TOWARD AN UNDERSTANDING OF FUNCTIONAL LINKAGES BETWEEN HABITAT QUALITY, QUANTITY, AND DISTRIBUTION; AND SUSTAINABLE SALMON POPULATIONS: A REVIEW OF ANALYTICAL APPROACHES AND RECOMMENDATIONS FOR USE IN WRIA 9

Prepared for

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Funded by the WRIA 9 Forum
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EXECUTIVE SUMMARY

This report summarizes the current status of research and assessment in the WRIA 9 planning area, and provides a preliminary evaluation of six analytical approaches (e.g., models, statistical methods, qualitative approaches) that could be used to evaluate the functional linkages between salmon and their habitat. The modeling approaches reviewed included Ecosystem Diagnosis and Treatment (EDT), EDT-Light, SHIRAZ, Qualitative Habitat Assessment (QHA), Salmonid Watershed Assessment Model (SWAM), and Cumulative Risk Initiative (CRI). These approaches were selected because of their previous or current use in habitat-based modeling and salmon conservation planning in the Pacific Northwest. Several other analytical approaches (e.g., STREAM Tool, PSNER nearshore assessment method) were briefly considered but judged inadequately developed for the purposes of this review. We also considered what we refer to as the "Ecological Synthesis Approach." As the name implies, this approach incorporates input from multiple sources, including empirical data on salmon abundance and distribution, model outputs, and historic versus current comparisons, to generate conservation hypotheses.

The results of our review of salmon research and assessment in the WRIA 9 planning area documents the availability of considerable information on the current status of salmon in the Green/Duwamish watershed, as well as the status of salmonid habitat. These data will be of considerable value in developing conservation hypotheses and in establishing the current baseline from which to judge future changes in salmon abundance, productivity, diversity, and distribution. However, one recurring limitation of these data was the inability to partition the contribution of hatchery strays versus natural production. A high proportion of hatchery-produced fish on the spawning grounds makes it difficult to estimate the productivity of the naturally reproducing populations that are the focus of Endangered Species Act recovery plans. The current program (initiated in 1999) to mass mark all hatchery fish chinook salmon should, in time, eliminate this problem.

The results of our review of the habitat models and other analytical tools suggested that all of the models and tools could make a significant contribution to salmon conservation planning. However, they all had limitations, and none stood out as an approach that WRIA 9 should depend upon exclusively. A brief description of each model and a summary of our conclusions regarding their use follows.

EDT and EDT-Light

EDT and EDT-Light are scientific models developed by Mobrand Biometrics, Inc. to describe the relationship between quantity and quality of habitat and fish performance. This is accomplished using a detailed set of functional relationships (many assumed) or "rules" to generate model outputs in the form of relative abundance (capacity), productivity, and life history diversity of a focal species—in this case chinook salmon. EDT and EDT-Light are basically the same models; the only difference is the amount of quantitative data required and the number of survival factors utilized. EDT and EDT-Light are proprietary models; therefore WRIA 9 would have limited opportunity to fully understand the "inner workings" of the model, including the functional relationships that drive the model. Nevertheless, EDT and EDT-Light are turnkey models that are run by a qualified group of biologists. EDT and EDT-Light have been used by the Co-Managers in the Green/Duwamish Watershed, but results have not been made available to the WRIA9 Technical Committee.

SHIRAZ

SHIRAZ is a relatively new scientific population simulation model developed by Dr. Ray Hilborn of the University of Washington. The model allows the user to track fish populations through their life stages and habitats, and then back to the spawning grounds. A transformation function allows hatchery spawners in the river to produce natural fish (based on the input of stray rates). Stochastic variability and uncertainty in functional relationships can be introduced into the model, and then multiple simulations can be used to develop a distribution of outcomes or quasi-confidence intervals based on model assumptions. This approach can also be used to examine extinction risk or population trends over time following initiation of a habitat action. SHIRAZ runs on a Microsoft Excel platform and will probably become available to the public in the future. Currently, the Muckleshoot Indian Tribe is using SHIRAZ in the Green/Duwamish Rivers and NOAA Fisheries is applying SHIRAZ to the Snohomish River.

QHA

QHA is a simplified, qualitative version of EDT that was developed by Mobrand Biometrics, Inc. for rapid application to a watershed. QHA provides a structured, qualitative approach to analyzing the relationship between a given fish species and its habitat. It does this through a systematic assessment of the condition of selected aquatic habitat attributes (sediment, water temperature, etc.) that are thought to be keys to biological production and sustainability. Attributes are assessed for each of several stream reaches or small watersheds within a larger hydrologic system. Habitat attribute findings are then considered in terms of their influence on a given species and life stage. QHA relies on the knowledge of natural resource professionals with experience in a given local area to describe physical conditions in the target stream and to create a hypothesis about how the habitat would be used by a given fish species. The hypothesis consists of weights (i.e., importance of factors) that are assigned to life stages and habitat attributes, as well as a description of how reaches are used by different fish life stages. These result in a composite weight that is applied to a physical habitat score in each reach. This score is the difference between a rating of physical habitat in a reach under the current condition and a theoretical reference condition. Given the level of knowledge of fish populations and habitat conditions in the Green/Duwamish, QHA would be relatively easy to apply.

SWAM

SWAM is not a model *per se*, but rather the application of a statistical tool that links habitat attributes and conditions to salmon production. It utilizes empirical data and estimates variability in the relationship between habitat and spatial distribution of fish. In its simplest form, SWAM identifies correlations between spawner or juvenile density and habitat or landscape characteristics. Once identified, these relationships can be used to predict fish density in habitats made available after, for example, removal of barriers. The relationships also provide evidence for habitat features that may have the greatest restoration and protection potential. SWAM involves spatial distribution and relative abundance, but it does not involve productivity and diversity. Two recent applications of SWAM by NOAA Fisheries have been “successful” (i.e., correlations detected), but these applications also demonstrate the low correlation between landscape characteristics and fish density in a watershed. These observations imply that protection of existing habitat is especially important.

CRI

CRI is not a single model, but a set of statistical tools that are used to estimate annual population growth rate of a population or group of populations, estimate extinction risk of those populations, and identify life stages where increased survival would have the greatest effect on productivity. At the center of the CRI approach is the Leslie matrix population model. The CRI approach has been used by NOAA Fisheries throughout the Columbia River basin and in selected Puget Sound watersheds, including to a limited degree the Green/Duwamish. A more detailed application in the Green/Duwamish Rivers will require additional information on life stage specific mortalities. It would be appealing to use CRI in conjunction with one of the other tools such as EDT or SHIRAZ, with the latter providing more specific guidance on habitat actions. CRI does not evaluate diversity or spatial distribution of chinook populations. CRI has been used by NOAA Fisheries in the Green/Duwamish watershed.

Ecological Synthesis Approach

The Ecological Synthesis Approach is neither a model nor a statistical tool; rather it is a conceptual approach to developing conservation hypotheses using multiple sources of data and analytical and modeling results. The emphasis is on using current information on salmon abundance, productivity, life history, and habitat use to develop hypotheses regarding habitat restoration and preservation actions. Although important in the application of any ecological planning tool, a rigorously designed monitoring and evaluation plan is an absolute requirement, and should be developed in concert with the conservation hypotheses. Given the level of current information, the availability of a conceptual research plan, and the previous application of several habitat models, the Ecological Synthesis Approach is worthy of strong consideration in the WRIA 9 planning area.

A noteworthy shortcoming of all the models and analytical tools reviewed was their failure to specifically incorporate or address functional linkages in estuarine and nearshore marine environments. This is not surprising since the fundamental nature of these linkages is poorly understood. This will obviously be a major obstacle in the development of any more comprehensive scientific model. As in freshwater habitat, but with even less empirical data, assumptions will need to be made about linkages between these habitats and survival.

In the end, the answer to the question, "Are models necessary?" is not unequivocally "yes" or "no." There are arguments that can be made for either answer. Clearly, models can help in:

- Organizing data (a process that can identify data gaps)
- Developing hypotheses about potential restoration or protection activities
- Documenting the process leading to a land-use decision
- Tracking progress toward population recovery

For WRIA 9, an appealing choice is a combination of CRI and SHIRAZ, combining the strengths of both statistical and scientific models and taking advantage of existing efforts. The attractiveness of this approach would be predicated on the public availability of SHIRAZ.

However, the predictive power of any ecological model is limited, and the models we reviewed here are no exception. There are clearly other ways to organize data, develop hypotheses, document process, and track recovery. For example, the Ecological Synthesis Approach or a similar approach could use a combination of empirical and derived data on fish utilization (both current and historic) in combination with model outputs (e.g., CRI, SHIRAZ, EDT) to identify and prioritize important habitats for enhancement. Ultimately, no matter what the choice of analytical tool or approach, the value of any restoration and preservation action must be judged on the basis of empirical data that comes from a rigorous monitoring and evaluation program.

1 INTRODUCTION

The listing of 26 "species" of Pacific salmonids (27 including bull trout) along the U.S. west coast in the 1990s catalyzed a major effort on the part of federal, state, local, and tribal governments to identify and prioritize opportunities and actions to rebuild depleted populations. Perhaps nowhere in the coastal corridor have the challenges been as great as they are in the urban centers, such as Seattle, Portland, and the San Francisco Bay Area. Unquestionably, the greatest single obstacle to recovery and delisting in these areas is the loss of freshwater spawning and rearing habitat. Without adequate habitat to meet the essential biological needs of the species, there is little hope of achieving the long-term goals of delisting and sustainability.

The resources necessary for salmonid recovery, including public support and funding, are finite; therefore, responsible, defensible and biologically meaningful choices of recovery actions are critical. To support these efforts, several analytical tools and models have been developed to assist resource managers in identifying and prioritizing preservation and restoration options. In this report we review several of the most commonly used analytical approaches, subject them to a coarse-scale screen for usefulness in WRIA 9, and provide a preliminary recommendation for their application.

1.1 WRIA 9 and Salmon Recovery

In Washington State, the salmon recovery effort is organized around Water Resource Inventory Areas, or WRIAs. The WRIA structure involves the division of the state into 62 areas for water and aquatic resource management. In the mostly urbanized Puget Sound basin, there are 23 WRIAs. Although many Puget Sound WRIAs share a common feature of mixed land use, perhaps none does so to the degree of WRIA 9. From its headwaters in the Cascade Mountains about 30 miles north of Mount Rainier, the Green River flows some 93+ miles through a mosaic of forests, agricultural land, and urban development before entering Elliot Bay through the highly industrialized Duwamish Waterways. The diverse landscape of the WRIA 9 planning area also includes some relatively rural areas, e.g. Vashon/Maury Island nearshore habitat. This diversity of landscapes and land use makes salmon conservation planning in WRIA 9 particularly challenging.

The WRIA 9 Strategy for Salmon Habitat Planning is designed to produce by May 2005 a long-term Habitat Plan. The Habitat Plan is the final product of a collaborative planning process with four linked steps and associated products:

1. Reconnaissance Assessment
2. Near-Term Action Agenda
3. Strategic Assessment
4. Habitat Plan

The first of the four steps, the Reconnaissance Assessment, was completed in December 2000 with the publication of the Habitat Limiting Factors and Reconnaissance Assessment Report. This report provides a summary of what is known about current and past salmonid species and habitat conditions in the Green/Duwamish and Central Puget Sound Watershed, and establishes a baseline for evaluating future changes and actions. The baseline will serve as a reference for the implementation of an adaptive management program. The report also identifies factors for decline in the WRIA, key findings, and associated data gaps—all of which contributed to the drafting of the Near-Term Action Agenda. This information was supplemented with the completion of the Reconnaissance Assessment of the State of the Nearshore Ecosystem in May 2001 (Williams et al. 2001).

As the name suggests, the Near-term Action Agenda provides preliminary guidance for policy makers to determine immediate and near-term actions to help restore and protect habitat for chinook salmon and bull trout. The document describes what local governments, environmental groups, and others are doing now for salmon habitat in the watershed, and goes on to recommend actions, research, and changes to local government policies and programs.

The Strategic Assessment is the third product of the watershed planning process for the Green/Duwamish and Central Puget Sound Watershed. The Strategic Assessment will provide the scientific foundation for the Habitat Plan. Specific tasks include:

1. Update technical strategy
2. Assess historic conditions (habitat and populations)
3. Assess current conditions (habitat, populations, water quantity and quality)
4. Compare historic and current conditions

5. Evaluate limiting factors and fish utilization
6. Characterize functional linkages
7. Identify currently functioning and necessary future conditions
8. Complete Strategic Assessment report and Habitat Plan appendices

The ultimate product of the planning process will be a Habitat Plan. The specific goals of the Habitat Plan are:

1. To protect and restore physical, chemical and biological processes in the freshwater, marine and estuarine habitats on which salmonids depend
2. Protect and restore habitat connectivity
3. Protect and improve water quality and quantity conditions to support healthy salmonid populations
4. Provide an implementable plan that supports salmon recovery

This report responds to Task 6.1a of the Strategic Assessment work plan. Task 6.1a is designed to evaluate analytical tools and strategies for evaluating functional linkages between salmon productivity and habitat. Depending on the results of this evaluation, a second component of this task could be the application of a model (or models) to WRIA 9 as part of a decision support framework that will assist in identifying, prioritizing, and tracking the results of habitat preservation and restoration projects.

In this report, we summarize the current status of research and assessment in the WRIA 9 watershed and provide a preliminary evaluation of six analytical tools (e.g., models and statistical methods) that could be used to evaluate the functional linkages of salmon and their habitat. The modeling approaches reviewed include Ecosystem Diagnosis and Treatment (EDT), EDT-Light, SHIRAZ, Qualitative Habitat Assessment (QHA), Salmonid Watershed Assessment Model (SWAM), and Cumulative Risk Initiative (CRI). These approaches were selected because of their previous or current use in habitat- based modeling and recovery planning in the Pacific Northwest. Several other analytical approaches (e.g., STREAM Tool, PSNER nearshore assessment method) were briefly considered but judged inadequately developed for the purposes of this review. We also considered what we refer to as the "Ecological Synthesis Approach." As the name implies, this approach is built on a strategy to incorporate input from multiple sources (e.g., empirical data on salmon abundance and distribution, model outputs, and historic versus current comparisons) to generate conservation hypotheses. In the end, all of these approaches should be viewed as "works in progress." The model developers and practitioners are constantly modifying and testing new algorithms, modifying assumptions, and incorporating new information into their approaches. Hence, our views and comments apply only to the "state of the model" as was available to us via user manuals, reports, web pages, and, in some cases, direct discussions with the developers. In addition, the time allocated for this coarse-scale review was limited, and not all questions that arose during our review were answered. To resolve these issues will require additional information from the model developers, and more detailed review and analyses.

For each of the analytical approaches reviewed, we have summarized the general nature and function of model or tool, and evaluated its practical application in WRIA 9 against a standard set of criteria. These criteria were designed to assess the usefulness of the model or tool in the habitat planning process. The report concludes with our preliminary recommendations on the use of habitat-based ecological models in the WRIA 9 planning process.

1.2 Ecological Modeling

Ecological models have been used for over a century in the management of natural resources, conservation science, and risk assessment. In its simplest form, an ecological model is a mathematical expression (or more often a set of mathematical expressions) that can be used to describe or predict endpoints such as population abundance, productivity, species interactions, etc. As a general rule, ecological models simplify complex biological and environmental processes. Therefore they should be viewed as an "approximation of the real world." An appropriately conservative perspective is to consider model outputs as hypotheses until they can be verified by empirical observations.

Ecological models are a useful and logical approach to organizing and communicating information. Depending on their complexity and the quantity and quality of data upon which the model draws, models can serve many purposes. For purposes of this brief introductory text, the terms models and analytical tools will be considered to be synonymous. In reality, however, models are just one type of analytical tool. Further, one can think of models in terms of being a more complete mathematical representation of an ecological interaction, and of analytical tools as focusing on a more defined interaction. However, rather than add to the endless debate on this largely semantic issue, we will make no distinction between these two terms.

Models can be classified in many ways. Some of the more commonly used classification systems include perspective, scope, and scale of output. Examples include ecosystem models, trophic models, population dynamic models, landscape models, and habitat models.

Models can also be classified based on intended use. Examples include those designed largely for exploring and enhancing the understanding of an ecological interaction, versus those created to make predictions, and that function in a decision-support environment. However, it should be recognized that the developer of a model has no control over how another person may use the model, and a model created to explore ecological interactions might be used to predict, e.g., the result of an environmental action.

Another way to look at models is based on dichotomies. Hilborn and Mangel (1997) in "The Ecological Detective" make the following distinctions.

1.2.1 Deterministic versus Stochastic Models:

Deterministic models are based on the premise that every event, act, or decision is the inevitable consequence of known mechanisms; that there is virtually no uncertainty involved. In contrast, stochastic models are constructed on the premise that some of the parameters are uncertain—typically varying with a fixed range—and hence will produce results in the form of a probability distribution.

1.2.2 Statistical versus Scientific Models

Statistical models are those built on statistical relationships among parameters. They frequently involve the use of regression analyses, and their construction typically involves extending the relationship among parameters beyond their measured interaction. A scientific model is built more from a general understanding of how "nature works," and the interaction of variables. In reality the distinction between the two is often blurred by the fact that our general understanding of how "nature works" is built on a foundation of knowledge that is a mix of statistical relationships and hypotheses on the mechanisms and processes that control ecological linkages.

1.2.3 Static versus Dynamic Models

As the terms suggest, static models produce a result that does not change over time, and dynamic models produce results that do change. Another way of viewing the difference is that a static model helps one understand the behavior of a system at rest whereas a dynamic model helps one understand the behavior of a system as it changes over time. Dynamic models explicitly consider growth, decay, and oscillations.

1.2.4 Quantitative versus Qualitative Models

In their simplest forms, quantitative models produce detailed, numerical results, whereas qualitative models produce general descriptions about responses.

1.2.5 General Considerations

An overarching consideration in either building a new model or applying an existing tool is model complexity—and the interplay among simplicity, transparency, number of assumptions, and availability of data to parameterize the model. In the end no model output should be considered as more than a hypothesis. Thus the combining of a model with a rigorous monitoring and evaluation tool is an absolute requirement.

There are several benefits to using a model in natural resource planning that accrue regardless of which model or models are used. In general, a model helps one to establish a conceptual framework for how to think about ecological relationships and linkages, and to organize knowledge relevant to the topic. The latter goes a long ways toward revealing critical data gaps. At the same time models can be an excellent way to sort knowledge into categories based on degree of certainty, and be explicit about assumptions. It is, however, important to note that not all models are transparent about making the assumptions apparent to the user. Lastly, models can document the thinking and rationale for a particular decision—creating a lasting record of the decision process.

