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        Many contemporary fisheries and wildlife issues are complex,

messy, and divisive. Most share a set of common characteristics

including a lack of comprehensive scientific information, a limited

understanding of biological processes, a scarcity of agency staff,

time, money, and a tendency for differences over policy preferences to

end up as debates over scientific information. When pressured to

provide policy relevant science to decision makers, agency scientists

are often left with no choice but to rely on some form of expert

opinion. Information based on expert opinion may be valuable, but to

be most useful in decision making, it must be perceived as being

accurate, transparent, and calibrated by some measure of uncertainty.

Formal methods of eliciting and using expert opinion are becoming more

common in fisheries and wildlife management. Decision-support models

are one such method but are still fairly new and untested for fish and

wildlife problems. Using Oregon's Coastal Coho Salmon *Oncorhynchus

kisutch* Evolutionarily Significant Unit (ESU) as a case study, the

usefulness of Ecosystem Management Decision Support (EMDS) to assess

watershed condition for coho salmon recovery was examined. To create

the model, expert opinion was elicited using a formal Delphi process.

We found that the Delphi technique is relatively inefficient and

impractical for eliciting expert opinion on such topics as complex as

watershed condition. We also identified ways that normative science can influence the consensus building process. Once our decision-support model was constructed we determined that it was not particularly useful for assessing watershed condition for coho salmon at the population level due to the lack of data. Data for all of the road parameters in the knowledge base were either nonexistent, or not available because they are privately owned or require extensive GIS analysis. In this case study we evaluated the tradeoffs of these formal methods: improving credibility and transparency came at the cost of time and procedural efficiency. Formal methods of eliciting and applying expert opinion for assessments are no panacea. Managers and decision makers will need to weigh these pros and cons on a case by case basis when contemplating whether these tools will add appreciable value to their assessments.

The Utility of a Decision-Support Model to Assess Watershed
Condition for Salmon Recovery

by
Tyler G. Mintkeski

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Tyler G. Mintkeski, Author

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INTRODUCTION

The Role of Expert Judgment in Salmon Recovery

Recovering US Endangered Species Act (ESA) and Canadian Species at Risk Act (SARA) listed stocks of anadromous salmon *Oncorhychus spp.* is a central focus of natural resource management agencies in the Pacific Northwest of North America. Beyond the legal mandate, the economic, social, and ecological importance of salmon in this region is broadly accepted by the public, but specific recovery strategies are controversial and recovery remains an illusive goal. After years of analysis and the expenditure of billions of dollars, salmon runs are still greatly reduced compared to pre-1850 levels (Meengs and Lackey 2005).

Salmon recovery is an example of a contemporary natural resource problem commonly known as a "wicked problem" (Rauscher 1999). Their shared characteristics include: inherent ecological complexity, fragmented or competing interest groups and stakeholders, a general lack of data, incomplete scientific understanding of the problem and the consequences of management actions, large but unknown costs, lack of organized approaches, and high uncertainty. Additionally, the exact problem may be difficult to define and the solutions obscured because of multiple interrelated, compounding factors (e.g. changing political goals, dueling scientists, and the

continued use of ineffective approaches to solve these problems).
Often, these challenges are exacerbated by a lack of financial
resources and time constraints.

Given that it has the characteristics of a wicked problem,
effective salmon recovery requires the collaboration and
communication between scientists and decision-makers. In this
relationship, decision-makers are under pressure to implement polices
that achieve their organization's specific legal or policy mandates
whereas scientists are expected to inform management decisions by
providing the "best available scientific information" that is timely,
relevant, and meaningful. Bisbal (2002, 2006) suggests that, although
popular in use and even required by the ESA to guide salmon
conservation, the definition of the "best available science" is
vague. There is no consensus on what counts as the "best available
science", how to differentiate between the best science and the rest,
or how to determine the amount of science available (Bisbal 2002,
Bogert 1994). When confronted by the wicked characteristics of the
problem of salmon recovery, particularly incomplete data coupled with
complexity and urgency, the "best available science" is often expert
judgment.

Expert judgment is a valuable, even essential, source of
information for the management and recovery of salmon (Magnuson et
al. 1995). From national scientific panels to individual fisheries
biologists, scientists interpret information and provide judgment at
many levels that influence salmon management decisions. It is assumed

that experts have the ability to make judgments and decisions based on incomplete data and imprecise understanding (Regan et al. 2004, Johnson and Gillingham 2004). Experts' additional challenge is to synthesize expert opinion in a way that is easy to understand and useful for decision making. In contrast to inferences based solely on empirical data, experts can provide a synthesis perspective gathered from a combination of experience, personal observation, and published data (Johnson and Gillingham 2004). Also, expert judgment can substitute for empirical data that is cost prohibitive and time consuming to collect (Rushton et al. 2004, Johnson and Gillingham 2004).

The use of expert judgment deserves caution based on its subjective nature. An expert may have a sound technical understanding of a subject, but there is no assurance that an expert's judgment process will follow the rules of rational thought[1] or that the judgment will amount to useful information. Expert-derived information is susceptible to being undermined by personal values, perceptions of risk, and cognitive heuristics[2] (Regan et al. 2004). Also, an expert's reasoning is not transparent. It is impossible to

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[1] According to Cleaves (1994) rationality in judgment means "the person who estimates, values, or chooses thoroughly uses available information and is aware of alternatives and their implications and that the judgment is coherent, consistent with similar judgments, in agreement with general laws or probability, and understood by users.
[2] Heuristics are psychological rules which have been proposed to explain how people make decisions, come to judgments and solve problems, typically when facing complex problems or incomplete information. These rules work well under most circumstances, but in certain cases lead to systematic cognitive biases (Tversky and Kahneman 1982).

understand an expert's logic or hidden reasoning underlying his or her assumptions (Regan et al 2004). Therefore, expert based assessments and decisions are difficult to repeat. Lack of repeatability can potentially weaken the credibility of decisions and assessments based on expert judgment by hiding inconsistencies, values, illogical assumptions, or "normative" science ("science which presupposes a particular policy position or perspective") (Lackey 2004). As a result, expert judgment that is presumed to be biased may be not be accepted for use—even if it is not biased. Scientists perceived as biased have lost their credibility, and policymakers will likely ignore any scientific information they provide (Rykiel 2001). The worst case is when management decisions are made based on biased or misleading information that unexpectedly and irretrievably damages the resource or result in undesirable consequences (Johnson and Gillingham 2004).

Like scientific information, expert judgments are most useful if they are calibrated by a measure of uncertainty, communicated intelligibly and meaningfully, and most importantly, if they are perceived as credible (Ellison 1996). The credibility of expert judgment is dependent on its transparency, repeatability, and defensibility, qualities affected in part by how expert judgment is elicited. Methods of eliciting expert judgment may be formal or informal. Formal methods for elicitation explicitly document information and sources, use consensus building, and demonstrate transparently logic paths and assumptions. One formal method of expert solicitation is the Delphi technique in which judgment is

solicited anonymously from an expert panel, summarized, and returned to the each expert for reconsideration (Crance 1987). The process is repeated until consensus is reached.

The Delphi technique is just one formal method to elicit and integrate expert opinion. Alternatives methods to the Delphi technique include one-shot group averages, group discussions, and the Nominal Group technique. One-shot group averages provide a single chance for expert panelists to provide their input before averaging the group's answers. Its advantage is speed. In general, one-shot group averages lack enough time for participants to give their most thoughtful input and do not allow participants to hear each other's ideas that could influence and help refine their own ideas. Group discussions between experts are unrestricted during a face-to-face meeting. They are administratively difficult to coordinate and expensive to bring all participants together. Group discussions are susceptible to group dynamics (e.g. dominant individuals control the decision process) and can obscure objective information (Clayton 1997). The Nominal Group Technique uses the Delphi process in a face-to-face setting without the anonymity of expert input (participants read their answers aloud to the group for feedback) (Delbecq et al. 1975). In addition to sharing the same cost and administrative problems as the basic group discussion method, the lack of anonymity may influence how individuals participate. The advantages of the Nominal Group technique are structured input and summarized feedback. Informal methods to elicit expert judgment have no formal rules for

how information is gathered or combined and may be as simple as asking a single expert a few casual questions.

Once elicited, expert judgment is applied to the decision making process. Like elicitation, these methods of decision making can also be informal or formal. Formal methods are defined as models that demonstrate more transparently how a specific conclusion is reached. As an example, decision support models are computer models that capture logical evaluation procedures for consistent application to a decision process (Gallo et al. 2005). They allow the user to observe how model parameters are related and where data synthesis occurs in the evaluation process. When discrepancies in model outputs occur, the causes can be determined. Informal methods (e.g. black box models) provide little ability judge the quality or validity of resulting assessments because the user cannot evaluate the inner workings of the model. Consequently, formal methods of acquiring and applying expert judgment are most credible in decision making.

Neither informal or formal methods for eliciting or applying expert judgment is inherently the best choice. Both methods have pros and cons and are suitable for different circumstances and situations. Essential considerations include time constraints, data availability, resources, complexity of goals, the number of experts, whether or not consensus is needed, and then subsequently, how to build consensus. Formal methods require more time, money, planning, technical models, explicit procedures, and depending on the problem, a large number of experts. Informal methods are time-efficient, have no constraints or

formal rules, and may be as simple making a few phone calls to a single expert for advice.

The purpose of this paper is to evaluate, through a case study, the utility of formal methods to both elicit and apply expert judgment to the salmon recovery. Using Oregon's Coastal Coho Salmon *Oncorhynchus kisutch* Evolutionarily Significant Unit (ESU) as a case study (Figure 1), the usefulness of a decision-support model to assess watershed condition is evaluated. We ask: do using formal elicitation and application methods add appreciable value to the assessment? To do this an expert panel was assembled and instructed to build a decision-support model for the Ecosystem Management Decision Support (EMDS) system designed specifically to assess the ecological condition of watersheds for coho salmon within the ESU. The purpose of the model is to provide a transparent, objective, expert-based tool for the comprehensive and consistent assessment of each of the 21 major basins in the ESU (Figure 1). Our interests were as much about the process of formally eliciting expert judgment as they were about the product- the coho decision-support model. The three objectives were to determine: (1) if eliciting expert judgment using a formal method (Delphi technique) added utility to the process; (2) if experts could agree on a model of watershed condition for coho within a realistic time frame; and (3) if the coho decision-support model could be built and function with existing data.
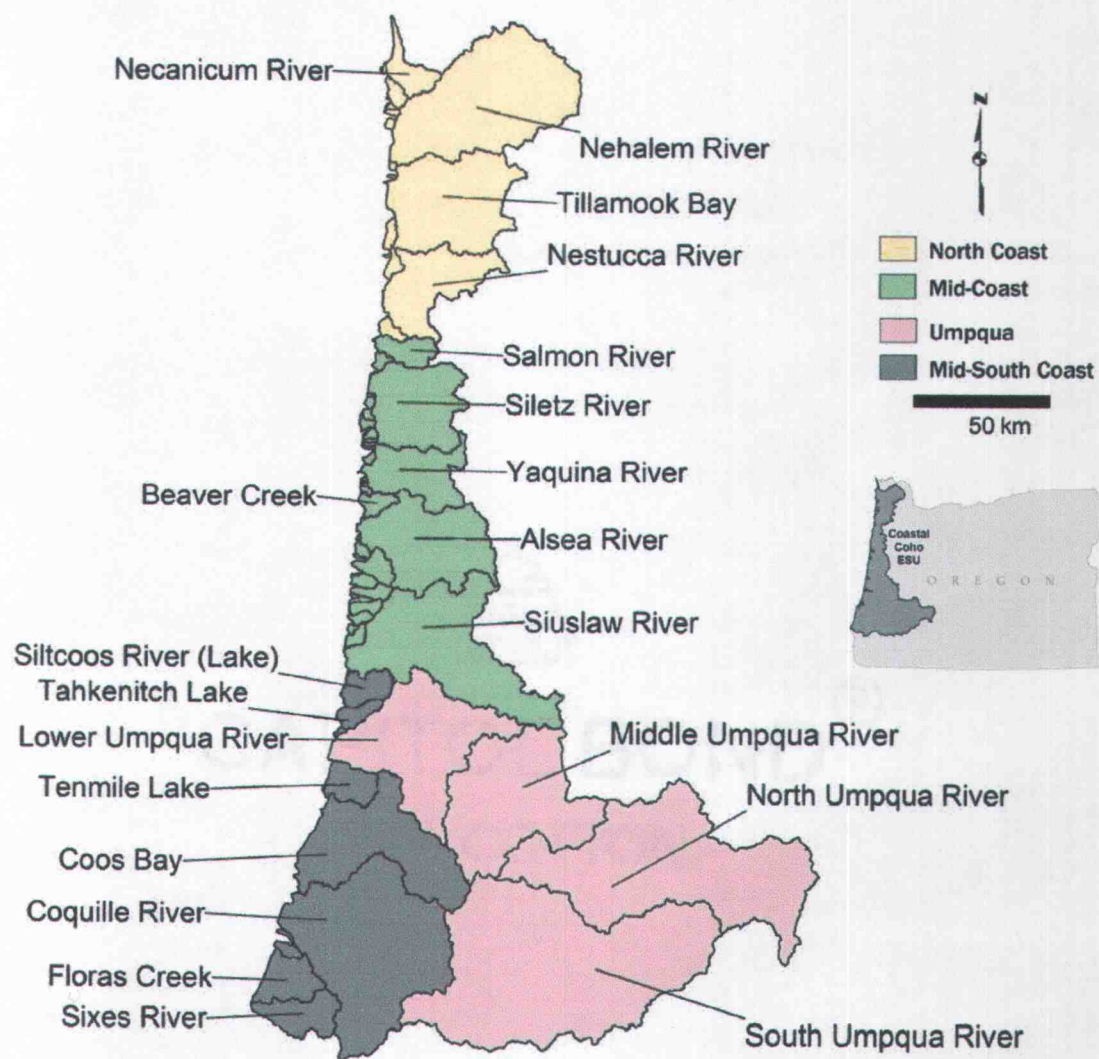
Figure 1. Map of the Oregon Coastal Coho ESU (Evolutionarily
Significant Unit). This map shows 3 spatial resolutions: (1) ESU. The
Oregon Coastal Coho ESU extends from the Columbia River south to Cape
Blanco; (2) Monitoring Area (colored areas). The ESU is divided into
4 distinct monitoring areas for data collection; and (3) Population.
The ESU contains 21 independent populations of coho, which correspond
to the major river or lake basins along the coast.

