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Puget Sound Chinook Salmon Recovery: A Framework for the Development of Monitoring and Adaptive Management Plans

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Executive Summary

Chinook salmon (*Oncorhynchus tshawytscha*) were listed in Puget Sound under the U.S. Endangered Species Act (ESA) in 1999. In response, a coalition of public and private stakeholders, called the Shared Strategy for Puget Sound, developed a Chinook salmon recovery plan. The resulting Puget Sound Chinook Salmon Recovery Plan (the Recovery Plan) contained both regional (i.e., Sound-wide, Volume I) and local scale (i.e., watershed-wide, Volume II) chapters. The Recovery Plan was submitted to the National Marine Fisheries Service (NMFS) in 2005, and in 2006 NMFS issued a required Supplement to the Recovery Plan, concluding that the Recovery Plan met the requirements of the ESA and adding addition elements. Among these, the supplement identified a critical need to develop and implement a rigorous monitoring and adaptive management framework to assess the effectiveness of actions and progress towards recovery.

This document was developed by the Puget Sound Recovery and Implementation Technical Team (PSRITT) to provide a formal monitoring and adaptive management framework (the framework) for assessing Puget Sound Chinook salmon recovery. Monitoring and adaptive management have occurred at the watershed and regional scales as implementation of the Recovery Plan has proceeded. However, the lack of a formal framework has meant that there is no standardized vocabulary or shared common approach to articulate the key assumptions of the chapters in Volume II, to test assumptions across chapters, or to connect the local, watershed scale information in Volume II with the regional scale information in Volume I. This gap limits the collective ability of resource managers to assess the effectiveness of salmon recovery efforts across the region, to identify uncertainties, and to update priorities and actions in the Recovery Plan. Furthermore, the framework is intended to help salmon recovery managers formalize their local scale monitoring and adaptive management plans using a common approach.

We developed the framework using concepts taken from the Open Standards for the Practice of Conservation (Open Standards). Open Standards is a scalable, adaptable system widely used to design, manage, and monitor conservation projects. The framework builds on several interrelated categories of information, or "elements". These elements are as follows:

- *Ecosystem components* – Species, ecological systems/habitats, or ecological processes that are chosen to represent and encompass the full suite of biodiversity in the project area for place-based conservation.
- *Key ecological attributes* (KEAs) – Patterns of biological structure and composition, ecological processes, environmental regimes, and other environmental constraints necessary for an ecosystem component to persist.
- *Indicators* – Measures of condition or status.
- *Pressures* – Factors delivering direct stresses to ecosystem components.

- **Stresses** – Altered or degraded key ecological attributes.
- **Contributing factors** – Factors affecting human-induced actions, events, or natural processes that are not drivers or direct pressures but that affect the condition of ecosystem components.
- **Drivers** – The ultimate human-induced actions, events, or natural processes that underlie or lead to one or more pressures.
- **Strategies** – A group of actions with a common focus designed to achieve specific objectives and goals.

These elements function as building blocks of conceptual models that describe the relationships between strategies, pressures on ecosystem components, and recovery goals and objectives in order to determine what kind and level of intervention is likely to be most effective. Open Standards includes companion software (Miradi) to create graphical depictions of these conceptual models. Miradi software is also used to develop "results chains", which are diagrams derived from the conceptual models depicting assumptions or hypotheses that link short-, medium-, and long-term actions and results in an "if…then" fashion. Development of a monitoring and adaptive management plan consistent with the framework is not contingent on the use of the Miradi software, as we recognize other data management tools may already be in use in some watersheds.

We used the scientific literature on Pacific salmon and salmonid ecosystems and also the Recovery Plan chapters to describe the elements above for Chinook salmon in the Puget Sound region. We identify 14 ecosystem components and their associated KEAs. These ecosystem components are Chinook salmon, the two ecosystems – freshwater habitats, and estuarine and marine habitats – used by Chinook salmon, and finally, the species and food web processes upon which Chinook salmon depend.

We provide example indicators of KEAs that can be tailored to the individual watershed recovery plans. The list of indicators presented in this document is provided as an example and is neither prescriptive nor all inclusive. However, we do recommend watershed managers work together to develop common indicators in order to attain a common region-wide measure of progress.

We identify linkages between major life cycle segments and events that represent the Chinook salmon ecosystem component and the habitat ecosystem components. Each life cycle segment and event is associated with habitat types used by Chinook salmon during particular life stages. This association is necessary to connect the habitat-related ecosystem components with the Chinook salmon ecosystem component in the framework. The habitat-related ecosystem components are organized into a hierarchical watershed, reach, and habitat unit scale classification. These classifications are intended to include all habitats utilized by Chinook salmon across their life history or contributing to the formation and maintenance of Chinook salmon habitat. Our intent is that every habitat-forming ecosystem process should be

incorporated in the framework regardless of whether the process occurs upstream, upslope, or otherwise outside of habitats accessible to Chinook salmon.

We catalog and describe 26 potential pressures based on modification of International Union of Conservation of Nature (IUCN) classification of pressures. This common list provides the foundation for pressure assessments within and across different watersheds.

Applying the framework to develop watershed-specific monitoring and adaptive management plans requires a series of steps that builds on the technical information contained in the watershed chapters in Volume II of the recovery plan and new information gained since the chapters were prepared. These steps are as follows:

1) Develop a preliminary watershed-specific conceptual model
2) Update the conceptual model with new information
3) Conduct a viability assessment
4) Assess pressures
5) Create results chains
6) Link results chains to monitoring
7) Develop a monitoring plan
8) Develop an adaptive management plan.

We describe the tools useful for completing these steps, and suggest the use of Miradi software. Watershed planners may have other more appropriate or sophisticated tools that they wish to use for a given step.

Collecting the information needed to evaluate the progress of salmon recovery across an ESU and using it to adapt recovery strategies and actions is not simple. A successful approach to collecting information, evaluating actions, and informing decisions made at the local, regional, or national levels needs to provide consistency across multiple scales and geographies, while being flexible enough to capture unique differences. We know of no such approach elsewhere. The framework and process we describe here are designed to address this need for a scalable, flexible approach to managing recovery planning in a complex ecosystem. Use of this framework is intended to help managers describe and refine their assumptions regarding the magnitude and extent of recovery actions needed at the scale of the natural processes they are intended to affect, so that the actions produce expected responses that can be measured, evaluated, and improved.

Acknowledgments

Abbreviations and Acronyms

BFW   bankfull width
DO   dissolved oxygen
ESA   Endangered Species Act
ESU   evolutionarily significant unit
GIS   geographic information system
KEA   key ecological attribute
LWD   large woody debris
MRV   marine riparian vegetation
NMFS   National Marine Fisheries Service
Plan   Puget Sound Salmon Recovery Plan
PSNERP   Puget Sound Nearshore Ecosystem Restoration Project
PSP   Puget Sound Partnership
RITT   Recovery Implementation Technical Team
SAV   submerged aquatic vegetation
Skagit Plan   Skagit Chinook Recovery Plan
SSHIAP   Steelhead Habitat Inventory and Assessment Program
TRT   Technical Recovery Team
VSP   viable salmonid population
WDFW   Washington Department of Fish and Wildlife
WDNR   Washington Department of Natural Resources

CHAPTER I: Framework Structure

Introduction

Chinook salmon (*Oncorhynchus tshawytscha*) were listed as threatened in Puget Sound under the U.S. Endangered Species Act (ESA) in 1999 (NMFS 1999). In response to this listing, a coalition of local, state, federal, tribal, business, agricultural, and non-profit organizations—the Shared Strategy for Puget Sound—established a process to develop a salmon recovery plan, in coordination with the Puget Sound Technical Recovery Team (TRT) appointed by the National Marine Fisheries Service (NMFS). Volume I of the resulting Puget Sound Chinook Salmon Recovery Plan (hereafter called "the Recovery Plan") provides a regional scale overview of recovery. Volume II of the Recovery Plan consists of individual chapters which describe information specific to each of the 14 Chinook salmon watersheds identified by the TRT in the Puget Sound region. In addition, there is a chapter on nearshore marine recovery relative to Chinook salmon. Volumes I and II of the Recovery Plan were submitted to NMFS for review in 2005.[1] NMFS issued a supplement to the Recovery Plan in 2006, and then finalized both documents the following year. The supplement identified the development of a rigorous monitoring and adaptive management framework as a critical component to Recovery Plan implementation that was left incomplete (NMFS 2006).

