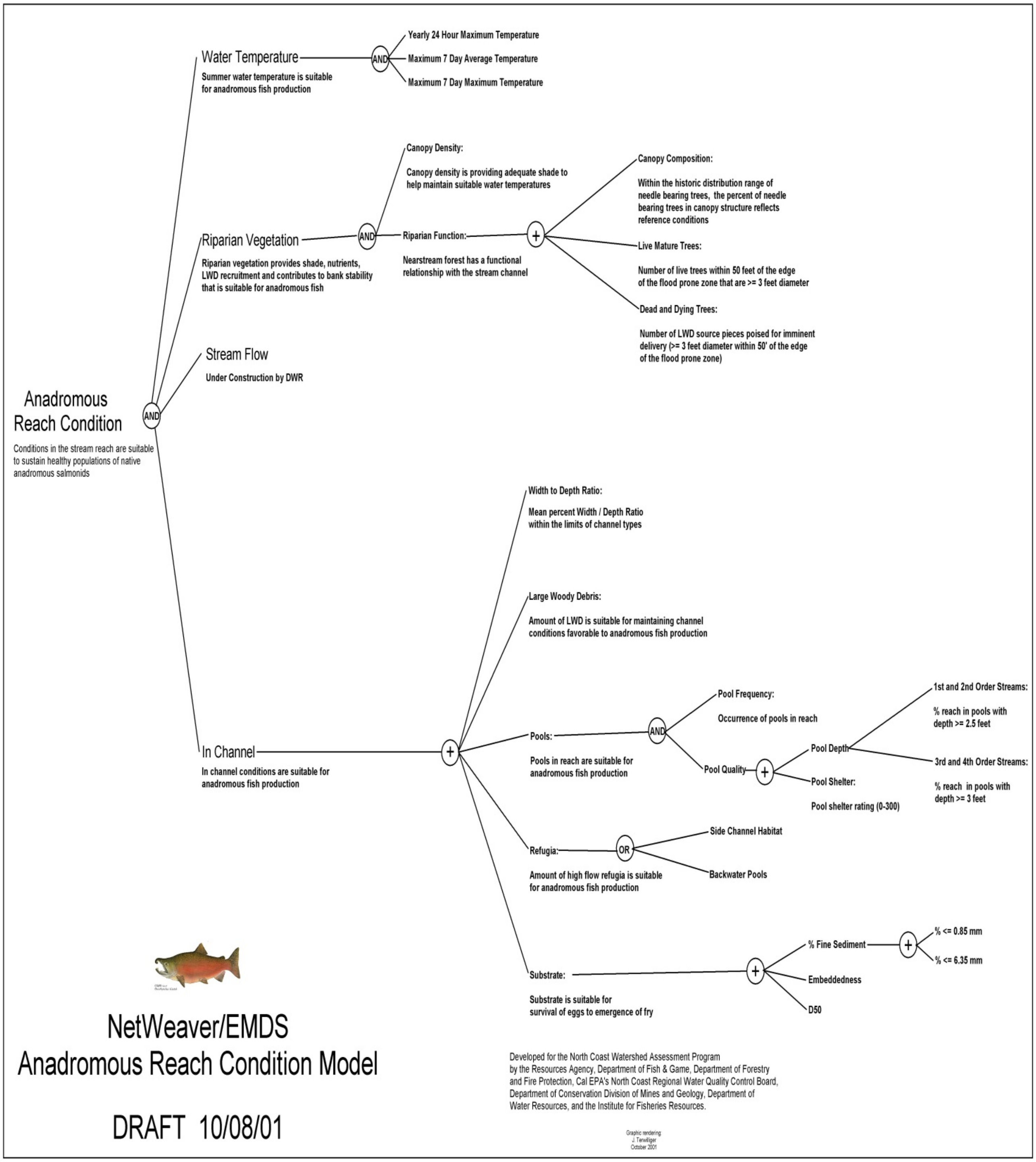

Figure 1. NCWAP EMDS Anadromous Reach Condition Model.

Table 1. Reference Curve Metrics for EMDS Stream Reach Condition Model.

Stream Reach Condition Factor	Definition and Reference Curve Metrics
Water Temperature	
Summer MWAT	• Maximum 7-day average summer water temperature. • <45^o F fully unsuitable, 50-60^o F fully suitable, >68^o F fully unsuitable. • Water temperature was not included in current EMDS evaluation.
Riparian Function	
Canopy Density *****	• Average percent of the thalweg within a stream reach influenced by tree canopy. • <50% fully unsuitable, ≥85% fully suitable.
Seral Stage	Under development
Vegetation Type	Under development
Stream Flow	Under development
In-Channel Conditions	
Pool Depth *****	• Percent of stream reach with pools of a maximum depth of 2.5, 3, and 4 feet deep for first and second, third, and fourth order streams respectively. • ≤20% fully unsuitable, 30 – 55% fully suitable, ≥90% fully unsuitable.
Pool Shelter Complexity *****	• Relative measure of quantity and composition of large woody debris, root wads, boulders, undercut banks, bubble curtain, overhanging and instream vegetation. • ≤30 fully unsuitable, ≥100 - 300 fully suitable.
Pool frequency	Under development
Substrate Embeddedness *****	• Pool tail embeddedness is a measure of the percent of small cobbles (2.5" to 5" in diameter) buried in fine sediments. • EMDS calculates categorical embeddedness data to produce evaluation scores between –1 and 1. The proposition is fully true if evaluation sores are 0.8 or greater and -0.8 evaluate to fully false.
Percent fines in substrate <0.85mm (dry weight)	• Percent of fine sized particles <0.85 mm collected from McNeil type samples. • <10% fully suitable, > 15% fully unsuitable. • There was not enough of percent fines data to use Percent fines in EMDS evaluations.
Percent fines in substrate < 6.4 mm	• Percent of fine sized particles <6.4 mm collected from McNeil type samples. • <15% fully suitable, >30% fully unsuitable. • There was not enough of percent fines data to use Percent fines in EMDS evaluations.
Large Woody debris	• The reference values for frequency and volume is derived from Bilby and Ward (1989) and is dependent on channel size. • Most watersheds do not have sufficient LWD surveys for use in EMDS.
Refugia Habitat	• Refugia is composed of backwater pools and side channel habitats and deep pools (>4 feet deep). • Not implemented at this time.
Pool to Riffle Ratio	Under development
Width to Depth Ratio	Under development
***** indicates factors currently used in analysis.	