2. CASE STUDY

Challenges of Assessing Watershed Condition

Deciding if, where, and when to restore habitat to help recover salmon is one example of a wicked problem that is dependent in part on expert judgment. Habitat restoration is a controversial issue because of high costs and uncertain benefits to salmon recovery, disagreements over how and where funds are allocated, and potential for social dislocation (e.g. restricted property rights and land uses).

Watershed assessment is the first step in the process of habitat restoration and helps determine the recovery potential of watersheds. Assessment is a difficult task because the factors that comprise watershed condition are interrelated, with compounding and potentially counterintuitive influences on salmon. The ecological condition of a watershed is a function of interacting geomorphological surfaces, physical processes and biological communities further influenced by natural and human disturbances (Stanford and Ward 1992, Pess et al. 2002) (Figure 2).

Beyond the inherent complexity of watersheds, successful assessments of watershed condition must overcome many technical challenges (Reeves et al. 2004, Dai et al. 2004), including: (1) making consistent evaluations across watersheds with differing spatial extents; (2) aggregating multiple, diverse, and potentially

confusing variables; (3) characterizing and quantifying
relationships.
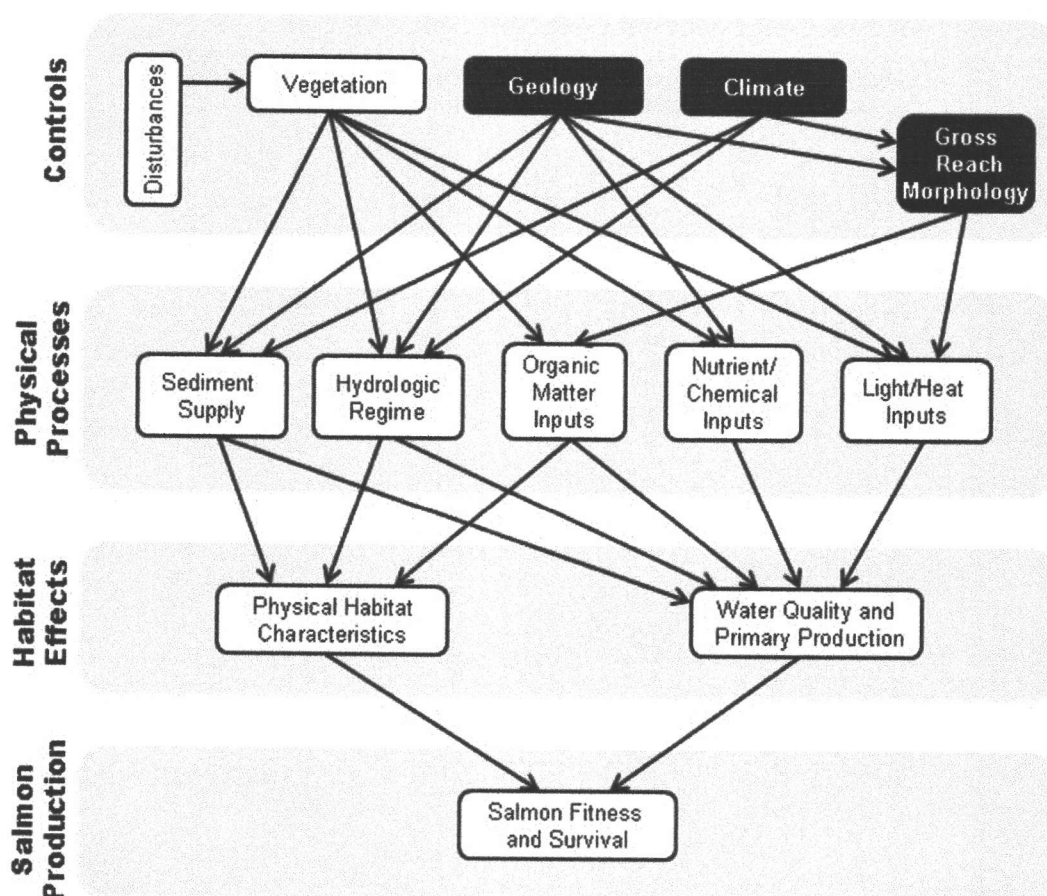
Figure 2. Relationships between watershed controls and physical
processes on habitat characteristics, and between habitat and salmon
fitness and survival. The black boxes indicate controls not affected
by anthropogenic disturbances. Adapted from Pess et al. (2003).

among processes and variables (e.g. in-stream condition variables to
upland processes); (4) combining the best available scientific data
with expert judgment objectively; and (5) communicating results that
are accurate, comprehensible, and relevant to diverse constituencies.

There is no universally accepted method for assessing watershed condition. Agencies and organizations generally chose watershed assessment methods for which they have sufficient existing data and that help answer specific questions relevant to their policy goals. Methods are often challenged by competing stakeholders and resource users.

The most popular scientific approach to ecological condition assessment relies heavily on statistical models. The advantages of using statistical models are empirical objectivity, rigor, and the ability to test a hypothesis with little attachment to policy (ISAB 2003). Reeves et al. (2004) contends that it is difficult to assess watershed conditions using traditional statistical methods because they are complex, require technical expertise, and their results can be confusing to decision-makers. Ellison (1996) points out that few decision-makers have the scientific training to interpret conclusions based on "technical jargon". Also, assessing watershed condition requires evaluating cumulative effects of many parameters. Generally, statistical assessments evaluate multiple parameters independently, but struggle to synthesize or combine them into an index (Reeves et al. 2004, Dai et al. 2004). In addition, the relationships among watershed parameters and their influences on watershed condition are not precisely understood, nor are they ever likely to be (Schmolt et al. 2001). Therefore, expressing these relationships credibly with statistical models is difficult and often impossible.

Ecosystem Management Decision Support (EMDS)

It is becoming more common for watershed assessments to be based largely on the judgments of expert biologists who arguably may be better able to assess complex and information-poor problems (Lee 2000). One assessment method that formally incorporates expert judgment with empirical data is knowledge-based decision-support models (DSM). A knowledge-based DSM is a method of documenting a formal, logical organization of information for evaluation and interpretation (Reeves et al 2004). It helps the user explicitly organize and evaluate large quantities of diverse data and synthesize these data into a single score based on user-defined rules. This allows the evaluation process to be applied consistently and transparently.

Ecosystem Management Decision Support (EMDS) system is a non-proprietary knowledge-based DSM developed cooperatively by the U.S. Forest Service and the U.S. Environmental Protection Agency. As a computer-modeling tool, EMDS integrates knowledge-based reasoning (NetWeaver Logic Engine) into a GIS (ArcView) environment for ecological landscape assessment (Dai et al. 2004). It is not a statistical or simulation model nor was it designed for prediction. Rather it is an indicative model able to infer the condition of a landscape based on the synthesis of data and model structure (Figure 3). The creators of EMDS (Reynolds et al. 2002) assert two basic reasons for using knowledge based reasoning for landscape assessments: (1) the components of the problem and their relations

are so inherently abstract that mathematical models are difficult or impossible to formulate; or (2) a mathematical model is possible in theory but current knowledge is lacking or too imprecise to create one.

EMDS allows the user to define watershed condition, select the parameters that characterize the watershed (physical and biological indicators), define their evaluation criteria using evaluation curves (Appendix 1 Figure 2), and determine the relations among all the parameters in an explicit conceptual diagram (the knowledge-based decision-support model) (Figure 3). Once populated with spatially explicit data the system evaluates and aggregates the data hierarchically based on the user defined rules to determine overall watershed condition. Model output comes in the form of tables, graphs, and color-coded maps displaying watershed condition scores (Appendix 1 Figure 3). One program in EMDS system can also rank the influence of individual parameters on the overall model. Reynolds and others explain the EMDS system (2000, 2002, 2003 and 2004). Detailed information is available on the EMDS website (http://www.institute.redlands .edu/emds/) and in Appendix 1.

EMDS has certain strengths, some of which are well documented, that make it useful for assessing the ecological condition of watersheds. It has an explicit and intuitive model structure that is
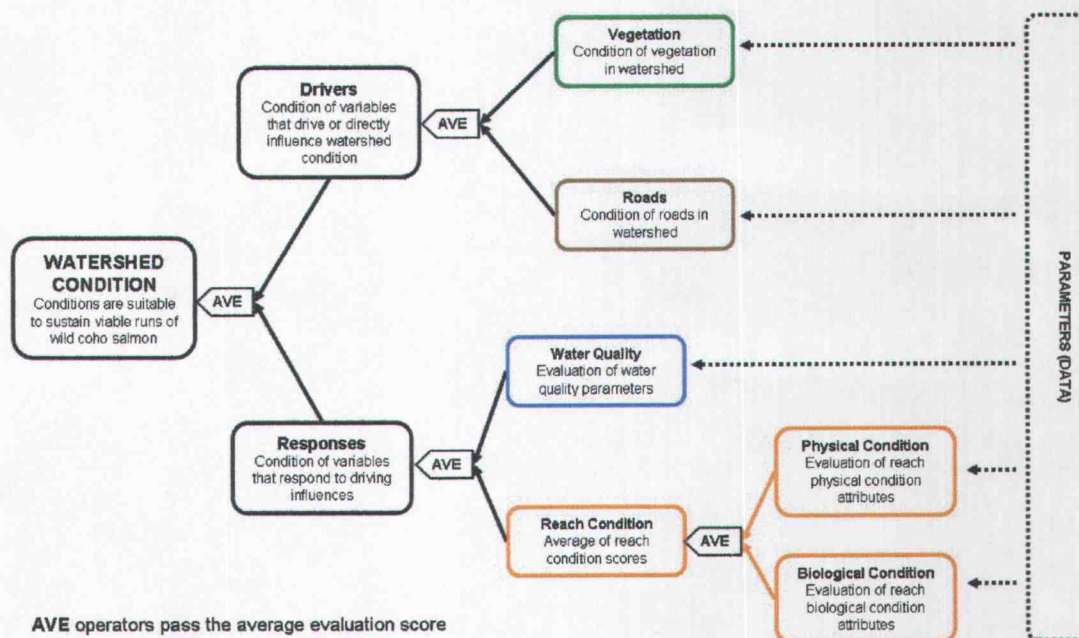
Figure 3. AREMP's knowledge-based decision-support model for Washington/Oregon Coast Range Province used as a template for the coho knowledge base. Modified from Gallo et al. (2005). Examining the model template from right to left show how individual parameters are aggregated hierarchically into categories until all are combined in an overall score of watershed condition. The general watershed parameter categories are arranged vertically in 4 colored branches. The top two are vegetation (green) and roads (brown), which are combined to form the watershed condition "drivers" category. All of the parameters in the drivers category directly influence watershed condition. The bottom two categories are water quality (blue) and reach condition (orange), which are combined to form the "responses" category. All the parameters in this category respond to the drivers. The reach condition score (orange) is the average condition score for all the reaches in the watershed. Technically this is an independent network, but it functions as part of the watershed condition knowledge base and therefore the two are combined in the same diagram for conceptual purposes. The reach condition score is an aggregate of biological and physical conditions. The AREMP template incorporates AVE operators at each junction (small boxes) where scores from antecedent are averaged. None of the nodes are weighted.

easy to manipulate and communicate (Dai 2004, Bleier et al. 2003, Reeves 2004, Gallo et al. 2005, Reynolds and Hessburg 2005). The EMDS map-based outputs of watershed evaluation scores are easy to

understand and communicate (Bleier et al. 2003, ISAB 2003). The model is able to combine empirical data from disparate sources (including spatially explicit data) with expert judgment (ISAB 2003, Jensen 2000). Any part of the model (e.g. parameters, fuzzy curves, network structure) can be easily modified and updated as new knowledge and information becomes available (NCWAP 2002, Reeves 2004, Dai et al. 2004, Gallo et al. 2005). The ability of the modeling software to "turn off" nodes allows EMDS to function with incomplete information (Jensen et al. 2000, Pess et al. 2003). And, its ability to make assessments as multiple spatial scales allows inclusion of multiple agency jurisdictions and land ownerships (Pess et al. 2003, Dai et al. 2004, Gallo et al. 2005).

EMDS also has weaknesses and concerns that limit its use: (1) it has weaker basis for scientific prediction than traditional mathematical models validated with empirical data (ISAB 2003); (2) results of the model are qualitative and only indicate quality of watershed condition (Dai et al. 2004); and (3) to be most useful decision support models in general require communication between analysts and decision makers about risk, probability, and uncertainty which is difficult (ISAB 2003).

The use of EMDS for assessing ecological condition is recent. Several studies have used it to assess watershed condition (Jensen et al. 2000, Reynolds et al. 2000, Reynolds and Reeves 2003, Pess et al. 2003, Dai et al. 2004, Reynolds and Reeves 2004, Reynolds and Hessburg 2005). In general these papers unveil EMDS as a new tool,

describe its abilities, and provide small case studies or examples of its use to assess watershed condition. Reynolds and Reeves (2003 and 2004) also developed prototype models to evaluate habitat suitability for salmon but were only used to demonstrate the abilities of EMDS.