1.3 VSP and Recovery

Conserving and rebuilding sustainable salmonid populations is more complicated than simply meeting an arbitrarily determined abundance goal over an equally arbitrary time period. Acknowledging this fact early in the recovery planning process, NOAA Fisheries developed what they refer to as a Viable Salmonid Population, or VSP. Based on the current understanding of population attributes that lead to sustainability, the VSP construct is the goal of ESA recovery. According to McElhany et al. (2000), a VSP is "an independent population of any Pacific salmon (genus Oncorhynchus) that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a 100-year time frame."

McElhany et al. (2000) identify four key parameters for evaluating population viability status: abundance, population growth rate or productivity, population spatial structure, and diversity. Although NOAA Fisheries has chosen not to provide quantitative criteria for each of the parameters, these parameters are measurable and should not be thought of as boxes to be checked on a data sheet with easily defined pass/fail criteria. They are, in fact, critical factors influencing extinction risk. The reason that certain other parameters, such as habitat characteristics and ecological interactions, were not included among the key parameters is that their effects on populations are implicitly expressed in the four key parameters.

1.3.1 Population size

Population size is perhaps the most straightforward of the VSP parameters, and is an important consideration in estimating extinction risk: all other factors equal, a population at low abundance is intrinsically at greater risk of extinction than is a larger one. The primary drivers of this increased risk are the many processes that regulate population dynamics—particularly those that operate differently on small populations. Examples include environmental variation and catastrophes, demographic stochasticity, selected genetic processes, and deterministic density effects. Although the negative interaction between abundance and productivity may protect some small populations, there is obviously a point below which a population is unlikely to persist.

1.3.2 Productivity or population growth rate (λ)

Productivity or population growth rate (λ) is a key measure of population performance in a species' habitat. In simple terms, it describes the degree to which a population is replacing itself. A $\lambda = 1.0$ means that a population is exactly replacing itself (one spawner produces one spawner in the next generation); where as $\lambda = 0.9$ means that the population is declining at a rate of 10 percent annually—a trend that is obviously not sustainable in the long term. Conversely, $\lambda = 1.1$ indicates a population is increasing 10 percent, a circumstance that likewise cannot continue ad infinitum since all habitats have an upper limit or carrying capacity. Over the long term, $\lambda = 1.0$ would indicate that a population is stable, sustainable, and near carry capacity. If one were forced to choose a single parameter to measure the status of a population it would logically be productivity.

1.3.3 Spatial structure

Spatial structure, as the term suggests, refers to the geographic distribution of individuals in a population unit and the processes that generate that distribution. Distributed populations that interact genetically are often referred to as metapopulations. Although the spatial distribution of a population, and thus its metapopulation structure, is influenced by many factors, none are perhaps as important as the quantity, quality, and distribution of habitat. One way to think about the importance or value of a broad geospatial distribution is that a population is less likely to go extinct from a localized catastrophic event or localized environmental perturbations.

1.3.4 Biological diversity

Biological diversity within and among populations of salmon is generally thought to be a key to sustainability. High diversity is often described as nature's way of hedging its bets—a mechanism for dealing with the inevitable fluctuations in environmental conditions: More is better from an extinction-risk perspective.

NOAA Fisheries has been perfectly clear about the importance of the VSP parameters in recovery planning. However, they have been far less clear about minimum levels, "comfort zones," or other points on a curve that they would consider to meet requirements for delisting. In April 2002, the Puget Sound Technical Recovery Team released preliminary guidance and planning ranges for several chinook salmon populations, but did not include the populations in WRIA 9. In the absence of these, the fisheries co-managers have been developing their own "recovery targets," but have not yet made them available to the WRIA 9 Technical Committee. Nonetheless, the VSP attributes will be used, and any analytical tools used to identify and prioritize the preservation or restoration of habitats must take into account how the action contributes to VSP. WRIA 9 has elected to use NOAA Fisheries' VSP guidance in its Strategic Assessment.

2 SUMMARY OF INFORMATION COLLECTED TO DATE IN WRIA 9

The quality of model output is directly linked to the quality of the model inputs. Any model used in the evaluation of functional linkages in WRIA 9 will require inputs on salmonid population and habitat characteristics. These existing data on salmonids and habitat in WRIA 9 will dictate the amount of site-specific information that can be used as model inputs, and will be one indicator of the degree of certainty associated with the model outputs. In addition, existing data sets may be a better fit for some models than others, depending on the required input parameters. At the same time, the availability of empirical data (as distinguished from derived data or model outputs) may suggest alternative approaches to habitat planning. One such approach is summarized in Section 4.1.7: Salmon Ecology and Current versus Historic Habitat Approach (Ecological Synthesis Approach).

The current section provides a summary of chinook population and habitat information that are or will be available as possible inputs for any model or alternative approach used to evaluate functional linkages in WRIA 9. This section is organized primarily to provide an overview of ongoing research and modeling efforts that are underway or planned in WRIA 9. This includes activities being conducted as part of the WRIA 9 Strategic Assessment Work Plan, as well as separate modeling or prioritization efforts that are underway by entities such as King County, City of Seattle (Seattle), NOAA Fisheries, Muckleshoot Indian Tribe (MIT), and the Washington Department of Fish and Wildlife (WDFW). The remainder of the section is an overview of current and historic information on the chinook population and habitats in WRIA 9. Chinook population information is summarized for each of the four key parameters for evaluating a population's viability status (McElhany et al. 2000). Current and historic habitat information was researched to determine the state of the knowledge on habitat quality, quantity, and spatial distribution.

2.1 WRIA 9 Approach

WRIA 9 is preparing a Strategic Assessment to provide the scientific foundation for recommendations in its Habitat Plan. Multiple areas of investigation are underway or planned that will provide key information for understanding conditions in WRIA 9 and contribute to efforts to characterize functional linkages between habitat processes, habitat characteristics, and salmonid survival. The Work Plan for the Strategic Assessment includes three approaches for evaluating conditions in WRIA 9 that can support an evaluation of functional linkages: historical versus current conditions, limiting factors analysis, and an assessment of fish habitat utilization. In addition to the projects conducted as part of the Strategic Assessment, separate efforts by King County, NOAA Fisheries, the MIT, and WDFW focus on salmonids and their habitats in WRIA 9. Following is a brief description of these investigations. More information on the types of data provided by these investigations is provided below in the description of "Existing Data."

The WRIA 9 Strategic Assessment Work Plan lays out an approach for gathering historic and current information on salmonid populations and habitats in the WRIA. Historic and current salmonid population information will be collected or compiled for each of the four key VSP parameters. For example, since 1998 efforts have been underway in the Middle and Lower Green River, estuary, and nearshore to investigate juvenile salmonid utilization. Historic and current habitat information will be compiled or characterized throughout the mainstem Green/Duwamish River, as well as in the estuary and nearshore areas. Using this information, a technical comparison of historic and current conditions will be conducted. This comparison will identify the most significant changes to habitats and evaluate changes in salmonid populations using the VSP parameters. This evaluation has the potential to indicate which VSP parameter(s) have been changed the most, and thus may require more focused efforts for recovery than others.

An evaluation of limiting factors for salmonid survival and fish utilization in WRIA 9 is also underway as part of the Strategic Assessment. The goal of this work is to identify the limiting factors for the various salmonid life stages and consider how these limiting factors may affect the population's viability status. Data gaps identified in this effort will be addressed through the strategic development and implementation of a research framework. This task includes the development of a salmonid survival research framework and a conceptual model for natural Green River chinook.

While these Strategic Assessment projects are being conducted, the WRIA 9 Technical Committee developed a Technical Strategy (June 30, 2003) to help prioritize initial salmonid conservation and recovery actions in the Green/Duwamish River watershed and nearshore areas of WRIA 9. The Technical Strategy outlines three high-priority watershed goals that initial actions should focus on:

- Protect currently functioning habitat and habitat-forming processes from degradation, primarily in the Middle Green River sub-watershed and nearshore areas of Vashon-Maury Islands
- Connect the Upper Green River sub-watershed by restoring access for salmonids
- Restore/enhance habitat that contributes to adequate juvenile salmonid survival, primarily in the Lower Green River, Duwamish River, and nearshore sub-watersheds

In a separate effort, King County has funded an investigation of highly productive areas for salmonids (core areas) in WRIAs 7, 8, and 9. Martin et al. (2002 review draft) have drafted a framework for identifying freshwater, estuarine, and nearshore core areas. The core area concept is an important tool in conservation planning; however, NOAA Fisheries guidance documents do not provide criteria for how they should be identified. The core areas framework provides options for how best to identify core areas in the freshwater, estuary, and nearshore.

NOAA Fisheries is nearing completion of a GIS-based evaluation of historic and current chinook spawning areas. The analysis is intended to quantify potential chinook spawning areas based on stream gradient and channel width (Sanderson, pers. comm.) The differences in historic and current spawning areas are due to barriers to fish passage that now exist and changes in the seral stage of the riparian zone. Inputs to the quantification of spawner capacity include redd density and spawners per redd data based on data from the Skagit and Stillaguamish Rivers. Substrate conditions are not used in the analysis. Separate information on each WRIA is expected to be available online by September 2003. NOAA Fisheries is initiating a similar effort to quantify historic and current juvenile chinook potential capacity.

The MIT has contracted Dr. Ray Hilborn from the University of Washington to develop a salmon population model that has been named SHIRAZ (see review in Section 4.1.3). The SHIRAZ model entails developing a series of functional linkages to be synthesized in a broader characterization of salmonid production. The development of the SHIRAZ model for Green River chinook is nearly finished; however, it will not be released to the public until it is complete (Warner pers. comm.).

WDFW is developing an EDT-Light analysis (see review in Section 4.1.2) of functional linkages in WRIA 9. Their strategy is to use the information that is currently available in the Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP) to population the model. At this time, no model results have been made available to the public (Lakey, pers. comm.).

2.2 Existing Data

2.2.1 Salmonids

The WRIA 9 Strategic Assessment Work Plan has identified a number of tasks that will provide information on current and historic salmonid population characteristics used to evaluate a population's viability. In general, there is some useful current information on all four VSP parameters; however, an overriding issue for most of the information collected to date is the inability to unambiguously distinguish the hatchery produced components from the naturally-spawned components of the returning adult salmonids. For this reason, there is limited understanding of the naturally-spawned salmon contribution to the fish observations. With the implementation of mass marking of all hatchery chinook beginning in 1999, this limitation should be largely resolved.

The term naturally-spawned as used in this report refers to salmon that were spawned and reared in the natural habitat. In this way the term includes fish that are descendents of wild salmon with no hatchery genetic contribution and fish that are descendents of parents with some hatchery production in their lineage.

2.2.1.1 Historic Early 20th Century

The historic conditions described in this report are for salmon runs in the early 20th century. In a more traditional use of the term, historic would refer to the conditions before the colonization by Euro-Americans in the mid-1800s. However, only limited information was identified. The early 20th century conditions described in this report are based on the early 1900s information compiled by Kerwin and Nelson (2000) and the 1938 to 1942 calculations provided by Fuerstenberg et al. (1996).

2.2.1.1.1 Abundance

Kerwin and Nelson (2000) summarize the limited reliable information on historic salmon runs in WRIA 9. Run size, harvest, and spawning escapement data for the Green River are unavailable prior to the mid-1960s (Kerwin and Nelson 2000). The only information on chinook returns to Puget Sound in the early 1900s is commercial and sport harvest data in the Strait of Juan de Fuca and Puget Sound (Kerwin and Nelson 2000). Hatchery records from the Green River Hatchery on Soos Creek (river mile [RM] 34) and from an egg collection facility located at the City of Tacoma's diversion dam (RM 61) provide information that has been used to reconstruct adult returns. The Green River Hatchery on Soos Creek was constructed in 1904, but egg takes began in 1903 for the purpose of obtaining hatchery brood stock and supplying the hatchery with eggs. Based on egg take and literature obtained, fecundity averages, Grette and Salo (1986) calculated adult female returns to the Green River Hatchery on Soos Creek following its construction in 1904. Grette and Salo (1986) calculated that the number of adult female chinook spawned at the Green River Hatchery on Soos Creek ranged from 192 in 1903 to 7,308 in 1935. Kerwin and Nelson (2000) note that it is likely that escapements were underestimated because the weir used to assist the counting effort often washed out.

Estimates of adult returns and smolt production to the Upper Green River basin prior to construction of the dam in 1911 were also compiled by Kerwin and Nelson (2000) and are summarized below. A hatchery facility constructed immediately downstream of the Tacoma Headworks Dam in 1911 operated until 1921. Hatchery records from this facility show that as many as 280 female chinook were spawned annually at the facility (Grette and Salo (1986); Table 1). However, these numbers very likely underestimate the actual run size (Kerwin and Nelson 2000). Based on hatchery records of the number of fish spawning, Grette and Salo (1986) estimated that between 174 and 272 chinook adults returned upstream of the Tacoma Headworks Dam prior to its construction. Grette and Salo (1986) determined that the chinook which spawned at the Tacoma Headworks Dam were a spring chinook stock. Kerwin and Nelson (2000) observed that this conclusion is important because most biologists feel that spring chinook are now extinct, or returning in such low numbers as not to constitute a distinct stock. Further, the holding of a spring chinook stock at the hatchery facility at the Tacoma Headworks Dam would entail a holding period of weeks or months in order for the fish to reach sexual maturation. This is considered likely to have induced a higher mortality rate in the facility's holding pond.

Fuerstenberg et al. (1996 draft) broadly summarizes salmonid abundance and distribution in WRIA 9 during the 1930s. Fuerstenberg et al. estimated the chinook escapement to be 55,197 annually between 1938 and 1942, and 10,300 annually between 1987 and 1991. However, as Kerwin and Nelson (2000) note, no citation was provided for their numbers, nor has the Muckleshoot Indian Tribe agreed to the numbers (R. Malcom pers. comm. as cited in Kerwin and Nelson (2000).

NOAA Fisheries is nearing completion of a GIS-based analysis of potential spawning areas to estimate historic chinook capacity in WRIA 9 and other WRIAs in the Puget Sound region. (Sanderson, pers. comm.) In the nearshore, very little information on chinook distributions is available. Williams et al. (2001) briefly summarize two reports that provide a glimpse of chinook distributions.

2.2.1.1.2 Productivity

No specific information was available on historic productivity in WRIA 9, except for the commercial and sport harvest data from the Strait of Juan de Fuca and Puget Sound (Kerwin and Nelson 2000).

2.2.1.1.3 Genetic/Life History Diversity

Historically the Green/Duwamish watershed had runs of spring and summer/fall chinook; however, the spring run is considered extinct or in such low numbers that it is undetectable. (WDF et al. 1993). Spring chinook runs exist in the White River, which is believed to have moved between the Green and Puyallup River drainages, but has been diverted away from the Green River since 1906 (Kerwin and Nelson 2000).

A general discussion of chinook life history diversity in Kerwin and Nelson (2000) indicates the potential for four life history strategies in the Green/Duwamish watershed:

1. Yearlings that spend over a year in freshwater before migrating to the marine environment
2. Fingerlings that spend months in the freshwater and days in the estuary before migrating to the marine environment
3. Fry/fingerlings that spend days to months in the freshwater and months in the estuary before migrating to the marine environment
4. Emergent fry that spend only days in the freshwater before spending months in the estuary before migrating to the marine environment

Kerwin and Nelson (2000) reported that two of these life strategies are now uncommon or absent from the Green River; the first and the third life strategies are believed no longer to occur in the Green River. Recent research in WRIA 9 suggests that the third life strategy is less common or absent, while the fourth is usually present (Kerwin and Nelson 2000).

2.2.1.1.4 Distribution

NOAA Fisheries is nearing completion of a GIS-based analysis of potential chinook spawning areas in rivers throughout the Puget Sound region, including the Green River (Sanderson pers. comm.). This analysis estimates the uppermost extent of chinook distribution based on channel gradient and channel width. Brian Collins and others at the University of Washington are reconstructing historic channel configurations to be used in the analysis.

2.2.1.2 Current

2.2.1.2.1 Abundance

WDFW and the Tribes have reconstructed chinook spawning escapements and stock-specific harvests since 1968. The harvest estimates are based on commercial harvests in Puget Sound with no consideration of commercial British Columbia or recreational landings. An appendix to Kerwin and Nelson (2000) describes the assumptions and limitations of such a run- reconstruction effort. To account for Green River chinook salmon harvested in fisheries other than commercial net harvests in Puget Sound, NRC (1999) integrated annual distributions of total mortalities (including incidental mortalities) associated with each fishery in each geographic region (PSC 1999) with the WDFW harvest data to reconstruct total annual returns of chinook salmon to the Green River (Kerwin and Nelson 2000).

An effort is underway to reconstruct the naturally-spawned chinook portion of runs and escapements to the mainstem Green River between 1989 and 1997. Prior to 1999, hatchery-produced fish were not mass-marked; therefore, hatchery fish could not be visually distinguished from naturally-spawned fish on the spawning grounds. An investigation of hatchery straying rates between 1989 and 1997 estimated from coded-wire-tag recoveries in hatchery fish on the spawning ground, indicates approximately 56 percent (range 25 to 83 percent) of adults on the spawning ground are of hatchery origin (Cropp, pers. comm. as cited in Kerwin and Nelson 2000). Similarly derived estimates of the contribution of naturally spawned adults to escapement at Soos Creek and Newaukum Creek are 39 percent (range 1 to 76 percent) and 45 percent (range 15 to 79 percent), respectively (Cropp, pers. comm. as cited in Kerwin and Nelson 2000). However, in a separate analysis of coded-wire-tag data from the Green River, the NMFS West Coast Salmon BRT (2003 review draft) estimated that 70 percent of chinook adults on the spawning ground are of hatchery origin.

As part of the WRIA 9 Strategic Assessment Work Plan, juvenile salmonid investigations have been conducted throughout the anadromous zone of the mainstem Green/Duwamish River and the estuary and nearshore in recent years. Juvenile chinook abundance in the Middle Green River has been investigated by R2 Consultants in the years 1998 to 2000 and 2002 as part of a contract with the Seattle District U.S. Army Corps of Engineers. This study also provided information on spatial distribution, habitat use, and growth rates. In the Lower

Green/Duwamish River, juvenile chinook distributions were investigated using a beach seine in 2001 to 2003 by King County. The Port of Seattle has funded juvenile salmonid monitoring in the Duwamish River and Elliott Bay in 1998, 2000, 2002, and 2003. Seattle is monitoring juvenile salmonid utilization of the Seattle Marine shoreline. The Seattle District U.S. Army Corps of Engineers quantified seasonal fish abundance and residence time in off-channel habitats in the Duwamish estuary. Dr. Greg Ruggerone and Eric Volk (NRC and WDFW) are using otolith chemistry and daily growth rings to estimate residence time in the Duwamish estuary and freshwater habitats. King County investigated juvenile salmonid distributions in the nearshore between 2000 and 2002. These investigations, coupled with screw-trap sampling by WDFW since 2000, can provide useful information on all four parameters of population viability identified in McElhany, et al. (2000).