Figure 2 shows the NCWAP EMDS model parameters in relation to work done by Ziemer and Reid (1997), and is a modification of Ziemer and Reid's figure titled "The Shape of the Problem". The original figure was used to show the complex linkages among natural and human-related phenomena which combine to affect salmonids in freshwater streams. Here it is redrawn to show more of the flow of various factors (from top to bottom), with annotation of the parameters that were included in NCWAP EMDS models. Graphics such as these help to conceptualize the interrelationships of the problems facing salmonids, and serve as a basis for building models that reflect these complex systems.

In creating the EMDS models listed above, NCWAP scientists used a "top-down" approach. For example, the Stream Reach Condition model began with the proposition: *The overall condition of the stream reach is suitable for maintaining healthy populations of native coho salmon, Chinook salmon, and steelhead trout.* A knowledge base (network) model was then designed to evaluate the “truth” of that proposition, based upon data from each stream reach. The model design and contents reflected the specific information NCWAP scientists believed was needed, and the manner in which data should be combined, to test the proposition.

In evaluating stream reach conditions for salmonids, the model uses data on several environmental factors. The first branching of the knowledge base network (*Figure 3*) shows that information on in-channel condition, stream flow, riparian vegetation and water temperature are all used as inputs in the stream reach condition model. In turn, each of the four branches is progressively broken down into more basic data components that contribute to it (not shown). The process is repeated until the knowledge base network incorporates all information believed to be important to the evaluation.

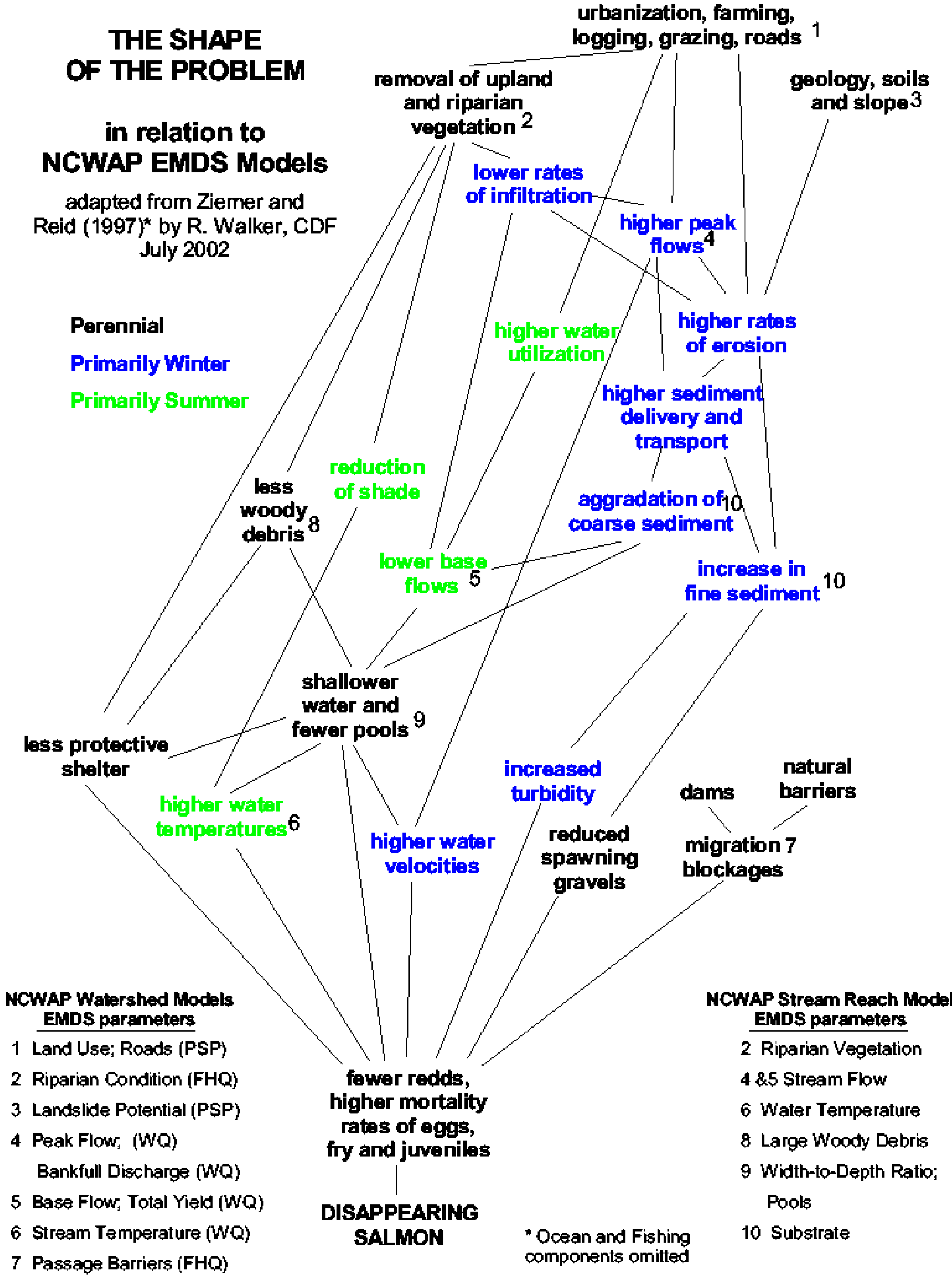

Figure 2. Modified from Figure 1 of Ziemer and Reid (1997) "The Shape of the Problem" to show the relationship between EMDS model parameters and the conceptual diagram of problems facing salmon in north coast California freshwater streams. Abbreviations used for watershed models above are: PSP – Potential Sediment Production model; FHQ – Fish Habitat Quality model; WQ – Water Quality model. Figure from NCWAP (2002).