Examples where EMDS has been applied to real ecological problems are limited. Three interagency programs have adopted EMDS as a tool to drive landscape assessment programs. The Rogue Basin Restoration Technical Core Team (RBRTT) used EMDS to assess watershed condition and identify restoration priorities in the Applegate River sub-basin in Southwestern Oregon (RBRTCT 2004). California's North Coast Watershed Program (NCWP) is using EMDS as an assessment tool in a larger project to improve information and management of watershed and fisheries conditions (NCWAP 2002). EMDS was selected specifically to help evaluate and synthesize information on watershed and stream conditions important to salmon (Bleier et al. 2003). NCWP experts are still in the stages of refining the knowledge base for their model.

The multi-federal agency Aquatic and Riparian Effectiveness Monitoring Program (AREMP) is the largest ongoing effort using EMDS. AREMP is characterizing the ecological condition of watersheds and aquatic ecosystems for the area managed under the Northwest Forest Plan (Reeves et al. 2004). The program's goal is to report on the Northwest Forest Plan's effectiveness across the region, to track trends in watershed condition over time, and to provide information for determining causal relationships to help explain those trends.

ARMEP's models use monitoring data to estimate watershed condition by aggregating upslope, riparian, and in-channel indicators (Figure 3). Prior to using EMDS, the U.S. Forest Service and the Bureau of Land Management evaluated watershed variables independently and therefore, could not easily determine ecosystem or watershed condition as a whole (Reeves et al. 2004). After review of other methods, EMDS was chosen because of its ability to deal with uncertainty, incorporate expert opinion, and guide monitoring efforts. It has been useful to decision-makers in helping to identify changes in watershed condition in the last 10 years.

Oregon Coastal Coho Salmon ESU

The Oregon Coastal Coho Salmon Evolutionary Significant Unit (ESU) is well-suited for testing the usefulness of EMDS to evaluate watershed condition for salmon recovery decisions. The ESU includes all naturally spawned populations of coho salmon in Oregon coastal streams south of the Columbia River and north of Cape Blanco (Figure 1). An ESU is defined legally as a distinctive group of Pacific salmon in terms of their evolution and reproductive isolation from other conspecific populations. The ESU contains 21 independent populations of coho salmon, which correspond to the major river or lake basins along the coast. Independent populations are those thought to occur in basins with sufficient habitat in the past to have persisted through several hundred years of normal variations in marine and fresh water conditions (Nicholas et al. 2005).

Since 1997, The Oregon Coastal Coho ESU has been the focus of a collaborative conservation effort developed under a planning framework called the Oregon Plan for Salmon and Watersheds (Oregon Plan). The Oregon Plan, administered by the Oregon Watershed Enhancement Board (OWEB), brings together various governmental entities, interest groups, and stakeholders to implement salmon restoration and conservation strategies.

In the spring of 2005, OWEB completed a formal assessment of the Oregon Coastal Coho ESU (hereafter referred to as the Coho Assessment) to evaluate Oregon Plan conservation efforts targeting the ESU and also to help inform the federal government's ESA listing decision. Based in part on the conclusions of the assessment, NOAA Fisheries decided to drop its proposal to re-list the ESU as threatened in January of 2006. Whether listed under the ESA or not, wild coho salmon populations in the ESU are well below historical levels and so are of continuing policy concern (Meengs and Lackey 2005). Multiple stakeholders with largely mutually exclusive policy goals continue to disagree over the listing status, the credibility of science that support it, and the thoroughness of Oregon's Coho Assessment in particular.[3] In the midst of the controversy, Oregon has an ongoing, long-term commitment to recover and conserve the ESU. The recent Coho Assessment is a foundation for future conservation

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[3] Stakeholder comments about the Coho Assessment can be viewed on the following webpage:
ftp://nrimp.dfw.state.or.us/oregonplan/reports/Comments/

activities including recovery planning, monitoring, and more effective investment of restoration funding.

The Coho Assessment examined threats to the viability of the ESU including: marine habitat, harvest, hatchery impacts, stream complexity, fish passage, water quality, water quantity, and other factors. Three spatial resolutions were evaluated: the entire ESU, the monitoring area, and the area corresponding to independent populations (Figure 1). OWEB chose to focus the evaluations at the population level because it is at this level that restoration and management actions are targeted to improve the viability of the ESU as a whole (Nicholas et al. 2005). The Coho Assessment required gathering a large, diverse suite of the best available scientific data and information from state and federal natural resource agencies [U.S. Forest Service (USFS), Bureau of Land Management (BLM), Oregon Department of Environmental Quality (ODEQ), Oregon Department of Fish & Wildlife (ODFW), Oregon Department of Forestry (ODF)], private entities, and watershed councils. This was the first attempt to pull together all the monitoring data collected for the ESU since the start of the Oregon Plan in 1997. Oregon state agencies alone spent a total of $15.9 million on coho related monitoring from 1997 to 2003, not including monitoring by watershed councils, federal agencies, or private landowners (OWEB 2005).

Using this information and expert judgment in multiple group work sessions the Coho Assessment team identified the primary and secondary risk factors for each of the 21 independent populations.

This process, lasting over a year, concluded that stream complexity was the most common primary risk factor (13 of 21 populations) and water quality was the most common secondary risk factor (15 of 21 populations) (Nicholas et al. 2005). How these conclusions were reached is not transparent and may not be repeatable because the informal process of building consensus of opinions is not explicitly described in the Coho Assessment.

Considering these conclusions, the large suite of available data, the reliance on expert judgment, and the goal of managing the ESU with a watershed-scale approach (GNRO 2005), a formal assessment of watershed condition for each of the 21 populations could be valuable for the management and recovery of the ESU. While watershed assessments have been completed for over 97% of the ESU (Nicholas et al. 2005), they have been completed by different organizations, using various methods, at different scales, with different information and are therefore difficult to compare.

We chose the Coastal Coho ESU case study because there is a need and opportunity for an alternative watershed assessment method that is transparent and repeatable, systematic, comparable, comprehensive, and easy to understand. EMDS is one tool that could be used to assess the coarse-scale status and trends of condition for the 21 watersheds (corresponding to the independent populations), thereby providing useful information for recovery activities. The EMDS system could also provide an alternative method for determining what specific factors are limiting to coho and thus provide a

starting point for estimating the recovery potential for each watershed.

METHODS

An expert panel was assembled to build a knowledge-based DSM for the EMDS system to assess the ecological condition of watersheds for coho salmon within the Coastal Coho ESU (hereafter coho decision-support model). Ideal panel size varies in the literature from 5-25 experts (Clayton 1997, Crance 1987). Potential experts were chosen subjectively based on three criteria: (1) high familiarity with coho salmon biology and ecology on the Oregon coast; (2) well established in their careers; and (3) credible reputations for producing and contributing sound science. Panelists were selected that were perceived to not have a stake in the outcome of the project because the model had the potential to influence future coho salmon management decisions. We decided to exclude potential expert panelists who had participated in the recent Coho Assessment. With their intimate knowledge of the assessment's results and controversies, we thought that they could potentially influence the process and results. A total of 16 experts were identified and solicited to participate but only 6 volunteered. Professionally, the experts on the panel to build the coho decision-support model represented state and federal agencies, non-profit organizations, and private consulting firms specializing in coho salmon related, research and management. All participants were ensured complete confidentiality.

One panelist had participated in AREMP's process to build decision-support models to evaluate watersheds in the region of the Northwest Forest Plan. Although this expert had the advantage of previous experience with decisions-support models, the expert was allowed to participate because so few others volunteered.

Expert judgment was elicited from the panelists using the Delphi technique (Crance 1987). Delphi is a formal, structured process for soliciting and aggregating individual judgments about a specific topic into group consensus using questionnaires. The Delphi concept is based on the premises that opinions of experts are justified as inputs to decision-making where absolute answers are unknown; and a consensus of experts will provide a more accurate response to a question than a single expert (Crance 1987). The Delphi process occurs via correspondence eliminating the need for participants to travel and coordinate schedules. This also facilitates the requirement that panel members participate anonymously. Anonymity reduces disruptive social-emotional behaviors that diminish focus on task-oriented activities and compromise panel members' responses (e.g. pressure to conform) (Clayton 1997).

The Delphi exercise to create the coho decision-support model began with submitting a questionnaire to each of the expert panelists (Appendix 2). Each panelist completed the questionnaire by answering the questions, providing comments, and rating the confidence of their answers. Throughout the exercise the panelists were asked to submit

written comments on their frustrations, concerns, and suggestions about the model. When the questionnaires were returned, the moderator summarized the comments, tabulated the answers and submitted a follow-up questionnaire including the same set of questions, a summary of the feedback from the previous round, and an updated model diagram. The panelists then had the opportunity to re-answer the questions after reviewing all of the other participants' anonymous comments. All suggested changes and additions to the model had to be approved by the majority of the expert panelists.

Before the Delphi process began each panelist was provided with: (1) the panel's objective to create an EMDS model to assess the ecological condition of watersheds for coho salmon within the Coastal Coho ESU; (2) the definition of watershed condition[4]; (3) background EMDS information (Appendix 2); and (4) AREMP's skeleton knowledge base for evaluating the ecological condition of Pacific Northwest coastal watersheds as a template (Figure 3). In an anticipated effort to reduce the time to teach the experts about decision-support models, AREMP's model was provided as an example of knowledge base

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[4] For the coho decision-support model a watershed in "good" condition means that it has the ability to provide high-quality habitat for coho salmon. In other words, watershed conditions are suitable to sustain viable runs of wild coho salmon; where "viable" signifies that coho salmon populations generally demonstrate sufficient abundance, productivity, distribution, and diversity to be sustained under the current conditions (Nicholas et al. 2005). Therefore, watershed processes (represented by parameters) are intact, and functioning adequately to provide and maintain habitat for coho salmon and other native species that compose the ecosystem. The system must be able to recover to desired conditions when disturbed by either natural events or anthropogenic activities (Reeves et al. 2004).

structure and logic. AREMP's model is the most comprehensive knowledge-based decision-support model for watershed assessment and has the longest record of use (Gallo et al. 2005). Panelists were also provided with a list of all the relevant watershed parameters that were used in some form in Oregon's Coho Assessment, representing data from state and federal agencies used to characterize instream, riparian, upland and biological conditions (Appendix 2 Table 1).

The questionnaire charged the panelists with coming to agreement on what parameters should be included in the model, the structure of the model, and how the model should operate based on available data, literature, and their own knowledge and opinions. The first question was selecting parameters to use in the coho decision-support model. Parameters were required to meet the following criteria: (1) they must act as surrogates or indicators of watershed processes that influence coho; (2) data for the parameters must currently exist (from field surveys or GIS) and be available to the public; and (3) data for the parameters must exist for the entire region encompassed by the coastal coho ESU. Once the parameters were selected, the moderator assessed their ability to meet the criteria and then constructed their evaluation curves (Appendix 1 Figure 2) using existing data and literature. The second question was to develop the coho decision-support model structure. The third question was to decide how to aggregate parameters scores at each junction in the model. The final question was to weight any parameters deemed necessary.

As the moderator, I was in charge of all administrative tasks including corresponding with the panelists (e.g. answering questions and enforcing deadlines), creating questionnaires, and processing panelist responses.

RESULTS

Delphi Process

The Delphi process to build the coho decision-support model lasted 8 months and included 4 rounds of questionnaires. Even though the questionnaire instructed experts to respond within 10 days, the questionnaires were returned between 3 days and 7 weeks. The rate at which questionnaires were summarized and returned in each subsequent round was effectively controlled by the slowest participant. Crance (1987) estimated that amount of time between mailing two consecutive questionnaires in a Delphi exercise is 4-6 weeks. In this project, the range was 4-8 weeks. In two instances a questionnaire from a single participant was not returned and no explanation was given when prompted requiring the process to continue on to the next round without input from that panelist.

Two members on the expert panel dropped out at different times during the process due to other obligations and priorities. After soliciting various other potential expert panelists, only one vacancy was filled for the last round in the process. There was no way to measure the influence of the new expert panelist, but it was clear

from the quality and thoroughness of the comments that the panelists was very engaged in the process and might have influenced the model more if having participated from the beginning.

The amount and quality of feedback in written responses varied considerably among participants. Some participants wrote extensively while others replied with single word answers. Certain participants consistently used the diagram of the model to draw their ideas and make suggestions with pictures, whereas others relied exclusively on written input. Overall, amount of information returned from 4 of the 6 respondents decreased as the exercise progressed. This could have resulted from a loss of interest or as result of fatigue from the repetitive nature of the questionnaires and the apparent slow progress in reaching consensus. In the later rounds of questioning some experts gave no rationale to support some of their answers or input. When asked to clarify and support those judgments, they wrote "See my response in the previous questionnaire," instead of describing their reasoning again for the group to help improve their stance.