The WDFW screw trap is located on the mainstem at RM 34.5. This location avoids trapping out-migrating hatchery fish from the Green River Hatchery that enter the mainstem via Soos Creek at RM 34.0, but misses that portion of naturally produced chinook from spawning areas lower in the river (Seiler et al. 2002). Malcom (2002) found that between about 10 and 32 percent of spawning occurred in the Lower Green River between 1998 and 2000. Seiler et al. (2002) prepared an estimate of juvenile chinook abundance in the entire Green/Duwamish River using the assumption that one-third of the chinook spawning occurred downstream of the mainstem screw trap. In 2000, WDFW operated a smaller screw trap at RM 0.8 on Soos Creek, just upstream of the hatchery, to estimate natural production in the tributary. Seiler et al. (2002) estimated that approximately 25 percent of the total natural production in the Green/Duwamish came from Soos Creek, where excess hatchery adults are released to spawn above the hatchery.

2.2.1.2.2 Productivity

Information to estimate trends in productivity of Green River chinook salmon are available from data on both juveniles and adults. Trends in productivity of adult chinook salmon are available based on spawning ground surveys conducted by WDFW and the MIT since 1968. Analysis by NRC (1999) provides an estimate of annual chinook returns to the Green River since 1968. Using WDFW and MIT spawning run data gathered from 1986 to 1997, Kerwin and Nelson concluded that escapements of more than 6,060 fish tended to result in a higher percentage of returns in subsequent generations than did smaller escapements (Kerwin and Nelson, 2000).

Data on juvenile chinook downstream migrants from the WDFW screw traps on the mainstem and Soos Creek provide good information on productivity in the Middle Green River and tributaries. Seiler et al. (2002) estimated egg-to-migrant survival as 7.3 percent for chinook above the mainstem trap and 3.8 percent for chinook in Soos Creek. It is hypothesized that the reduced survival rate in Soos Creek is due to redd superimposition. Such estimates will be possible for each year the screw traps are operated.

2.2.1.2.3 Genetic/Life History Diversity

Chinook salmon in the Green River consist primarily of summer/fall run fish (Kerwin and Nelson 2000). Historically, a spring run has occurred in the watershed, but the diversion of the White River to the Puyallup River, the re-routing of Lake Washington and Cedar River to the Ship Canal, the construction of the Tacoma Headworks Dam, and the construction of the Howard Hanson Dam have combined to eliminate access to much of the headwater habitat typically needed by spring chinook (Grette and Salo [1986] as cited in Kerwin and Nelson (2000)). A general discussion of chinook life history diversity in an appendix to Kerwin and Nelson (2000) characterizes the abundance of the fingerling rearing trajectory (described in Section 2.2.1.1.3) of fingerlings (>70 mm) as abundant, and fry/fingerlings (45mm to 70 mm) as present. The emergent fry and yearling life history trajectories were characterized as uncommon. In a comparison of WDFW screw trap data and beach seine sampling in the Lower Green River at RM 12.7, Nelson and Boles (review draft 2003) report that a reasonable period for naturally-spawned 0+ chinook rearing in the Lower Green River ranges from a few days to five months. Age data from returning adults are available from 1980 to present. This information is available through the WDFW and is based on scale analysis.

Recent juvenile chinook investigations, such as Seiler et al. (2002), Nelson and Boles (2003), and data from unpublished data collected by King County, in the Middle Green, Lower Green/Duwamish, estuary, and nearshore areas of WRIA 9 provide useful information on life history diversity. Analysis of data collected at the WDFW screw traps indicated bimodal timing distribution for natural 0+ chinook (Seiler et al. 2002). An early peak of small juveniles (average fork length 40 mm) moved past the trap between late February and early March, while a second peak of larger smolt outmigrants (average fork length 72 mm) occurred from early May to early June. Seiler et al. (2002) estimated that in 2000, 76 percent of the naturally produced chinook migrated as fry and 24 percent as smolts (fingerlings).

Kerwin and Nelson (2000) provide a summary of available information on the genetic diversity of salmonids in the Green River. Of the 44 percent of natural spawners determined not to be of hatchery origin (based on coded wire tag studies between 1989 and 1997), it is not possible to determine what portion does not have any hatchery genetic contribution in its ancestry (Kerwin and Nelson 2000). Coded wire tag recovery efforts have continued since 1998.

Green River chinook are generally very similar to a number of hatchery-bred and naturally spawning stocks distributed throughout Puget Sound (Kerwin and Nelson 2000). However, there have been no significant transfers of other chinook stocks into the Green River. Genetic analysis of chinook spawning naturally in Newaukum Creek indicates they are genetically identical to Green River Hatchery fish. One indication of possible changes in genetic frequencies over time is the apparent shift in return timing of chinook from the Green River Hatchery on Soos Creek. Over a 38-year period, the timing of returns has shifted one week earlier. Although this is a minor shift, it could be significant in terms of genetic integrity due to the commingling of large numbers of hatchery-bred and naturally-spawned chinook on the spawning grounds; it may also have led to a shift in spawning time and fry emergence.

2.2.1.2.4 Spatial Distribution

The spatial extent of chinook distributions in WRIA 9 is presented in Kerwin and Nelson (2000); however, the authors acknowledge the potential for underestimation of distribution in small tributaries due to limited observations. Freshwater distributions of chinook have been described based on the collective knowledge of participants in the WRIA 9 mapping project.

Data on chinook distribution and utilization within the anadromous zone is available from the spawning ground database compiled by WDFW and the MIT. Chinook spawn naturally in the Middle Green River and upper portions of the Lower Green River mainstem (above approximately RM 24), as well as in Soos and Newaukum creeks which enter the mainstem at RM 34 and 40.7, respectively (Kerwin and Nelson 2000). Malcom (2002) drafted an analysis of the annual variation in the distribution of spawning chinook in the mainstem Green River using data from 1997 to 2000. This analysis includes estimates of spawner densities in 0 to 2 mile reaches of the mainstem.

The Tacoma Headworks, completed in 1913 and located at RM 61, blocked fish passage to the Upper Green River. As part of the Tacoma Water Habitat Conservation Plan (HCP), an adult fish passage facility will be put in place to truck migrating adult salmon upstream from a collection facility at RM 61 to the upper end of the Howard Hanson Dam Reservoir. (RM 72; USFWS and NMFS 2001) Since 1982, large numbers of juvenile salmon and steelhead have been released annually in the Upper Green River above the Howard Hanson Dam (RM 64.5; Kerwin and Nelson 2000). Kerwin and Nelson (2000) summarize the operation and success of these planting efforts.

Recent investigations in the Middle Green and Lower Green/Duwamish River, such as Seiler et al. (2002), and Nelson and Boles (2003) provide useful information on the spatial distributions and habitats utilized by juvenile chinook in the river. In addition, investigations of estuarine and nearshore salmonid distributions have been conducted by King County, the U.S. Army Corps of Engineers, and the Port of Seattle. As part of the core areas work for King County, juvenile chinook salmon distributions in the nearshore waters of Vashon Island were investigated in 2002 (Martin Environmental and Shreffler Environmental 2002).

2.2.2 Habitat

2.2.2.1 Historic

Historic alterations to the "plumbing" of rivers in WRIA 8, 9, and 10 are summarized in Kerwin and Nelson (2000). As part of the WRIA 9 Strategic Assessment Work Plan, Collins et al. at the University of Washington are preparing the historical aquatic habitats in the Middle Green River, the Lower Green/Duwamish River, and estuary. In a similar investigation of North Puget Sound watersheds, Collins and Sheikh (2003) used GIS to map historical channel and vegetation communities during the early Euro-American settlement, or approximately 1870-1880. The Strategic Assessment Work Plan includes additional analysis of the Upper Green River and nearshore portions of WRIA 9, but these tasks are not yet underway. NOAA Fisheries is just beginning an analysis to quantify historic juvenile chinook potential that will rely upon the work of Collins et al. (Sanderson pers. comm.).

2.2.2.2 Current

An overview of habitat conditions in the Green/Duwamish River, including water quality, is contained in an appendix to Kerwin and Nelson (2000). The current quantity, quality, and distribution of fish habitat in WRIA 9 have been investigated in a series of studies that have been recently completed or are nearing completion. These studies extend from the Upper Green River to the Duwamish estuary. Additional assessment in the nearshore portions of WRIA 9 is planned. A baseline assessment of instream habitats in the Middle Green (RM 64.5 to RM 32) was conducted in 2001 (R2 2002). Anchor Environmental is currently conducting a similar assessment in the Lower Green/Duwamish River (RM 32 to 6). These baseline assessments provide data on distribution of habitat types, pool characteristics, riparian conditions, large woody debris/log jams, and shoreline connectivity to the riparian zone. Data are available every 300 m with summary statistics provided at the reach level, with reaches generally ranging in length from three to 12 miles, depending on river homogeneity.

As part of efforts to expand water storage behind the Howard Hanson Dam, the U.S. Army Corps of Engineers conducted an analysis of side channel habitats in the Green River. The study identified side channel habitats below the dam and the impact of river flow levels for side channel connectivity and surface area (USACE 1998). Fifty-nine side channels were evaluated between RM 34 and 61.

A Habitat Conservation Plan (HCP) sponsored by Tacoma Water was approved in 2001. The HCP establishes a flow regime for the river to maintain minimum flows, in consideration of salmonid needs, throughout the year. The HCP has a term of 50 years. Water quantity conditions are also being evaluated as part of the WRIA 9 Strategic Assessment Work Plan.

Water quality conditions are being assessed and modeled to identify where water quality may be a factor in the decline of salmon. An ongoing assessment has prepared an estuarine model from RM 12 to Elliott Bay. Additional research will focus on temperature, dissolved oxygen, fine sediments, metals, and fecal coliform. A Water Quality Assessment of combined sewer overflows in the Duwamish River and Elliott Bay was completed in 1999 (DREBWQAT 1999).

2.3 Data Gaps and Uncertainties

Until recently, a primary limitation to understanding the condition of the natural chinook salmon population in WRIA 9 has been the inability to distinguish hatchery fish from naturally produced fish. Therefore, spawning ground data probably overestimate the numbers of naturally produced spawners because spawning ground estimates include progeny of naturally spawning parents that return to the spawning ground, plus hatchery fish that may stray to the spawning grounds. In the NMFS status review for chinook, Myers et al. (1998) cited the uncertainty of hatchery strays on natural chinook production as one of the key concerns leading to the ESA listing of Puget Sound chinook. Observations on the percentage of hatchery and naturally-spawned salmon on the spawning grounds will be collected, starting in 2003, through the mass marking of chinook produced in hatcheries starting in 1999. Future data collection efforts should be able to better distinguish between hatchery fish and naturally produced adults on the spawning ground.

Additional information is needed on survival rates among salmonid life stages from the time of egg deposition up to their movement from the nearshore areas of Puget Sound to the ocean.

Recently initiated investigations (i.e., within the last five years) and the implementation of mass marking of hatchery-produced juvenile chinook will contribute greatly to identify data gaps in WRIA 9. However, due to the short time frame of the databases and the fact that they were collected during a period of reduced salmon returns with unknown hatchery contribution to observed patterns there remains a moderate level of uncertainty regarding the naturally produced chinook population in WRIA 9. As studies in the WRIA continue to create longer-term databases and the contribution of hatchery and naturally produced individuals are distinguished, the understanding of chinook population in WRIA 9 will be greatly enhanced.

3 GENERAL APPROACH TO REVIEWING MODELS

3.1 Model Selection

Six models were selected for coarse-scale review and comparison: EDT, EDT-Light, SHIRAZ, QHA, SWAM, and CRI. These were selected based on their stated purpose, history of use, and potential for use in WRIA 9. At an early stage in this project, this list was vetted with the WRIA 9 Technical Committee Subgroup and agreed to as representing the approaches under consideration. However, as the review progressed it became apparent that an approach which incorporated information from multiple sources should also be considered. The Ecological Synthesis Approach utilizes a combination of empirical data on population biology, model outputs, and current versus historic comparisons to generate conservation hypothesis. This approach takes full advantage of the hypotheses developed by the ongoing WRIA 9 Research Framework project.

3.2 Sources of Information

In reviewing each model we obtained information from a variety of sources, including published manuscripts, users' manuals, descriptions from web pages, application reports, and—in most cases—discussions with the model developers and users or clients. A critique of each model's application to watersheds other than WRIA 9 is beyond the scope of this project.

3.3 Approach

In the sections below, we briefly review the history of the model, and present a brief description of its conceptual basis and how it "works." Ultimately, each of the models is compared and contrasted using the following criteria designed to provide a uniform assessment of their potential to contribute to the development of a habitat plan for WRIA 9. The WRIA 9 Technical Committee Subgroup reviewed these screening criteria at an early stage of this project.

- Can the tool use existing information or does it require the collection of new information?
- Does the tool use primary or derived data? Does it distinguish between the two?
- Can the tool provide output that is relevant to the determination of VSP (abundance, productivity, life history diversity, spatial distribution)?

- What are the model's definitions for abundance, productivity, life history, and spatial distribution?
- How does the model factor in abundance, productivity, diversity, and spatial structure in predicting its results?
- Can the tool accommodate different harvest rates?
- Can the tool accommodate the full range of anthropogenic effects on habitat (chemical contaminants, temperature changes, barriers, etc.)?
- Can the tool distinguish between hatchery and natural production?
- How does the model define natural production?
- Does the model factor in straying rates?
- Does the tool distinguish among changes in freshwater, estuarine and marine conditions and their effects on productivity?
- Can the tool be applied in freshwater, estuarine, and nearshore environments?
- Can the tool be used to identify and prioritize recovery actions, and gauge progress toward recovery?
- Does the tool give a confidence interval or a measure of uncertainty for prioritized actions?
- Does the tool give a range for projected abundance levels and productivity rates?
- Does the tool consider extinction risk in evaluating and prioritizing recovery actions?
- Has the output from the tool been validated against empirical information?
- Is the way the tool "works" transparent to the user and easily understood by a decision maker and the informed public?
- Is the tool in the public domain?
- Can a third party "run" the model, and use the results in an adaptive management framework?
- How long does it take to apply the tool?
- How much does it cost to apply the tool?

4 RESULTS

4.1 Model Summaries and Comparisons

4.1.1 Ecosystem Diagnosis and Treatment (EDT)

The Ecosystem Diagnosis and Treatment (EDT) method was developed by Mobrand Biometrics, Inc. (MBI) to "provide a practical, science-based approach for developing and implementing watershed plans." It was designed with the intent to simultaneously consider and evaluate linkages between habitat and salmon productivity, capacity, life history diversity (Mobrand et al. 1997). According to MBI, "it should be used to identify key limiting factors (their nature and location) and to identify those enhancement actions most likely to achieve specified biological objectives for a target population." The appropriate role of EDT is thus in the initial design of an enhancement project, in the design of a monitoring and evaluation plan for such a project, and in refinement or revision of a project after a significant amount of monitoring and evaluation data has been collected" (MBI 2002a). To a limited extent, EDT also considers spatial distribution of populations by tracking them in a geospatial environment, but does not explicitly deal with metapopulation structure. Ultimately, the intent of EDT is to link potential resource management actions (i.e., habitat manipulations) to three of the four VSP parameters: productivity, abundance, and diversity. However, this requires the user to translate potential recovery actions into changes in model inputs, a task that is speculative for many actions (e.g., riparian buffers) and environmental attributes (e.g., water quality).

The EDT method was developed in the mid 1990s through applications of the approach to watersheds in the Columbia River basin. According to the MBI web page (www.mobrand.com), "EDT has been used to develop fish and wildlife plans for the Grande Ronde and Deschutes rivers in Oregon, the Clark Fork River in Montana, and the Cowlitz, Yakima, and Nisqually rivers in Washington." More recently it has been applied to the Snohomish, Puyallup and other Puget Sound watersheds, and it is now being applied to the Lake Washington/Cedar River/Sammamish watershed (WRIA 8). It is a popular model because it addresses some of the key issues of watershed planning, including habitat restoration and protection of key habitats. Although EDT is a relatively new salmon habitat model, it is the oldest of the models considered in this report and it has been applied to many more locations in the Pacific Northwest than have other models.

A number of reports and documents have been produced by MBI to describe EDT, including its general concept, basics of the analytical framework, and functional relationships linking landscape and habitat features to the salmon performance criteria (productivity, capacity, diversity). In addition there are several MBI reports presenting the results of EDT's application to Pacific Northwest watersheds (e.g., MBI 2001a describes results for the Puyallup watershed). Although these documents are useful for gaining insight into the EDT approach, it is important to note that a comprehensive users' manual has not been released to the public.

4.1.1.1 EDT Model Concept

EDT is a scientific model that links physical habitat to biological performance of salmon populations (MBI 2002b). Importantly, EDT is considered a working hypothesis and not necessarily a final product of how habitat and other factors affect salmon populations. As noted by Dr. Lars Mobrand (pers. comm.), "we must have insightful models to generate meaningful hypotheses that, in turn, must be tested and revised by statistical models" (i.e., empirical based correlations). In other words, it is important *not* to view the EDT model as a highly accurate representation of factors affecting salmon populations. Also, EDT was not designed to predict year-to-year abundances in adults. Instead, MBI (2002a) noted that "the precise degree of impact of a change in habitat on a population may not be as important as knowing the relative impact (compared to other environmental alterations) and the kinds of environmental changes necessary to improve (or degrade) performance to some specific degree." MBI (2002a) noted that they use EDT to "guide land and water use management for the benefit of fish, not to manage fish populations." Although Mobrand noted that it is important to test models like EDT with empirical evidence, output from EDT has only been quantitatively tested once. (The results were favorable: Yakima River adult salmon. Mobrand, pers. comm.) In comparison, other scientific models discussed below have not been tested with empirical data, whereas statistical models (e.g., SWAM) are generated from empirical data and can provide a measure of confidence.