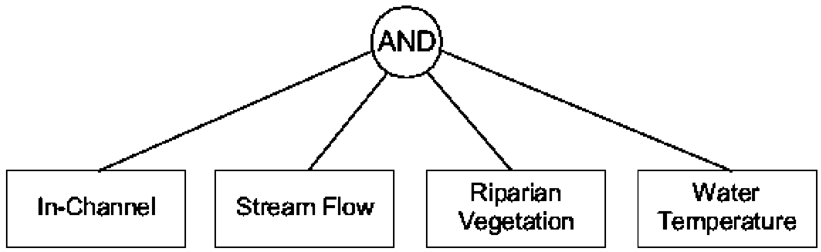

Figure 3. EMDS Stream Reach Knowledge Base Network. EMDS uses knowledge base networks to assess the condition of watershed factors affecting native salmonids.

Although model construction is typically done top-down, models are run in EMDS from the "bottom up". That is, data on the stream reach is entered at the lowest branches of the network tree (the "leaves"), and is combined progressively with other information as it proceeds up the network. Decision nodes are intersections in the model networks where two or more factors are combined before passing the resultant information on up the network. For example, the "AND" at the decision node in Figure 3 means that the lowest value of the four general factors coming in to the model at that point is taken to indicate the potential of the stream reach to sustain salmon populations.

EMDS models assess the degree of truth (or falsehood) of each model proposition. Each proposition is evaluated relative to simple graphs called "reference curves" that determine its degree of truth/falsehood, according to the data's implications for salmon. *Figure 4* shows an example reference curve for the proposition "*the stream temperature is suitable for salmon*". The horizontal axis shows temperature in degrees Fahrenheit, while the vertical axis is labeled "Truth Value" and ranges from –1 to +1. The line shows what are fully unsuitable temperatures (-1), fully suitable temperatures (+1) and those that are in-between (> -1 and <+1). In this way, a similar numeric relationship is required for all propositions evaluated in the models.

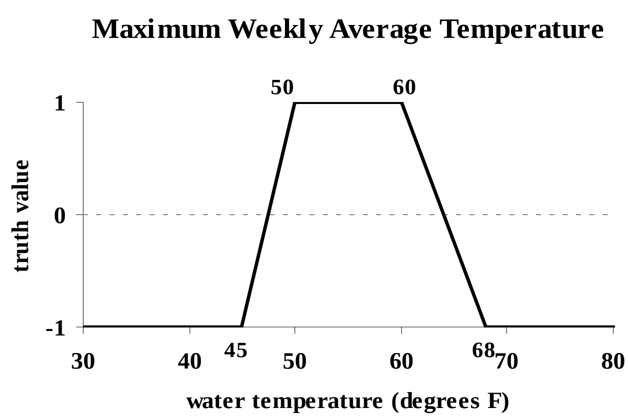

Figure 4. EMDS Reference Curve. EMDS uses this type of reference curve in conjunction with data specific to a stream reach. This example curve evaluates the proposition that the stream's water temperature is suitable for salmonids. Break points can be set for specific species, life stage, or season of the year. Curves are dependent upon the availability of data.

Proposition evaluations do not always result in simple "true" vs. "false" assessments – a strength of EMDS is its capability to determine degrees of truth or falsehood, or in effect, the degree to which the proposition is supported in the model by the evidence. For each evaluated proposition in the network, the result is a number between –1 and +1. The number relates to the degree to which the data support or refute the proposition. In all cases a value of +1 means that the proposition is "completely true", and –1 implies that it is "completely false", with in-between values indicating "degrees of truth" (i.e., values approaching +1 being closer to true and those approaching –1 converging on untrue). A zero value means that the proposition cannot be evaluated based upon the data available. Breakpoints (where the slope of the reference curve changes) in the *Figure 4* example occur at 45, 50, 60 and 68 degrees Fahrenheit. For the Stream Reach model, NCWAP fisheries biologists determined these temperatures by reviewing relevant scientific literature.

For many NCWAP parameters, particularly those related to upland geology and management activities, little or no scientific literature was available to assist in determining breakpoints. Because of this, NCWAP used a more empirically-based approach for breakpoints. Specifically, for each evaluated parameter, the mean and standard deviation were computed for all planning watersheds in a basin. Breakpoints were then selected to rank each planning watershed for that parameter in relation to all others in the basin. NCWAP staff used a simple linear approximation of the standardized cumulative distribution function, with the 10th and 90th percentiles serving as the low and high breakpoints (*Figure 5*).

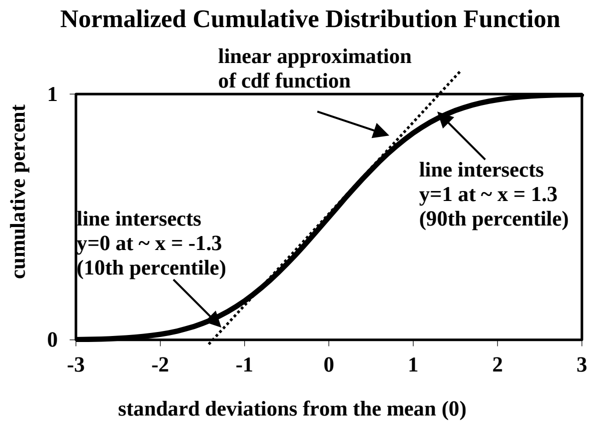

Figure 5. Using the 10th and 90th percentiles as breakpoints (as with Land Use) is a linear approximation of the central part of the normalized cumulative distribution function

The science review panel recommended that this method developed by NCWAP scientists be changed. They advised to use a set of reference watersheds from the region, compute the distributions of land use and other parameters from those watersheds to determine breakpoints. At this point CWPAP staff have not had the resources to select the reference watersheds, nor to process the data for them. This issue will be addressed in future watershed assessments and the breakpoints adjusted as information from reference watersheds becomes available.