Coho Decision-Support Model

The resulting coho decision-sport model (Figure 4) is the outcome of the Delphi process. It presumably represents the best way of logically organizing the selected parameters by this panel for evaluating the ecological condition of watersheds relative to their ability to sustain viable runs of wild coho salmon. The average of
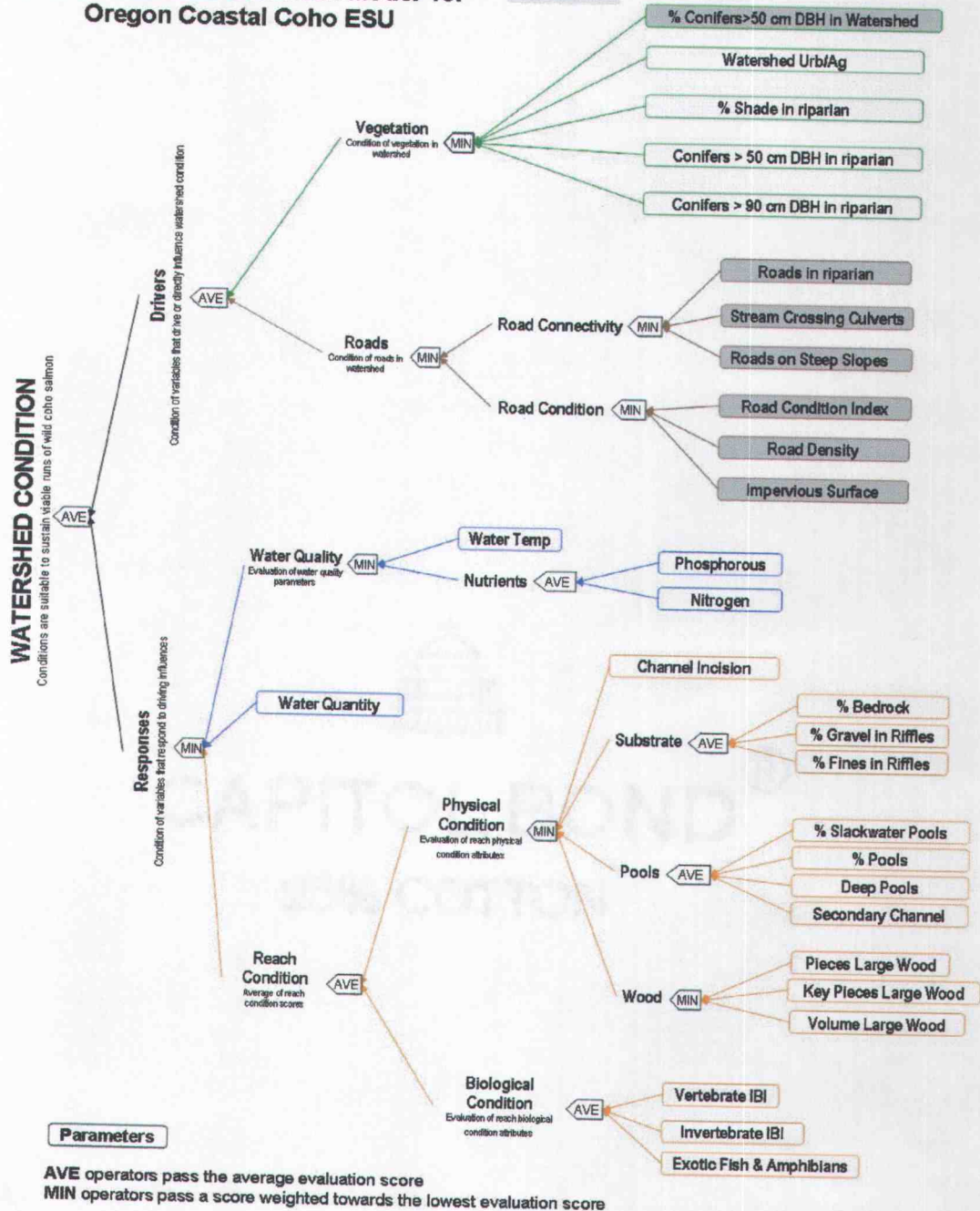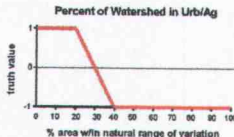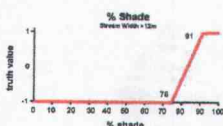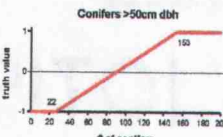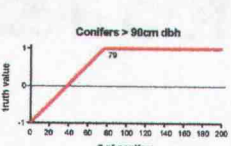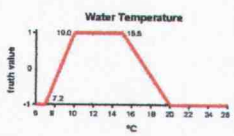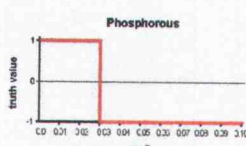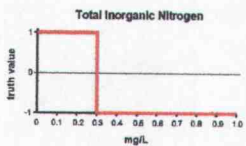
Figure 4. Diagram depicting the coho decision-support model for the EMDS system built by experts in a Delphi process to evaluate the ecological condition of watersheds for the Oregon Coastal Coho ESU. Parameters are enclosed in boxes. Arrows indicate direction of aggregation.

the panelists' certainty about the coho decision-support model structure was moderate. Like the AREMP template (Figure 3), watershed condition is an average of the evaluation scores of the Drivers and Responses nodes. The Drivers node is an average of the Vegetation and Roads nodes. The parameters in the Vegetation category include both riparian and upland indicators. The Roads Condition parameters are further divided into Road Connectivity and Road Condition categories. The Response node evaluates to the lowest score of the Water Quality, Water Quantity, and Reach Condition nodes. Water Quality is divided into Temperature and Nutrient categories. Like the AREMP model, the Reach Condition network (orange) feeds directly into the Watershed Condition knowledge base. The Reach Condition node is an average of Physical Condition and Biological Condition. Physical Condition is divided into 4 categories: Channel Incision, Substrate, Pools, and Wood. All of the terminal nodes in the knowledge base (in boxes) are parameters where raw data enters the model.

A list of all the parameters in the coho knowledge base, their definitions, evaluation curves, corresponding evaluation criteria, data sources, and rationale for use are shown (Table 1). All of the parameters in the knowledge base (except the road parameters) were previously used in Oregon's Coho Assessment. They belong to the suite of field survey and GIS monitoring data collected and managed by multiple state and federal agencies both before and after the implementation of the Oregon Plan in 1997. Evaluation curves for each

Table 1. Coho decision-support model parameters to evaluate the ecological condition of watersheds for the Oregon Coastal Coho ESU. Parameter definitions, evaluation curves, corresponding evaluation criteria, data sources and rationale are shown.

Parameter and definition	Evaluation curve	Evaluation Criteria and source	Data Source and Rationale
Vegetation			
Watershed in Urb/Arg Percent of watershed area in urban or agricultural land use. Metric: %		Suitable < 20%, unsuitable > 40%, (AREMP)	ODF using USGS data Indicator of sediment input and runoff potential affecting flow regime.
% Shade in Riparian Percent of 180 degree sky that is shaded by trees or other topographic features. Metric: %		Unsuitable < 76%, suitable > 91 (ODFW*)	ODFW Rationale: Influences stream temperature, and is easily influenced by human activity.
Conifers > 50cm dbh in Riparian The number of conifers > 50cm dbh within 30 m of both sides of the river per 305 m of primary stream length. Metic: #		Unsuitable < 22, suitable >153 (ODFW*)	ODFW Rationale: Index of potential future sources of large wood recruitment, and highly responsive to management.
Conifers > 90cm dbh in Riparian The number of conifers > 90 cm dbh within 30 m of both sides of the river per 305 m of primary stream length. Metic: #		Unsuitable = 0, suitable > 79. (ODFW*)	ODFW Rationale: Index of potential future sources of large wood recruitment, highly responsive to management.
Water Quality			
Water Temperature Evaluation of the 7-day average maximum water temperature. Metric: °C		Poor < 7.2°C or >20°C, good is 10 to 15.5°C. This criteria is from California's North Coast Watershed Assessment Program (NCWAP) and was constructed for coho and Chinook.	ODEQ Rational: Temperature affects fish distribution, fitness and physiological processes.
Phosphorous Evaluation of total phosphorous concentration (mg/L) in the watershed. Metric: mg/L		Poor > 0.03 mg/L, 25th percentile of reference sites. (ODEQ)	ODEQ Rationale: essential nutrient in aquatic ecosystems.
Nitrogen Evaluation of the total inorganic nitrogen concentration in the watershed. Metric: mg/L		Poor > 0.3 mg/L 25th percentile of reference sites. (ODEQ)	ODEQ Rationale: essential nutrient in aquatic ecosystems.
Water Quantity	No metric decided by expert panel	Metric undecided by expert panel	OWRD

Rational: coho salmon need adequate stream flow to survive

Physical Condition

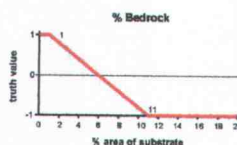|			
Channel Incision	Undecided. Expert panel did not agree on metric because data was not found until after Delphi process ended.	Undecided. Expert panel did not agree on metric because data was not found until after Delphi process ended.	ODFW Rational: Indicator of stream connectivity to flood plane, important habitat for juvenile coho salmon.
% Bedrock Visual estimate of stream substrate composed of solid bedrock. Metric: %	% Bedrock (truth value vs % area of substrate)	Poor >11%, Good <1%. (ODFW*)	ODFW Rational: Measure of lack of substrate complexity that is potential factor for decline; not suitable spawning habitat.
% Gravel in Riffles Visual estimate of stream substrate composed of 2-64mm diameter particle in riffles. Metric: %	% Gravel in Riffles (truth value vs % area of substrate)	Undesirable <26, Desirable >54 (ODFW*)	ODFW Rational: Measure of spawning habitat.
% Fines in Riffles Visual estimate of substrate composed of <2 mm diameter in riffles. Metric: %	% Fine Sediment in Riffles (truth value vs % area)	Unsuitable >22, suitable <8, (ODFW*)	ODFW Rational: Can influence the survival of eggs and alevins in the substrate by reducing oxygenation or physically preventing emergence.
% Slackwater Pools % of primary channel area represented by slackwater pool habitat (beaver pond, backwater, alcoves, and isolated pools). Metric: % area	% Slackwater Pools (truth value vs % of channel area)	Undesirable <0, Desirable >7. (ODFW*)	ODFW Rational: Measure of channel morphology, important low velocity habitat for juveniles. Note: Low occurrence of this variable leads to high variability in estimate
% Pools % of primary channel area. represented by pool habitat. Metric: % area	% Pools (truth value vs % of total channel area)	Undesirable <19, Desirable >45 (ODFW*)	ODFW Rational: Measure of channel morphology, important low velocity habitat for juveniles.
Deep Pools Pools > 1 m deep per km of primary channel. Metric: # / km	Deep Pools / km (truth value vs # of pools)	Undesirable =0, Desirable >4 (ODFW*)	ODFW Rational: Measure of channel morphology, important low velocity habitat for juveniles.
Secondary Channel % total channel area represented by secondary channels. Metric: % area	% Secondary Channel (truth value vs % of total channel area)	Undesirable <0.8, Desirable >5.3 (ODFW*)	ODFW Rational: Measure of channel complexity, important low velocity habitat for juveniles. Note: High variability in data
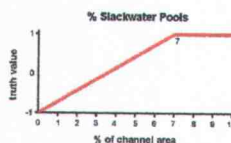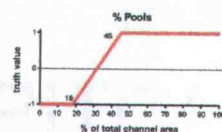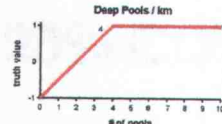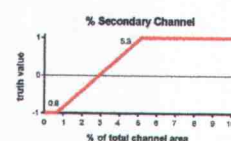
		for this variable results in low statistical power
Pieces Large Wood # of pieces of wood > 0.15 m diameter x 3 m length per 100 m primary stream length. Metric: # / 100 m	Pieces Large Wood / 100m truth value # of pieces	Undesirable <8, Desirable >21 (ODFW*) ODFW Rational: Measure of instream roughness, and a critical component of salmon habitat.
Volume Large Wood Volume of wood > 0.15 m x 3 m length per 100 meters primary stream length. Metric: m³ / 100 m	Large Wood Volume truth value m³ / 100 meters	Undesirable < 17, Desirable >58. (ODFW*) ODFW Rational: Measure of instream roughness, and a critical component of salmon habitat.

Biological Condition

Vertebrate IBI An index of biotic condition based on species diversity that was created for coldwater streams in Western Oregon and Washington. Metric: index score 1-100.	Vertebrate Community Score truth value Index Score	Poor < 50, 25th percentile of reference sites (ODEQ standard) ODEQ Rational: Indicator of biological stream condition.
Macroinvertebrate River Invertebrate Predication and Classification System, or RIVPACS. Metric: Uses the observed over expected (O/E) score. Index score 0-1.0 EPT.	Invertebrate Community Score truth value Index Score	Poor , 0.9, 25th percentile of reference sites, (ODEQ standard) ODEQ Rational: Indicator of biological stream condition.
Exotic Fish & Amphibians An index of biotic condition based on species diversity. Metric: Presence/Absence	Exotic Fish and Amphibians truth value Presence / Absence	Absence in fully suitable, Presence is fully unsuitable (ODEQ standard) ODEQ Rational: Indicator of stream condition, community integrity, and competition.

* Based on quartiles derived from reference data (optimum OR Plan and Basin reaches within the distribution of coho salmon-land use, riparian vegetation, <5% gradient). Source ODFW, unpublished data.

of these parameters were constructed using available information from

ODFW and ODEQ[5] where benchmarks had been created to evaluate data for

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[5] ODEQ created benchmarks for water quality conditions based on water quality standards (ODEQ 2005). For the parameters without established standards evaluation criteria were made at the 25th percentile of the distribution of data from reference sites within the ESU (ODEQ 2005). Similarly, ODFW used quartiles from reference data within the ESU to establish evaluation criteria for instream and vegetation parameters (ODFW 2005). The benefit of constructing evaluation curves from

the Coho Assessment (Table 1). These benchmarks are evaluation

criteria used to differentiate between suitable and unsuitable

condition and translate directly into evaluation curves. Where

evaluation criteria were either unavailable or insufficient,

alternative sources were used to build evaluation curves.[6]

The remaining parameters in the coho knowledge base that are shaded

(Figure 4) received strong unanimous support from the expert

panelists to be included in the model because of their important

contribution to the model as a whole, but failed to meet all 3 of the

criteria for inclusion. Their respective reasons for not meeting the

criteria are indicated (Table 2). These parameters are included in

the decision-support model to indicate data gaps and ideally to

suggest future monitoring needs. No evaluation criteria are given for

the road parameters in Table 1. The parameters Incision and Water

Quantity both met the criteria for inclusion but the panel couldn't

agree on metrics or evaluation criteria. The expert panel agreed that

a Lake parameter should be included in the model but did not agree on

its definition, metric, or placement in the knowledge base.