In simple terms, EDT draws upon an environmental database and a set of mathematical algorithms to compute productivity, capacity, and life history diversity parameters for the targeted population. EDT does not predict fish abundance through successive life stages and regions, nor does it produce a time series of population abundance. Moreover, EDT does not attempt to derive a fundamental property of population performance from observations or relationships. Importantly, "EDT assumes that all such relationships are known and states them explicitly" (see comment below on EDT rules). The computer and EDT model are used to integrate many individually simple premises (see below) and to deduce their implications in terms of productivity, capacity, and life history diversity. The effects of cumulative changes in habitat can be assessed. EDT can predict these performance variables based on input of current, historical, or hypothetical environmental conditions. Thus, in some Puget Sound watersheds, EDT has been used to estimate the spawning capacity of selected habitats prior to European intervention.

The EDT model is deterministic (i.e., the mathematical relationships used by EDT are assumed to represent the underlying mean (or normal) values of the relationship after excluding "noise" produced by year-to-year variability and measurement error). Stochastic variation is an important reality of our world, yet it is not part of EDT. Stochastic variation influences the precision about the underlying mean relationship. "Noisy" relationships (low precision) suggest that we have less certainty about mean values (i.e., the relationship is less predictable). The deterministic nature of EDT implies that each underlying relationship has the same level of certainty or predictability even though empirical observations indicate they do not. Nevertheless, as part of the EDT process, notes are recorded about the level of confidence for each deterministic relationship. The inability of EDT to address stochastic variability may or may not be an important issue depending on how stochastic variability in the real world influences the variety of underlying relationships.

4.1.1.2 Model Description

The mathematical construct underlying EDT is the Beverton-Holt stock-recruitment model[1] (Figure 1) (Beverton and Holt 1957). The Beverton-Holt model is commonly applied to lesser abundant salmon species, such as chinook salmon, and many marine fish species. (A similar mathematical construct, the Ricker Model, is often applied to more abundant species like sockeye and pink salmon.) The Beverton-Holt model describes the relationship between spawners and the number of progeny (adults) that survive to return to the natal river (typically before harvests). As shown in Figure 1, both productivity and capacity of a salmon population can be described by the function. Productivity is the slope of the curve when the population is near zero (i.e., productivity is a measure of survival at low population density). Its value is therefore considered independent of population size and is dependent on environmental quality. As population size increases, survival will decline in response to density-dependent factors leading to the leveling off of recruitment as the population reaches maximum size. Capacity is the asymptote of the curve and it describes maximum population size. Both productivity and capacity can be measured from empirical data using the Beverton-Holt equation (see Moussalli and Hilborn 1986).

EDT utilizes a finding by Moussalli and Hilborn (1986) showing that "if the life history of a population consists of a sequence of density-dependent stages linked by density-independent survival rates, and if the density-dependent stages take the form of the Beverton-Holt stock recruitment curve, then a single Beverton-Holt curve will describe the entire life history." EDT therefore assumes that each life stage of salmon can be described by the Beverton-Holt function and that the cumulative recruitment function is also described by the Beverton-Holt function. This assumption is generally reasonable, but there are examples in the literature where density-dependent stages might not take the form of a Beverton-Holt curve. One such example is when predation on salmon fry is depensatory (i.e., the proportion of a population killed decreases with increasing population size)—a trend that can lead to extinction [Peterman and Gatto 1978]). A sigmoid functional response of a

[1] The Beverton-Holt and Ricker stock-recruitment relationships are often referred to as models, curves, or functions. These terms are used interchangeably in the literature and in this report, but they all refer to the mathematical relationship developed by Beverton-Holt and Ricker.

predator can also trap a population at low levels. Depensatory mortality and population traps are more likely to occur when population levels are low, especially among populations listed as threatened or endangered. It is also important to note that there is considerable variability in the recruitment curve, which might be explained by underlying relationships if they were known. An example of this variability for a spawner-recruitment curve for natural Green River chinook salmon is shown in Figure 2.

Thus, a series of recruitment curves underlies the EDT model, representing each life stage of each life history trajectory[2]. Although cumulative productivity throughout these life stages is independent of population size, capacity is calculated from both productivities and capacities of each life stage (see Moussalli and Hilborn 1986 or Mobrand et al. 1997 for equation). In other words, capacity is influenced by both environmental quantity and quality, whereas productivity is influenced only by environmental quality.

4.1.1.3 Linkages Between Salmon Productivities and Habitat

For a given reach [3], productivity (P) for a given life stage is calculated from a set of 16 "independent" multiplicative survival factors (F_i):

$$P = P_0 \cdot F_1 \cdot F_2 \cdot \cdot \cdot \cdot F_{16}$$

—where $0 < F_i < 1$, and P_0 is the maximum productivity for the life stage (MBI 2002b). Because maximum productivity of a given life stage is not known, MBI uses expert opinion (based on interviews with fishery biologists) to estimate potential maximum survival rates for each life stage under optimal, low-density conditions. Values of P_0 for Columbia River chinook salmon are shown in Table 2. For example, productivity (survival) of 0-age transient rearing chinook fry is 36 percent, that of 0-age resident rearing fry is 70 percent, and that of 0-age migrant is 96 percent. These values, which are derived from expert opinion, establish the maximum potential survival

[2] *Trajectory* refers to the various life history patterns of chinook salmon, including stream type (i.e., yearling migrants) and ocean type (age-0 migrants). Ocean type chinook may have additional trajectories that differ according to residence time and location of residence in freshwater.

[3] *Reach* is a user-defined area with somewhat homogeneous characteristics.

rates of each life stage under optimal habitat conditions. MBI (2002b) does not explain, for example, what causes 64 percent mortality of the 0-age transient rearing chinook fry, but presumably justification for this level of unexplained mortality is provided in the model notes. The 16 independent survival factors (F_i) lower the survival depending on quality of the habitat as defined by the rules associated with each survival factor (F_i).

The 16 "Level 3" survival factors (F_i) are listed in Table 3; each factor can potentially influence each salmon life stage. As previously noted, these estimates are assumed to be at low population density, and population density has an additional reduction cost that is dependent on the capacity of the reach (see capacity below). Importantly, few or no empirical relationships exist between survival and many of these factors; the effect on fish is an indirect effect rather than a direct one. Thus, the survival effect can be difficult to empirically quantify.

EDT has a multiple-step process that leads to the Level 3 survival factors. At the bottom of the information pyramid are "Level 1" environmental descriptions such as location, dimensions, land use, land cover, and biotic and abiotic environmental data (MBI 2002b)[4]. Level 1 data are used to characterize the ecosystem in terms of "ecological attributes or correlates." Finally, a predetermined suite of "Level 2 environmental attributes" are used to calculate Level 3 survival factors. All together, EDT utilizes 46 Level 2 correlates in order to calculate the 16 survival factors. For example, Level 3 Predation is influenced by the following Level 2 Environmental Correlates: predation risk (primary correlate), fish community richness, fish species introductions, temperature, and hatchery outplants. Each of the 46 Level 2 correlates have a ranking from 0 to 4 where 0 indicates little or no effect and 4 signifies severe impact on *relative* survival. For those few attributes where detailed relationships may be available, the user can assign a decimal to the ranking (e.g., "3.3" instead of "3") (MBI 2003b). Sensitivity analyses can be run to determine whether these finer-scale ratings make a difference in model results. Each ranking is associated with a unique survival value (referred to as "sensitivities" and expressed as a percentage). All Level 2 correlates are combined using an exponential function that associates

[4] There is little description of Level 1 variables in the reports. Variable identification begins with Level 2 and Level 3.

greater mortality with rankings of 3 and 4. MBI (2001b) notes that this exponential function should be replaced with statistically established correlations as more information becomes available.

In summary, the model user selects what they believe is an appropriate ranking (0-4) for each Level 2 correlate in each river reach, based on categorical definitions for each ranking for each correlate. Level 2 correlates have predetermined default survival values that are combined in an exponential function to estimate each of the 16 Level 3 survival factors (F_i). The 16 F_i survival factors and the maximum survival value (P_0) are then multiplied to calculate the productivity for the life stage in the given reach. As described, EDT appears to be a very data-intensive process. The functional relationships between habitat and survival are known as the model "rules." These rules are reportedly derived from the technical literature when possible. But few or no empirical data exist for many of the rules, and the rules are often based on expert opinion. Many of the rules can be viewed in an unpublished document located online (www.edhome.org/rules.htm). Relationships between survival and habitat features and the initial benchmark survival values (Table 3) have been the subject of considerable scientific debate.

Many of the survival values or rules used in EDT (i.e., values assigned to the 0 to 4 rankings) are based on expert opinion. This introduces a source of potential bias and error, as in many cases there is disagreement among biologists regarding the relative importance of, for example, different mortality factors. In such cases, ranges in the ranking of controversial values can be used for input. Although acknowledging the weakness of expert opinion, MBI notes that the expert-opinion approach "avoids the burden of proof associated with purely statistical analyses and avoids the dilemma of not having enough data." The survival values are supposed to be independent of population size, but obviously it can be difficult to study survival when few fish are available. When possible, EDT incorporates values derived from empirical studies published in the scientific literature. As an example of this, MBI (2001b) shows the relationship between percent fines in spawning sediment and survival. This is one of the few examples in the literature where habitat quality has been empirically related to salmon survival. However, the rules do not incorporate the uncertainty in the relationships even when empirical studies describe this uncertainty. As part of the EDT process, notes are recorded about the "level of proof," for each Level 2 correlate (1 = well accepted empirical evidence; 4 = speculative), and whether rule is based on categorical or continuous data. Furthermore, notes about the data and assumptions that can be made are also documented (e.g., "no water temperature data available for Creek *A*, so values from adjacent Creek *B* used").

Key Habitat is listed as one of 16 Level-3 survival factors, but it is actually a process for weighing habitat types in a reach (pools versus glides, etc.) that are most supportive of that life stage (G. Blair, pers. comm.). Key habitat is used in the capacity calculation.

Like that of SHIRAZ, model output from EDT is dependent upon the accuracy of the key functional relationships. This raises a question with regard to scientific models: Should a model incorporate a functional relationship if it is not accurately known, or should models include numerous relationships that may have some effect on salmon survival but for which the quantitative relationships are poorly understood? This issue continues to engender discussion.

4.1.1.4 Linkages Between Habitat and Salmon Capacity

As noted above, cumulative capacity for a watershed is related to both the capacities and productivities of each reach. Cumulative capacity can be calculated through rearrangement of the Beverton-Holt function as shown by Moussalli and Hilborn (1986).

MBI (1999) states "the capacity parameter for the trajectory segment is computed from reach width, percent of key habitat (within a reach), a food quality rating, segment productivity, and density for the life stage. First, the weekly benchmark density at the beginning of the segment is back calculated, correcting for change in size of fish during life stage (the model includes a size versus density function). Segment capacity is then calculated as the cumulative capacity for the segment duration" using the Beverton-Holt function and "including a multiplicative adjustment for percent of key habitat, reach width and food factor." Reach length is also utilized in the capacity calculations. Mobrand noted that the process used to calculate capacity is similar to that used to calculate productivity (pers. comm.).

However, there was little documentation for the capacity calculations provided in the EDT materials we reviewed. For example, documentation for the rule for the "food quality rating" was not found. Moreover, EDT capacity calculations utilize a maximum fish density as a starting point for each life stage, but such values were not available in the documents we reviewed. On the other hand, the fish capacity issue can be especially difficult to quantify for chinook salmon because there are many potential life histories, some of which may be behaviorally modified. A strength of EDT is that it can keep track of different life history trajectories, and is able to incorporate a total capacity estimate when two or more trajectories overlap in the same habitat (e.g., fry and fingerling migrants in the estuary) (G. Blair, pers. comm.).

4.1.1.5 Application of Model Selection Criteria

The Project Team and the WRIA 9 modeling subcommittee developed a set of criteria (in the form of questions) to compare and contrast the models, and to assist the WRIA 9 Technical Team in its assessment of the added value of using one or more of the habitat models to support decision making. A summary of these results is shown in Table 4.

The primary goal of EDT is to examine the relationship between habitat quantity and quality and viable salmon population criteria. In WRIA 9, some existing data could be used, including data available from WDFW's SSHIAP database, additional data recorded in King County reports, and new data collected through the historical conditions reports. Importantly, EDT "rules" linking salmon habitat in the estuary and nearshore marine habitats have not been developed, although MBI is currently working on these rules (estuarine rules possibly completed in February 2004; nearshore later). As with most freshwater rules, the new rules for estuarine and nearshore habitats will be based on expert opinion. Mobrand noted that the capacity of Puget Sound and estuaries will be much larger and therefore productivities in these habitats will likely drive the models. Data collected as part of the King County funded "CORE Areas" study could be useful in this regard, but early findings of this study highlighted difficulty in associating salmon abundance with habitat features in nearshore marine areas.

Key model outputs are capacity, productivity, and life history diversity (performance criteria). Life history diversity is shown as the percentage of each trajectory surviving to adult stage. Spatial distribution is not a readily quantifiable characteristic of VSP. However, spatial distribution is implicit within the input data and output results of EDT (i.e., reach-by-reach plots). The model also provides reach-by-reach graphs that highlight reaches which have the highest potential for restoration and protection. These plots are undoubtedly very appealing to land-use planners. The model can be run to incorporate the effects of harvest, chemical contamination, temperature, and barriers, but the output is predicated on the assumptions built into the model (e.g., the rule for how chemical contamination affects survival of a specific life stage). "What if"-type scenarios regarding shifts in ocean productivity can be run using EDT. The contribution of hatchery fish to natural spawners in the river can be modeled and factors can be developed to examine first generation effects of reduced fitness, if rules are developed. EDT can treat hatchery and natural chinook as separate stocks and can model competition effects based on certain assumptions. However, the model does not define "natural" salmon. Factors associated with fish barriers (e.g., passage survival, predation) can be addressed with EDT. EDT does not evaluate the risk or probability of extinction because it is a steady-state, deterministic model as opposed to a simulation model such as SHIRAZ. However, if the user alters habitat conditions so that habitat quality is exceptionally low, EDT can produce values that indicate extinction of all or individual trajectories.

The cost of running EDT in WRIA 9 is difficult to estimate. Since EDT is not in the public domain, a potential user would have to negotiate price with MBI. Lars Mobrand noted in our interview with him that the cost to run EDT on 6-7 small chum streams in southern Puget Sound was approximately $30,000, or approximately $230 per reach. These cost estimates may not be applicable to WRIA 9.

The cost to run EDT for WRIA 8 (Cedar/Sammamish Basin) was approximately $220,000 for chinook and coho streams and habitats, but this entailed extensive data collection, workshops involving multiple agencies and organizations, and training to run the model on the web-based program. The training will enable WRIA 8 members to change environmental attributes and run new model scenarios, but it will not address how to change either underlying rules or benchmark survival values (J. Hall, pers. comm..). Application of EDT in WRIA 8 is probably more complex and costly than it would be in WRIA 9.

An attractive aspect of using EDT in WRIA 9 is that it has been used in all but two watersheds in Puget Sound, and many of the "bugs" have been fixed. Also, virtually all of the freshwater "rules" have been developed; therefore agencies do not need to spend time with this very time consuming aspect of EDT. Also, EDT can be used even in the face of limited information on habitat attributes and conditions. When empirical data are not available, EDT relies on expert opinion and extrapolation of information from adjacent or similar reaches for inputs on habitat quality. However, some field data collection is typically needed to help verify some of the assumptions. Importantly, EDT produces answers to key questions that are quite relevant to the needs of land-use managers. It integrates the cumulative impacts of land-use decisions. Often EDT is run using current conditions, and then compared with results using historic (template) conditions in order to approximate how changes in habitat have influenced salmon performance.

EDT also has several limitations. As noted above, the model is not in the public domain; applying the model and subsequent scenario testing requires a contract with MBI. Recently, MBI developed an online version of EDT that can be accessed by registered users (MBI 2003a, b)[5]. Authorized sub-basin work group members can edit the habitat attribute datasets and run new model scenarios from their personal computers. As a scientific model, EDT is built upon assumptions about how habitat affects salmon survival, and these assumptions are less visible to users. Compared with many scientific models, EDT has an exceptionally large number of input

[5] Web-based EDT models for the Nisqually and Puyallup watersheds are available for registered users (www.mobrand.com/edt/accounts/register.jsp). The public can access the models, but they cannot alter datasets or run new scenarios.

parameters (e.g., for each life stage: 16 Level 3 survival factors that are based on 46 Level 2 environmental correlates). Most of these relationships are based on expert opinion, with the most critical assumptions being about how habitat affects survival and capacity. Mobrand noted that in most applications, approximately 80 percent of the habitat variables are neutral, having no effect on outcome. However, the variables that are neutral do tend to vary between watersheds (e.g., neutral factors in WRIA 8 might be important factors in WRIA 9). Although a number of useful reports on EDT have been compiled, there is not a single comprehensive report that documents the details of EDT, including rules that would allow technicians to fully understand how it works. Nevertheless, EDT documentation and model function continue to improve, and we note the recent addition of the web-based EDT.

In our discussion with Mobrand, we asked several questions about results of comparisons of model outputs to independently collected empirical data. Mobrand indicated that EDT has not been extensively field tested or verified, except for adult spawners on the Yakima River (MBI 2002a). MBI (2002a) evaluated EDT by applying observed spawner abundance to a Beverton-Holt function derived from EDT and compared results with observed values. The authors concluded that EDT performed reasonably well for both estimates of smolts and adults.

EDT has been the subject of at least two scientific reviews, with mixed results. In the less critical of the two, the Independent Scientific Advisory Board (ISAB) concluded that EDT by itself was not comprehensive enough to serve as the sole support tool for conservation planning in the Columbia River basin, but that its real strength was in "formulating working hypotheses." A second review by the National Marine Fisheries Service' (NMFS 2000) Salmon Recovery Science Review Panel (RSRP) was exceptionally critical:

> *"EDT exemplifies how modeling should not be done. It is over-parameterized, includes key functional relationships that cannot be known and cannot be tested, creates a false sense of accuracy, yet introduces error and uncertainty. Its very complexity makes it difficult to determine the effect of various assumptions and parameter values on the model's behavior and relation to data. The attempt at quantification through subjective*

'expert opinion' compounds these fatal weaknesses, especially the model's inability to confront and improve with confrontation of data."

The review panel recommended continuing development of various modeling approaches in combination with experiments involving factors influencing survival. Since these reviews, EDT has undergone some revisions and has been applied to numerous watersheds in the Columbia River and Puget Sound.