Background

Despite the lack of a formal framework, monitoring and adaptive management have occurred at the local (i.e., watershed) and regional (i.e., Puget Sound) scales as part of the effort to implement the Recovery Plan. At the local scale, this work has focused primarily on site-specific monitoring of habitat restoration projects and salmon. In some watersheds, it has also included the development of monitoring and adaptive management plans. At the regional scale, this work has fallen into three categories: monitoring of salmon by the state and tribal co-managers; nascent habitat monitoring programs that address state-wide questions; and a draft monitoring and adaptive management plan associated with Volume I. For this third category, the draft was written but never finalized (Shared Strategy for Puget Sound 2007), and no comparable approach associated with Volume II was developed.

These efforts to conduct monitoring and adaptive management help address specific needs at both the local and regional scales, but there is currently no way to 1) uniformly frame the assumptions stated in the various chapters in Volume II, 2) incorporate new monitoring information regarding these assumptions, 3) test similar assumptions across multiple watersheds, or 4) connect the local scale information in Volume II with the regional scale information in

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[1] Document may be found online at http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Recovery-Plan.cfm

Volume I. Additionally, we are limited in our ability to assess the effectiveness of individual salmon recovery efforts and to identify uncertainties and priorities for change across the Puget Sound region. In response, we developed a science-based structure and process —or—"framework" for creating local scale monitoring and adaptive management plans that will allow consistency across the Puget Sound region.

Purpose and Scope

This framework allows inclusion of watershed-specific conditions by incorporating information stated in Volume II of the Recovery Plan. It also enables the monitoring and adaptive management plans for individual watersheds to be compared via common terminology and principles. Our purpose in developing the framework was to retain the individual salmon recovery approaches developed for each watershed while also providing the consistency required for a regional scale assessment of Chinook salmon recovery.

In this document we define parameters important to Chinook salmon and the ecosystems that support Chinook salmon. We also define linkages of anthropogenic impacts (both social and economic) to Chinook salmon and the ecosystems on which they depend. This process can be applied via eight steps to develop monitoring and adaptive management actions and plans within each watershed. These watershed-scale monitoring and adaptive management plans will give us the ability to track changes in Chinook salmon population performance and habitat change, and to inform management decisions on all scales (watershed, cross-watershed, and regional). Our framework is currently developed for Chinook salmon, but can be adapted to other salmonid species such as summer chum (*O. keta*) and steelhead (*O. mykiss*), both of which are listed as threatened in Puget Sound.

The Open Standards Approach

We designed the framework to be consistent with the Conservation Measures Partnership's Open Standards for the Practice of Conservation, or "Open Standards." The Open Standards approach provides a scalable, adaptable system for assembling the concepts, methods, and terminology widely used in the design, management, and monitoring of conservation projects (CMP 2007). This approach is intended to facilitate shared learning among disparate conservation projects, and to guide the development and implementation of effective monitoring and adaptive management plans. More specifically, the Open Standards approach is designed to help practitioners identify conservation targets, actions related to those targets, the status of those targets, and ways to measure or monitor changes and, ultimately, to adapt actions.

Open Standards encompasses five main steps commonly applied to conservation projects (Figure 1). These steps are: 1) conceptualize the project, 2) plan actions and monitoring, 3) implement actions and monitoring, 4) analyze, use, and adapt monitoring information, and 5) capture and share learning with stakeholders (Figure 1). These steps form an iterative cycle which can be refined and adapted over time as new information is developed and shared, and form a true adaptive management process.

As described above, Volume II of the Recovery Plan contains 14 watershed (local scale) chapters and a chapter describing nearshore marine salmon recovery. These chapters include Chinook salmon recovery goals and prioritized management actions and monitoring needs. Additional work has also been implemented in the watersheds since the plans were approved in 2007. Our framework is designed to incorporate all of this information into a common language and format by applying Step 1 and Step 2 of the Open Standards approach (Figure 1). Monitoring plans will then be developed and implemented by applying Steps 2 and 3 of the Open Standards approach (Figure 1). In Step 4, data gained through implementation of monitoring plans and actions will be used to evaluate the impacts of projects and to adapt the plans accordingly. Finally, the critical step (Step 5, Figure 1) identified in the Open Standards approach to monitoring and adaptive management addresses the importance of sharing (project lessons and products) with stakeholders and project partners. Development and use of our framework is also intended to improve sharing of information among and between project partners and stakeholders throughout all steps. Our framework provides a scientific basis for evaluating the status of Chinook Salmon Recovery Plan implementation in a common format that may be used by managers and policy leaders region-wide.

The Open Standards approach includes a companion software package called "Miradi" which practitioners can use to develop, visualize, and track these steps (see https://miradi.org/). Miradi is an open source software package and is now available for free (https://miradi.org/download). We utilized this software to create a "template" which contains all of the components of our framework that are described within this document. The template is a Miradi file intended for use as a "starting point" by practitioners who are developing watershed-specific monitoring and adaptive management plans. However, practitioners need not use Miradi or this template to apply the framework.

Elements of the Framework

Our framework defines several interrelated categories of information, or "elements," based on the Open Standards approach. The elements are: ecosystem components, key ecological attributes, indicators, pressures, stresses, contributing factors and drivers, and strategies with associated actions. Brief definitions of the elements are listed below and adapted from Salafsky et al. 2008 and FOS 2009. In order to improve consistency with terminology used by the Puget Sound Partnership (PSP), some element names differ from those used in Open Standards. Therefore, the elements are listed below by framework name with the corresponding Open Standards or Miradi name included in italics, if different (see Appendix A for a detailed crosswalk of terminology common to this framework, Open Standards, and Miradi).

1. Ecosystem Components (*Conservation Targets*). Ecosystem components are the things we care about conserving. They can be individual species, habitat types, ecological processes, or ecosystems chosen to encompass the full breadth of conservation objectives for a specific project. In our framework, ecosystem components are *priorities for salmon recovery*, such as Chinook salmon or their natal estuary habitats.

2. Key Ecological Attributes. Key ecological attributes (KEAs) are the characteristics of an ecosystem component that, if present, would support a viable component but, if missing or altered, would lead to loss or degradation of the component over time. KEAs can be used to assess the status of a component, develop protection and restoration objectives for conservation, and focus monitoring and adaptive management programs. In our framework, KEAs are *characteristics necessary for salmon recovery*, such as the abundance and productivity of Chinook salmon, or the tidal hydrology of estuary habitats.

3. Indicators. Indicators are specific units of information measured over time that document changes in the status of a KEA or another element (e.g., a pressure). Indicators can be measured directly or computed from one or more directly measured variables. Indicators should be measurable, precise, consistent, and sensitive (TNC 2007). In our framework, indicators are *metrics to assess salmon recovery*, such as the annual number of Chinook salmon spawners for a population, or the length of tidal channel habitat in an estuary.

4. Pressures (*Direct Threats*). Pressures are the proximate human activities or processes that have caused, are causing, or may cause the destruction, degradation, and/or impairment of ecosystem components. Natural phenomena are also regarded as pressures in some situations. Pressures include both stressors and the sources of stressors. In our framework, pressures are *proximate limitations on salmon recovery*, such as commercial harvest of Chinook salmon, or levees and tidegates in estuary habitats.

5. Stresses. Stresses are attributes of an ecosystem component's ecology that are impaired directly or indirectly by human activities. Stresses are equivalent to altered or degraded KEAs. Stresses are not pressures, but rather degraded conditions or "symptoms" that result from pressures. In our framework, stresses are *symptoms of limitations on salmon recovery*, such as reduced Chinook salmon spawner abundance or altered tidal hydrology in estuary habitats.

6. Contributing Factors (*Factors*). Contributing factors describe the context for why a pressure becomes a concern. They are the underlying, human-induced actions or events—usually social, cultural, political, institutional, or economic—that enable or otherwise add to the occurrence or persistence of pressures. Contributing factors encompass indirect threats, existing conditions, and root causes, as well as opportunities. Therefore, they can have either negative or positive effects. A political or legal constraint in the regulatory system that allows transportation corridors to damage the tidal hydrology of an estuary exemplifies a contributing factor with a negative effect.

7. Drivers (*Factors*). Drivers are similar to contributing factors in that they represent the conditions underlying the occurrence or persistence of a pressure. For the purposes of this framework, we distinguish between drivers, which tend to be outside the scope of strategies and actions in the local scale recovery plans (e.g., climate change, market forces), and contributing factors, which are addressed by specific strategies and actions (e.g., lack of public awareness, deficient funding). Further, drivers differ from contributing factors in that they also include non-human events and forces such as natural disasters. Combined, drivers and contributing factors can be thought of as the *ultimate limitations on salmon recovery.*

8. Strategies and Actions (*Strategies and Activities*). Strategies are groups of actions designed to achieve specific conservation goals, pressure reduction objectives, or intermediate outcomes. Collectively, they reduce pressures, capitalize on opportunities, or restore natural systems. In our framework, strategies and their associated actions are *approaches to address limitations on salmon recovery*, such as increasing habitat protection.