NCWAP map legends used a seven-class system for depicting the EMDS suitability-values, but CWPAP staff reduced the number of suitability classes to four in order to more simply and effectively describe the suitability of instream habitat for salmonids. Stream or reach habitat with values at or near +1 are classified as "high suitability", and those habitats with values at or near –1 are classified as "low suitability". Between the high suitability and low suitability classes, there are two categories of intermediate suitability which are unlabeled in the figure legends.

In EMDS, the data that are fed into the knowledge base models come from GIS layers stored and displayed in ArcView. In our analysis, we imported suitability values into attribute tables and created data layers for graphical representation of suitability by stream and reach in ArcMap.

Advantages Offered by EMDS Based Analysis

The EMDS type analysis offers a number of advantages for use by CWPAP. Instead of being a hidden "black box", each model has an open and intuitively understandable structure. The explicit nature of the model networks facilitates open communication among agency personnel and with the general public through simple graphics and easily understood flow diagrams. The models can be easily modified to incorporate alternative assumptions about the conditions of specific environmental factors (e.g., stream water temperature) required for suitable salmonid habitat.

Using ESRI GIS software, CWPAP mapped the factors affecting fish habitat and showed how they varied across a basin. Models provided a consistent and repeatable approach to evaluating watershed conditions for fish, and maps from supporting levels of the model showed specific factors that taken together determined the overall watershed condition. This latter feature can help identify what is most limiting to salmonids, and thus assist with prioritization of restoration projects or modification of land use practices.

Another feature of the system is the ease of running alternative scenarios. Scientists and others can test the sensitivity of the assessments to different assumptions about the environmental factors and how they interact, through changing the knowledge-based network and breakpoints. “What-if” scenarios can be run by changing the shapes of reference curves (e.g., *Figure 4*), or by changing the way the data are combined and synthesized in the network.

Analysis tools can be applied at any scale, from reach specific to watershed-wide. The spatial scale can be set according to the spatial domain of the data selected for use and issue(s) of concern. Alternatively, through additional network development, smaller scale analyses (i.e., subwatersheds) can be aggregated into larger hydrologic units. With sufficient sampling and data, analyses can be done on single or multiple stream reaches.

CWPAP did not use the EMDS based analysis exclusively for watershed synthesis. The program used various other approaches for further exploration of fish-environment relationships.

Management Applications of Watershed Synthesis Results

EMDS based analysis results can be applied at the basin scale to assess current watershed status. Maps depicting those factors that may be the largest impediments, as well as those areas where conditions are very good, can help guide protection and restoration strategies. The model can also help assess the cost-effectiveness of different restoration strategies. By running sensitivity analyses on the effects of changing different habitat conditions, it can help decision makers determine how much effort is needed to significantly improve a given factor in a watershed and whether the investment is cost-effective.

At the project planning level, EMDS based model results can help landowners, watershed groups and others select the appropriate types of restoration projects and locations (i.e., planning watersheds or larger) that can best contribute to recovery. Agencies will also use the information when reviewing projects on a watershed basis.

The main benefit of using this type of system to perform limiting factors analyses is flexibility, and through explicit logic, easily communicated graphics, and repeatable results, it provides insights into the relative importance of the constraints limiting salmonids in North Coast watersheds. CWPAP will use these analyses not only to assess conditions for fish in the watersheds and to help prioritize restoration efforts, but also to facilitate an improved understanding of the complex relationships among environmental factors, human activities, and overall habitat quality for native salmon and trout.

Limitations of the EMDS Model and Data Inputs

At the time of the production of this report, we have not been able to implement all of the recommendations made by our peer reviewers. Therefore, current model outputs should be used with caution. CWPAP will continue to work to refine and improve the EMDS model, based on the peer review.

While EMDS based syntheses are important tools for watershed assessment, they do not by themselves yield a course of action for restoration and land management. Analysis results require interpretation, and how they are employed depends upon other important issues, such as social and economic concerns. In addition to the accuracy of the expert opinion and knowledge base system constructed, the currency and completeness of the data available for a stream or watershed will strongly influence the degree of confidence in the results. External validation of the model using fish population data and other information should be done where possible.

One disadvantage of linguistically based models such as EMDS is that they do not provide results with readily quantifiable levels of error. However, CWPAP staff are developing methods of determining levels of confidence in the analysis results, based upon data quality and overall weight given to each parameter in the model.

CWPAP will use the EMDS framework only as an indicative model, evaluating the quality of watershed or instream conditions based on available data and the model structure. It is not intended to provide highly definitive answers, such as those from a statistically-based process model. It does provide a reasonable first approximation of conditions through a robust information synthesis approach; however, specific outputs need to be considered and interpreted in combination with other information sources and an understanding of the inherent limitations of the model and its data inputs. It also should be clearly noted that this analysis does not assess the marine phase of the salmonid lifecycle, nor does it consider fishing pressures.