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reference data rather than literature or expert judgment is that they
are specific to the ESU.
[6] The Water Temperature evaluation curve was taken from California's
North Coast Watershed Assessment Program (NCWP 2002) because it was
created specifically for coho, whereas ODEQ's temperature benchmark
was a more general standard. Evaluation curve criteria for the
parameter "Percent of Watershed in Urban/Agricultural Land" came from
AREMP because no other exists. From a review of published empirical
studies, the Pew Oceans Commission determined evaluation criteria for
"Percent Impervious Surface" and suggests a formula for determining
the percent of developed land that can be categorized at impermeable
(Beach 2002).

Table 2. Parameters that failed at least 1 of the 3 criteria to be included in the model: (1) They must act as surrogates or indicators of watershed processes that influence coho; (2) Data for the parameters much currently exist (in data bases or GIS layers) and be available to the public; (3) Data for the parameters must exist for the entire region encompassed by the coastal coho ESU.

Parameter and definition	Cause of exclusion from model
Vegetation	
% Large Conifers in Watershed	Data are proprietary (Oregon Forest Industries Council) and not in the public domain (Dent et al. 2005a).
Roads	
Roads in Riparian	No comprehensive GIS data available. BLM has a GIS layer (Ground Transportation Roads and Trails that could be used but would require significant GIS analysis and validation.
Stream Crossing Culverts	No comprehensive GIS data available. BLM has a GIS layer (Ground Transportation Roads and Trails that could be used but would require significant GIS analysis and validation.
Roads on Steep Slopes	No comprehensive GIS data available. BLM has a GIS layer (Ground Transportation Roads and Trails that could be used but would require significant GIS analysis and validation.
Road Condition Index	Oregon Department Forestry only has data available for 2 watersheds.
Road Density	No comprehensive GIS data available. BLM has a GIS layer (Ground Transportation Roads and Trails that could be used but would require significant GIS analysis and validation.
Impervious Surface	No comprehensive GIS data available. Significant GIS analysis and validation required.

After 4 rounds of questionnaires the following parameters were still being debated as to whether or not they should be included in the model: Percent Public Land in Watershed, 303d Listing, High Intrinsic Potential (HIP), Geology, Gradient, Morphology, and Bedrock Substrate.

The aggregation functions (Appendix 1) that determine how nodes are combined and passed on to subsequent nodes are shown at each junction in arrow shaped boxes (Figure 4). Unlike the AREMP template

that used only AVE operators the expert panelists chose to use MIN

operators for aggregating scores to following categories: Vegetation,

Roads, Road Connectivity, Road Condition, Water Quality, Responses,

Physical Condition and Wood. The MIN operator passes on the minimum

scores from those nodes being aggregated. Although consensus was

achieved for operator choice throughout the model, only 1 of the

expert panelists expressed total confidence in their choices.

Individual panelists expressed moderate to high uncertainty regarding

the selection of their own aggregation functions.

The expert panel chose not to weight any of the parameters in

the model. No one felt comfortable making explicit recommendations

without being able to manipulate the complete computer model because

of uncertainty about how the model would respond. Instead the panel

agreed on 3 parameters that should be weighted in the final model

based on their expert judgment and relevant literature (Reeves et al.

1989, Nickelson et al. 1992a, Nickelson et al. 1992b, Sharma and

Hilborn 2001, and Pess et al. 2002). These are: (1) Temperature; (2)

Pools (specifically Secondary Channels and Slackwater Pools); and (3)

the Wood category.

DISCUSSION

Delphi Process

Although the Delphi technique helped achieve the goal of

creating the coho decision-support model, whether it added

appreciable value to the outcome requires analyzing some of the difficulties of the process and concerns of its use.

The Delphi technique was selected for this case study primarily because bringing experts together from all over the Pacific Northwest would have been costly and logistically challenging. Administering the Delphi process via mail allowed experts to participate from distant locations from southern Oregon to northern Washington. This logistical benefit was also one of the Delphi technique's greatest drawbacks in that it slowed the process. It took 4 questionnaires and over 8 months to create the coho decision-support model. Crance (1987) found that generally 4 questionnaires are submitted before the process is complete. AREMP's preliminary EMDS knowledge base was built by experts over a 3-day group work session (Gallo, personal communication).

The largest obstacle in establishing parameter weights and choosing aggregation functions was that experts didn't have access to a functional computer model. This limited experts' abilities to make recommendations and offer suggestions. A group work session with computers, EMDS software, a draft model, and an EMDS expert could have reduced these difficulties and the resulting uncertainty but would have greatly increased the cost.

The Delphi technique is not well suited to building consensus on such complex topics as knowledge-based decision-support model structure. Highly complex subjects and open-ended questions can lead

to problems with transferring and quantifying feedback (Rowe and Wright 1999). After reviewing a cross section of published Delphi studies, Rowe and Wright (1999) determined that successful Delphi processes consist of questions that elicit numerical estimates about a topic. Quantitative feedback (e.g., averages, estimates, and probabilities) allows statistical aggregation of responses. Rowe and Wright (199) concluded that more study is needed to define appropriate topics and questions for the Delphi technique.

Creating the coho decision-support model structure required open-ended questioning. The model network contains a large quantity of information including parameters, rules for combining them, inter-parameter relationships, and weights. Dozens of ways are possible to organize the large number of parameters. While each expert may have a similar understanding of watershed condition indicators and ecological processes, each conceives watershed condition in their own unique mental picture. This mental picture is difficult to clarify and articulate. Suggesting dramatic changes to the model structure was challenging to rationalize and communicate to other expert panelists. When changes in model structure were suggested that differed substantially from the AREMP model, they were difficult for the moderator to understand (e.g., due to little explanation or rationale) and a challenge to add to the subsequent questionnaire in a way that would elicit a useful response. In each case where these changes were proffered they were unanimously rejected. This may have indicated poor communication in the Delphi process or uncertainty with straying from the established AREMP model structure. Making

large changes in the model structure would have required more questionnaires in the Delphi process because of the slow transfer of information relative to a group setting. Large changes in model structure could have been made more effectively in a group setting where the model structure could be drawn and edited more quickly.

Dai et al. (2004) reminds us of the fact that it is the experts that ultimately create the model in any expert-based modeling exercise. Therefore in theory, a different expert panel with a different number of panelists would have created a different model. Rowe and Wright (1996) found that more accurate experts changed their answers less over rounds in the Delphi process than those who were initially less accurate or less "expert". This may affect the outcome of a Delphi process and highlights the importance of the expert selection process.

The moderator has a certain amount of leverage, control and influence in the Delphi Process. Most of the literature focuses on the objective role of the expert panelists but the potential of the moderator to influence the process is seldom addressed. For example, when summarizing information from responses to present in the following questionnaire, the moderator had to be selective about what information would be most relevant and useful and what information would be distracting. Sorting through these comments cost more administrative time. Clayton (1997) points out that one of the values of the Delphi technique is being able to eliminate irrelevant information from the feedback process before it spawns time-consuming

tangents that are common in group discussions. This ability to provide controlled feedback has the potential to be abused. A biased moderator or even one under a time deadline could direct the outcome either intentionally or unintentionally. Therefore credibility may be just as important for the moderator as it is for the expert panelists.

One common problem in group decision-making that the Delphi technique attempts to remedy is the undue influence of dominant individuals. Dominant participants through their language and social behavior can control and direct the outcome of group decision making exercises in face-to-face settings. In some instances, experts that expressed dominant and confident ideas initially deferred to others later in the process. This occurred in later rounds of the exercise after multiple attempts to weight certain model parameters. After two rounds of apparently confident input one panelist wrote: "I defer to the others who might have more expertise in this specific area." As a consequence, those experts whose opinions endured, won out in the end.

The overall quality of the responses in a Delphi exercise is influenced by the interest and commitment of the expert panelists (Delbecq et al. 1975, Crance 1987, and Clayton 1997). Making the questionnaire a priority over other professional and personal obligations requires high motivation since other people are not present (Crance 1987). This may reduce a panel member's efforts to consider thoroughly and respond completely to all the elements of the

questionnaire and influence the final outcome (Clayton 1997). It is important to note that all panelists were volunteers. Had they been paid or required by their employers to participate, the detail and timeliness of their responses may have differed.

Imprecise communication impeded the consensus building process and frustrated both the moderator and panelists. One example that was debated over 3 questionnaires was the differences between watershed potential, watershed suitability, and watershed condition. Some participants saw these as vastly separate entities and were reluctant to continue in the Delphi exercise until they were resolved and made explicit. Other participants expressed no concerns and were apparently unaffected by the discussion. A potential remedy could have been a training session implemented before the Delphi process to cover not only definitions but model background and function as well. This could have been accomplished by the moderator traveling to the panelists individually or via phone.

The final coho decision-support model is similar in structure to the AREMP model. Both models have the same initial categories and similar arrangement. Providing the AREMP model as a template in the Delphi process likely influenced this outcome. The AREMP model was originally provided to illustrate to the panelists an example of a proven decision-support model. In future studies we recommend providing additional model options as learning tools to decrease the focus on this individual model.

Building unbiased consensus was the ultimate goal of the Delphi process, but should consensus really be the goal? Keith (1996) argues that although valuable for forming a credible best estimate of current scientific knowledge, combining experts' judgments is undesirable. Consensus gives the illusion that all members in the decision making process are satisfied, masking any conflicts or differing opinions. To create the coho knowledge base all members presented unique and sometimes stubborn judgments but were forced to compromise during the process. A majority approval of an alteration or addition to the coho decision-support model resulted in a permanent change even when one or two individuals were in disagreement. Peterson et al. (2005) describes consensus as fatal to democratic decision making because differences and conflicts are obscured and final consensus is perceived as the ultimate truth. Keith (1996) warns that certain methods of building consensus produce answers that are acceptable to all rather than seeking the most correct answers. Whether or not the coho knowledge base is viewed as the best answer considering the best current science and expert judgment, it must certainly be viewed as just one alternative that can and will change as new judgments and information are added.

Utility of EMDS

The effective use of EMDS to evaluate watershed condition for coho in Oregon's Coastal Coho ESU was severely constrained by lack of data (Table 3). For some parameters no data are available, for others the data are privately owned, and for many of the Driver parameters

the data are GIS based and require analysis. The majority of the data that are available are statistically robust enough to make assessments at the ESU or monitoring area levels but not at the population (basin) level. Data consistency is also an issue. Multiple state and federal agencies, private companies, and advocacy groups are involved in monitoring efforts for the Coastal Coho ESU. They all collect different data at different spatial extents and resolutions, and using different methods, varying year to year. Since the Coho Assessment, OWEB created and maintains a data warehouse to make data more accessible, but determining data availability, coverage, sources, and who to contact for more specific information is still difficult.

Table 3. Insufficient data exists to make watershed assessments at the population scale. The following shows which categories of parameters have suitable data for assessments at each of the three scales: ESU, Monitoring area, and population.

Parameter Categories	Data Source	Scale		
		ESU	Monitoring Unit	Population
Vegetation parameters	ODFW[1]	Yes	Yes	-
Water Quality	ODEQ[2]	Yes	Yes	-
Water Quantity	OWRD[3]	Yes	Yes	Yes
Physical Condition	ODFW	Yes	Yes	Select basins
Biological Condition	ODEQ	Yes	Yes	-
Roads	BLM[4]	-	-	-

[1]Oregon Department of Fish and Wildlife
[2]Oregon Department of Environmental Quality
[3]Oregon Water Resources Department
[4]Bureau of Land Management (potential source of GIS data)

Both the panel of experts in this case study and the authors of the Oregon coastal coho assessment rated roads as one of the primary drivers of watershed condition that influence coho. One of the goals

of the Oregon Plan is to reduce the effects of roads on streams and aquatic habitat (Mills et al. 2005). As outlined by Mills and others (2005), the primary effects of roads on streams and coho include restricting fish passage, delivering sediment, altering aquatic habitat, and changing hydrology and stream flow.

Several road parameters for the model were suggested by ODF experts (Mills and Dent per communication) that were consistent with recommendations of the Independent Multidisciplinary Science Team (IMST). These were the density of stream crossing culverts, road density in riparian areas, and road density on steep slopes. Comprehensive, high-quality data for these road parameters are unavailable at this time. The BLM has a GIS layer (Ground Transportation Roads and Trails) that could be used to find road density in both riparian and steep hill slope areas, but this would require significant GIS analysis and, the road data are inconsistent and lacking among different land ownerships. To make the layer useful, a ground survey would be necessary to validate missing roads and calibrate for the quality of roads (Mills per verbal communication). As part of the Oregon Plan a program to monitor roads consistently across forest ownerships has been proposed but not yet implemented.

One parameter that was suggested by the coho decision-support model expert panel members and used in the past by others as an indicator of the effects of roads on streams is overall watershed road density. But Mills and others (2005) caution that this is not a

reliable indicator unless all roads are in similar condition, location, and built with the same practices.

A potential future parameter for the model might be road condition. Oregon Department of Forestry has developed a Road Information Management System with an explicit procedure for evaluating road condition based on numerous factors including the relative risk of influencing aquatic and riparian habitat. To date this has only been used for two watershed analyses on state forest roads but would be more useful if expanded to all land ownerships and watersheds across the coho ESU.

One prominent factor that inhibits the wide spread use and acceptance of EMDS is skepticism among experts. Use of the EMDS system for assessment of ecological condition is relatively new and unexplored. AREMP is the only organization that has used and continues to use EMDS successfully to assess watershed condition (Gallo et al. 2005). The NCWAP experts who built, and are still refining their initial model, voiced skepticism about the model function, abilities, usefulness, and rigor (NCWAP 2002). One expert on their team called it a "yet-to-be validated working hypothesis of the factors that define watershed condition" (NCWAP 2002). The RBRTCT's assessment of EMDS to identify and prioritize restoration needs in the Applegate Sub-basin lends some credence to the concerns of the NCWAP team. The RBRTCT concluded that using EMDS to average scores from causal processes and instream response variables did not improve their ability to accurately evaluate watershed condition or

provide management direction (RBRTCT 2004). They found that their model was more useful when broken down into smaller clusters of parameters.