4.1.2 EDT-Light

EDT-Light was developed by MBI as a more streamlined version of EDT that is quicker and less costly to apply. EDT-Light is based on the same model framework as EDT and the output is essentially the same. All Level 3 survival factors and rules that link habitat to survival are the same. The primary difference between the two models is that EDT-Light is based even more on expert opinion for input of quality and quantity of habitat. As a result, EDT-Light requires less time and effort to implement. EDT-Light also assigns priority labels to the 46 Level 2 Environmental Correlates. These priority labels are defined as follows (Lestelle and Blair 2000):

Global: attributes that should be completed in all reaches
High: attributes that should be reviewed and would apply to most reaches
Low: attributes that may apply in a few circumstances but probably have low importance
Unique: attributes that would apply in unique circumstances, may be important in few reaches

Data are entered into a questionnaire built with the Microsoft ACCESS 2000 program. Qualitative and descriptive information are entered into a Watershed Assessment Questionnaire. Some of this information is available from SSHIAP files that are available at http://www.nwifc.wa.gov/sshiap2. For each reach, the user is asked to rank (0 to 4) each of the 46 Level 2 Environmental Correlates based on definitions of each rank (pop-up menu provided). The user can also specify whether this rank is for current or historic conditions. For some variables, such as temperature, monthly mean data can be applied. User notes are recorded, such as level of proof (1 to 4) for each ranking, and written comments can be added to a cell. If the level of proof is ranked as speculative

(4), then the user is asked to provide a range of values. Once these data have been entered for all reaches in the watershed, MBI runs the EDT model. The model output is essentially the same as EDT.

EDT-Light has been applied to selected watersheds in the Puget Sound region and possibly other areas. It has been available since at least early 2000.

4.1.2.1 Application of Model Selection Criteria

Not surprisingly, the EDT-Light and EDT are reviewed similarly when judged against the screening criteria (Table 4). EDT-Light is largely an expert opinion model and it generally relies on opinions regarding the ranking of specific habitat attributes. Although it can utilize whatever data are available, the EDT-Light process also involves best scientific judgment when data are not available. In Puget Sound, EDT-Light was used by WDFW as a decision making tool to describe how much additional information was needed. In most cases, the application of EDT-Light was expanded to the full EDT model and results of EDT-Light were not documented in a report (Lakey, 2003b, pers. comm.).

4.1.3 SHIRAZ

The SHIRAZ model was recently developed by Dr. Ray Hilborn of the University of Washington under a contract with MIT. MIT contracted Hilborn to develop SHIRAZ because they were uncomfortable with EDT because it was 1) proprietary and could not be run by MIT biologists, and 2) EDT included numerous functional relationships (i.e., links between habitat and survival) that were based on expert opinion (Warner, pers. comm.). Although SHIRAZ is relatively new, the basic model framework is similar to numerous other simulation models developed by Hilborn over the years. SHIRAZ is not currently in the public domain, but Hilborn (pers. comm.) has indicated that a web-based version is likely to become available within a year.

Currently, SHIRAZ is being applied by MIT to chinook salmon in the Green/Duwamish, Puyallup, and Lake Washington watersheds. MIT is further along in its application of the model for the Green/Duwamish River basin in seven reaches. The Green River has fewer tributaries and fewer chinook salmon stocks than the other basins. Key goals of the MIT effort are to utilize SHIRAZ to develop chinook recovery goals for the watersheds and to assist in stock recovery planning. MIT recognizes that the Lake Washington drainage and the White River are no longer part of the Green/Duwamish basin; therefore their development of recovery goals does not include plans to convert these two drainages back into the Green/Duwamish basin. In addition to the MIT effort, NOAA Fisheries is currently applying SHIRAZ, in conjunction with PRISM dynamic hydrology models, to the Snohomish watershed (Scheurell, pers. comm.). Presently, the NMFS effort is focused in the Snoqualmie sub-basin, but they anticipate completing their analyses of the Snohomish watershed within a few months. EDT has also been applied to the Snohomish Basin, and NMFS will compare results from SHIRAZ and EDT.

4.1.3.1 SHIRAZ Model Concept

SHIRAZ, like EDT, utilizes the Beverton-Holt recruitment curve (Figure 1) and the Moussalli and Hilborn derivation (1986) showing that the Beverton-Holt function can be applied throughout the life history stages of Pacific salmon (see discussions in EDT about this assumption). The definitions of capacity and productivity are the same. Both approaches rely on input of functional relationships that are critical to the output of the models.

However, there are important differences between the models.

- EDT can be run by third parties, who may make use of a recent web-based version of EDT that enables registered users to run new model scenarios without alteration of the underlying biological rules. The online version also enables unregistered users to become familiar with the model, but they cannot alter the environmental attribute values and develop new scenarios. In contrast, SHIRAZ is a model built on a Microsoft Excel platform that can be run and completely manipulated by the user, but SHIRAZ is not in the public domain. The SHIRAZ program code (macros) is included in the Excel workbook and can be altered by the user.
- Whereas EDT comes with numerous functional relationships built into the model (and therefore little additional effort required by the user), SHIRAZ requires that the user specify these relationships. Functional relationships

are critical to EDT and SHIRAZ type models. Development of these functional relationships probably requires the most effort when applying SHIRAZ to a watershed (Scheurell, pers. comm.); however, as noted by Hilborn, it gives the user more control over model functioning and the user knows exactly what assumptions are made. Like EDT, SHIRAZ can utilize expert opinion, but the NMFS approach in the Snohomish basin has attempted to limit the functional relationships in the SHIRAZ model to those that are empirically based.

- SHIRAZ lets the user use stochastic inputs, such as year-to-year fluctuations in marine survival, river flow, temperature, and dissolved oxygen; whereas EDT is deterministic (mean values only).
- SHIRAZ is a dynamic simulation that incorporates time dynamics of habitat, hatcheries, and harvests; whereas EDT provides discrete singular values for habitat conditions used in a model run. SHIRAZ output includes calculated productivities and capacities for each stock, area, and life history stage; it tracks fish though time. In contrast, EDT provides the reach-by-reach data in terms of habitat restoration or protection potentials and it does not literally track fish through habitats as does SHIRAZ. Importantly, simulation runs can be used to evaluate model sensitivity. At this time, SHIRAZ does not specifically calculate life history diversity, whereas EDT calculates the percentage of each life history trajectory in the population. However, the life history diversity calculation can easily be added to SHIRAZ.
- The Excel-based SHIRAZ model includes all macros, and these can be modified, if desired, by the user/programmer. These macros are the basic framework of the SHIRAZ model, so the internal workings of SHIRAZ are transparent to users familiar with programming code. In contrast, MBI, who provides technical support for all aspects of the EDT modeling procedure, controls the internal model framework, including the relationships between salmon survival and habitat characteristics. One very useful exercise suggested by Hilborn would be to compare model outputs from SHIRAZ and EDT using the same functional relationships. We strongly suggest making such a comparison in the WRIA 9 planning area.

4.1.3.2 Model Description

Hilborn (2003) prepared a users' manual that describes the basics of how to implement SHIRAZ. SHIRAZ operates in an Excel workbook environment and can be run on any computer that runs this program. SHIRAZ utilizes macros in Excel to run the model; these macros can be viewed and edited by the user. The program includes a series of worksheets, including input sheets for habitat areas, life history stages, stocks, and functional relationships. Output worksheets provide data such as abundance and productivities per life stage, per habitat area, and per year of the model simulation.

The manner in which SHIRAZ calculates productivities and capacities is shown in Fig. 3. This approach is analogous to the calculation of productivities by EDT and appears to be analogous to the calculation of capacities by EDT. The following description of the SHIRAZ model was based on the users' manual. However, Hilborn notes that SHIRAZ can incorporate information from other modeling or data collection efforts.

For example, NOAA Fisheries estimated the potential spawning capacity of chinook salmon in the Snohomish watershed using a coarse-scale approach, then used this estimate of capacity as a starting point in the SHIRAZ simulation. The coarse-scale estimate of spawner capacity is based on the following two-step approach, which has been applied to all watersheds in Puget Sound and is still under revision as new information becomes available (B. Sanderson, NMFS, pers. comm.). First, within a watershed, all reaches that have channel width greater than 5 m and gradient less than 4 percent are assumed to be potential habitat for spawning chinook salmon. Second, chinook salmon redds per km were estimated from stream surveys conducted in the Skagit and Stillaguamish by D. Montgomery, University of Washington (note: WDFW data could be used but it requires more effort), and redds were converted to total spawners per km using an expansion of 2.5 spawners per redd (WDFW data). Fish density values were applied to the total stream distance of potential spawning habitat to calculate potential capacity. These values represent current conditions. Historic spawner capacity was calculated by including areas upstream of anthropogenic barriers and by applying a factor that accounts for greater spawning density in reaches surrounded by forest lands. Clearly, this approach is coarse scale and it is going through some revisions taking into account new information on barriers and on the lower limit of spawning in the watershed.

4.1.3.2.1 Stages

SHIRAZ tracks fish by life history stage. In a typical salmon model the traditional life history stages would be spawners, eggs, fry, smolts, ocean age 1, ocean age 2, etc. However, the user can explicitly include summer rearing, winter rearing, estuarine rearing, etc.; the life history can be divided into as many stages as needed. For each stage the user specifies 1) the proportion maturing at that stage, 2) the fecundity of mature females of this age, and 3) whether this stage carries over the beginning of the year (January 1). This allows SHIRAZ to track the fish at different stages. There is no "correct" definition of stages: the user can break the life history into months or weeks throughout the fish's freshwater residence. The basic decision about stages depends upon the resolution the user wants to consider when judging impact on survival by habitat factors. It is important to note that all fish of the same stock and year of birth will be in the same stage at the same time—so the user cannot subdivide stages and look explicitly at different emergence times as a function of, for example, temperature. (This type of question might arise in the Green River if one wanted to assess how temperature change due to water flow regulation might affect incubation temperatures, or if one wanted to assess the effect of the shift in spawn timing as a result of hatchery operations; see Ruggerone and Weitkamp 2003). Although SHIRAZ does not presently split life stages according to emergence timing, we think appropriate functions could be built into the model to examine these effects.

4.1.3.2.2 Habitat Areas

SHIRAZ explicitly considers and tracks the number of fish alive by area, year, stock and life history stage. The natural definition of areas in SHIRAZ is stream reaches, and conceptually the stream reaches could be very small—a few hundred meters—but so far in practice SHIRAZ has divided watersheds into 10 to 40 reaches (e.g., in the Snohomish Watershed, the areas are major named tributaries within each sub-basin; e.g., Snoqualmie R). Estuarine areas can also be explicitly considered either as a single estuarine area or, potentially, multiple ones. The movement model (described below) can be used to partition fish among areas for rearing in stream reaches, or again, potentially among specific estuarine areas.

4.1.3.2.3 Stocks

SHIRAZ allows for multiple stocks which can be used to represent 1) different life history strategies (ocean type versus stream-type chinook), 2) naturally produced versus hatchery fish, and 3) different species. Hilborn does not specifically mention additional juvenile life history trajectories, but it appears trajectories for fry and fingerling migrants could be modeled. However, like the EDT model, functional relationships between habitat and survival need to be developed. In principal, fry versus fingerling migrant trajectories could be modeled with the movement model.

For each stock there are two main concepts. First, each stock can have different life stages. For example, an ocean-type chinook does not exhibit winter rearing, so if both ocean and stream type are to be considered in the same model, they must be considered stocks. Secondly, stocks can be used to represent hatchery and naturally produced fish and the manual notes that the user should always distinguish between them.

4.1.3.2.4 Transformation

An important SHIRAZ concept is transformation (i.e., at the time of spawning one stock can transform into another—naturally spawning hatchery fish can "become" naturally spawned fish in the next generation. Another possible application is to create a life history trajectory, such as obligatory estuarine-rearing fish, that represents a specified segment of the total juvenile subyearling population. The transformation feature of SHIRAZ may be important in the Green River given the level of straying in the watershed. Also, the transformation feature may help account for shifts in life history trajectories that seem to be environmentally induced, as suggested by Ruggerone and Weitkamp

(2003). For example, high spring flows may lead to greater numbers of fry migrants, or cold temperature may lead to higher numbers of yearling migrants.

4.1.3.2.5 Habitat Indicators

The user must specify a set of habitat indicators for each habitat area. These indicate habitat quality and quantity. They can be detailed physical factors such as gradient, stream width, percent pool, vegetation cover, or quantities such as rearing area, spawning area. Values of each habitat indicator for each area are entered into a worksheet table. This is the primary method in which habitat is included in SHIRAZ. In contrast to EDT, habitat indicators can change gradually over time by exponential or logistic growth (or decay), but do not change from year to year in a stochastic way. (Both of these functions differ from EDT.) For stochastic variables (e.g., flow, temperature, etc), the user must define the variables as described below.

4.1.3.2.6 Stochastic Variables

Stochastic variables change from year to year, but unlike habitat indicators, they are not explicitly assigned to individual areas. In SHIRAZ, stochastic variables are specified by a random distribution function (uniform, normal or log-normal) and are randomly generated (these can be quickly altered with a button). Stochastic variables would normally be used to represent flows, temperature, dissolved oxygen, etc. Since such factors tend to be highly correlated in space, the normal method is to specify one stochastic variable for each major section of a watershed, and have survival rates tied to the value of this variable over many (if not all) areas.

4.1.3.2.7 Functional Relationships

Functional relationships are critical to models like SHIRAZ and EDT since they are the relationships on which model output depends. In SHIRAZ, functional relationships are used to calculate survival at each life history stage based on habitat indicators and stochastic variables. At each life history stage the survival from that stage to the next stage is determined by productivity and capacity, and these are calculated as functions of habitat indicators or stochastic variables. The basic "habitat model" consists of specifying how habitat indicators and stochastic variables relate to productivity and survival, and a range of graphical functional forms are available to develop these relationships. SHIRAZ, at present, does not come with a series of built-in functional relationships. The MIT have developed numerous relationships for application of SHIRAZ to WRIAs 8, 9, 10, but these relationships are not presently available to the public. NOAA Fisheries has developed several functional relationships for application of SHIRAZ to the Snohomish watershed that would presumably be available to subsequent users of the model. NOAA Fisheries does not plan to incorporate as many relationships as MIT. Hilborn plans to accumulate a series of functional relationships for each life state and habitat area that could be stored in a library and be shared among user groups.

Like EDT, model output from SHIRAZ is dependent on the accuracy of the key functional relationships. This raises a similar question: should a model incorporate a functional relationship if it is not accurately known, or should models include numerous relationships that may have some effect on salmon survival but for which the quantitative relationships are poorly understood? This issue continues to be open to debate.

4.1.3.2.8 Movement

SHIRAZ allows fish to move between areas, and once movement takes place SHIRAZ tracks the number of fish by stage, stock, year, area of birth, and current area of residence. As a result, when spawning takes place these fish know where their natal area is and can return to it. The movement model allows for movement between any (and/or all) life history stages. Movement can be specified either by a fixed preference (i.e., what portion of fish from area "I" move to area "J") or by letting the fish be allocated to areas based on their expected survival in that area (i.e., the ideal *free* distribution). A parameter is provided so the model can calculate a "mixed" solution, in order that the allocation might be half weighted by intrinsic probabilities and half by trying to maximize survival. For each stage where movement is allowed, the user must provide a matrix of intrinsic probabilities of movement, which at the very least should represent the physical structure of the watershed, so that fish will move downstream, and not upstream (unless they actually do so).

4.1.3.2.9 Time

SHIRAZ has two basic concepts of time. First, there are life stages, many of which will take place within the same year and are calculated sequentially within the year. The second time component is "among years." SHIRAZ keeps track of fish over time and outputs the number of fish by area, stage, year, and stock.

4.1.3.3 Application of Model Selection Criteria

Existing data in the Green/Duwamish watershed can be used for input into SHIRAZ. However, some additional analyses and organization of these data may be needed prior to model input. NOAA Fisheries is already using a GIS approach in the Green/Duwamish River to estimate salmon spawner capacity as a starting point for SHIRAZ. In addition, recent and ongoing fish studies in the watershed will provide some information on fish life histories, spatial distribution, residence time, and straying that can be utilized. Depending on the nature of the functional relationships used in the model, new data might be required. Cost of applying SHIRAZ to the Green/Duwamish watershed is difficult to estimate, but Scheurell estimated that four person-months would be necessary to apply it to the Snohomish watershed, with the greatest effort involving development of functional relationships (Scheurell, pers. comm.). A similar level of effort would be expected for the Green/Duwamish River.

SHIRAZ can provide output that is relevant to the determination of VSP criteria: abundance, productivity, life history diversity, and spatial distribution. The model does not calculate life history diversity (percent of each trajectory in population), but all relevant data are available to make such calculations. Spatial distribution can be graphed by habitat area and stock. SHIRAZ could potentially be enhanced to incorporate metapopulation dynamics (i.e., exchange of adults between subpopulations).

Like EDT, SHIRAZ can accommodate the full range of anthropogenic factors, including harvest, environmental contaminants, temperature change, and barriers. However, like all scientific models, the model requires the user to specify the functional relationships between the habitat variables and salmon survival. SHIRAZ can use empirically based relationships or it can use expert opinion. The NOAA Fisheries application of SHIRAZ is primarily limited to use of empirical data rather than expert opinion. Models like SHIRAZ provide a framework for organizing a large body of data and assessing cumulative effects of a multitude of factors. As noted by MBI, the intent of these models is to help planners "see the forest through the trees." However, they depend upon reasonably accurate functional relationships. Time and effort to develop functional relationships for SHIRAZ and EDT might be extensive, especially in estuary and nearshore areas where these relationships have not been developed through previous projects.

The transformation sub-routine is an important component that would allow evaluation of hatchery straying and potential genetic effects on survival (again, relationships need to be built). Competition between hatchery and naturally produced fish can be incorporated as well.

SHIRAZ is a dynamic population simulation model that can incorporate changes in freshwater, estuarine, and marine conditions on salmon productivity. Stochastic variability (several types) and uncertainty in functional relationships can be easily introduced to the model (note: the user manual indicates that uncertainty has not yet been built into these relationships, but this would be easy to do with the built-in random number generator). SHIRAZ tracks populations through time (observed in spreadsheet): output is shown for each year (e.g., 100 years or more). But like EDT, SHIRAZ must rely on specified functional relationships that link habitat features to salmon survival.

Like EDT, SHIRAZ was developed to help planners identify and prioritize recovery actions. Currently, SHIRAZ is best suited to help decide what habitat areas might be best suited for rehabilitation. For example, in the Snohomish watershed, riparian buffers are considered to be one management action to help salmon recovery.

SHIRAZ does not include a functional linkage between forest cover and salmon survival. Instead, the model user (NOAA Fisheries) has a hypothesis on how buffers might benefit salmon survival (e.g., buffers will likely lead to reduced sedimentation and therefore greater egg-to-fry survival). Thus, the user asks the question: what happens to salmon production if sediment in spawning gravels in this area is reduced to X percent, or various levels in between, versus similar changes in sediment in other areas? Model simulations are run to determine in which areas (e.g., upper watershed or lower watershed) sediment reduction would provide the greatest beneficial effect on salmon. Comparing results of many model runs provides a level of confidence. In contrast to EDT, each simulation run will produce different results due to the stochastic variables and to error terms introduced into functional relationships. The range and variability of the model runs provides an estimate of uncertainty.