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II.The Stream Reach Condition Model: An Explanation of Model Parameters and Data Sources

Introduction

The stream reach knowledge base uses all available data for a stream reach to test the proposition: *Conditions in the stream reach are suitable to sustain healthy populations of anadromous salmonids.*

The stream reach knowledge base is composed of four logic networks relating to environmental factors that affect anadromous salmonid habitat conditions: 1) Water Temperature; 2) Riparian Vegetation Function; 3) Stream Flow; and 4) In Channel Conditions (*Figure 1*). The overall Stream Reach Condition is determined by combining the four evaluations through the "AND" logic node. This evaluates to "true" (+1) when all the network evaluations are "true", "false" (-1) if any of the four network evaluations is "false", or a numerical value between +1 and –1, showing the degree to which the above proposition is "true".

A complete summary of the Stream Reach Condition knowledge base used in the model is presented below. For each parameter in the model, its proposition, definition and explanation are presented. The CWPAP model used data from four factors: canopy density, pool depth, pool shelter complexity, and cobble embeddedness. Other factors are included in the parameter and data source discussion but have not yet been implemented due to lack of data and/or undeveloped reference curve metrics.

Model Parameters and Data Sources

Water Temperature (not yet implemented)

Proposition:

Summer water temperature is suitable sustain healthy populations of anadromous salmonids.

Definition:

Water temperature at the reach level is evaluated by comparing the 7-Day Maximum Average Temperature (7DMAT) collected from instream monitoring sites to the experimentally and empirically based Maximum Weekly Average Temperature (MWAT) for summer rearing juvenile anadromous salmonids. Additional metrics will provide a broader based evaluation including:

1) Yearly 24 hour maximum temperature
2) Maximum weekly maximum temperature

The Maximum Weekly Average Temperature (MWAT) is a calculated value based on experimental and empirical data, and is defined as the upper temperature limit recommended for a specific salmonid life stage (Armour 1991). The MWAT is essentially the upper temperature that fish can withstand for long durations and still maintain healthy populations (Sullivan et al. 2000). The experimental calculation for the MWAT is:

$$MWAT = OT + \frac{UUILT - OT}{3}$$

- **OT = Optimal Temperature** reported for a particular species and life stage. In the CWPAP analysis, summer juvenile rearing is used.
- **UUILT = Upper Ultimate Incipient Lethal Temperature** is the highest temperature at which tolerance does not increase with increasing acclimation temperatures.

Explanation:

The 7DMAT measured from continuous temperature recorders is compared to reference values derived from experimentally and empirically determined MWATs for anadromous salmonids. The NCWAP team used one MWAT value across all streams rather than attempting a site specific or species specific approach. Reference values for the MWAT were selected from a synthesis of relevant studies, including those reviewed by Stillwater Sciences (1997):

> "Stein et al. (1972) reported that growth rates in juvenile coho salmon slow considerably at 18˚C, and Bell (1973) reported that growth of juvenile coho ceases at 20.3˚C. Decreases in swimming speed may occur at temperatures over 20˚C (Griffiths and Alderdice 1972). Empirical studies by Hines and Ambrose (2000) determined that the number of days a site exceeded an MWAT of 17.6˚C (63.7˚F) was one of the most influential variables predicting coho presence and absence".

Welsh et al. (2001) suggested that an MWAT greater than 16.7˚C (62.0˚F) may preclude the presence of coho salmon in the Mattole River.

Data Sources:

Measurements from field observations.

Reference Values:

The proposition for water temperature is fully true if MWAT values are between 50 and 60˚F, and are fully false below 45˚F and above 68˚F (*Figure 6*).

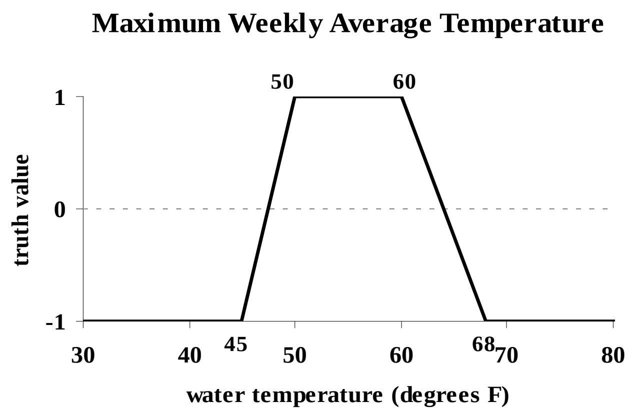

Figure 6. Breakpoints for MWAT truth values.

Riparian Vegetation

Proposition:

Current riparian vegetation provides sufficient shade, nutrients, large woody debris recruitment, and contributes to bank stability to maintain healthy populations of anadromous salmonids.

Definition:

The riparian vegetation assessment consists of an evaluation of canopy density, which shades the stream channel, and an evaluation of the near-stream forest's ability to provide LWD and nutrients to the stream channel. Seral stage and species composition is still under construction; only canopy density data used was used to assess riparian vegetation in the analysis.

The Riparian Vegetation Function network is composed of an evaluation of:

1) Canopy Density

and the mean value of the evaluation of:

2) Canopy Species Composition
3) Live Mature Trees
4) Imminent Source of Large Woody Debris.

Canopy Density

Proposition:

Canopy density is provides adequate shade to help maintain suitable water temperature and nutrient input to maintain healthy anadromous salmonid populations.

Definition:

Canopy density is the percent of stream influenced by tree canopy measured with a spherical densiometer from the center of a stream habitat unit.

Explanation:

Shade from streamside canopy helps to reduce stream water temperatures, especially during summer months. This parameter measures the adequacy of the vegetation in performing this important role.

The California Department of Fish and Game's Salmonid Stream Habitat Restoration Manual recommends, in general, that revegetation projects should be considered when canopy density is less than 80% (Flosi et al. 2010). Everest and Reeves (2006) reported that in westside forests the amount of solar radiation reaching the stream channel is approximately 1 - 3% of the total incoming radiation for small streams and 10 -25% for mid-order (3rd to 4rth order) streams.

Data Sources:

Measurements from field observations collected during DFW stream surveys.