The experts working on the coho decision-support model also expressed skepticism throughout the Delphi process. This revolved around model structure, parameter relationships, and the ability of the knowledge base to provide more than a theoretical schematic of watershed condition. The following are typical comments from the Delphi questionnaires.

It seems that the drivers, which should influence the response variables are disconnected from the response variables in the model. What happens if the response variables don't follow the drivers?

The structure of the model is seriously flawed. The model lacks integration of the natural capacity of a watershed to produce coho salmon.

I do find the overall structure of the model a little odd as I usually think of drivers of habitat broad-scale features such as geology, morphology, etc., with more specific factors influences reach level productivity…Your model seems to have repeated the drivers of basic potential and habitat condition which I don't really understand though perhaps I'm not clear on how the model works.

Although the coho decision-support model provided these experts with an opportunity to explicitly conceptualize watershed condition relative to coho, demonstrating the utility of EMDS will require validation, repetition, and continual peer review.

The Oregon Coho Assessment states that AREMP's use of EMDS to characterize the ecological condition of watersheds and aquatic

ecosystems for the area managed under the Northwest Forest Plan is "broadly applicable to federal forestland in the Coastal Coho ESU" (Nicholas et al. 2005). Given this and the list of strengths above, why did not Oregon use an EMDS watershed assessment model for at least some part of the 2005 Coho Assessment? When asked ODFW offered four reasons: (1) ODFW in not a land-management agency; (2) Generally, the stream information that ODFW collects and uses is at a smaller reach scale; (3) ODFW's assessment methods are more fish centric opposed to habitat centric; and (4) there are no available funds to implement a new model that would require software, skilled personnel, and potentially a different and more rigorous sampling effort.

Additional work is needed to make the current version of the coho decision-support model a useful and functional tool for watershed assessment. The model must be exposed to a broader group of experts for their edits and recommendations. The model could then be implemented into the EMDS system and run with real, or in the case of the Road parameters, mock data. The influence of each of the parameters to the overall output could be assessed. Parameters that have little influence or duplicate another parameter's influence could potentially be removed. If the model performed satisfactorily, and provided useful information about watershed condition, a decision would need to be made about whether to use part(s) of model alone, use the model without the road parameters, or invest in acquiring the necessary road parameters for a comprehensive model. If long-term use

of the model was desired, a monitoring effort guided by the specific needs of the coho decision-support model would be ideal.

CONCLUSION

At the population level the EMDS system was not useful for assessing watershed condition for coho due to the lack of data. As a whole, data for a majority of the parameters in the coho decision-support model were robust enough for assessments at the extent of the ESU and at the monitoring area. In addition, data for all of the road parameters in the knowledge base were either nonexistent, or not available because they are privately owned or require GIS analysis. These findings prevented completing and running the coho knowledge base in the EMDS system. If the data did exist, or if it is gathered during future monitoring efforts, EMDS might be valuable to those managing the ESU, especially since the fundamental coho knowledge base exists as well as the evaluation curves for the majority of parameters based on empirical data (reference conditions) and literature.

EMDS is an objective, transparent, and repeatable watershed assessment tool (Bleier et al. 2003, Dai et al. 2004, Reeves et al. 2004, Gallo et al. 2005, Reynolds and Hessburg 2005.) But some experts, including members of the panel on this study, are skeptical of the abilities of EMDS. As AREMP's program matures, the usefulness of EMDS may become more credible and acceptable for use in other wicked problems like salmon recovery. Even now it has potential

because, at the very least, the coho decision-support model helps experts to define watershed condition for coho, points out data gaps, monitoring needs, and provides a framework for generating new hypothesis and testing assumptions about the relationships among watershed parameters.

Based on the case study reported here, eliciting expert judgment through a Delphi process does not add appreciable value to creating a decision-support model for watershed assessment. The Delphi technique is not a foolproof method of eliminating bias or personal values and should not be assumed to be inherently superior to more informal methods. Normative science can still enter into the system from the moderator or from dominant individuals—particularly when building consensus on uncertain topics where some experts default to others when they perceive the apparent confidence of others as more certain than their own knowledge.

In addition the coho decision-support model is complex and not suitable to being created through a Delphi process due to the slow nature of the process via mail and overall inefficient transfer of information in a questionnaire/response format. The results could have been generated in a single day-long group session using a Nominal Group technique. All of the time saved could have been more valuable than preserving the anonymity of the panelists plus the cost of bringing everyone together.

Assessments can be no better than the information on which they are based (Lawrence et al. 1997). Although in theory different experts would have each created a different model, we believe that the dominant driver for how the coho decision-support model turned out was probably the AREMP template that was provided to the experts in the beginning. The similarity between the coho knowledge base and the AREMP knowledge base seemed predictable. In the end, some of the most useful insights from the experts were the areas of high uncertainty or no consensus. These areas, like High Intrinsic Potential (HIP), suggest important and necessary areas of focused future research because experts were either unfamiliar with them or weren't convinced that they would be appropriate for use in the coho decision-support model.

We conclude that in the case of the Oregon Coastal Coho ESU, using formal methods of eliciting and applying expert judgment have many limitations and added marginal value. Compared with group meetings the Delphi technique is relatively inefficient and impractical for providing information to decision makers and dealing with complex, urgent, wicked problems like salmon recovery. The EMDS system is currently unusable at the preferred spatial scale (the ESU) but provides a way to build consensus and understanding about watersheds, their processes, and influences on coho salmon. If the misssing data were available the coho decision-support model would function in the EMDS system but would still need to pass muster among a more extensive group of experts and decision-makers before being adopted by any agency for use.

Given the plethora of wicked natural resource issues that exist, there will be a continued reliance on experts to provide crucial information to decision makers. To be most useful expert judgment must be relevant, credible, timely, and communicated effectively. The formal methods of eliciting and applying expert judgment should aid in meeting these criteria. In this case study we analyzed the tradeoffs between these formal methods in that improving credibility and transparency came at the cost of time and procedural efficiency. Formal methods of eliciting and applying expert opinion for assessments are no panacea. Managers and decision makers will need to weigh the pros and cons on a case by case basis when contemplating whether these tools will add appreciable value to their decision-making.

BIBLIOGRAPHY

Beach, D. 2002. Coastal sprawl: the effects of urban design on aquatic ecosystems in the United States. Pew Oceans Commission, Arlington, Virginia.

Bisbal, G. A. 2002. The best available science of the management of anadromous salmonids in the Columbia River Basin. Canadian Journal of Fisheries and Aquatic Sciences 59: 1952-1959.

Bisbal, G. A. 2006. Learning to decide and deciding to learn: conduits to wild salmon in 2100? Pages xx-xx *in* R. T. Lackey, D. H. Lach, and S. L. Duncan, editors. Salmon 2100: the future of wild Pacific salmon. American Fisheries Society. Bethesda, Maryland.

Bleier, C., S. Downie, S. Cannata, R. Henly, R. Walker, C. Keithley, M. Scruggs, K. Custis, J. Clements, and R. Klamt. 2003. North Coast Watershed Assessment Program (NCWAP) Methods Manual. California Resources Agency and California Environmental Protection Agency, Sacramento, California. http://www.ncwap.ca.gov/pdf/NCWAP_Methods_Manual_Final.pdf

Bogert, L. M. 1994. That's my story and I'm stickin' to it: is the "best available" science any available science under the Endangered Species Act? Idaho Law Review 31: 85-150.

Clayton, M. J. 1997. Delphi: a technique to harness expert opinion for critical decision-making tasks in education. Educational Psychology: An International Journal of Experimental Educational Psychology 17(4): 373-386.

Cleaves, D. A. 1994. Assessing uncertainty in expert judgments about natural resources. General Technical Report SO-1 10. U.S.D.A. Forest Service Southern Forest Experiment Station, New Orleans, LA. July 1994.

Crance, J. H. 1987. Guidelines for using the Delphi technique to develop habitat suitability index curves. Biological Report 82(10.134). National Ecology Center, U.S. Fish and Wildlife Service, Fort Collins, Colorado.

Dai, J. J., S. Lorenzato, and D. M. Rocke. 2004. A knowledge-based model of watershed assessment for sediment. Environmental Modeling & Software 19: 423-433.

Delbecq, A. L., A. H. Van DeVen, and D. H. Gustafson. 1975. Group techniques for program planning—a guide to nominal group and Delphi processes. Scott Foresman and Company, Glenview, IL.

Dent, L., and A. Herstrom. 2005a. Land use and land cover characteristics in the Coastal Coho ESU. Oregon Plan Assessment

Part 4J OP Technical Report 3.
http://nrimp.dfw.state.or.us/OregonPlan/

Ellison, A. M. 1996. An introduction to Bayesian inference for
    ecological research and environmental decision-making. Ecological
    Applications 6(4): 1036-1046.

Gallo, K., S. H. Lanigan, P. Eldred, S. N. Gordon, and C. Moyer.
    2005. Northwest Forest Plan—the first 10 years (1994-2003):
    preliminary assessment of the condition of watersheds. General
    Technical Report PNW-GTR-647. Portland, OR: U.S. Department of
    Agriculture, Forest Service, Pacific Northwest Research Station.

Gordon, S., and K. Gallo. 2002. EMDS decision support model approach
    the evaluation of watershed condition. Prepared for the State-
    Federal Monitoring Program. Northwest Forest Plan: Regional
    Ecosystem Office Monitoring Publications Page.
    http://www.reo.gov/monitoring/watershed/docs/A120602_9_SGordon_DSM
    _white_paper.pdf.

Governors Natural Resource Office (GNRO). 2005. Oregon coastal coho
    assessment, part 3a: policy for the evaluation of conservation
    efforts; the certainty that the conservation effort will be
    implemented. Salem, Oregon.

Independent Science Advisory Board (ISAB). 2003. Decision support
    models as tools for developing management strategies: examples
    from the Columbia River Basin, Chapter 10. Pages 233-242 in R. C.
    Wissmar and P. A. Bisson, editors. Strategies for Restoring River
    Ecosystems: Sources of Variability and Uncertainty in Natural and
    Managed Systems. American Fisheries Society, Bethesda, Maryland.

Jensen, M. E., K. Reynolds, J. Andreasen, and I. Goodman. 2000. A
    knowledge-based approach to the assessment of watershed condition.
    Environmental Monitoring and Assessment 64: 271-283.

Johnson, C. J. and M. Gillingham. 2004. Mapping uncertainty:
    sensitivity of wildlife habitat ratings to expert opinion. Journal
    of Applied Ecology 41: 1032-1041.

Keith, D. W. 1996. When is it appropriate to combine expert
    judgments? Climate Change 33: 139-144

Lackey, R. T. 2004. Normative science. Fisheries 29(7): 38-39.

Lawrence, P. A., J. J. Stone, P. Heilman, and L. J. Lane. 1997. Using
    measured data and expert opinion in a multiple objective decision
    support system for semiarid rangelands. Transactions of the ASAE
    40(6): 1589-1597.

Lee, D. 2000. Assessing land-use impacts on bull trout using Bayesian
    belief networks. Pages 127-147 in S. Ferson and M. Burgman,
    editors. Quantitative Methods for Conservation Biology. Springer,
    New York.

Magnuson, J. J., F. W. Allendorf, R. L. Beschta, P. A. Bisson, H. L. Carson, D. W. Chapman, S. S. Hanna, A. R. Kapuscinski, K. N. Lee, D. P. Lettenmaier, B. J. McCay, G. M. McNabb, T. P. Quinn, B. E. Ridell, and E. E. Werner (Committee on Protection and Management of Pacific Northwest Anadromous Salmonids, National Research Council). 1995. Upstream: Salmon and Society in the Pacific Northwest. National Academy Press, Washington.

Meengs, C. C., and R. T. Lackey. 2005. Estimating the size of historical Oregon salmon runs. Reviews in Fisheries Science 13: 51-66.

Mills, K., L. Dent, J. Paul, and B. Riggers. 2005. Reducing effects of roads on salmonids under the Oregon Plan. Oregon Plan Assessment Part 4J, Technical Report 1. http://nrimp.dfw.state.or.us/OregonPlan/

Nickelson, T. E., J. D. Rodgers, S. L. Johnson, and M. F. Solazzi. 1992a. Seasonal changes in habitat use by juvenile coho salmon (Oncorhynchus kisutch) in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 49(4): 790-794.

Nickelson, T. E., M. F. Solazzi, S. L. Johnson, and J. D. Rodgers. 1992b. Effectiveness of selected stream improvement techniques to create suitable summer and winter rearing habitat for juvenile coho salmon (Oncorhynchus kisutch) in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 49(4): 790-794.

Nicholas, J., B. Macintosh, and E. Bowles. 2005. Oregon coastal coho assessment, part 1: synthesis of the Oregon coastal coho assessment. Oregon Watershed Enhancement Board and Oregon Department of Fish and Wildlife, Salem, Oregon. ftp://nrimp.dfw.state.or.us/oregonplan/reports/FinalReports/

North Coast Watershed Assessment Program (NCWAP). 2002. EMDS Science and Practitioner Review Panel. Unpublished data. http://www.ncwap.ca.gov/pdf/EMDS_Review_Report.pdf

Oregon Department of Environmental Quality (ODEQ) 2005. Oregon plan for salmon and watersheds, Oregon coastal coho assessment water quality report, Part 4(B) DEQ Water Quality. Oregon Department of Environmental Quality, Salem, Oregon. http://nrimp.dfw.state.or.us/OregonPlan/

Oregon Department of Fish and Wildlife (ODFW). 2005. Factors for decline and break points (unpublished data). Oregon Department of Fish and Wildlife, Salem, Oregon.