We drew from existing documents to define elements 4–8 (Appendix B). Elements 1–3 are developed in Chapter II of this document, where we've identified 14 ecosystem components associated with Chinook salmon recovery in the Puget Sound region, and defined key ecological attributes and potential indicators for each component. This provides the essential technical relationships associated with salmon recovery to inform a monitoring and adaptive management framework. In Chapter III we provide general and specific examples of the application of these elements to generate local scale and regionally consistent monitoring and adaptive management plans to guide Chinook salmon recovery.

Regional Scale Application

The use of this framework enables information regarding Chinook salmon recovery to be summarized and assessed at local watershed scales, but also combined to assess recovery at the regional scale, and also across multiple watersheds. For example, we can have greater confidence and better understand regional priority pressures by evaluating the key pressures from all fourteen watersheds (i.e., utilizing our framework), rather than if regional pressures are only analyzed at a larger regional scale. In addition, our framework allows us to report on the status of habitat types (e.g., how floodplain habitats are currently functioning across the ESU) by analyzing the results of explicitly stated goals across all fourteen watershed. And, we will be able to compare monitoring results across multiple watersheds, for example, on a specific strategy such as "education and outreach" or "habitat restoration". Comparing information on monitoring across multiple watersheds can help inform watershed practitioners where and how they may more effectively work together, and/or how the tools and techniques to implement strategies may be correlated across watersheds.

Monitoring and Adaptive Management

Generally defined, monitoring is the act of collecting and evaluating information needed to answer questions related to how well a conservation project or strategy is working, and helps identify the conditions under which actions are likely to succeed or fail (CMP 2007; Stem et al. 2005). A monitoring plan defines which information needs to be collected and then describes how and where it will be collected, who will collect it, and how it will be analyzed and summarized for decision-makers. Several types of monitoring can be incorporated into a monitoring plan (USDA and USDI 1994), including:

- Implementation Monitoring. This type of monitoring tracks whether proposed actions were executed or accomplished as designed, answering questions such as *"Were priority projects implemented. If so, when and by whom? If not, why not?*

- Status and Trends Monitoring. This type of monitoring describes current conditions and changes over time in the organisms and habitats we care about, by answering questions such as "*What is current spawner abundance? Has it increased or decreased since listing? Has riparian forest cover increased or decreased since listing?*"

- Effectiveness Monitoring. This type of monitoring evaluates whether implemented actions achieved the desired outcomes. By definition, it assesses the operational effectiveness of management actions, answering questions such as "*Did side channels form following the removal of bank armor? Did residual pool depth increase after the installation of log jams? Were the objectives of a management action met?*"

- Validation Monitoring. This type of monitoring determines whether the assumed cause-and-effect relationships between management actions and outcomes are valid. It answers questions such as "Will *side channels form if bank armor is removed? Do pool depths increase if log jams are installed?* Effectiveness and validation monitoring are related and are complementary, since it is necessary to know that a) actions are being achieved (effectiveness monitoring) and b) the effect is caused by the action, as hypothesized (validation monitoring).

As described above, there is a need to track and manage all of these types of monitoring throughout the Puget Sound Chinook salmon ESU in order to assess and comply with recovery status and goals. By organizing information (including current assumptions, working hypotheses, recovery goals, recent research, and planned restoration actions) and then applying it to this framework, watershed groups will have the ability to specifically define monitoring goals and activities (including the four types of monitoring described above), and thus devise their watershed monitoring plans. These plans will vary depending on the conditions and characteristics of each watershed, and the current status of knowledge and specific actions being pursued. The mechanism for how this will be achieved through application of the framework is further defined in Chapters II and III below.

Many methods, or protocols, exist for collecting the information needed for each type of monitoring (e.g., see https://salmonmonitoringadvisor.org/ or http://monitoringmethods.org/). We do not address which specific protocols should be employed in the application of this framework to devise monitoring and adaptive management plans. However, many other monitoring-related projects are currently underway in the Puget Sound region (Appendix C). Our framework was developed alongside – both in context of and providing context for – these other projects.

Adaptive management is "learning by doing," and then applying what has been learned to improve the "doing." Anderson et al. (2003) identify three approaches: active adaptive management, passive adaptive management, and evolutionary problem solving. Each approach emphasizes different considerations for how to implement directed changes from learning by

doing, and each has different strengths and weaknesses. The defining qualities of an effective adaptive management plan are: 1) the approaches used are scientifically based and produce measured outcomes, 2) measured outcomes are compared against expected outcomes, and 3) management actions are modified according to what was learned (Anderson et al. 2003).

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Chapter II: Ecosystem Components

Defining ecosystem components is the first task outlined in the Open Standards approach (Figure 1). Our framework identifies four broad categories of ecosystem components relevant to the recovery of Chinook salmon in the Puget Sound region. These categories are: 1) Chinook salmon, 2) Chinook salmon freshwater habitats, 3) Chinook salmon estuarine/marine habitats, and 4) the other species and food webs related to Chinook salmon. Fourteen ecosystem components are identified within these four categories (Table 1).

Greene and Beechie (2004), Greene et al. (2005), Scheuerell et al. (2006), and both volumes of the Puget Sound Salmon Recovery Plan define and document life cycles and life history stages for Puget Sound Chinook salmon. Based on this work, we identify five major life cycle segments for Puget Sound Chinook salmon, each of which encompasses one or more life cycle events (Table 2). The Chinook salmon ecosystem component includes these life cycle segments and events. Each Chinook salmon life cycle segment or event is associated with habitat types (Table 2, Appendix D). Through this association we connect habitat ecosystem components with the Chinook salmon ecosystem component in our framework.

Identifying ecosystem components for habitats used by Chinook salmon involves classification. The ecological literature contains numerous efforts to classify environments and habitats. Review of the history and development of these classifications (e.g., Naiman et al. 1992, Montgomery and Buffington 1997, Lombard 2006) suggests several key conclusions: 1) hierarchical classifications best encompass the various ecological processes and attributes operating at different spatial and temporal scales; 2) physical, process-based classification systems offer a unifying approach for understanding landscape controls on habitat-forming processes and the effects on habitat characteristics; and 3) no existing classification system adequately links physical controls and processes with biological controls and processes (e.g., zoogeography, community structure, species interactions, population dynamics). Nevertheless, conceptual diagrams linking physical controls and processes to biological responses (Figure 2) have been used to describe freshwater, estuarine and marine habitats (e.g., Bartz et al. 2006, Fresh 2006, Simenstad et al. 2006) and to plan salmon recovery actions (Beechie et al. 2003a). Therefore, our framework employs existing classifications and conceptual diagrams to identify habitat-related ecosystem components, but applies them to Chinook salmon recovery in Puget Sound.

Key Ecological Attributes and Indicators
for Chinook Salmon

<u>Background</u>

McElhany et al. (2000) listed four parameters for evaluating Pacific salmonid populations that fit the definition of key ecological attributes (KEAs): abundance, productivity or population growth rate, spatial structure, and diversity. Because the topic of the paper was the criteria for a population to be viable, these four have become known in the salmon recovery community as "viable salmonid population" (or VSP) parameters. There is obviously, then, a close relationship between determining whether a population is a VSP and determining viability status in the Open Standards system. Applying a classification of KEAs often used by Open Standards practitioners (TNC 2007), the VSP parameters can be categorized as size (abundance), condition (productivity and diversity), and landscape context (spatial structure).

Another essential paradigm for understanding salmon population performance is the basic life cycle model. Although all organisms have a life cycle, the migratory and semelparous nature of Pacific salmon make the life cycle particularly useful for analyzing the factors that contribute to persistence, especially because particular life stages can be associated with particular habitats (Figure 3). It is convenient to regard the overall population growth rate as the product of survival rates between life stages through an entire life cycle. This basic model has been the foundation of salmon population management for many years (e.g., Paulik 1973). Its central position today is illustrated by the fact that the life cycle is the organizing principle for two key references for Pacific salmon (Groot and Margolis 1991 and Quinn 2005). As stated above, our framework identifies several major life cycle segments and events for Puget Sound Chinook salmon. Table 2 and Figures 4 and 5 depict the relationship between these segments/events and various freshwater, estuarine and nearshore marine habitat types.