SHIRAZ can also provide an indicator of extinction risk. For example, model simulations can be run 100 times, each for a period of a hundred years or more. Stochastic variation and uncertainty built into the function relationships may cause some model runs to lead to extinction. The percentage of simulations leading to extinction provides an indicator of extinction risk.

The underlying modeling framework that supports SHIRAZ has been under development by Hilborn for a number of years, but the SHIRAZ model was developed under contract with MIT and it is relatively new (in development over the past two years). SHIRAZ model runs have not been tested or verified. Currently, SHIRAZ is not in the public domain. It is possible that a web-based version of a model like SHIRAZ will be developed by Hilborn within the next year and will be made available to the public (Hilborn, pers. comm.).

4.1.4 Qualitative Habitat Assessment (QHA)

Chip McConnaha of MBI developed the Qualitative Habitat Assessment (QHA) tool for use in the Columbia Basin. Much of the following text was extracted from the User Guide (McConnaha and Parkin 2003). QHA is intended for use in stream environments at sub-basin and provincial scales. The number of reaches or small watersheds where

QHA results would be meaningful is between approximately 20–25 and 300–400 reaches.

QHA relies on the same conceptual framework as EDT. There are, however, several important differences. While each of the habitat characteristics used in QHA is also used in EDT, EDT considers many more habitat factors and, wherever possible EDT, links these more directly to measurable data. QHA, by contrast, relies solely on the judgment of knowledgeable professionals to draw these linkages. EDT relies on a set of biological rules derived from the technical literature when possible to establish the relationship between a species and its habitat, whereas QHA relies on professional judgment to make this connection. EDT uses a series of life history trajectories to model the movement of fish through its environment over several life stages and over the entire life history; QHA collapses life history into fewer stages. Importantly, QHA treats each stream reach or small watershed as an independent static unit, whereas EDT evaluates the connectivity of reaches and the variation in conditions within a year. Again, QHA relies on the knowledge of experts to "think through" life history dynamics. EDT analysis can incorporate information on out-of-sub-basin effects (i.e., survival outside of the natal sub-basin including ocean survival and harvest); QHA does not consider conditions outside the sub-basin. Lastly, EDT produces a series of numerical products that estimate productivity, abundance, and related factors that give an indication of how well habitat supports fish. As a qualitative technique, QHA does not generate these outputs but rather produces an index of habitat condition and a series of products that suggest directions for management.

4.1.4.1 Model Concept

QHA provides a structured, *qualitative* approach to analyzing the relationship between a given fish species and its habitat. It does this through a systematic assessment of the condition of several aquatic habitat attributes (sediment, water temperature, etc.) that are thought to be key to biological production and sustainability. Attributes are assessed for each of several stream reaches or small watersheds within a larger hydrologic system. Habitat attribute findings are then considered in terms of their influence on a given species and life stage.

QHA relies on the knowledge of natural resource professionals with experience in a given local area to describe physical conditions in the target stream and to create a hypothesis about how the habitat would be used by a given fish species. The hypothesis consists of weights (i.e., importance of factors) that are assigned to life stages and habitat attributes, as well as a description of how reaches are used by different fish life stages. These result in a composite weight that is applied to a physical habitat score in each reach. This score is the difference between a rating of physical habitat in a reach under the current condition and a theoretical *reference* condition.

The ultimate result is an indication of the relative restoration and protection value for each reach and habitat attribute. QHA also provides a means to compare restoration and protection ratings to other biological and demographic information of the users' choosing. QHA includes features for documenting the decision-making process and describing the level of confidence that users have in the various ratings.

QHA should not be considered a sophisticated analytical model. QHA simply supplies a framework for reporting information and analyzing the relationships between a species and its environment. It is up to knowledgeable scientists, managers, and planners to interpret results and make decisions regarding these relationships and to determine the actions that might be taken to protect or strengthen these relationships.

4.1.4.2 Model Description

QHA makes use of the Microsoft Excel spreadsheet program. The method involves the comparison of current versus reference habitat conditions (e.g., historic or, possibly, "optimal" conditions). Habitat attributes that are included in the model include:

- Riparian condition
- Channel structure
- Habitat diversity
- Fine sediment
- High flow

- Low flow
- Oxygen
- Low winter temperature
- High summer temperature
- Pollutants
- Artificial obstructions

These attributes are thought to be the main habitat drivers of fish production and sustainability, but it is possible to add additional characteristics. Presently, MBI is considering adding genetics, exotic species, and disease. Habitat attributes are rated according to the following rating scheme:

0 = < 20% of optimum
1 = 20% to 40% of optimum
2 = 40% to 60% of optimum
3 = 60% to 80% of optimum
4 = 80% to 100% of optimum

Like EDT, confidence in these ratings are ranked (0 to 4) and not otherwise used in the model calculations. However, graphics showing confidence in habitat attributes by reach can be used in the process of identifying restoration and protection measures.

QHA examines three basic life history stages: 1) spawning and incubation, 2) growth and feeding, and 3) migration. Each stage is ranked using a 3, 2.5, 2, 1.5, and 1 scale, with 3 defined as the most important. The reason for ranking is to define the life stage that will be used to evaluate the importance of the various habitat characteristics for each reach or small watershed.

Next, the user rates each habitat characteristic for each habitat utilization life stage. The scale is as follows:

0 = no effect
1 = does effect
2 = critical effect

By rating both life stages and habitat characteristics, the user establishes a simple hypothesis concerning how a given species interacts with its environment in the sub-basin. QHA applies the hypothesis to the information developed in the reference and current condition tables to develop a series of products.

A restoration rankings table is generated using the following algorithm:

$$\text{Restoration Attribute Score}_{ij} = (\text{Reference}_{ij} - \text{Current}_{ij}) * \text{LSWeight}_{ijk}$$

—where the Restoration Attribute Score is for reach *i* for attribute *j*. *LSWeight* is the weight assigned to the attribute (*j*) for the highest ranked life stage (*k*) using the reach (*i*). Current habitat conditions are subtracted from reference habitat conditions (e.g., historic or "optimal" conditions). This equation results in a number that provides a relative indication of the effect of restoring conditions beyond the current condition. The reach score is the simple sum of the individual attribute scores. A similar equation is used to evaluate the value of protecting modeled reaches.

QHA produces a series of tables that 1) describe the physical habitat, 2) establish an hypothesis concerning how species interact with the natural environment, and 3) identifies where restoration and/or protection activities may be the most productive. Taken as a whole, these tables offer a means to focus the attention of biologists and planners and track the decision process. They do not, however, constitute a complete assessment.

4.1.4.3 Application of Model Selection Criteria

QHA can be applied to the Green/Duwamish watershed using existing data because it relies on opinion of the individuals involved in the modeling exercise. QHA does not provide output that is relevant to VSP because it does not attempt to quantify abundance, productivity, diversity, spatial distribution, or extinction risk. Rather, it is a tool designed to help guide habitat restoration or protection planning during its initial stages.

QHA does incorporate some anthropogenic influences on habitat, as noted above, but it does not consider effects of hatcheries and straying. QHA was designed for stream reaches and it has not been applied to estuarine and nearshore marine habitats.

QHA utilizes Excel workbooks and has a well written implementation guide. Thus, the modeling procedure and output is transparent and likely understood by the user. The model and user manual and Excel template is available from the Northwest Power and Conservation Council. Cost of applying QHA to the Green/Duwamish watershed would be relatively low because it is based on expert opinion and requires relatively little time if user is familiar with all areas of the watershed.

4.1.5 Salmonid Watershed Analysis Model (SWAM)

SWAM is a statistical modeling approach developed by NMFS scientists (B. Feist, pers. comm.). SWAM comprises a series of spatial and statistical analyses that relate salmonid population counts (e.g., redd counts, adult counts, juvenile counts) in streams in a particular basin to habitat characteristics. SWAM involves the correlation of fish abundances with large scale habitat features (anthropogenic and natural). It provides a map of where the highest densities of fish in a particular basin are likely to occur, a series of ecological hypotheses about factors driving salmon abundances in a particular basin, and a list of important factors to consider when setting up monitoring projects or management experiments.

An example of SWAM is the recent study by Pess et al. (2002) who related a time series of spawner counts collected at numerous reaches in the Snohomish River to habitat data characterized from geo-spatial data layers of land-use type (e.g., grazing, water diversions, logging, mining, urbanization), landscape characteristics (e.g., geology, topography, vegetation), and climatic conditions (e.g., air temperature, precipitation). Coho salmon abundance on the spawning grounds was found to be correlated with wetland occurrence, local geology, stream gradient, and land use activities. Approximately 50 percent of the annual variation in spawner distribution was accounted for by several habitat characteristics included in the model (alternatively, 50 percent of the variation was not explained by any of the tested variables).

The SWAM approach was also applied to chinook salmon in the Snake River Basin. Feist et al. (2003) found that redd density was correlated with watershed scale factors such as climate, geology, wetlands, and terrain ($R^2 = 0.30$; i.e., 30 percent of variation in redd density was explained by the habitat features, whereas 70 percent was not explained). In contrast, reach level factors were poorly correlated with redd density ($R^2 = 0.16$).

The scientists who developed the SWAM approach note that relationships between ``habitat and salmon abundance over time can be used to predict relative salmonid densities in areas of the basin that lack abundance data, including areas that are newly opened to colonizing salmon" (B. Feist, pers. comm.). The empirical models developed with SWAM can be used to predict changes in fish populations in response to changes in habitat features that were found to influence the populations. In this manner, recovery planners can identify habitat features and relationships that can be used to predict which locations can be restored.

4.1.5.1 Model Description

SWAM is a statistical model and therefore it is very different from EDT and SHIRAZ. SWAM requires a time series of fish population data, such as spawner density or juvenile density per reach. Without field data, the SWAM approach cannot be applied. Fish population data are then correlated with estimated habitat characteristics within the local reach and in the upper watershed area. Statistical tests, including multiple regressions and other techniques, are applied to the datasets to determine which habitat characteristics explain the distribution of spawners or juveniles. Confidence intervals and coefficient of determination (R^2) can be calculated to provide an estimate of certainty in the correlation.

Statistical models such as SWAM require fish and habitat data from a number of reaches over approximately 10 or more years. (more data increases power of statistical tests; i.e., ability to detect statistical significant relationships.)

4.1.5.2 Application of Model Selection Criteria

SWAM is a publicly available approach that requires area-specific fish and habitat data over a time series. Existing spawner distribution data in the Green River would be well suited for SWAM. Existing coarse-scale habitat information can be utilized, though some additional habitat data collection may be necessary. Cost of applying SWAM to the Green River primarily involves organization of existing habitat data and applying statistical techniques to search for correlations between habitat and spawner density. Potentially, SWAM might be applied to examine relationships between the habitat and distribution of juveniles, but currently this does not appear appropriate for the Green River. For juveniles, ongoing field studies may provide the best linkage between habitat and juvenile densities.

SWAM utilizes a different approach to look at VSP criteria. SWAM is based on the spatial distribution and relative abundance of juvenile or adult fish. It may be able to predict distribution and abundance based on historic conditions, but as shown by the two recent applications of SWAM, habitat characteristics (as defined in studies) often explain relatively little about the relative abundance of spawners in a basin. SWAM does not directly address VSP criteria such as life history diversity and productivity; it does not address extinction risk.

SWAM can assist recovery planning by identifying coarse scale habitat features that are correlated with areas having highest spawning density (or juvenile density). It can also be applied to sub-basins where there are few data to predict fish use. This application might be useful, for example, if a new watershed is made available by removing a fish passage barrier. Likewise, SWAM can be used to identify habitats needing highest protection, or habitat characteristics that might have greatest potential for restoration. The correlation coefficient is a measure of certainty versus uncertainty. Confidence intervals can be developed for predictions based on the empirical models. SWAM does not provide a method for gauging progress toward recovery other than by providing a prediction about the effect of an action on fish distribution and fish density. SWAM does not specifically address anthropogenic factors such as chemical contamination, temperature change, harvests, or hatcheries.

4.1.6 Cumulative Risk Initiative (CRI)

The Cumulative Risk Initiative (CRI) is an ongoing effort of the Northwest Fisheries Science Center (NWFSC/NOAA) that assesses salmonid population trends and the impact of various actions on those trends. This project uses the following approach. First, the team analyzes data regarding the "Four Hs" (habitat, harvest, hatcheries, and hydropower) to assess the impact of these factors on salmonid population growth. Concurrently, the team assesses the risk of extinction and constructs population models using current survivorship estimates for each life stage. These models can identify the times or stages at which changing survivorship will yield the largest impact on population growth rates. Follow-up work entails examining whether such changes in survivorship are biologically feasible and what management options will yield the best results. Finally, as conservation actions are implemented, NOAA Fisheries, in collaboration with other regional scientists, hopes to engage in ecological experiments to test hypotheses about the relationships between management actions and salmon populations.

4.1.6.1 Model Description

CRI is a statistical approach that requires empirical data. The four key steps to a CRI analysis are:

1. Estimate the risk of quasi-extinction for known populations (i.e., probability of reaching one spawner within 100 years).
2. Construct demographic projection matrices that depict current demographic performance rates which can be used to calculate annual population growth rates (λ) (assuming "current conditions").
3. Perform sensitivity analyses to assess where in the life cycles of salmonids there are the greatest opportunities for promoting recovery, as measured by changes in the annual population growth rate. This can be done in several different ways. The simplest is to manipulate the values in baseline matrices to represent particular demographic improvements, and calculate the percent increase in annual population growth rate that results. This increase in annual population growth can then be converted into an estimated reduction in quasi-extinction risk. (Note: this approach to finding potential actions for

recovery is similar to that applied by NOAA Fisheries when using SHIRAZ in the Snohomish.)

4. For those demographic improvements that give a noteworthy response in terms of population growth, identify management actions that might accomplish those improvements, and use statistical analyses or experimental studies to determine whether there is evidence that those improvements are actually feasible with the management action being considered.

The primary data used by CRI are time series of population counts, and recruits per spawner ratios. Typically, age structure of the population, harvest rates, fecundity, and age-specific survival rates are also utilized in this approach. From this, one can calculate an extinction risk, and estimate how much is needed to increase annual population growth to mitigate this risk. This is typically shown by comparing percent change in annual population growth rate (λ) with the probability of extinction. The probability of extinction is calculated using the "Dennis model," which is described in more detail by Dennis et al. (1991) and CRI (2000).

4.1.6.2 Assumptions

The Dennis approach to estimating extinction risks (Dennis et al. 1991) entails several critical assumptions and restrictions:

- Population counts must be an exhaustive survey of the population or a fraction thereof so that the time series is indeed a Markov process
- The variability estimated by the modified Dennis approach is a measure of environmental variability and not sampling error
- The variance increases with tau (τ), the time increment over which the change is calculated
- The yearly rates of population growth are log-normally distributed
- Although the populations themselves may be increasing or decreasing (i.e., they may show a trend), there should be *no* trend in the rates of decline or increase (i.e., the rate of decline or increase should not grow progressively worse or better)
- Over the range of population sizes examined, the rates of population change are assumed to be independent of the density of fish

CRI (2000) discussed these assumptions in relation to salmon and they implemented modifications to the original model in an attempt to satisfy some of the assumptions.

4.1.6.3 Application

The approach can be used to simulate the consequences of reduced harvest, and other management actions. Importantly, for many management actions (almost everything other than harvest reductions) it is not certain whether a given action will accomplish the desired demographic improvement. Therefore, CRI recommends a feasibility study, where the dependent variable will typically be recruits per spawner, number of spawners, smolts pers spawner, smolt-to-adult returns, or survival during a particular life stage. Correlations are then sought between these measures of salmonid productivity and variables such as number of hatchery releases, fraction of stream miles failing to meet EPA water quality standards, etc.

4.1.6.4 Scale

CRI is most effective when applied to distinct populations, or collections of populations. This is because it focuses on population growth rate and a population's risk of extinction. The spatial scale over which CRI best operates ranges from sub-watershed to sub-basin or basin. As it is currently developed, CRI is not equipped to deal with an entire province or region comprising many populations and multiple ESUs. CRI would not be used at the fine scale of a particular reach or stream. CRI could not inform us about reach-specific or small-scale management actions. The output of CRI often takes the form of: "if this, then the expected response is ___". CRI does not deal with individual fish, and it does not deal with life history diversity. In the absence of data and statistical relationships, the CRI does not venture very far with its analysis.

4.1.6.5 Measures of performance

The primary measure of performance for CRI is average annual rate of population growth. This core measure is then the basis for two additional measures of performance: risk of extinction over 10 years and 100 years, and the percentage by which annual population growth is expected to increase with some management action. Although it is impossible to validate "risk of extinction" as a performance measure, annual population growth rate and the percentage of change in the annual population growth rate can be validated; these are both measurable, and in fact are routinely available from the type of spawner or redd counts typically made for salmonids.

4.1.6.6 CRI's general philosophy and aims

CRI's three most distinctive features are:

1. An emphasis on simplicity and simple models, so that others outside NOAA Fisheries can repeat their own analyses with slight modifications of the assumptions, new data, different time periods, different levels of risk averseness, etc.
2. A staunch empiricist's skepticism: there is a premium placed on relationships supported by data, and that otherwise must be expressed as "if this, then that" statements.
3. A focus on population dynamics or demography as the window through which management actions are evaluated (as such, CRI focuses on factors that have large or measurable effects on population dynamics).

4.1.6.7 Application of Model Selection Criteria

CRI's primary analytical tool is a statistical population model that estimates annual population growth rate. Most data necessary to apply this model to the Green/Duwamish watershed are available, but survival rates during specific life stages may need to be estimated or assumed (Note: some are data available on egg-to-fry and release-to-recovery survival). CRI only addresses the productivity and abundance criteria of VSP; it does not address diversity or spatial distribution.

CRI can assist in recovery planning efforts. CRI can be useful in identifying which life stages require the greatest protection, or those life stages having the greatest restoration potential in terms of effective annual population growth and risk of extinction. As noted above, the approach involves specification of a survival shift during a specific life stage that might be expected from a particular restoration measure, then estimating this effect on annual population growth rate. In this manner, the user identifies the life stage that is most critical to population growth rate. Of course, assumptions must be made about the effect of the restoration effort on survival of the life stage. CRI in itself does not link habitat to salmon population dynamics.