Oregon Watershed Enhancement Board (OWEB). 2005. 2003-2005 Oregon plan biennial report, volume 2. Oregon Watershed Enhancement Board, Salem, Oregon.

Pess G. R., D. R. Montgomery, R. E. Bilby, E. A. Steel, R. E Bilby, B. E. Feist, and H. M. Greenberg. 2002. Influence of landscape characteristics and land use on coho salmon (Oncorhynchus kisutch) abundance in the Snohomish River, Washington State, USA. Canadian Journal of Fisheries and Aquatic Sciences 59: 613-623.

Pess, G. R., T. J. Beechie, J. E. Williams, D. R. Whitall, J. I. Lange, and J. R. Klochak. 2003. Watershed assessment techniques and the success of aquatic restoration activities. Pages 185-201 *in* R. C. Wissmar and P. A. Bisson, editors. Strategies for Restoring River Ecosystems: Sources of Variability and Uncertainty in Natural and Managed Systems. American Fisheries Society, Bethesda, Maryland.

Peterson, N. M., M. J. Peterson, and T. R. Peterson. 2005. Conservation and the myth of consensus. Conservation Biology 19(3): 762-767.

Rauscher, M. H. 1999. Ecosystem management decision support for federal forests in the United States: a review. Forest Ecology and Management. 114: 173-197.

Regan, T. J., L. L. Master, and G. A. Hammerson. 2004. Capturing expert knowledge for threatened species assessments: a case study using NatureServe conservation status ranks. Acta Oecologica 26: 95-107.

Reeves, G. H., D. B. Hohler, D. P. Larsen, D. E. Busch, K. Kratz, K. Reynolds, K. F. Stein, T. Atzet, P. Hays, and M. Tehan. 2004. Effectiveness monitoring for the aquatic and riparian component of the Northwest Forest Plan: conceptual framework and options. General Technical Report PNW-GTR-577. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Oregon.

Reeves, G. H., F. H. Everest, T. E. Nickelson. 1989. Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington. General Technical Report USDA Forest Service Pacific Northwest Range Experimental Station.

Reynolds, K. M., and G. H. Reeves. 2003. Role of knowledge-based systems in analysis and communication of monitoring data. Pages 189-210 *in* D. E. Busch, and J. C. Trexler, editors. Monitoring Ecosystems: Interdisciplinary Approaches for Evaluating Ecoregional Initiatives. Island Press, Washington.

Reynolds, K. M., and G. H. Reeves. 2004 Analysis and communication of monitoring data with knowledge-based systems. Pages 95-104 *in* H. Gucinski, C. Miner and B. Bittner, editors. Proceedings: Views From the Ridge-Considerations for Planning at the Landscape Scale, Vancouver, WA. General Technical Report. PNW-GTR-596. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, Oregon.

Reynolds, K. M., and P. F. Hessburg. 2005. Decision support for integrated landscape evaluation and restoration planning. Forest Ecology and Management 207: 263-278.

Reynolds, K. M., M. Jensen, J. Andreasen, and I. Goodman. 2000. Knowledge-based assessment of watershed condition. Computers and Electronics in Agriculture 27: 315-333.

Reynolds, K. M., S. Rodriguez, and K. Bevans. 2002. Ecosystem management decision support 3.0: user guide. USDA Forest Service, Pacific Northwest Research Station, Corvallis, Oregon.

Rogue Basin Restoration Technical Core Team (RBRTCT). 2004. Ecological management decision support analysis of the Applegate sub-basin, final report. http://www.restoretherogue.org/model/index.html

Rowe, G., and G. Wright. 1996. The impact of task characteristics on the performance of structured group forecasting techniques. International Journal of Forecasting 12: 73-89.

Rowe, G., and G. Wright. 1999. The Delphi technique as a forecasting tool: issues and analysis. International Journal of Forecasting 15: 353-375.

Rykiel, E. J. 2001. Scientific objectivity, value systems, and policymaking. Bioscience 51(6): 433-436.

Schmoldt, D. L., J. Kangas, and G. Mendoza. 2001. Basic principles of decision making in natural resources and the environment. Pages 1-133 in D. L. Schmoldt, J. Kangas, G. A. Mendoza, and M. Pesonen, editors. The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making. Kluwer Academic Publishers, Boston.

Sharma, R., and R. Hilborn. 2001. Empirical relationships between watershed characteristics and coho salmon (Oncorhynchus kisutch) smolt abundance in 14 western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58: 1453-1463.

Stanford, J. A., and J. V. Ward. 1992. Management of aquatic resources in large catchments: recognizing interactions between ecosystem connectivity and environmental disturbance. Pages 91-124 in R. J. Naiman, editor. Watershed Management: Balancing Sustainability and Environmental Change. Springer-Verlag, New York.

Tversky, A., and D. Kahneman. 1982. Judgment under uncertainty: heuristics and biases. Pages 3-22 in D. Kahneman, P. Slovic, and A. Tversky, eds. Judgment Under Uncertainty. Cambridge University Press, Cambridge.

APPENDICES

APPENDIX 1.

Ecosystem Management Decision Support (EMDS)

In the knowledge-based decision support modeling approach, watershed assessment is a multi-criteria evaluation in which experts select the parameters that characterize the watershed, define their evaluation criteria, and determine the relations between those parameters. A simplified diagram of the structure and function of the knowledge base is shown in Appendix 1 Figure 1. It resembles a tree diagram similar to a flow chart where parameters that act as surrogates or indicators of watershed processes that influence overall watershed condition are arranged hierarchically based on current scientific understanding of their processes, and logical relationships with one another. Parameters are represented by nodes where connections and direction of influence are indicated by arrows. The complete knowledge base can be thought of a mental map of logical dependencies among watershed parameters (Reynolds and Hessburg 2005).

The terminal nodes on the right are the individual watershed parameters (e.g. stream temperature, pool frequency, riparian canopy, etc.) where raw data enter the model for evaluation against pre-established reference conditions in fuzzy logic curves (herein evaluation curves)(Appendix Figure 2). Fuzzy logic is a formal branch of mathematics that deals with quantifying imprecise parameters and their relationships with other parameters. Its use is ideal in ecosystem evaluation because ecosystems and their components have few specified points where "good" condition turns to "poor" condition

Combined Score ← Aggregate ← Evaluate/Normalize ← Watershed Parameters (data)
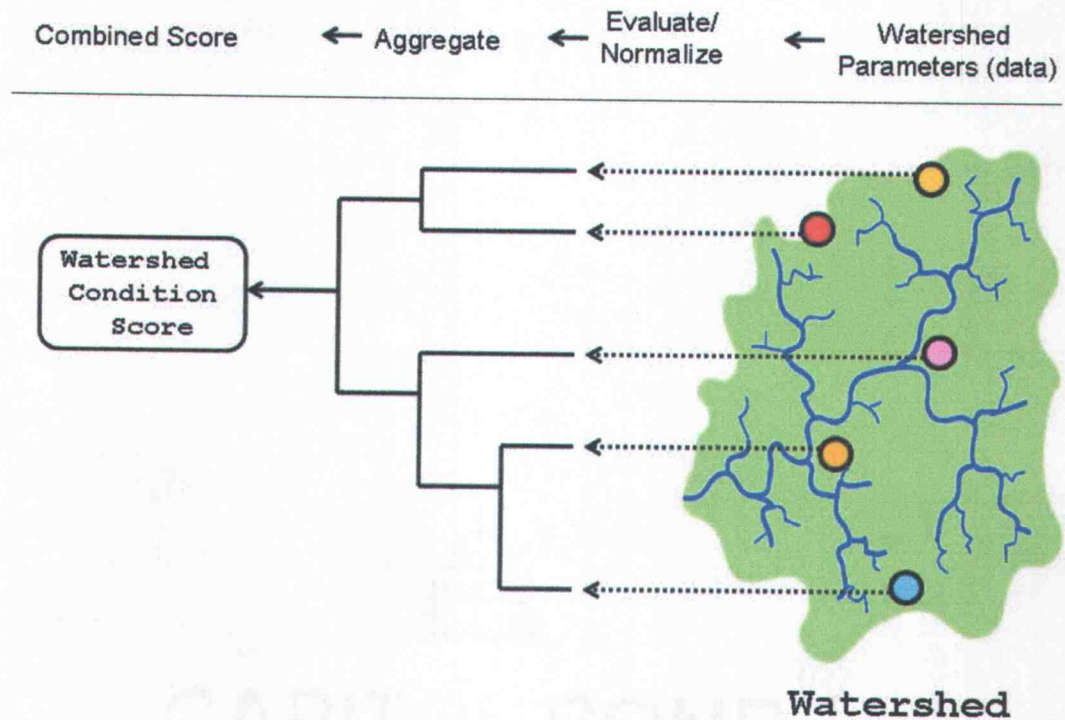
Appendix 1 Figure 1. Conceptual diagram of an EMDS knowledge base to evaluate watershed condition.

(Reeves et al. 2004). Instead conditions generally transition along a gradient which is what fuzzy logical tries to display. Fuzzy curves are similar to habitat suitability curves in that they define the benchmarks or break points for good and poor condition.

Each evaluation curve defines the criteria that the data must meet in order to fully support the proposition of the model: that the attribute is in good condition (or in this case, that the condition of the attribute is suitable for sustaining viable populations of coho). Evaluation curves are constructed based on a combination of available literature, empirical evidence, and expert judgment. Data

is then evaluated and normalized based on this criterion and given a score between +1 to -1. A score of +1 indicates that the parameter is in good condition or is fully suitable to sustain viable runs of wild coho. Conversely, a score of -1 indicates the parameter is fully unsuitable. Evaluation scores between +1 and -1 reflect the gradient between good and poor conditions. Converting scores to this simple, common scale of +1 to -1 facilitates comparing and aggregating scores later in the model (Gordon and Gallo 2002).
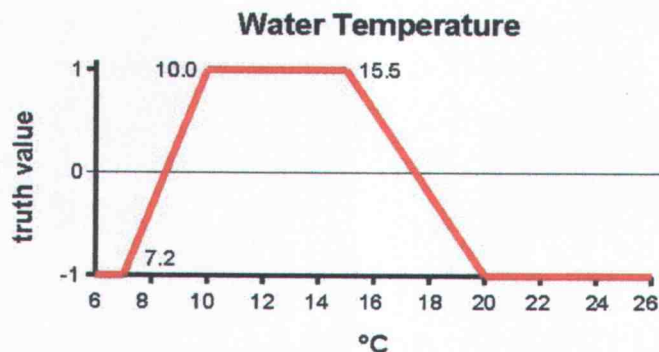
Water Temperature

Appendix 1 Figure 2. This evaluation curve represents the evaluation criteria for water temperature. This curve is based on literature and empirical data for coho and Chinook salmon and was created by experts from California's North Coast Watershed Assessment Program (NCWAP). Here if water temperature is between 10.0 and 15.5°C it is evaluated as fully suitable to sustain coho (+ 1.0) or in "good condition." Temperatures cooler or warmer than this window would receive declining scores.

After evaluation, individual model parameter scores are aggregated hierarchically at multiple junctions. For example, an intermediate level node may combine multiple parameters into general categories of instream, riparian, and upland conditions. Any given node assesses the proposition that all the factors leading to it are in suitable condition at that level. Ultimately all parameters scores in the network are aggregated logically into a single score of

watershed condition (between +1 and -1), reflecting its condition relative to coho suitability.

At each junction in the network where two or more parameters are aggregated, expert defined rules determine how scores are aggregated and passed on to the subsequent level. These aggregation functions, called logic operators, can pass on the minimum score, average score, or maximum score from those being combined. Minimum "MIN" operators pass a score weighted towards the lowest evaluation score. MIN is used primarily to allow one indicator to override other indicators. Average "AVE" operators pass on the average evaluation score. AVE is used so that indicators in good and poor condition balance each other out. Maximum "MAX" passes the highest evaluation score and therefore presents an optimistic view of condition. These operators, like the configuration of the model, are based on current scientific understanding of the parameter, their processes, and logical relationships with one another. In addition to operators each node in the model can be assigned a weight.

Model output comes in the form of tables, graphs, and color coded maps (Appendix Figure 3) displaying watershed condition scores or parameter influence rank to the overall model. Scores (between +1 and -1) are generally are broken into a 7 classes for ease of comparison and to improve understanding and communication of results (Appendix Table 1).
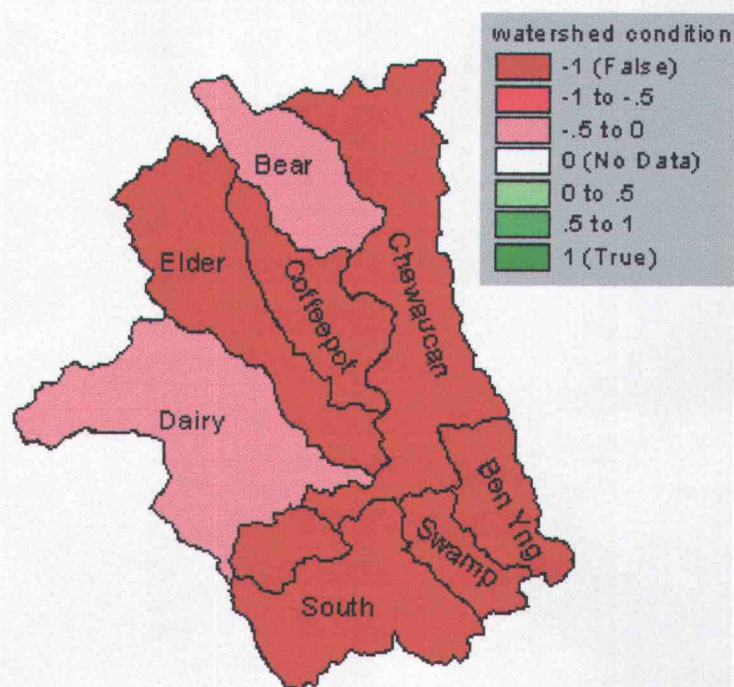
Appendix 1 Figure 3. An example map of EMDS model evaluation results showing color coded rankings of watershed condition. Source: EMDS website, http://www.fsl.orst.edu/emds/.