<u>Key Ecological Attributes and Indicators</u>

We define Chinook salmon KEAs to correspond with the VSP parameters described by McElhany et al. (2000). We include three aspects of productivity (survival rate, fish growth, and population growth), two aspects of diversity (life history and genetic), abundance, and spatial structure. These seven KEAs are important throughout the Chinook salmon life cycle (Tables 3 and 4).

Indicators for each KEA (i.e., VSP parameter) and relevant life cycle segment and event are listed in Tables 3 and 4. Indicators are not designated in all table cells because some are problematic to measure (e.g., abundance of sub-adults) or redundant (e.g., genetic diversity measures at different life stages). However, future applications could include indicators in cells that currently have none, or indicators that are shown here may need to be modified.

Based on further assessment of the difficulty or redundancy of measuring certain indicators, we reduced the list of indicators to a fundamental set (Tables 3 and 4). We considered both feasibility of measurement and possible relationships between the KEAs. A

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subset of the indicators from the full list may be applicable in any single watershed. Choice of indicators remains a decision to be made at the local watershed management scale.

Some indicators are directly measurable, while others are computed from additional measurements, which may or may not be indicators in the framework (Tables 5 and 6). For example, the average size at age of spawners (an indicator of productivity) is directly measureable from escapement samples. Likewise, the number of spawners (an indicator of abundance) is directly measureable through a full census, although it is often estimated from two other indicators: number of redds and sex ratio of spawners. The number of spawners, is also used in conjunction with the number of fish recruited to fisheries (another abundance indicator) to compute recruits per spawner (an indicator of productivity). Other indicators are not directly measurable, nor are they computable from additional measurements appearing elsewhere in the framework. Three indicators of genetic diversity (effective population size, alleles per locus, and gene flow) exemplify this in that each depends on allele frequencies determined from genetic analyses of tissue samples taken from spawners or juveniles. These indicators are ascribed to the "spawning" life cycle event when individual populations are assumed to be segregated (Table 3), but, in theory, they could be measured at any life stage. It is noteworthy that, while methods for measuring and calculating abundance and productivity indicators are generally well established in salmon management, there are few comparably vetted methods for spatial structure and diversity indicators (see Fresh et al. 2009). Stresses (i.e., altered KEAs) to Chinook salmon at specific points in their life cycle are identified in Appendix B (Table B-2a).

Key Ecological Attributes and Indicators

for Freshwater Habitats

Background

We define five ecosystem components for the freshwater habitats relevant to Chinook salmon recovery: uplands, large channels (main channels > 50 m bankfull width (BFW)), small channels (main channels < 50 m BFW), side channels (secondary channels in main channel floodplain), and other floodplain waterbodies (lacustrine and palustrine habitats) (Tables 1, 7). We recognize that these ecosystem components and their associated key ecological attributes occur at multiple spatial and temporal scales (Frissell et al. 1986), however we focus at the hierarchical scale of individual watersheds and smaller segments (reaches and habitat units, defined in km and m, respectively) for this framework (Figure 6, Table 7). At the watershed scale, we utilize habitat classification systems described by Beechie et al. (2003a, b, 2005), Bisson et al. (1988), and Cowardin et al (1979). Beechie et al. (2005) described habitat types for large rivers. Bisson et al. (1988) identified habitats and channel hydraulics of smaller streams, and Cowardin et al. (1979) categorized wetland and deepwater habitats. Each habitat is further subdivided into finer scales of organization: reaches and habitat units (Table 7; Cowardin et al. 1979, Bisson et al. 1988, Beechie et al. 2005). Bisson et al. (1988) described rapid and cascade habitats in addition to those unit scale habitats described by Beechie et al. (2005). Cowardin et al. (1979) classified wetland and deepwater habitats as riverine, lacustrine, and palustrine, with further breakdown into subsystem and class categories. Not all Puget Sound watersheds contain each of these habitats. Also, if other habitats in a watershed do not fall into this classification system (and are deemed important to Chinook salmon) we urge individual watershed groups to modify the framework as necessary, preferably so modifications nest within this classification scheme.

Key Ecological Attributes and Indicators

We use a basic conceptual diagram in which high-level landscape controls govern ecosystem processes, which in turn affect the physical, chemical and biological characteristics of freshwater habitats (Figure 2; Spence et al. 1996, Beechie and Bolton 1999, Roni et al. 2002). We incorporate and define these ecosystem processes in our framework as KEAs (Tables 8 and 9). For convenience, we follow Beechie et al. (2003a) in organizing these KEAs into watershed and reach scale processes. Watershed scale processes are those with multiple, widely distributed sources, whereas reach scale processes are those that affect one or more adjacent reaches.

Chinook salmon at various life stages depend on freshwater habitats that are maintained when both watershed and reach scale processes are healthy, intact, and functioning properly. A healthy ecosystem with a diversity of habitat types promotes a diversity of Chinook salmon life history types and population resilience (McElhany et al. 2000, Fresh et al. 2009, Greene et al. 2010). Changes and interactions between physical, chemical and biological processes at the watershed and reach scales control the complexity and diversity of habitats (Figure 7; Beechie et al. 2010). KEAs, and their associated indicators, should have the ability to detect gradations of ecosystem process and function and should be applicable across all spatial and temporal scales appropriate for the process. The following descriptions of watershed and reach scale processes

provide context for our defined KEAs. Table 10 lists these KEAs, as well as some associated KEA and pressure indicators. The indicators are presented as examples and are neither prescriptive nor all inclusive. A list of stresses, or altered KEAs, is included in Appendix B (Table B-2b).

I. Sediment Dynamics

Sediment dynamics include the processes that supply, transport, and deposit sediment within freshwater watersheds. Upland and riparian hill-slopes, and stream banks are the primary sediment supply locations within a watershed. Mass wasting (landslides and debris flows), surface erosion, and bank erosion result in sediment supply to these aquatic habitats. Riverine features are formed (e.g., bars, islands, plane-bed channels) as a result of deposition (or accretion) of sediment, and disappear as a result of further downstream transport of these sediments (Church 2002). Local variation in sediment delivery rates, routing, and composition determines the type and quality of habitat (Sullivan et al. 1987). For example, sediment supply affects water quality, and the development and persistence of structures used for salmon reproduction and cover (Poff et al. 1997). Transport of sediment (suspended and bedload) occurs along a continuum of reaches within the watershed. Sediment input and output must be adequate to form and maintain habitat-type diversity and complexity. Sediment supply affects the distribution and productive capacity of spawning, incubating and freshwater rearing life stages of Chinook salmon (Dauble et al. 2003).

Various low gradient habitats (pools, riffles, dune-riffles, etc.) are lost over time if sediment supply is altered or increased. Sediment supply dynamics can be altered in three general ways:

1. increased delivery of sediments to stream channels from mass wasting or upslope erosion (e.g., related to groundcover/canopy loss, road-related sediments, surface and groundwater rerouting);

2. decreased delivery of sediments caused by the installation of a dam, channelization, bank hardening, or loss of floodplain connectivity;

3. changes in sediment transport and storage due to either a) increases or decreases in abundance of woody debris or beaver dams, b) modified stream gradient and confinement (channelization, incision, head-cutting), or c) remobilized stored sediments (channel avulsion, bank erosion).

Two KEAs are identified for sediment dynamics:

- **KEA I-1**: Sediment delivery, and

- **KEA I-2**: Sediment transport and storage.

II. Hydrology

Hydrology refers to the distribution, patterns, duration and magnitude of stream flows resulting from precipitation, evaporation, transpiration, runoff, and routing. Water is necessary to build and sustain the habitats required for complex aquatic species assemblages. Natural and

managed hydrological regimes create and maintain aquatic habitats through bankfull flows (typically 1.5 to 2.0 year recurrence) and episodic flood flow events (Leopold 1994). The resulting aquatic habitats and their spatial distribution are dynamic and subjected to seasonal high and low flows that are a primary control on fish passage and timing, as well as, the distribution and timing of fish rearing, growth (including condition), and survival (Poff et al. 1997). Stream flow (both high and low) and provide hydraulic diversity (variation in water depths and velocities) that is dynamic both spatially (reach) and temporally (season, year). Diverse and complex habitat structure includes shallow edge and low velocity refugia for salmonids (Bain et al. 1988), as well as higher velocity areas for spawning or feeding. Connectivity of floodplain habitats is also very important for a fully functional hydrological regime (Fullerton et al. 2010)

Hydrology affects the distribution and timing of pre-spawning and spawning Chinook salmon entering freshwater habitats, as well as the dispersal of juvenile Chinook at various life stages to rearing habitats and their migration to estuarine, nearshore, and offshore marine habitats (McClure et al. 2008). Extreme hydrological events (floods, low flows) can have both episodic and/or catastrophic impacts on the survival of adults and juveniles due to displacement, and cause density-dependent population controls on spawning and rearing (Waples et al. 2008). They can also have a major impact on the life history diversity and spatial structure of populations.