Reference Values:

The proposition for Canopy Density is fully true if field observations are 85 percent or above and fully false if field observations are below 50 percent (*Figure 7*).

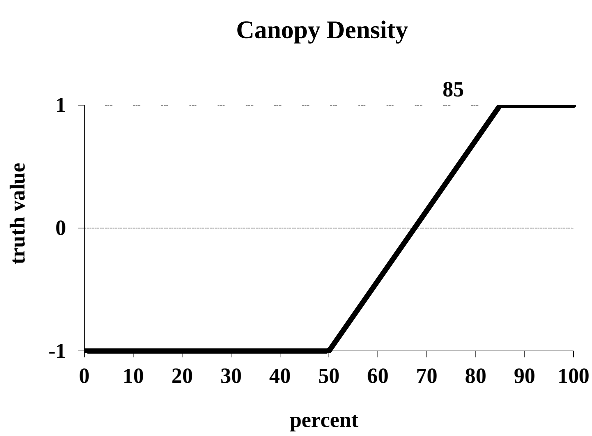

Figure 7. Breakpoints for Canopy Density

Riparian Function

Canopy Species Composition (not used in analysis)

Proposition:

The canopy species composition is within the range of historic species distribution and is suitable to maintain healthy anadromous salmonid populations. This factor is not yet implemented in the model.

Definition:

The similarity of species and life forms between the current vegetation and that which existed prior to Euro-American colonization.

Explanation:

The species composition of riparian vegetation can indicate recent historical events that have occurred in and near the stream reach. Some areas currently dominated by broad-leafed trees were dominated in the past by conifers. This can indicate that disturbances have occurred in the watershed, which resulted in this change in species composition. Also, conifers tend to provide more cooling in their shade than broad-leaf trees.

Data Sources:

Measurements from field observations.

Reference Values:

The proposition is fully true if the observed canopy species composition has a high degree of similarity to the pre-Euro-American range of species composition and fully false if it has a low similarity.

Live Mature Trees (not yet implemented)

Proposition:

The number of live trees three feet or greater in diameter at breast height within a riparian buffer zone is sufficient to maintain conditions needed to support healthy anadromous salmonid populations. Reference values have not been developed for this factor.

Imminent Source of Large Woody Debris (LWD) (not yet implemented)

Proposition:

The number of LWD sources poised for imminent delivery to the stream channel is suitable to maintain channel conditions suitable to support anadromous salmonid populations. Reference values have not been developed for this factor.

Stream Flow (not yet implemented)

Proposition:

The stream flow regime is suitable to sustain healthy populations of anadromous salmonids. This subnetwork of the Stream Reach model is being developed by the Department of Water Resources and was not included in the Stream Reach Condition Model.

In-channel Conditions

Proposition:

In-channel conditions are suitable to support healthy anadromous salmonid populations.

Definition:

In-channel conditions are determined by the mean truth value returned by the evaluation of 5 networks:

1. Large Woody Debris
2. Width to Depth Ratio
3. Pool Habitat
4. Winter Habitat
5. Substrate Composition.

Width-to-Depth Ratio (not yet implemented)

Proposition:

The Width-to-Depth Ratio of the stream reach is suitable for sustaining healthy populations of anadromous salmonids. Reference value curves have not been developed for this factor.

Large Woody Debris (not yet implemented)

Proposition:

The amount of in channel Large Woody Debris (LWD) is suitable for maintaining channel conditions to support healthy populations of anadromous salmonids.

Definition:

The target reference values for LWD frequency and volume is derived from Bilby and Ward's (1989) channel-width dependent regression for unmanaged streams in western Washington. The relationships between channel width and number of pieces (Bilby and Ward 1989) and "key" pieces of LWD (Fox 1994) are presented in the Pacific Lumber Company Habitat Conservation Plan, Aquatic Properly Functioning Condition Matrix (work in progress 1997).

Explanation:

Large woody debris is important to stream ecosystems because it exerts considerable control over channel morphology, particularly in the development of pools (Keller et al. 1995). Petersen and Quinn (1992) noted that LWD is associated with the majority of pools in forested streams, and there is a direct correlation between the amount of LWD present and the pool volume, pool depth and percentage of pool area in streams. Stillwater Sciences' Preliminary Draft Report (1997) suggested that LWD and its associated rearing habitat may be the most important limiting factors for coho salmon populations in coastal Mendocino County streams. The North Coast Regional Water Quality Control Board, in cooperation with the California Department of Forestry (Knopp 1993), stated that LWD benefits all life stages of salmonids by:

- creating holding pools used by adults during migration;
- retaining spawning gravels;
- creating slack water areas where juveniles can feed on drift;
- providing essential cover from predators and freshets (Murphy and Meehan 1991); and
- increasing the frequency and diversity of pool types (Bilby and Ward, 1991).

Juvenile salmonids, especially coho salmon, appear to prefer habitats with deep (>45 cm), slow (<15cm/s) areas in or near instream cover or roots, logs, and flooded brush (Bustard and Narver 1975), especially during freshets (Tschaplinski and Hartman 1983). Shirvell (1990) found that 99% of all coho salmon fry were observed in areas downstream of natural or artificial rootwads, during artificially created drought, normal, and flood stream flows.

Data Sources:

Measurements from LWD field surveys.

Reference Values:

Not yet developed.

Pool Habitat

Proposition:

The pool frequency, pool depth, and pool complexity observed in the stream reach is suitable to support healthy populations of anadromous salmonids.

Definition:

The Pool Habitat sub-network evaluation is composed from evaluations of:

1) Pool Frequency, and
2) Pool Quality:
   a) Pool Depth
   b) Pool Shelter Complexity

Pool Frequency (not yet implemented)

Proposition:

The number of pools observed during stream surveys is within the suitable frequency range for the channel type, gradient, bankfull width, and channel confinement of the stream reach.

Definition:

The number of pools observed per unit length of stream reach.