Appendix 1 Table 1. EMDS model outputs of +1 to -1 are arranged in a 7 class system to facilitate comparison and communication.

Score range	Class
+1.0	Fully suitable or highest suitability
0.99 to 0.50	Moderately suitable
0.49 to 0.01	Somewhat suitable
0.0	Uncertainty
-0.01 – 0.49	Somewhat unsuitable
-0.50 – 0.99	Moderately unsuitable
-1.0	Fully unsuitable or lowest suitability

APPENDIX 2.

Example Questionnaire provided to panelists

EXAMPLE QUESTIONNAIRE

Thank You

Thank you for agreeing to serve as an expert panelist for this project. I have asked you to participate because of your knowledge about coho salmon *Oncorhynchus kisutch* and their relationship to freshwater habitat conditions. I realize that you have other responsibilities and priorities and therefore I value any time and input you can lend to this project. Your participation and ideas shared in this exercise will remain anonymous. I hope you are able to continue participating on this panel. Thank you again for your time and efforts. I look forward to receipt of your input.

Instructions

The purpose of this exercise is to create a decision-support model (DSM) to assess the ecological condition[7] of watersheds for coho salmon within Oregon's Coastal Coho ESU (coastal watersheds between the mouth of the Columbia River and Cape Blanco). This expert panel exercise is necessary because field data and literature are currently inadequate for developing such a model. The goal is to come to agreement on the structure of the proposed model, what parameters should be included in the model, and how the model should operate. This is the 1st of probably 4 rounds in this exercise. Background information is provided at the end of this document to explain the model.

Below each question are specific instructions. Please consider all of the provided information when answering each question. There is room for your comments, ideas, logic, references, etc. As best you can, please include reasons for your answers. It is important that you use your "gut" feeling or opinion, even if no data are available. If you do mention a reference, please include enough information for me to find the source. Please rate the confidence of your answers on a scale of 1-5 (i.e. 1= gut feeling, 5= extensive documentation). You may also want to draw or create diagrams to share your ideas. For that I am mailing you a paper copy of this questionnaire with a self addressed stamped envelope for its return. Also, feel free to share this questionnaire and work through its questions with your co-workers and other colleagues.

If you have any questions don't hesitate to call or email me. Please return your response within 10 days. I will receive your returned comments, summarize all of the participants' input, and send you a new questionnaire. This process will continue until the panel of experts has come to agreement.

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[7] For a watershed to be ecologically intact it means: (1) the processes necessary to create and maintain habitat conditions for native species and especially coho are intact; (2) current habitat conditions support coho; and (3) the system has the potential to recover to desired conditions when disturbed by large natural events or by land management activities.

Model Use

The Aquatic and Riparian Effectiveness Monitoring Plan (AREMP) for the Northwest Forest Plan uses Decision support models to characterize ecological condition of watersheds and aquatic ecosystems. To do this, the AREMP assessment team uses a decision support modeling tool called Ecosystem Management Decision Support (EMDS), which consists of GIS, database, and decision-support software components. EMDS enables AREMP users to evaluate monitoring data from instream, riparian, and upslope conditions, and then aggregate the information into an overall score of watershed condition. Experts were consulted in an informal group process to create AREMP's model. This involved deciding which parameters to use and then creating the rules for how to evaluate and aggregate them.

I am building a coho-centric DSM to assess watershed condition for Oregon's coastal coho salmon ESU that is based on AREMP's coastal watershed model. I will use both the same modeling program, structure, and rules for arranging and aggregating watershed parameters. The only major difference between the two models is the parameters. The parameters I have chosen all come from the State's assessment of the coastal coho salmon ESU. Criteria to evaluate each of the parameters will be provided by the state agencies that manage the data sets. These criteria for evaluating the data are relevant to coho salmon, are specific to the ESU, and were used in Oregon's coastal coho salmon assessment.

Model Basics and Structure

A decision-support model is simply a method of documenting a formal, logical organization of information for evaluation and interpretation. This allows for the decision process to be applied consistently and transparently.

A simplified diagram of the structure and function of the model is shown in Figure 1. This decision-support model has two primary functions. First, it evaluates individual data and secondly, it aggregates this information into an over all assessment of condition.

Figure 1.

Combined Score
↑
Aggregate
↑
Evaluate / Normalize
↑
Watershed Parameters (data)
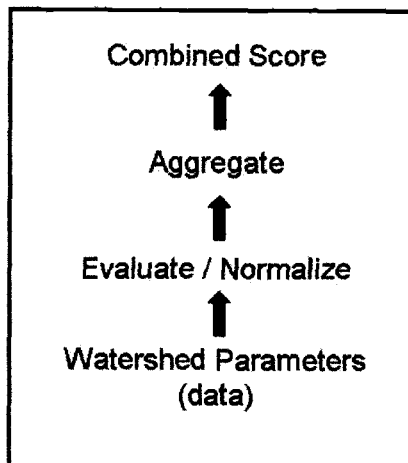
For each parameter used in the model, experts must develop criteria to evaluate the data. The approach is similar to developing habitat suitability curves and defining the benchmarks or break points for good and poor condition. Data is then evaluated and normalized based on this criterion and given a score between +1 to -1. A score of +1 indicates that the parameter is in good condition or is fully suitable to sustain healthy runs of wild salmon. Conversely, a score of -1 indicates the parameter is fully unsuitable. Evaluation scores between +1 and -1 reflect the gradient between good and poor conditions. Converting scores to this simple scale of +1 to -1 facilitates comparing and aggregating scores later in the model.

After evaluation, individual parameter scores are aggregated into an overall score of condition in multiple, sequential steps in a model structure that resembles a tree diagram, as illustrated by the diagram of the proposed model (Figure 2). The model structure is important because it determines the logical arrangement of parameters. At each junction where two or more

parameters are aggregated, expert defined rules determine whether the minimum score, maximum score, or average score will be passed on to the subsequent level. Experts may also chose to weight certain parameters for added influence at each junction where they are combined. Parameters are aggregated logically until all the parameters in the model have been combined. The final watershed condition score is also a number between +1 and -1, reflecting its condition relative to coho suitability.

From the top down you'll notice 4 colored branches of the proposed model structure (Figure 2). The top two are vegetation (green) and roads (brown), which are combined to form the watershed condition drivers category. All of the parameters in the drivers category directly influence watershed condition. The bottom two branches are water quality (blue) and reach condition (orange), which are combined to form the responses category. All the parameters in this category respond to the drivers. The reach condition branch (orange) is aggregates biological and physical conditions.

At each junction where two or more parameters are aggregated there are small boxes containing the words "AVE" or "MIN." These are called operators and they determine how antecedent parameters are combined. MIN operators pass a score weighted towards the lowest evaluation score. MIN is used primarily to allow one indicator to override other indicators. AVE operators pass on the average evaluation score. AVE is used so that indicators in good and poor condition balance each other out. An operator that is not on the current model but can also be used is MAX. MAX passes the highest evaluation score and therefore presents an optimistic view of condition.

Questions

Question 1: Model Structure

The main purpose of this exercise is to help develop and evaluate the model structure using expert opinion. Consider the structure of the model and the hierarchical arrangement of the parameters. What comments, suggestions, improvements, or concerns do you have? Would you change the structure in any way? What levels would you add or subtract?

Question 2: Parameters

The parameters I have chosen for my model must meet the following criteria: (1) They must act as surrogates or indicators of watershed processes and conditions that influence coho; (2) Data for the parameters much currently exist (in data bases or GIS layers) and be available to the public; (3) Data for the parameters must exist for the entire region encompassed by the coastal coho ESU. All of the parameters I selected for my model were used in Oregon's coastal coho ESU assessment. I have included a list of these parameters and their definitions at the end of this document.

Do you know of any other parameters that I have not included in the model that meet these criteria? Please list them, and include their source, rational for their use, and describe where they belong in the model structure.

How certain are you about your decision? (1=No certainty, 5=Very certain and have the literature to prove it.)

1   2   3   4   5

Question 3: Operators

The operators AVE (average), MIN (minimum), and MAX (maximum) determine how two or more parameters' scores are aggregated at each junction.

Examine the operators at each junction in the model. From your limited knowledge about the structure of this model and the role of operators, do you agree with the operators I have chosen? What changes, concerns, recommendations, or thoughts do you have?

How certain are you about your decision? (1=No certainty, 5=Very certain and have the literature to prove it.)

1   2   3   4   5

Question 4: Weighing Parameters

As of now, all of the individual parameters are weighted the same.

Would you weight any of these parameters differently than others? Which ones? Please give your rationale, comments and suggestions.

How certain are you about your decision? (1=No certainty, 5=Very certain and have the literature to prove it.)

1   2   3   4   5

Figure 2. The proposed model structure from AREMP. The structure, categories, and operators are all consistent with AREMP's coastal watershed condition model.
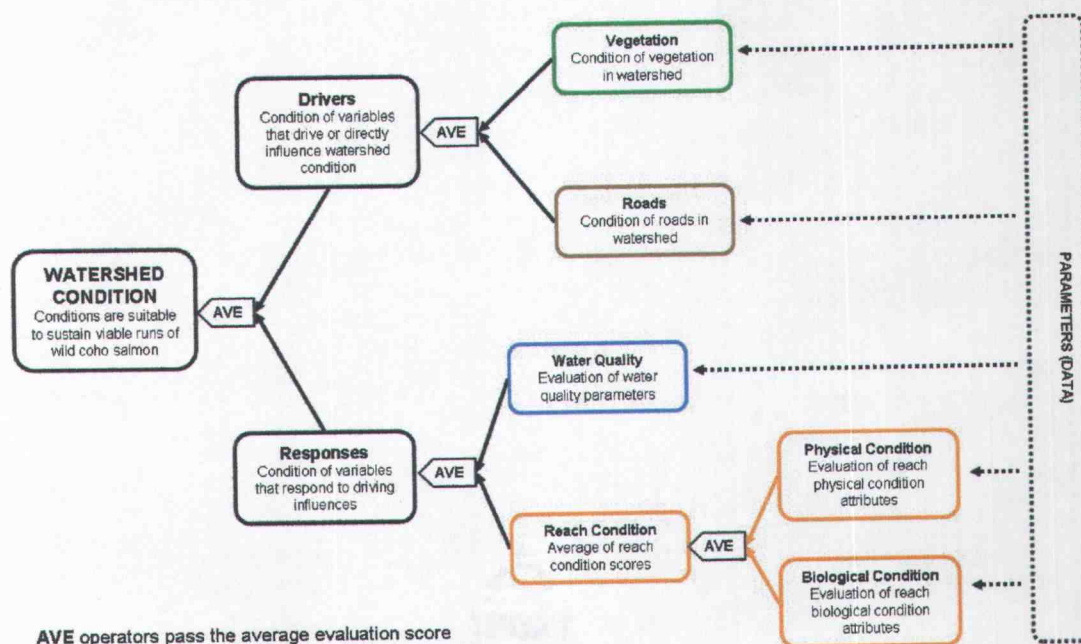

AVE operators pass the average evaluation score

Table 1. Parameters used in Oregon's assessment of the Oregon Coastal Coho Salmon ESU

Parameter	Definition
Percent of Watershed in Urb/Arg	Percent of watershed area in urban or agricultural land use
% Shade in Riparian	Percent of 180 degree sky that is shaded by trees or other topographic features
Conifers > 50cm dbh in Riparian	The number of conifers > 50cm dbh within 30 m of both sides of the river per 305 m of primary stream length
Conifers > 90cm dbh in Riparian	The number of conifers > 90 cm dbh within 30 m of both sides of the river per 305 m of primary stream length
Road Condition Index	State rating of 1-5 given to roads based on current condition including: erosion, washout potential, culverts limiting fish passage, and drainage
Roads in Riparian	Density of roads with 50m of the stream channel
Roads on steep slopes	Density of roads on slopes > 50%
Stream crossing culverts	Number of stream crossing culverts per kilometer
Phosphorous	Evaluation of total phosphorous concentration (mg/L) in the watershed
Nitrogen	Evaluation of the total inorganic nitrogen concentration in the watershed
pH	Hydrogen ion activity
Dissolved Oxygen	Evaluation of the average dissolved oxygen collected in the field surveys.
Water Temperature	Evaluation of the 7-day average maximum water temperature.
Fine Sediment	% fine sediment.
Total solids	Total solids concentration in water column as indication of suspended and dissolved component of sediment.
% Bedrock	Visual estimate of stream substrate composed of solid bedrock
% Gravel in Riffles	Visual estimate of stream substrate composed of 2-64mm diameter particle
% Fine Sediment in Riffles	Visual estimate of substrate composed of <2 mm diameter
% Slackwater Pools	% of primary channel area represented by slackwater pool habitat (beaver ponds, backwater, alcoves, and isolated pools).
% Pools	% of primary channel area. represented by pool habitat
Deep Pools / km	Pools > 1 m deep per km of primary channel
% Secondary Channel	% total channel area represented by secondary channels.
Pieces Large Wood	# of pieces of wood ≥ 0.15 m diameter x 3 m length per 100 m primary stream length.
Key Pieces Large Wood	# of pieces of wood ≥ 60 cm diameter & ≥ 12 m long per 100 m primary stream length.
Large Wood Volume	Volume of wood ≥ 0.15 m x 3 m length per 100 meters primary stream length.
Vertebrate Community Score	An index of biotic condition based on species diversity that was created for coldwater streams in Western Oregon and Washington
Macroinvertebrate Community Score	River Invertebrate Predication and Classification System, or RIVPACS.
Exotic Fish & Amphibians	An index of biotic condition based on species diversity.