For example, Kareiva et al. (2001) applied the CRI approach to Snake River spring/summer chinook salmon. They found that removal of lower Snake River dams alone would not be sufficient to stop extinction. This finding occurred because the annual population growth rate of this stock was most influenced by survival during the first year (primarily incubation) and during estuarine residence. The authors noted that improvements in dam passage survival during recent years also played a significant role in their findings, concluding that, had survival not been improved, the stock may have gone extinct in the near term.

Harvest rates and straying rates are important factors that should be addressed when using CRI. Confidence intervals in the projected annual population growth rates can be estimated. CRI has been applied to the Green/Duwamish watershed by NOAA Fisheries (2003) and annual population growth rates were estimated after assuming either zero percent reproductive success of hatchery fish spawning in the river, or a success rate equal to that of natural spawners. When reproductive success of hatchery strays was assumed to be equal to that of natural spawners, , then annual population growth rate of the Green River chinook salmon was less than 1, indicating population decline. Green/Duwamish chinook salmon had the lowest annual population growth rate of all chinook salmon populations in Puget Sound, based on NMFS assumptions about straying (average 70 percent hatchery fish on spawning grounds) and reproductive success.

CRI is within the public domain, but its application requires some familiarity with survivorship models and salmon population dynamics. Time and cost to apply CRI to the Green/Duwamish watershed are probably relatively low, since it has already has been used in this watershed by the Puget Sound Technical Recovery Team. Assumptions would be needed if CRI were to be applied to various life history stages; specifically, survival estimates of juveniles in each habitat type.

4.1.7 Salmon Ecology and Current Versus Historic Habitat Approach (Ecological Synthesis Approach)

Another approach to conservation planning could be based on the current (and ongoing) understanding of the life history of Green River chinook in relation to their current and historic habitat. Ruggerone and Weitkamp (2003) have developed a preliminary "conceptual model" of chinook life history in the Green River. This model is largely based on recent sampling of juvenile chinook salmon by King County, USACE, Port of Seattle, and various consultants. Earlier data were also examined but these data were confounded by the inability to distinguish hatchery versus natural chinook salmon prior to 1999 (no hatchery mass mark program). Potentially, conservation plans might be developed around recent observations of juvenile fish distribution, migration timing, residence time in habitat areas, and their growth in conjunction with the well known alterations in habitat throughout the basin. Researchers at the University of Washington are currently describing in detail historic habitat in WRIA 9.

Using this approach, recent fish observations coupled with current versus historic habitat conditions can be used to develop a series of conservation hypotheses that help to guide restoration and preservation efforts. Some hypotheses have already been developed as part of the ongoing WRIA 9 Research Framework project. For example, one current hypothesis is that the upper end of the estuary where fish initially reach marine waters is a key habitat for juvenile chinook salmon, especially "fry migrants" that leave the Middle Green River January through March. High densities of juvenile chinook salmon have been observed here during multiple years. Rearing habitat can be constructed here and fish use (numbers, residence time, growth) can be monitored. This approach is currently used by Goetz et al. (2003), who estimated fish use, residence time, and percentage of the population that utilized restored off-channel habitats in the Duwamish estuary. Chinook diet data were also collected and will be incorporated at a later date. In terms of habitat protection, Ruggerone and Weitkamp (2003) suggest that spawning (and embryo incubation) habitat deserves the highest degree of protection. The basis for this statement, in part, is that degradation of spawning habitat in one area may not be readily compensated by spawning habitat in another (partly because fish home back to spawning areas and do not search for habitat throughout a watershed), whereas juvenile salmon can move around and seek out rearing habitat that provides food, shelter from predators, and other requirements.

A monitoring program is an essential component of this approach. Monitoring would provide an indication as to the overall potential benefit of projects to the chinook population based on estimates of fish use. Although, by itself, this approach would not provide estimates on increased productivity, capacity, diversity, or spatial distribution of the entire chinook population relative to some benchmark, the improvements in productivity and capacity might be approximated by knowing the percentage of the population that utilize the new habitat, residence time of fish, growth, etc. Ultimately, the time to assess VSP criteria is during the adult return and spawning stage when salmon are most easily enumerated.

Restoration projects can be designed to target specific life history stages, based on field data collections and observations. A multiple-step approach could increase survival and diversity in life histories of chinook salmon by providing greater opportunities for fish to utilize a variety of habitats. For example, rearing habitat in the Duwamish estuary would likely be most beneficial to fry migrants that appear to spend more time in estuarine waters than fingerling migrants. Providing access to new habitat, such as that above Howard Hanson Dam, would increase spatial distribution of fish within the watershed, and it might enhance survival and diversity of juvenile life stages that rear in the reservoir (Ruggerone and Weitkamp 2003).

This type of an approach could address hatchery and naturally-spawned fish interactions, and harvest impacts, although not in a systematic, integrated approach as the models noted above.
In contrast to the models reviewed above, the "Ecological Synthesis Approach" described here is a less-structured approach that does not have an underlying framework or a series of *assumed* functional relationships upon which decisions are made. Instead, it is an intuitive approach based on empirical observations of how chinook salmon currently use habitats in WRIA 9 in the context of current versus historic habitat. Hypotheses about fish use of restoration projects are tested though quantitative monitoring projects. Another recent example of this Ecological Synthesis

Approach is from Chignik, Alaska, where a synthesis of research observations over the past 45 years documented natural habitat degradation and its impacts on salmon production, which in turn led to the development a series of hypotheses regarding habitat restoration (Ruggerone 2003).

An important feature of the Ecological Synthesis Approach is the potential to consider and incorporate a wide range of information in the formulation of conservation hypotheses, including outputs from the models and analytical tools reviewed in this report. It also affords the opportunity to more explicitly consider the VSP guidelines as part of the analytical framework. In WRIA 9, where results of EDT, SHIRAZ, and CRI may soon be available, using a synthetic approach that incorporates historic and current population and habitat information, multiple model outputs, and any other relevant data is an attractive option. In cases where the majority of the available information identifies the same or similar actions as having a high likelihood of success, the prioritization of habitat actions should be less controversial. In cases where different tools suggest different actions and priorities, the likelihood might be considered less assured, and process of agreeing on priorities will obviously be difficult. However, in either case the results of any action will ultimately be known only after its effectiveness is evaluated in a carefully designed monitoring program.

4.1.8 Other Analytical Tools

During the preparation of this report several additional analytical tools came to our attention that, when more fully developed and more generally available, may warrant closer consideration. Notable among these is a tool being developed by the Puget Sound Nearshore Ecosystem Restoration Project Science Team that focuses on the estuarine and nearshore marine zone. Because of the freshwater focus of the majority of the existing tools, an analytical approach specifically tailored for estuarine and nearshore assessment is definitely needed.

Another analytical approach that very recently came to our attention was STREAM Tool, an Excel spreadsheet-based, habitat-based model being developed by S.P. Cramer and Associates. Brief discussions with Steve Cramer suggested that the tool, when further developed, could be a useful analytical framework for linking habitat to fishery productivity, particularly in a landscape undergoing large-scale change.

5 CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the results of a coarse-scale review of a spectrum of salmon models designed to evaluate functional linkages between habitat and salmon performance. The purpose of this review was to assist WRIA 9 in determining the appropriate role and use of habitat-based models in developing a Habitat Plan for WRIA 9. Four of the models reviewed were scientific models (EDT, EDT-Light, SHIRAZ, and QHA) and two were statistical models (SWAM, CRI). The key difference between these types of models is that scientific models attempt to identify mechanisms affecting performance of salmon, whereas statistical models provide quantitative correlations between population performance and habitat characteristics. The scientific models tended to address more, if not all, of the VSP attributes, whereas the statistical models only addressed one or two attributes. All of the models had strengths and limitations, and none stood out to be an approach that WRIA 9 should depend upon exclusively.

As the review progressed it became increasingly clear that an approach utilizing a combination of information on current versus historic population status and habitat use, along with the different modeling results, would be perhaps the most powerful way to develop conservation hypotheses. This approach was termed "The Ecological Synthesis Approach" and was also subjected to review.

5.1 EDT and EDT-Light

EDT and EDT-Light are basically the same models; the only difference is the amount of quantitative data used in the model and the number of Level 3 survival factors utilized. Mobrand (pers. comm.) noted that EDT is typically influenced by only a few factors and that the remaining factors have a neutral effect. Given this, it makes sense to screen the factors first and decide which are most important to the Green River (and most relevant to potential management actions), and then focus on specific data needs. In other words, if EDT were applied to the Green/Duwamish, we would recommend a focused version of EDT-Light, with some supplemental data collection if critical data were missing. EDT and EDT-Light are proprietary models; therefore WRIA 9 would have less opportunity to fully understand the "inner workings" of the model, including the functional relationships that drive the model. Nevertheless, EDT and EDT-Light are turnkey models that are run by a qualified group of biologists.

5.2 SHIRAZ

SHIRAZ is a relatively new scientific model that has some appealing qualities. It is a population simulation model that allows the user to track fish populations through their life stages and habitats, and then back to the spawning grounds. A transformation function allows hatchery spawners in the river to produce natural fish (based on the input of stray rates). Stochastic variability and uncertainty in functional relationships can be introduced into the model, and then multiple simulations can be used to develop a distribution of outcomes or quasi confidence intervals based on model assumptions. This approach can also be used to examine extinction risk or population trends over time following initiation of a habitat action. SHIRAZ runs on a Microsoft Excel platform and will likely become available to the public in the future. A current limitation of SHIRAZ is that the library of potential functional relationships is small, although NOAA Fisheries is currently developing additional relationships. Moreover, functional relationships for estuarine and marine nearshore habitats would need to be developed. Importantly, however, the development of the functional relationships also engages the user with the key assumptions that drive the model, thereby providing a greater understanding of the model output. Finally, the MIT is currently developing SHIRAZ for use in the Green/Duwamish watershed.

5.3 QHA

QHA is a simplified, qualitative version of EDT that can be relatively quick to apply to a watershed. Although it may be interesting to apply QHA to the Green/Duwamish watershed, it should be done only in conjunction with other approaches.

5.4 SWAM

SWAM is not really a model, but rather an application of a statistical approach. Like CRI, it is appealing because it provides a description of the real world, including an indication of variability in the relationship between habitat and spatial distribution of fish. In its simplest form, SWAM identifies correlations between spawner or juvenile density and habitat or landscape characteristics. Once identified, these relationships can be used to predict fish density in habitats made available after, for example, removal of barriers. The relationships also provide evidence for habitat features that may have the greatest restoration and protection potential. SWAM involves spatial distribution and relative abundance, but it does not involve productivity and diversity. Two recent applications of SWAM by NOAA

Fisheries have been "successful" (i.e., correlations detected), but these applications also demonstrate the low correlation between landscape characteristics and fish density in a watershed. These observations imply that protection of existing habitat is especially important.

5.5 CRI

The CRI approach is appealing because it is primarily based on empirical relationships (i.e., quantified relationships from the "real" world). CRI has been applied by NOAA Fisheries (2003) to the Green River (population trend analysis), but further measurements or assumptions about survival of specific life stages may be needed before it can be used to address questions about the relative importance of individual life stages (e.g., spawning/egg incubation, rearing in Middle Green, Lower Green, Duwamish, nearshore marine, etc.) to population recovery. If the model can be appropriately applied, it can identify those life stages that, if survival improved, would provide the greatest increase in productivity. However, based on past and ongoing research, it is likely that assumptions would need to be made about survival in specific areas such as the Duwamish estuary, because these values do not exist and they are difficult to quantify (Ruggerone and Weitkamp 2003). If a critical life stage is identified, it would remain to be determined what type(s) of restoration measure(s) would be most beneficial to those key life stages. This suggests the potential for using CRI in conjunction with one of the other tools such as EDT or SHIRAZ, with the latter providing more specific guidance on habitat actions. CRI does not evaluate diversity or spatial distribution of chinook populations.

5.6 Ecological Synthesis Approach

The Ecological Synthesis Approach uses past and current research in WRIA 9, along with current and past habitat conditions, to develop a series of conservation hypotheses that can be tested through a monitoring and evaluation program. Some of these hypotheses are being developed in the ongoing WRIA 9 Research Framework. For example, ongoing research indicates juvenile salmon aggregate in the upper Duwamish estuary where marine and fresh waters initially meet. Salmon habitat in this area could be constructed, and a monitoring program developed to evaluate numbers, growth, and residence time of juveniles utilizing the newly constructed habitat. Available research suggests habitat in this area may be used most by "fry migrants" that leave the Middle Green River prior to mid-

April and seem to rear in the upper estuary. Monitoring and evaluation are necessary components of this approach in order to develop additional hypotheses regarding methods to enhance and restore key population characteristics. This approach is all-inclusive and the results from modeling efforts—as well as the basic information on salmon life history trajectories in other watersheds—can also be utilized to address specific goals and objectives of WRIA 9.

5.7 Final Conclusion

In considering the scientific models, it is important to recognize that they are built on hypotheses about how habitat influences salmon performance. Model results or findings are not necessarily the "truth;" all involve hypothetical functional relationships that are supported by varying levels of scientific proof. In the end, the model developer typically incorporates many assumptions. For example, EDT often utilizes assumptions (expert opinion) to link habitat attributes to survival; however, few empirical studies have quantified these relationships. Furthermore, studies that have correlated population performance with habitat characteristics typically show low correlation (e.g., Pess et al. 2002, Feist et al. 2003) indicating most of the variability remains unexplained. The value of scientific models is that a series of relationships can be organized into a framework, and then scenarios (habitat alterations) can be run to evaluate how population performance is influenced. This of course assumes that one can translate how actions change habitat conditions, and that the link between habitat change and salmon response is adequately understood. These model runs may help guide habitat restoration and protection actions, but they must also be coupled with further evaluations.

None of the models we reviewed was considered particularly useful in assessing the importance of estuarine or nearshore marine habitats. This is not surprising since the fundamental nature of these linkages is poorly understood. This will obviously be a major obstacle in the development of any scientific model. As in freshwater habitat, but with even less empirical data, assumptions will need to be made about linkages between these habitats and survival. For example, what is the capacity of nearshore habitats? In our interview with Mobrand, he speculated that it might be very large, however some newer studies are showing that salmon growth in the marine environment can be density-dependent and that density dependent growth can lead to significant mortality (Ruggerone et al. 2003; Ruggerone and Goetz 2003).

It is important to acknowledge that there are approaches to habitat planning that WRIA 9 might use that do not involve or rely solely on the use of models. One such approach (referred to as the Ecological Synthesis Approach) might be based on the current understanding of the life history of Green River chinook in relation to current and historic habitat. Recent field studies have generated data that provide a better understanding of how juvenile chinook salmon utilize available habitats. Conservation plans can be developed around these observations of fish distribution, migration timing, and residence time, in conjunction with model results and known alterations in habitat throughout the basin. A series of conservation hypotheses can be developed to guide restoration and preservation activities. The impact of restoration activities can be tested using the approach described by Goetz et al. (2003). These data provide an indication, based on estimates of fish use, to the overall potential benefit of projects to the chinook salmon, but they do not by themselves provide a direct measure of change in fish productivity, capacity, or diversity. Restoration projects could be designed to target specific life history trajectories of chinook salmon or to enhance the spatial distribution of the population.

In the end, the answer to the question, "Are models necessary?" is not unequivocally "yes" or "no." There are arguments that can be made for either answer. Clearly, models can help in:

1. Organizing data (a process that can identify data gaps)
2. Developing hypotheses about potential restoration or protection activities
3. Documenting the process leading to a land use decision
4. Tracking progress toward population recovery

For WRIA 9, an appealing choice is a combination of CRI and SHIRAZ, combining the strengths of both statistical and scientific models and taking advantage of existing efforts. The attractiveness of this approach would be predicated on the public availability of SHIRAZ. However, the predictive power of any ecological model is limited, and the models we reviewed here are no exception. There are clearly other ways to organize data, develop hypotheses, document process, and track recovery. For example, the Ecological Synthesis

Approach utilizes the biological data on fish utilization noted above (both current and historic) to identify and prioritize important habitats for enhancement. Ultimately, no matter what the choice of analytical tool or approach, the value of any restoration and preservation action must be judged on the basis of empirical data that comes from a rigorous monitoring and evaluation program.

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TABLES

Table 1
Number of Female Chinook Salmon Spawned at the Green River Eyeing Station 1911 to 1920
(Grette and Salo (1986), reproduced from Kerwin and Nelson (2000) Table HSP 1)

Reporting Period	Chinook	Comments
4/1/11 to 3/31/12	0	
4/1/12 to 3/31/13	136	
4/1/13 to 3/31/14	116	New trap constructed
4/1/14 to 3/31/15	87	Low water levels
4/1/11 to 11/30/15	101	
12/1/15 to 11/30/16	61	
12/1/16 to 3/31/17	0	
4/1/17 to 3/31/18	280	
4/1/18 to 3/31/19	259	
4/1/19 to 3/31/20	40	
4/1/20 to 3/21/21	16	

Table 2
Benchmark Productivity Survival Values by Freshwater Life Stage For Chinook Salmon in the Columbia River (MBI 2001b)

Life stage	Life stage duration (weeks)	Maximum life stage productivity survival
Spawning	1	1.00
Egg incubation	23	0.60
Fry colonization	2	0.75
0-age resident rearing	30	0.70
0-age transient rearing	8	0.36
0-age migrant	2	0.96
Inactive (full winter)	19	0.70
1-age resident rearing	8	0.97
1-age migrant	2	0.98
Migrant prespawner	8	0.92
Holding prespawner	8	0.98

Note: Values have been rounded. Assumed life stage durations are also shown. These values represent maximum potential survival of each life stage assuming optimal conditions at low fish densities. Level 3 survival factors are multiplied by these values to develop productivity of life stage. As shown, factors affecting survival in the marine environment are held constant and therefore have no effect on model results (i.e., not applied).