Explanation:

Not yet implemented.

Reference Values:

The proposition is fully true if the observed pool frequency has a high degree of similarity to the expected frequency range and fully false if it has a low similarity.

Pool Quality

The pool quality network is composed of an evaluation of pool depth and pool shelter complexity rating.

Pool Depth

Proposition:

The percent by stream reach length in primary pools is suitable to support healthy anadromous salmonids.

Definition:

Primary pools have a maximum depth of 2.5 feet or greater in first and second order streams, a maximum depth of 3 feet or greater for third order streams, and a maximum depth of 4 feet or greater in fourth order streams.

Explanation:

The percent by stream reach of adequately deep pools or primary pools is determined according to stream order. For this analysis, stream order is determined from streams displayed as solid blue lines on 1:24,000 USGS topo maps. The percent reach of primary pools is calculated by: length of primary pool habitat / stream reach length.

Data Sources:

Measurements from field observations collected during DFW stream surveys.

Reference Values:

The proposition for the Pool Depth evaluation is fully true if 33 to 55 percent of the reach is in primary pools and fully false if there is less than 20 percent or more than 85 percent primary pool habitat (*Figure 8*).

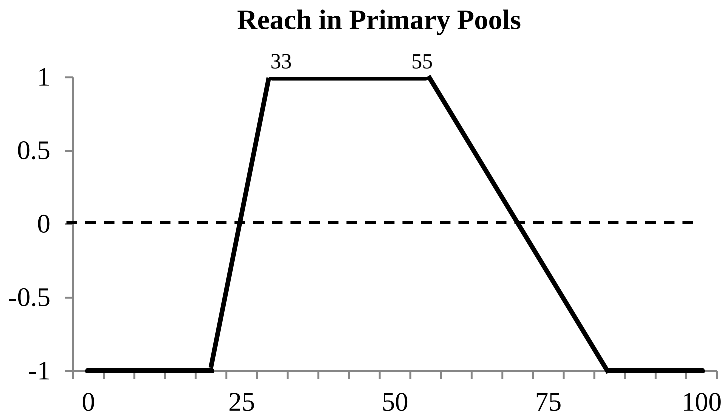

Figure 8. Breakpoints for Pool Depth.

Pool Shelter Complexity

Proposition:

The average pool shelter complexity is suitable to support anadromous salmonids.

Definition:

A DFG field procedure rates pool habitat shelter complexity (Flosi et al. 2010). The pool shelter rating is a relative measure of the quantity and composition of LWD, root wads, boulders, undercut banks, bubble curtain, and submersed or overhanging vegetation that serves as instream habitat, creates areas of diverse velocity, provides protection from predation, and separates territorial units to reduce density related competition. The rating does not consider factors related to changes in discharge, such as water depth.

Data Sources:

Measurements from field observations collected during DFW stream surveys.

Reference Values:

The proposition for the Pool Shelter Complexity evaluation is fully true if the pool shelter rating is 100 or greater and fully false if the pool shelter rating is 30 or less (*Figure 9*).

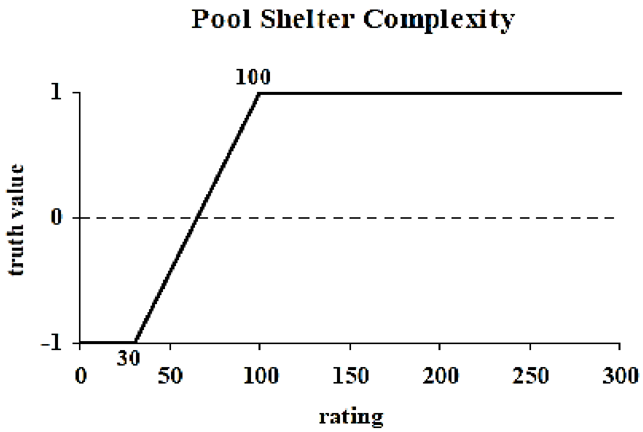

Figure 9. Breakpoints for Pool Shelter Complexity.

Refugia Habitat (not yet implemented)

Proposition:

The amount of backwater pools, deep pools and side channel habitats is suitable (especially as winter refuge) to support healthy anadromous salmonid populations.

Definition:

Refugia for this evaluation are composed of backwater pools, side channel habitat, and deep pools (>4 feet deep) identified from DFW's stream habitat surveys.

Explanation:

The majority of juvenile coho salmon in coastal streams appear to overwinter in deep pools, backwater habitats, or alcoves within the stream channel that have substantial amounts of cover in the form of woody debris and/or provide shelter from high winter flows (Bustard and Narver 1975, Scarlett and Cederholm 1984, Brown and Hartman 1988, Bell 2001). Swimming ability decreases with temperature and as water temperature falls below 9˚C, juvenile coho salmon become less active (Bustard and Narver 1975, Nieraeth 2010) and require rearing habitat that provides shelter during high winter flows.

Data Sources:

Measurements from field observations collected during DFW stream surveys.

Reference Values:

The proposition for the Refugia Habitat evaluation is fully true if 10 percent of the stream reach is side channel or backwater pool habitat and fully false if there is no such habitat in the stream reach (*Figure 10*).

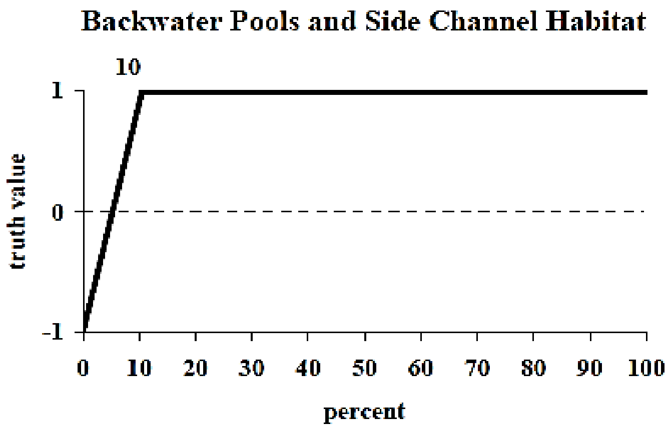

Figure 10. Breakpoints for percentage in backwater pools and side channel habitat.