Two KEAs are identified for hydrology:

- **K E A II-3**: High flow hydrological regime, and

- **K E A II-4**: Low flow hydrological regime.

III. Organic Inputs

This watershed process focuses on the processing of organic matter from riparian vegetation, salmon carcasses, and other allochthonous inputs. All natural surface water contains dissolved and particulate organic matter, and the amounts can be surprisingly high (Hynes 1970). Some of this matter is deposited in low velocity habitats (e.g., lakes, pools, and impoundments), while some is transported downstream and through the system (Hoover et al. 2010). Hynes (1970) concludes that there is likely a steady rain of minute particles of organic matter which ultimately forms food for animals. The type (dissolved and coarse/fine particulate matter) and amount of allochthonous organic matter inputs affect productivity at multiple trophic levels in the aquatic community (Vannotte et al. 1980; Bilby and Bisson 1992). Organic matter in aquatic systems is processed from a variety of source materials, ranging from logs (large woody debris, LWD) to leaves and even terrestrial insects. In rivers or streams with low light availability (i.e., streams shaded by riparian trees), aquatic food webs are often driven by detritus—processed organic matter which cycles through all trophic levels (Odum 1984). In addition to food web support, detritus (particularly LWD) serves a structural function in combination with streamflow by affecting bed scour and creating hydraulic diversity (Gregory et al. 1991; Gregory and Bisson 1997; Montgomery and Buffington 1997; Frissel et al. 1986). Vegetation removal and bank armoring, along with floodplain development, can impede recruitment and processing of detritus (Pess et al. 2005).

Two KEAs are identified for organic input:

- **KEA III-5**: Organic matter—inputs, and

- **KEA III-6**: Organic matter—retention/processing.

IV. Riparian

Riparian vegetation affects streambank stability, sediment supply, delivery of large woody debris (LWD) and organic litter, light and temperature (shading), composition of nutrients in aquatic habitats, and mediation of biotic interactions (Naiman and Décamps 1997). Riparian functions that depend on vegetation include maintaining instream water temperatures (through shade), bank stability (through vegetative root structure), primary food production (organic inputs through leaf litter and insects falling from trees over streams), recruitment of LWD, and sediment and nutrient trapping (Naiman and Décamps 1997). LWD recruitment sustains dynamic river morphology in forested floodplain river systems (Collins and Montgomery 2002, Naiman et al. 2010). This key ecological attribute is especially important in large mainstem, small mainstem, tributary, and off-channel habitats. Riparian function controls aquatic habitat quality, and lost riparian function can result in Chinook salmon life-stage specific productivity limitations, regardless of habitat quantity.

Riparian functions affect the quality and quantity of complex rearing habitats for all Chinook salmon freshwater life histories (McCullough 1999). Ecological function in the context of Chinook salmon within riparian areas is dependent upon the width of forest buffer adjacent to stream, i.e., wood input increases with an increasing width of forest buffer (Sedell et al. 1997). Other riparian functions (microclimate, litter fall, root strength, etc.) can be assessed in terms of stream buffer widths and continuity. Stream buffer width is typically impacted as a result of floodplain development causing riparian habitat loss, lack of continuity, bank hardening, and increased stream temperatures during low flow periods (Hauer et al. 2003).

Three KEAs are identified for riparian area function:

- **KEA IV-7**: Spatial extent and continuity of riparian area,

- **KEA IV-8**: Riparian community structure (e.g., species composition and seral stage), and

- **KEA IV-9**: Riparian function (e.g., recruitment, canopy closure etc.)

V. Nutrient Supply

Nutrients (e.g., nitrogen and phosphorous) are supplied naturally through the processing of organic matter by microbial and other biotic processes at lower trophic levels (Beechie et al. 2003a, b). Nutrients exert a strong control on primary productivity, and the consequent diversity and abundance of the aquatic community. Changes in riparian areas, point and chronic source inputs, stream channels, and biotic assemblages alter the flux and uptake of nutrients (organic and/or inorganic), which are the chemical constituents in water required for biological processes (Ward 1992). Growth and survival of juvenile Chinook salmon are affected by the type and

abundance of prey items and forage available. However, anthropogenic sources of nutrients (e.g., urban storm water, septic systems, agricultural runoff) enrich aquatic systems with nutrients and supply contaminants that may locally affect aquatic biota (e.g., macroinvertebrate communities), as well as the suitability of habitats for rearing juvenile Chinook salmon (Booth et al. 2004). Urban development also influences the concentration and yield of compounds that naturally occur in surface waters. For example, nitrogen yields from urban basins were the same order of magnitude as agricultural basins, and an order of magnitude higher than the yield from less-developed, forested basins (Embrey and Inkpen 1998). Further, chemical concentrations of pesticides and total phosphorous were more important than physical habitat features for identifying patterns of fish assemblages in low-gradient floodplain reaches of the Willamette River, OR (Waite and Carpenter 2000). Excess nutrients can shift aquatic communities away from preferred food items, and reduce water quality to a level that can result in physiological stresses to rearing Chinook salmon juveniles.

Contaminants as referred to here can be organic or inorganic, and can be derived from natural or unnatural sources, but they essentially have deleterious impacts on water quality and/or Chinook salmon growth, survival, and/or distribution. Water quality and contaminants are complex mechanisms which have profound impacts on the aquatic environment. They can vary greatly by watershed and by the degree of stress imparted. Contaminants can operate singly or in combination with other chemical constituents to effect Chinook salmon directly or indirectly via their habitat and/or food supply.

Two KEAs are identified for nutrient supply:

- **KEA V-10**: Nutrient concentrations (high, low),

- **KEA V-11**: Water quality, and

- **KEA V-12**: Nutrient cycling/flux.

VI. Floodplain-Channel Interactions

Interaction of rivers and floodplains affects capacity to deliver, supply, and store water, sediment, and wood (Bolton and Shelberg 2001). This attribute is especially important in large mainstem habitats. Floodplains generally contain numerous sloughs, side-channels, and other features that provide important spawning habitat, rearing habitat, and refugia during high flows (Beechie et al. 2001), and may be used by rearing salmonids for long periods of time. These off-channel areas provide an abundance of food with fewer predators than would typically be found in the river, and provide habitat for juvenile salmonids to hide from predators and conserve energy (Sandercock 1991). The importance of floodplain habitat to salmonids cannot be overstated. In the Skagit and Stillaguamish Basins, more than half of the total salmonid habitat is contained within the floodplain and estuarine deltas, while this habitat encompasses only ten percent of the total basin area (Beechie et al. 2001). Functional floodplains also moderate high flows by substantially increasing the area available for water storage (Ziemer and Lisle 2002). Water seeps into the groundwater table during floods, recharging wetlands, off-channel areas, shallow aquifers, and the hyporheic zone (Bolton and Shelberg 2001). Floodplains form in alluvial stream systems as a consequence of sediment input, sorting, transport and storage.

Floodplains are naturally subject to erosion and recruitment of stored sediments through channel migration and flood events (Pess et al. 2005). Connected floodplains provide instream habitat and support riparian processes. Secondary channels can have varied hydrologic connectivity with mainstem channels including direct surface water connections (periodic or continual), ground water connections, or both (Gregory et al. 1997; Beechie et al 2006b). These channels are classified based on a combination of hydrologic connection and gradient and confinement after Montgomery and Buffington 1997. The quantity and quality of available floodplain habitats can affect the life history diversity and spatial structure of Chinook salmon populations (Waples et al. 2009).

Human influence, both past and present, has degraded watersheds and wetlands, diminished the amount of available floodplain, and fragmented remaining intact floodplains throughout Puget Sound (Beechie et al. 2001, Pess et al. 2003). Floodplain impacts include the direct loss of aquatic habitat from human activities (filling), disconnection of main channels from floodplain channels with dikes, levees, revetments, and roads, and reduction of lateral movement of flood flows with dikes, roads, levees, and revetments (Pess et al. 2005). Decreased abundance of LWD results in degraded aquatic habitat quality and area (e.g., pools) due to altered sediment and wood supplies (Montgomery et al. 2003, Wohl et al. 2010). Dikes and riprap are used to control channel movement, and can cause channel incision, further isolating the channel and its hydrologic connectivity to the floodplain (Beechie et al. 2003a, b, Collins et al. 2003).