Table 3
Ecosystem Diagnosis and Treatment Level 3 Survival Factors (MBI 2002b)

Factor	Definition
Channel stability	The effect of stream channel stability (within reach) on the relative survival or performance of the focus species; the extent of channel stability is with respect to its streambed, banks, and its channel shape and location.
Chemicals	The effect of toxic substances or toxic conditions on the relative survival or performance of the focus species. Substances include chemicals and heavy metals. Toxic conditions include low pH.
Competition (with hatchery fish)	The effect of competition with hatchery produced animals on the relative survival or performance of the focus species; competition might be for food or space within the stream reach.
Competition (with other species)	The effect of competition with other species on the relative survival or performance of the focus species; competition might be for food or space.
Flow	The effect of the amount of stream flow, or the pattern and extent of flow fluctuations, within the stream reach on the relative survival or performance of the focus species. Effects of flow reductions or dewatering due to water withdrawals are to be included as part of this attribute.
Food	The effect of the amount, diversity, and availability of food that can support the focus species on the its relative survival or performance.
Habitat diversity	The effect of the extent of habitat complexity within a stream reach on the relative survival or performance of the focus species.
Harassment	The effect of harassment, poaching, or non-directed harvest (i.e., as can occur through hook and release) on the relative survival or performance of the focus species.
Key habitat	The relative quantity of the primary habitat type(s) utilized by the focus species during a life stage; quantity is expressed as percent of wetted surface area of the stream channel.
Obstructions	The effect of physical structures impeding movement of the focus species on its relative survival or performance within a stream reach; structures include dams and waterfalls.
Oxygen	The effect of the concentration of dissolved oxygen within the stream reach on the relative survival or performance of the focus species.
Pathogens	The effect of pathogens within the stream reach on the relative survival or performance of the focus species. The life stage when infection occurs is when this effect is accounted for.
Predation	The effect of the relative abundance of predator species on the relative survival or performance of the focus species.
Sediment load	The effect of the amount of the amount of fine sediment present in, or passing through, the stream reach on the relative survival or performance of the focus species.
Temperature	The effect of water temperature with the stream reach on the relative survival or performance of the focus species.
Withdrawals (or entrainment)	The effect of entrainment (or injury by screens) at water withdrawal structures within the stream reach on the relative survival or performance of the focus species. This effect does not include dewatering due to water withdrawals, which is covered by the flow attribute.

Note: Relative survival values for each of these 16 factors are based on a suite of habitat factors selected from 46 Level 2 Environmental Correlates (see MBI 2002b for list).

Table 4 (page 1 of 2)
Results of the Application of the WRIA 9 Screening Criteria to 6 Analytical Approaches Used in Salmon Habitat and Recovery Planning in the Pacific Northwest

	EDT	EDT Light	Qualitative Habitat Assessment	SHIRAZ	SWAM	CRI	Ecological Synthesis Approach
Can the tool use existing information or does it require the collection of new information?	Uses existing information, but often requires ground-truthing.	Uses existing information.	Uses existing information.	Uses existing information, but some new data collection may be needed depending on questions asked and level of certainty required.	Can use existing spawner distribution data and some habitat data, but some additional habitat data/coarse-scale analyses may be needed in Green R.	Many of the key data requirements are available, but assumptions needed about survival after incubation. Model has been applied to Green River by NOAA Fisheries	This approach not a "model". Recent data will help develop concepts of habitat use, but some data analyses remain. Some new data collection may be needed to address specific questions & refine details.
Does the tool use primary or derived data? If so, does it distinguish between the two?	Both. Functional relationships are based on expert opinion and literature; multiple steps to derive productivities. No differentiation in data source or quality.	Same as EDT	Derived, uses expert opinion for inputs. No quantitative data input.	Either, depending on user, but attempts to use documented relationships based on primary data. Levels of uncertainty can be applied. Can accept data from other modeling, e.g., UW-PRISM, NOAA Fisheries-coarse scale spawner capacity estimates.	Typically, primary data (observations) are used.	Primary data (observations) are used.	Primary data (observations) are used, but data from other watersheds considered when building hypotheses regarding chinook migration timing and interactions with habitats.
Can the tool provide output that is relevant to the determination of VSP…abundance, productivity, life history diversity, spatial distribution?	Yes, primary output is capacity, productivity, and life history diversity. Spatial distribution is part of input and can be interpreted from the output.	Same as EDT	No, purpose is to help guide habitat restoration/protection planning.	Yes, capacity and productivity at each life stage are outputs; spatial distribution is implicit; conceptually, diversity of life history types could be calculated. Recruits per spawner can be calculated.	Primarily involves fish density and spatial distribution.	Involves productivity, population trends, and probability of extinction.	Data collection can provide info on current VSP parameters. Additional assumptions may be used to estimate impact of restoration.
What are the model's definitions for abundance, productivity, life history, and spatial distribution?	Beverton-Holt: maximum abundance, survival at low density, % of each trajectory surviving.	Same as EDT	Not applicable.	Model follows fish abundance through time; otherwise same as EDT.	Abundance is typically measured as density; maps of spatial distribution can be produced.	Productivity is annual population growth (lambda, based on Dennis et al. (1991) model).	Recruitment curve estimates of abundance & productivity; spawner and juvenile spatial distribution; life history reflects size and timing.
How does the model factor in abundance, productivity, diversity, and spatial structure in predicting its results?	Capacity and abundance are parameters of Beverton-Holt curve. Diversity is number and percent of each trajectory surviving.	Same as EDT	Not applicable.	Same as EDT	Fish density is statistically linked to habitat features using correlation type methods. These relationships could be "functional relationships" in SHIRAZ and EDT.	Modified Dennis et al. (1991) survivorship model is used.	Empirical observations can provide estimates; habitat restoration effects based on percentage increase or direct observation & assumptions.
Can the tool accommodate different harvest rates?	Yes, harvest rates can be modeled into EDT to show spawner abundance, recruits per spawner, and diversity with and without harvest.	Same as EDT	No.	Yes, including on an annual basis (stochastic, or otherwise).	Only in the sense that escapement influences a redistribution of fish.	Yes, this is a key part of CRI.	Yes, this approach considers effects of harvest on escapement, total run size, and productivity, largely through Beverton-Holt or Ricker recruitment curve approach (actual data used).
Can the tool accommodate the full range of anthropogenic effects on habitat…chemical contaminants, temperature changes, barriers, etc.?	Yes, EDT focuses on anthropogenic effects as level 3 factors of survival. Assumptions must be made.	Same as EDT	Yes.	Yes, including uncertainty in effects, but rules needed.	From the perspective of spatial distribution, it may be possible to incorporate some variables.	Yes, indirectly. User assumes factor x has such an effect on life stage survival and effect is then modeled.	Potentially, but not simultaneously as in scientific models.
Can the tool distinguish between hatchery and natural production?	Natural stocks typically modeled. EDT can incorporate assumptions about competition and possibly fitness effects of interbreeding, but asumptions must be made.	Same as EDT	No.	Yes, can be entered as different stocks; hatchery stocks can transform to natural fish.	Only if the data sets identify hatchery vs. natural fish.	Yes, CRI (2000) discusses hatchery effects and notes importance of measuring contribution of strays.	Only if tools such as the mass marking and CWT programs are fully implemented and data are collected & analyzed.
How does the model define natural production?	The user defines natural production. For Green R, a rule on interbreeding may need to be developed.	Same as EDT	Not applicable.	Hatchery fish can transform to natural fish.	Defined by dataset.	User defined.	User defined, but typically progeny produced by natural and/or hatchery fish spawning in stream.
Does the model factor in straying rates?	Mean straying rate can be factored into EDT model.	Same as EDT	No.	Straying can be modeled and simulated; hatchery fish can transform to natural fish.	Typically, primary data (observations) are used.	Yes, recognizes need to identify contribution of strays.	Yes, if tools to identify stocks are implemented and appropriate data are collected in field.
Does the tool distinguish among <u>changes</u> in freshwater, estuarine and marine conditions and their effects on productivity?	Presently, model incorporates freshwater attributes; MBI is working on rules for estuary and nearshore marine. Stochastic changes in habitat are not modeled, but "what if" scenarios can be run.	Same as EDT	No.	SHIRAZ is a stochastic simulation model & can incorporate shifts or variability, but functional relationships must be defined for all habitats.	Typically not.	Yes, though estimates of survival during each stage are needed.	Only if experiments are designed to separate effects in each area. Comparisons between watersheds could be used to identify effects of freshwater versus marine factors.
Can the tool be applied in freshwater, estuarine, and nearshore environments?	Presently, model incorporates most freshwater attributes; MBI is working on rules for estuary and nearshore marine.	Same as EDT	It is a tool for freshwater streams only.	Yes, but functional relationships must be defined.	Yes.	Yes, if data are available.	Requires field studies to address specific questions.

Table 4 (page 2 of 2)
Results of the Application of the WRIA 9 Screening Criteria to 6 Analytical Approaches Used in Salmon Habitat and Recovery Planning in the Pacific Northwest

	EDT	EDT Light	Qualitative Habitat Assessment	SHIRAZ	SWAM	CRI	Ecological Synthesis Approach
Can the tool be used to identify and prioritize recovery actions, and gauge progress toward recovery?	Yes, this is a primary focus of EDT and its output. Output is based on model assumptions about habitat/fish relationships. "What if" scenarios can be run.	Same as EDT	Yes, it can help initial stages of habitat restoration/protection planning.	Yes, output is in terms of fish abundance, productivity; diversity can be calculated; output shows projected annual change associated with actions.	Yes, see Pess et al. (2002).	Yes, see Kareiva et al. (2000).	Yes, based on observations of habitat, abundance, growth, residence time, and migration timing of fish. Assumptions likely needed.
Does the tool give a confidence interval or a measure of uncertainty for prioritized actions?	No. EDT is deterministic and does not incorporate uncertainty into calculations. But scenarios may provide some sense of uncertainty.	Same as EDT	Provides a qualitative view of uncertainty based on opinion.	Built-in random error equations, simulation runs and sensitivity analyses can provide indicators of confidence.	Yes, see Pess et al. (2002).	Yes, confidence interval provided for population growth rate (lambda).	Possibly, but requires field work and assumptions.
Does the tool give a range for projected abundance levels and productivity rates?	EDT gives one set of values for each model run. User can change habitat features & get new values.	Same as EDT	No. QHA does not predict abundance/productivity.	Yes, model simulations can provide range in potential outcomes from actions.	Predictions are fish densities; ranges can be estimated.	Yes, confidence interval provided for population growth rate (lambda).	Only if assumptions are made.
Does the tool consider extinction risk in evaluating and prioritizing recovery actions?	Model "predicts" which trajectories will survive, but it does not provide probability or risk of extinction, but poor habitat can lead to findings of extinction.	Same as EDT	No.	Shiraz is a simulation model, therefore it may provide indication of extinction risk (see text), but this task has yet to be applied.	No.	Yes, CRI approach is to estimate extinction risk.	No.
Has the output from the tool been validated against empirical information?	Tested only in Yakima R.; model results compared well with data. "Reasonableness" of findings applied elsewhere.	We assume "reasonableness" test has been applied.	No.	No, SHIRAZ is a relatively new model, although its framework is based on past modeling.	SWAM is an empirical relationship, thus it provides level of confidence.	Impossible to validate extinction risk, but population growth rate can be validated.	Approach based on field observations; ultimate effect of actions can be approximated based on empirical data and assumptions.
Is the way the tool "works" transparent to the user and easily understood by a decision maker and the informed public?	Probably not. Multitude of data input makes it difficult to know how findings achieved. No comprehensive user manual, but many documents. However, model output is user friendly.	Same as EDT, but less data "rich"	Probably. QHA has a user manual.	Yes, SHIRAZ runs on Excel spreadsheet and it has a Users Manual; still modeling may not be easily understood by general public.	Probably.	CRI involves somewhat complicated statistical model, but results understandable by public.	Yes, but approach requires synthesis of data.
Is the tool in the public domain?	No. Model is run by exclusively by MBI and co-managers. Co-managers can alter environmental attributes but not the biological survival rules. MBI recently developed a web-based version in which the public can become familiar with the model (no alternative scenarios permitted).	Same as EDT	Yes. Available in Excel workbook form.	Not at present. Hilborn plans to write a new web-based version that would be publicly available.	Yes, it requires readily available statistical software.	Yes.	NA
Can a third party "run" the model, and use the results in an adaptive management framework?	Typically, changes in input & scenarios are given to MBI for additional model runs. Co-managers can alter habitat features of web-based version, but not the biological rules that determine survival. WRIA 8 is being trained on the web-version of EDT.	Same as EDT	Yes	Yes, SHIRAZ runs on Excel spreadsheet; the program can be modified by the third party.	Yes, the key to using SWAM is availability of existing data.	Yes.	NA
How long does it take to apply the tool ?	Depends on availability of data; data acquisition and data management requires most of time.	Less than EDT.	QHA is a qualitative approach based on expert opinion, therefore takes relatively little time.	M. Scheurell, NOAA Fisheries, suggested possibly 4 man-months for Snohomish basin; most time is development of functional relationships.	Probably months.	Model does not work on reach level. Effort is largely compiling available population data and applying statistical model.	Requires field observations and experimentation, some of which are underway. Ongoing studies need to be completed.
How much does it cost to apply the tool ?	MBI noted ~$30K for 6-7 small chum streams in south sound ($230/reach). Rate may not apply to Green R. Cost in WRIA 8 is $220K.	Likely less $ because no field testing: expert opinion & fewer variables considered.	Low cost. See above.	Unknown.	Unknown.	Low cost.	Requires synthesis of data, some is underway.
Applied in WRIA 9?	No.	Likely to begin in near future (Lakey, pers. comm.)	No.	Yes, application by MIT underway.	No.	Yes, by NOAA Fisheries but only to examine population trend. CRI could be re-run in WRIA 9 by third party.	Concept is emerging from WRIA 9 Research Framework effort.

Note: The models are Ecosystem Diagnosis and Treatment (EDT), EDT-Light, SHIRAZ, Qualitative Habitat Assessment (QHA), Salmonid Watershed Assessment Model (SWAM), and Cumulative Risk Initiative (CRI)

FIGURES

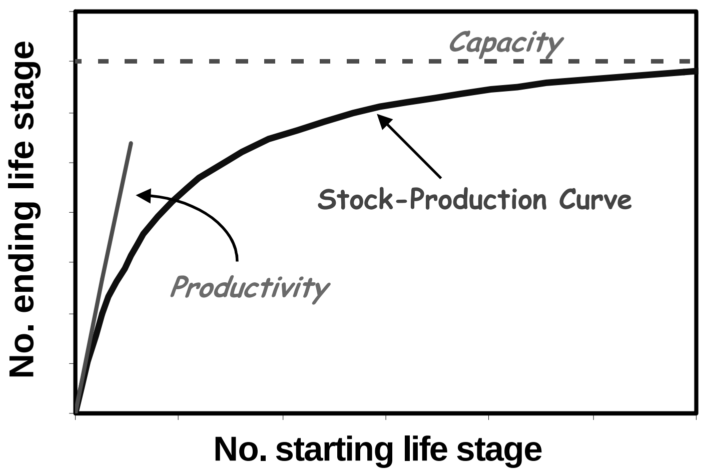

Figure 1

Example of Beverton-Holt stock-production relationship (from MBI 2002a). Productivity is the slope of curve near the origin.

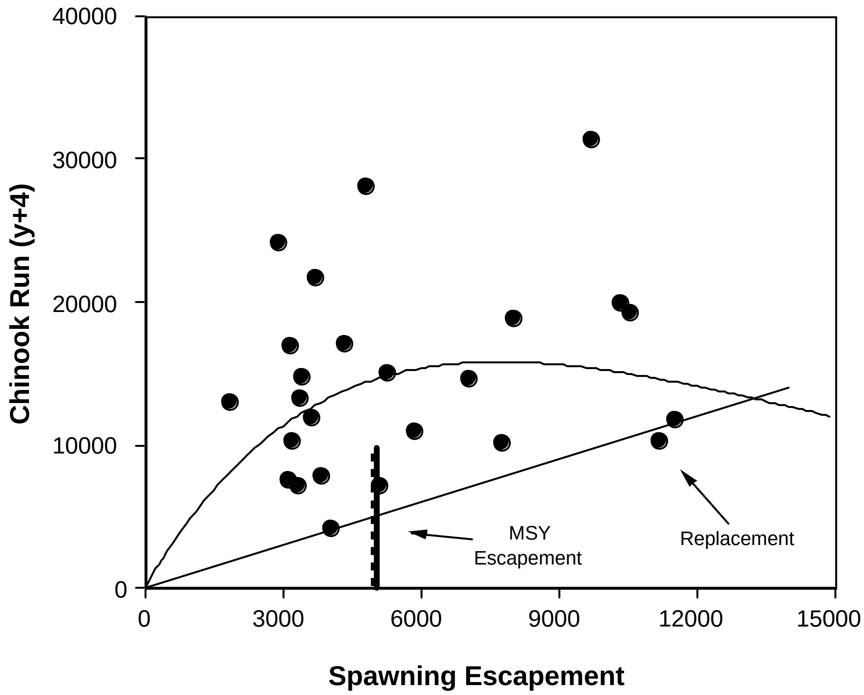

Figure 2

Relationship between parent spawning escapement and the number of adults produced by the parents, 1968-1992 (Weitkamp and Ruggerone 2000). This recruitment curve incorporates estimates of harvested fish in British Columbia and Puget Sound. Note the high variability in the relationship that reflects considerable year-to-year variation that is not explained by spawning escapement.

$$p = \bar{p}(m_{p_1} m_{p_2} \ldots m_{p_n})$$

$$c = \bar{c}(m_{c_1} m_{c_2} \ldots m_{c_n})$$

Where m_{p_n}, m_{c_n} are multipliers accounting for the effect of habitat indicator n

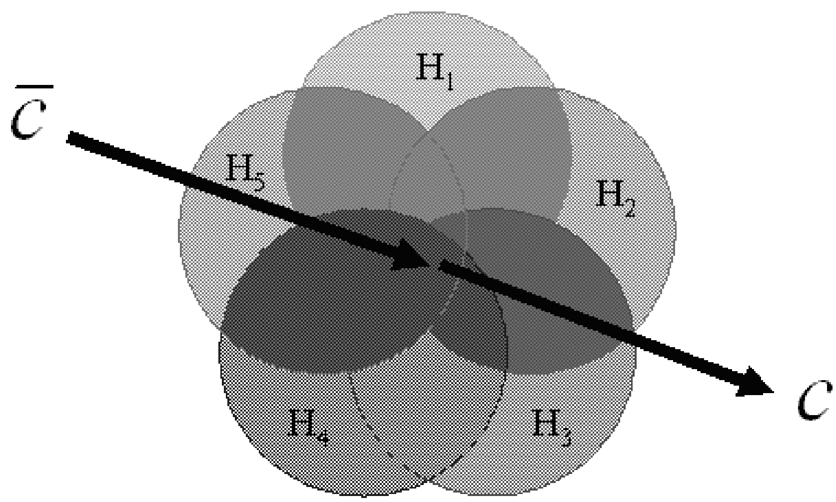

Figure 3

Calculation of productivities and capacities by SHIRAZ (Hilborn 2003). This approach is analogous to calculation of productivities by EDT and appears to be analogous to the calculation of capacities by EDT Capacity estimates from other methods can be used by SHIRAZ.