Substrate Composition

Pool Tail Embeddedness

Proposition:

The pool tail substrate provides suitable spawning material and promotes survival of salmonid eggs to emergence of fry.

Definition:

Pool tail embeddedness is a measure of the percent of small cobbles (2.5” to 5” in diameter) buried in fine sediments. Percent cobble embeddedness is determined at pool tail-outs where spawning is likely to occur. Average embeddedness values are placed into one of five embeddedness categories:

- 1 = 0 to 25%
- 2 = 26 to 50%
- 3 = 51 to 75%
- 4 = 76 to 100%
- 5 = unsuitable for spawning (impervious)

Explanation:

The EMDS based model used a weighted sum of embeddedness category scores to evaluate the pool tail substrate suitability for survival of eggs to emergence of fry. The percent embeddedness categories are weighted by assigning a coefficient to each category. The model rates embeddedness category 1 as fully suitable for egg survival and fry emergence and assigns a coefficient of +1 to the percent of embeddedness scores in category 1. Embeddedness category 2 is considered uncertain and given a coefficient of 0. Embeddedness categories 3 and 4 are considered unsuitable and are assigned a coefficient of -1. Category 5 values are omitted because they are composed of impervious substrate such as boulders, bedrock, or log sills. The values for each category are summed and evaluated in the analysis.

Data Sources:

Measurements from field observations collected during DFW stream surveys.

Reference Values:

A summary score of ≤ -0.8 is considered fully unsuitable and a score of ≥ 0.8 is fully suitable (*Figure 11*).

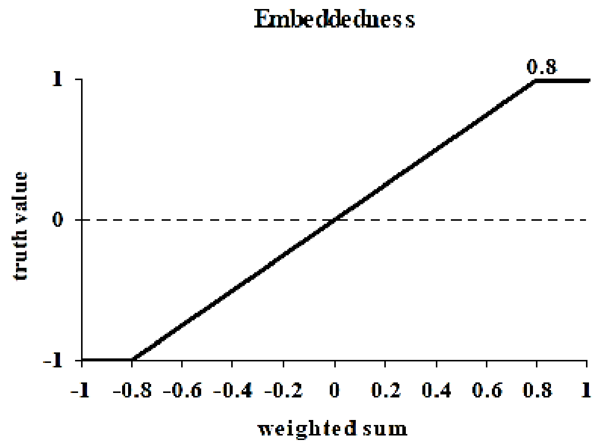

Figure 11. Breakpoints for embeddedness.

Percent Fine Sediment (not yet implemented)

Explanation:

Substrate composition is used as a suitability measure of pool tail sediments for survival of eggs to the emergence of fry. Sedimentation resulting from land use activities is recognized as a fundamental cause of salmonid habitat degradation (FEMAT 1993). Excessive accumulations of fine sediments reduce water flow (permeability) through gravels in redds. The percent of fine sediments is higher in watersheds where the geology, soils, precipitation or topography create conditions favorable for erosional processes (Duncan and Ward 1985). Fine sediments are typically more abundant where land use activities such as road building or land clearing expose soil to erosion and increase mass wasting (Cederholm and Reid 1987; Swanson et al 1987; Hicks et al 1991).

McHenry et al. (1994) found that when fine sediments (<0.85mm) exceeded 13% (dry weight) salmonid survival dropped drastically. Bjornn and Reiser (1991) showed that salmonid embryo survival dropped considerably when the percentage of substrate particles smaller than 6.35 mm exceeded 30 percent.

Data Sources:

Substrate samples collected from instream sites.

Reference Values:

Reference values curves for Percent Fine Sediment are presented in *Figure 12* and *Figure 13*.

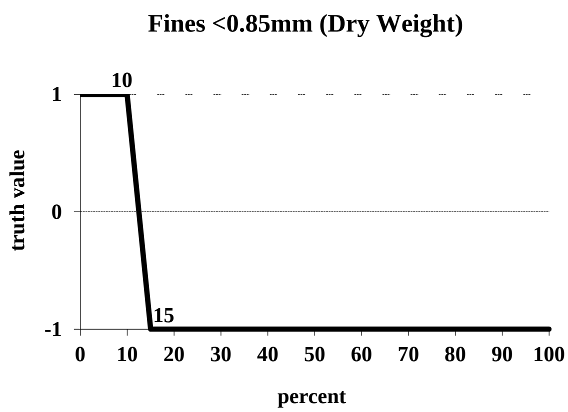

Figure 12. Breakpoints for Percent Dry Weight of Fine Sediments <0.85mm

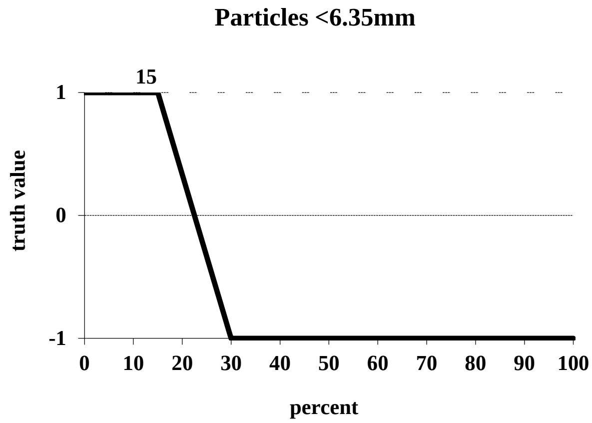

Figure 13. Breakpoints for Percent of Sediments <6.35mm

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