Two KEAs are identified for the floodplain/channel interaction watershed process:

- **KEA VI-13**: Floodplain—connectivity (e.g., to the main channel), and

- **KEA VI-14**: Floodplain—structure and function.

VII. Habitat Connectivity

Connectivity of habitats is necessary for the dispersal and migration of aquatic species, and, in the case of Chinook salmon, the development and expression of diverse life histories (Fullerton et al 2010). Connectivity can be described as the availability or access to habitats which are required by each Chinook life history stage. Further, the growth performance and size attained by individuals within some (but not all) habitats and life stages can strongly influence survival in current or subsequent life stages. Loss of connectivity due to seasonal, episodic, or artificial limits on volitional movements introduces local controls that effectively decrease the area of productive habitat in a watershed. This KEA represents a biological view and synthesizes the sediment, hydrology, and floodplain dynamics of other KEAs. Side channels, off-channel wetlands, and tidal marshes are important habitats utilized by Chinook salmon for feeding, rearing, refuge, and holding, given their connectivity to main migratory pathways.

Reconnection of isolated habitats is a primary objective in many restoration programs. Systematic methods can be used to restore habitats through barrier inventory, assessment, and allocation of funds to correct the fish passage problems. Cost-effectiveness of reconnection projects is easily determined by considering the habitat area restored, the average life span of a blockage (≈50 years), and the cost of the project (Pess et al. 2003).

One KEA is identified for habitat connectivity:

- **K E A V I I-15:** Habitat connectivity

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Key Ecological Attributes and Indicators

for Estuarine and Marine Habitats

<u>Background</u>

The need for a regionally consistent classification of estuarine and marine habitats is apparent when the individual chapters in Volume II of the Plan are viewed as a whole. These watershed-specific chapters tend to classify habitat differently, despite proposing restoration and protection actions that often follow common themes. Furthermore, not all chapters classify habitat based on natural processes and their controls. Instead, they use a mixture of natural processes, habitat types, and biota at various spatial and temporal scales in *a priori* assignments of habitat classes. These differences in classification among chapters would make regional scale assessment of monitoring and adaptive management in estuarine and marine systems difficult.

<u>Estuarine and Marine Habitat Components</u>

To support Puget Sound-wide and cross-watershed assessments of Chinook salmon monitoring and adaptive management we developed a comprehensive classification system for estuarine and marine habitats within Puget Sound that includes seven discrete ecosystem components (Table 11). Our classification system uses six hierarchical scales—broad habitats, system types, system subtypes, shoreline types, habitat zones and vegetative zones. Six of the seven ecosystem components are defined at the scale of system subtype and a single ecosystem component, Offshore Marine Systems, is defined at the system type scale (Table 11, Figure 8).

We consider the first four scales - broad habitats through shoreline type - to be geomorphic and "process-inferred" because the dominant natural process, or combination of processes, acting on a specific estuarine or marine habitat can be determined by the geomorphic signatures of those processes (including topographic relief) and/or previously mapped longshore drift. Thus, when monitoring the health of a process we do not measure or observe a process per se; rather we measure or observe a result created by a process (Shipman 2008, McBride et al. 2009). The seven estuarine and marine ecosystem components can be linked to large and small scale landscape controls, natural processes and biological responses based on a general conceptual diagram that is applicable region-wide (Figures 2, 7). In the estuarine and marine habitats of Puget Sound, controls and large scale processes include geology, topography, bathymetry, wave energy, freshwater inflow, tidal range, and sea level rise. These controls and processes differ across the region and form the basis of seven geographic basins within the United States portion of the Salish Sea (Appendix D; Figure D-1); the basin boundaries were chosen to follow natural breaks in geomorphology and large scale hydrodynamic processes (Simenstad et al. 2011).

Landscape controls and large scale processes generally are not influenced by the strategies and actions in the Recovery Plan, because they operate beyond the scope of the recovery planning area and its implementation period. However, they are considered in development of the estuarine and marine nearshore classification system and identification of key ecological attributes (see below) because they limit (or otherwise influence) the expression of the small scale natural processes that form habitat. In estuarine and nearshore habitats in

particular, these small scale processes include tidal, fluvial, and wave energy dynamics that cause water, sediment, large woody debris (LWD), and other detritus to form geomorphic habitat types at a variety of spatial scales.

Habitat and vegetative zones comprise the fifth and sixth scales, respectively, of our classification system and are found across multiple system types, subtypes, and shoreline types. Habitat zones are related to elevation differences and natural process signatures easily illustrated in bird's-eye or cross-section views of typical landforms (Figures 9 and 10). They are also included in the final column of Table 11. Vegetative zones, the smallest level in our classification system (not shown in Table 10) are features that live or accumulate on habitat zones. Vegetation zones include: 1) vegetation (marine riparian, saltmarsh, and submerged aquatic vegetation, including kelp, eelgrass, macroalgae, etc.); 2) detritus (marine, estuarine, freshwater, and terrestrial detritus, including LWD); and 3) substrate (sediment). Specific vegetation zones are associated with specific habitat zones. For example, marine riparian vegetation is associated only with habitat zones higher in elevation than extreme high tide. Submerged aquatic vegetation is associated only with lower intertidal or subtidal habitat zones to a depth determined by the lower limit of the photic zone. Some vegetative zones in our classification system (e.g., marine riparian, saltmarsh, and submerged aquatic vegetation) are also biotic response variables in the conceptual diagram (Figure 2) and are a result of multiple ecosystem processes.

Key Ecological Attributes and Indicators

To support development of watershed scale and regional monitoring plans that track the status and condition of estuarine and marine systems we have identified a set of key ecological attributes (KEAs) (Table 12) associated with six ecosystem process categories critical for Chinook salmon habitat formation and maintenance: coastal sediment dynamics, fluvial sediment dynamics, freshwater hydrology, tidal hydrology, tidal channel formation and maintenance, and detritus recruitment and retention. Two additional groups of KEAs have been developed to specifically address habitat connectivity and attributes that are influenced by multiple ecosystem processes. The set of KEAs was derived largely from a review of the Volume II chapters that include nearshore habitat, as well as several PSNERP technical reports (Finlayson 2006, Brennan 2007, Johannessen and MacLennan 2007, Mumford 2007, Penttila 2007, Shipman 2008, Clancy et al. 2009). The ecosystem process categories and associated KEAs listed in Table 12 are described below. Table 13 presents a summary of all KEAs organized by ecosystem process and ecosystem component. Table 14 expands on Table 13 and provides a list of KEAs relevant to each estuarine or marine component with example indicators for each KEA. Table 15 provides specific examples from the Skagit and hypothetical examples for each component that illustrate how component-specific indicators and KEAs are derived from the generic KEAs listed in Tables 12 and 13. KEAs also provide a framework for assessing the effects of pressures, or stressors, on ecosystem components. A list of stresses, or altered KEAs, is included in Appendix B (Table B-2b).

I. **Sediment Dynamics**— Coastal

Coastal sediment dynamics comprise the processes that supply, transport, and deposit shoreline sources of sediment within estuarine and marine systems. This includes coastal sediment dynamics associated with drift cells, major river systems and rocky shorelines. We also include wind/wave processes in each system which are a primary energy source for movement of coastal sediment.

Within drift cell systems, bluff backed beaches are the sediment supply shoreforms (Keuler 1988). Sediment transport and deposition also occur at bluff backed beaches (Finlayson 2006, Johannessen and MacLennan 2007). Coastal landforms (e.g., spits, tombolos, cuspate forelands) are deposition (or accretion) shoreforms where there is a net gain and storage of sediment (Shipman 2008). Pocket estuaries with lagoon habitat formed behind coastal landforms and are a byproduct of healthy drift cell sediment dynamics. Lagoon habitat is lost over time if coastal landforms erode away due to lack of sediment supply or blocked sediment transport within the drift cell. Sediment supply dynamics can be disturbed in two general ways:

1. over-supplied sediment caused by a) an increase in bluff erosion (due to sea level rise or an up-tick in storm frequency), b) loss of stabilizing bluff vegetation, or c) rerouting of surface or groundwater such that slope failure and erosion increase; or

2. under-supplied sediment caused by a) a change in the geologic material exposed to natural erosion, b) armoring/bulkheading toes of sediment bluffs such that sediment sources are isolated from wave energy, or c) blocking sediment transport such that sediments are moved to deeper water instead of proceeding down-drift.

Two KEAs related specifically to coastal sediment dynamic processes associated with drift cells have been identified:

- KEA I-1: Coastal sediment dynamics in drift cells - condition
- KEA I-2: Coastal sediment dynamics in drift cells - landscape context

Additional attributes of coastal sediment dynamics that are not exclusively related to drift cell systems are discussed below.

Not all Puget Sound shorelines are drift cell systems. Major river systems and rocky shorelines respond differently to the influence of wave energy. Rocky shorelines erode 10 to 100 times more slowly than bluff backed beaches (Keuler 1988). These shorelines thus have little or no beach area and no appreciable longshore sediment transport. The exception along rocky shorelines is the pocket beach (i.e., beaches in small rocky embayments). Sediment for the pocket beach is locally derived rather than delivered via longshore sediment dynamics. Variable erodability in rock or sediment types (e.g., a friable slate unit sandwiched between hard quartzite; glacial carved valley with till deposits), tectonic weaknesses (fractures or faults), and upland erosional weaknesses (mechanical erosion by ice, water, or trees) can make a rocky shoreline segment more susceptible to onshore wave erosion. Over time this susceptibility can evolve into an embayment with a wave-cut platform and a beach—a pocket beach. Beach sediments come from the eroding rock immediately up slope.

A pocket beach can be considered a 'closed system' because all sediment within the embayment evolves from the embayment itself. At some point, the issue of scale blurs the boundaries between very short drift cells and closed system pocket beaches. As pocket beaches age and erosion cuts deeper into the rocky shoreline, upland fluvial processes and erosion are more likely to intersect the pocket beach shoreline. Additionally, the energy of the system decreases as the deepening pocket beach forms a more protected shoreline. This decreased energy keeps sediment in the system longer rather than washing it off shore. Deepening plus stream sediment and water inputs and sloughing of upland eroded sediment can lead to the evolution of small drift cells and coastal landform development (berms, spits, tombolos) within the low energy embayment. Changes in sea level can hasten beach development or destroy beaches. These systems are fragile because of their minimal sediment input and slow evolution process.

Five KEAs related to all coastal sediment dynamic processes were identified:

- KEA I-3: Coastal sediment deposition and accretion - extent
- KEA I-4: Coastal sediment deposition and accretion - condition of sediment
- KEA I-5: Coastal sediment deposition and accretion - condition of impoundment
- KEA I-6: Coastal sediment supply - extent
- KEA I-7: Coastal sediment supply - distribution

Healthy drift cell and rocky shoreline pocket beach systems require wind driven waves to move coastal sediments. If waves are blocked from recruiting or moving sediment, all components of the drift cell and sediment source/deposition areas in pocket beaches are impacted (see KEA I and II). Localized impediments to wave energy (e.g., jetties) will change local sediment dynamics, causing silting in of enclosed areas and scouring in areas where waves are refracted (adding erosive energy to the wave). Submerged aquatic vegetation (SAV) is impacted by substrate changes and by changes in wave energy regime. Some types of SAV (e.g., certain kelps) depend on wave energy and would be negatively impacted by structures that block it, while other types of SAV (e.g., eelgrass) could be eroded by increases in wave energy.

Two KEAs related to wind and wave driven coastal sediment dynamics were identified:

- KEA I-8: Coastal sediment dynamics - extent (size or volume) of wind and wave dependent features
- KEA I-9: Coastal sediment dynamics - condition of wind and wave dependent features

II. Sediment Dynamics—Fluvial

Fluvial sediment dynamics include deposition and erosion of sediment from fluvial sources. In estuaries, these dynamics are driven by the fluvial energy of the entering river or stream as its discharge fluctuates. Actual sediment load of specific rivers or streams is a function of watershed conditions upstream and is covered in the section above on Key Ecological Attributes and Indicators for Freshwater Habitats. Changes in freshwater hydrology alter the

energy and thus the sediment carrying capacity of a river or stream. Lower discharge results in finer sediment, and less sediment overall delivered to an estuary. Higher discharge has the opposite effect, with more sediment delivered with a coarser sediment component included. Too much sediment builds estuaries to higher elevation habitat zones, while sediment starvation leads to lower elevation habitat zones and the possible loss of marsh, lagoon, and channels). Fluvial processes also assist in distributary channel formation (see KEA V-15 Tidal Channel formation and maintenance – extent of channels; and KEA V-16 Tidal Channel formation and maintenance – connectivity of channels).

Fluvial sediment dynamics can bury or erode SAV. This may happen naturally, however anthropogenic changes in the watershed can impact both water quantity (i.e., discharge; see KEA III) and water quality (i.e., salinity). Salinity and to some extent temperature will determine if, where, and what SAV can survive in estuaries and marine nearshore systems.

One KEA related to fluvial sediment dynamics was identified:

- **KEA II-10**: Fluvial sediment dynamics - condition

III. Hydrological Dynamics - Tidal

Tidal processes (e.g., timing and magnitude) form tidal circulation patterns (e.g., direction and velocity of currents) within the marine basins of Puget Sound. Tidal circulation affects salinity patterns, sediment transport, detrital transport, organismal movements, and patterns in primary and secondary production within marine basins. Water masses from separate sources (e.g., specific rivers, marine basins, or beyond) may differ in salinity, temperature, or suspended sediment concentration—and thus density. Tidal fronts form where water masses of contrasting density meet but do not mix immediately. These fronts trap and concentrate organic material and become a focus of primary and secondary production. Water masses from separate sources may also differ in dissolved oxygen (DO) and in nutrient and pollutant loads, which may cause differences in productivity. Tidal circulation can be affected by withdrawing water upstream, rerouting river outlets, and building structures such as jetties, causeways, dikes, groins, and marine hydropower installations.

Tides are fundamental to the structure and function of estuaries. Tidal circulation affects salinity patterns, sediment transport, detrital transport, organismal movements, and patterns in primary and secondary production. Tidal circulation, along with tidal inundation of estuarine wetlands, also affects the physical structure of habitats (e.g., by changing distributary channel and blind tidal channel geometry, and sediment sorting in benthic habitats). Consequently, these processes affect floral and faunal community composition and function throughout estuaries. Tidal inundation is impacted by dikes, culverts, tidegates, and fill. Tidal circulation can be affected by withdrawing water upstream, rerouting river outlets, and building structures such as jetties, causeways, dikes, and groins.

Tidal inundation of beaches (i.e., rocky, bluff backed, and coastal landform beaches) and estuaries determines the area and elevation of habitat and vegetative zones. Structures that intercept rising water and prevent tides from encroaching on land disrupt tidal hydrology and

displace tidally determined habitats and ecological communities that otherwise would have been present. These structures include dikes, fill, bulkheads, and other features built within the intertidal zone.

Two KEAs related to tidal hydrological dynamics were identified:

- **KEA III-11:** Tidal circulation - extent of dependent biological activity
- **KEA III-12:** Tidal circulation – dependent water condition

IV. Hydrological Dynamics—Freshwater

Freshwater discharge introduces sediment, nutrients, detritus, and pollutants to estuaries downstream. Discharge also alters estuarine water quality variables, such as temperature, salinity, DO, and pH. Anthropogenic activities that modify freshwater hydrology (via changes in water quantity or quality) will impact estuaries at river or stream mouths. For example, land clearing or development may cause silting in of the estuary (see KEA IV), and degraded water quality may impact estuarine fish, vegetation, and other wildlife.

Anthropogenic activities that modify freshwater hydrology will impact the nearshore and offshore marine water column within Puget Sound's marine basins as well as its estuaries. Increased water column turbidity due to land clearing, elevated contaminant loading due to development, and adverse changes in salinity and temperature due to water withdrawal or loss of riparian vegetation exemplify some potential impacts. Freshwater inputs can drive habitat diversity and complexity; alternatively they can deliver the upland's problems to the marine environment.

Two KEAs related to freshwater hydrological dynamics were identified:

- **KEA IV-13:** Freshwater hydrology - dependent water condition
- **KEA IV-14:** Freshwater hydrology - condition

V. Tidal Channel Formation and Maintenance

Distributary channels are the framework upon which large river estuaries, or deltas, are built. As a river delivers sediment to its delta, the delta progrades and the river progressively divides into distributaries. Thus, the processes of delta and distributary network formation are inextricably interrelated (Edmonds and Slingerland 2007, Stouthamer and Berendsen 2007). Distributaries are primarily formed by avulsion (Slingerland and Smith 2004) or channel bifurcation during mouth bar development and delta progradation (Edmunds and Slingerland 2007). Avulsions are thought to be caused principally by channel aggradation, which leads to differences in elevation between a channel and its floodplain, thereby creating a gradient advantage for a potential avulsion channel relative to the original channel. Loss of channel capacity from channel infilling also contributes to avulsion (Makaske 2001, Slingerland and Smith 2004).

Distributary network geometry is potentially the most important factor controlling delta landforms (Coleman 1988, Syvitski et al. 2005) and related hydrological, geological, and ecological processes. Because distributary network geometry in deltas affects the spatial distribution of salinity gradients and sedimentation patterns and these affect vegetation distribution in turn, distributary network geometry also affects fish and wildlife distribution patterns through its effect on habitat. Anthropogenic engineering significantly influences distributaries and the growth and evolution of their associated deltas (Pasternack et al. 2001, Syvitski and Saito 2007). Direct human impacts include distributary blockage or excavation to redirect river discharge. Indirect impacts include system modifications such as 1) dam construction, which moderates seasonal flood pulses, causing sediment retention in reservoirs, and 2) water withdrawals, which effectively reduce the drainage area of the watershed (Syvitski 2008).

Estuarine tidal channels are conduits for water, sediment, nutrients, detritus, and aquatic organisms, and thus link highly productive tidal marshes to the nearshore marine environment (Simenstad 1983, Odum 1984, Rozas et al. 1988, Pethick 1992, French and Spencer 1993). Tidal channels affect hydrodynamics (Rinaldo et al. 1999), sediment transport (French and Stoddart 1992), and the distribution and production of flora (Sanderson et al. 2000) and fauna (Levy and Northcote 1982, Halpin 1997, Williams and Zedler 1999, Hood 2002). Tidal channel formation and maintenance depend on tidal prism (i.e., the volume of water between low and high tides that flushes the channels during tidal exchange). Tidal prism can be impacted directly through the use of dikes and tidegates to limit flooding (Greene et al. 2012), or indirectly through the conversion of upslope marshes to farmland (Hood 2004). Sediment starvation can also result in marsh erosion, leading to the loss of tidal channels (Hood 2007a).

Two KEAs related to tidal channel formation and maintenance were identified:

- **KEA V-15:** Tidal channel formation and maintenance - extent of channels
- **KEA V-16:** Tidal channel formation and maintenance - connectivity of channels

VI. Detritus Recruitment and Retention

Detritus consists of a variety of materials, ranging from decaying SAV to marsh plants in subtidal and intertidal habitats, or from leaves to logs (i.e., LWD) in upland habitats. Food webs in tidal marshes are largely based on detritus (Simenstad 1983, Odum 1984). In addition to providing food web support, detritus (particularly LWD) serves a structural function by affecting blind tidal channel morphology and beach morphology. Detritus also supplies perches for wildlife, beach micro-habitat for invertebrates (Tonnes 2008), and nurse logs which affect vegetation community composition and succession (Hood 2007b). Sources of detritus include watersheds, marine riparian zones, tidal marshes, and intertidal/subtidal zones. Armoring of river banks and coastlines impedes recruitment of detritus.

Two KEAs related to detritus recruitment and retention were identified:

- **KEA VI-17:** Detritus recruitment and retention - extent
- **KEA VI-18:** Detritus recruitment and retention - extent of supply

VII. Habitat Connectivity

Connectivity of habitats is necessary for the dispersal and migration of aquatic species, and, in the case of Chinook salmon, the development and expression of diverse life histories (Fullerton et al 2010). Connectivity can be described as the availability of or access to habitats which are required by each Chinook life stage. Beamer et al. (2005) defined landscape scale habitat connectivity for juvenile Chinook salmon in a natal estuary and its adjacent nearshore marine basin in terms of the relative distances and pathways that salmon must travel to find habitat. Landscape connectivity was a function of both the distance and complexity of the pathway that salmon must follow to reach certain types of habitats (e.g., blind tidal channels and pocket estuaries). Specifically, connectivity decreased as the distance and complexity of the pathway increased. Localized habitat connectivity is synonymous with the concept of habitat opportunity proposed by Simenstad (2000) and Simenstad and Cordell (2000), and is applied to metrics reflecting a juvenile salmon's ability to "access and benefit from the habitat's capacity." Differences between empirical values of metrics (e.g., tidal elevation, water velocity, and temperature) and suitability standards for these metrics (e.g., standards for suitable juvenile salmon habitat) have been used to infer differences in local connectivity between estuarine habitats (Bottom et al. 2001). In tidegated estuarine channel systems additional data are needed to determine local connectivity, such as the percentage of time tidegate doors are open (Greene et al. 2012).

One KEA related to habitat connectivity was identified:

- **KEA VII-19:** Habitat connectivity condition

VIII. Multiple Ecosystem Processes

Many attributes of estuarine and marine systems are dependent on the proper functioning of multiple ecosystem processes. The KEAs included in this multiple ecosystem process group primarily represent critical habitat types for Chinook salmon. Indicators of the health of these attributes provide information about the underlying habitat-forming processes and conditions.

For example, natal estuaries are a critical habitat for juvenile ocean-type Chinook salmon and the extent and condition of estuarine habitats are a function of tidal and freshwater hydrology, fluvial sediment dynamics, as well as other ecosystem processes.

SAV beds provide direct habitat for juvenile Chinook many other species important to salmonid foodwebs. SAV distribution is limited by desiccation stress, salinity patterns, and water clarity. Likewise, spawning locations of forage fish (e.g., surf smelt, sand lance, and herring) are limited by physiological constraints on egg survival related to desiccation, oxygenation, and temperature stresses. Tidal inundation directly affects all of these factors; it also indirectly affects them through tidal (and wave) energy effects on beach substrate composition. Consequently, distributions of SAV and forage fish spawning are constrained to certain substrate

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types and tidal elevations. Tidal inundation and energy can be affected by shoreline armoring and constrictions on tidal flows such as tidegates and other marine engineering.

Ten KEAs related to multiple ecosystem processes were identified:

- KEA VIII-20: SAV beds - condition
- KEA VIII-21: SAV beds - extent
- KEA VIII-22: Estuarine habitats - extent
- KEA VIII-23: Estuarine habitats - condition
- KEA VIII-24: Estuarine habitats – distribution
- KEA VIII-25: Intertidal habitat zone - extent
- KEA VIII-26: Intertidal habitat zone - condition
- KEA VIII-27: Tidally influenced wetlands - extent
- KEA VIII-28: Tidally influenced wetlands - condition
- KEA VIII-29: Water quality

Key Ecological Attributes and Indicators

for Species and Food Webs

Background

Non-native species invasion, pollutant bioaccumulation, primary production, nutrient cycling and biotic interactions such as predation, competition and disease represent food web processes. In many cases, these processes underlie constraints on the production of at-risk native fish populations (ISAB 2011, Rice et al. 2011). While these underpinnings are apparent in theory, in the practice of recovery planning and implementation they are often overlooked. For example, many studies quantify the effects of biotic interactions on salmonids in general (e.g., Groot and Margolis 1991, Fresh 1997, NMFS 1997, Sanderson et al. 2009), and on Puget Sound Chinook in particular (e.g., Ruggerone and Goetz 2004, Arkoosh et al. 2004, Hanson et al. 2010, Duffy and Beauchamp 2011). However, consideration of these effects varies widely among salmon recovery plans, from inclusion as a footnote to a focal point. The lack of systematic attention to the effects of biotic interactions and other food web processes is attributed, in part, to gaps in scientific data (Ruckelshaus et al. 2002). The gaps persist because many interactions are difficult to measure. Filling these gaps through targeted monitoring is an important need.

This section of the framework, like the habitat-related sections above, relies on a simple conceptual diagram in which large and small scale processes affect habitat conditions, leading in turn to a biological response in Chinook salmon (Figure 2). Clearly, this response does not exist in isolation, but rather in concert with other organisms. Biotic interactions occur between Chinook and other species in all the life stages and habitats described above (Figures 4 and 5, Table 2). The intent of this section is not to identify every potential interaction with Chinook salmon, or to document all possible linkages with Chinook salmon in aquatic food webs. Rather, the intent is to provide a placeholder in the framework, enabling watershed groups with concerns about species and food webs to include them in their adaptive management and monitoring plans.

This section of the framework is based on Chapter 1a in the 2010 Puget Sound Science Update (Levin et al. 2010). In this chapter, Levin et al. use the Open Standards system to evaluate indicators for ecosystem components corresponding to four of the Partnership's statutory goals (species and food webs, habitats, water quantity, and water quality). Here, we tailor the parts of their work that relate to species and food webs, Sound-wide, by adding four categories of ecological relationships to limit the range of species to include only those relevant to Chinook as 1) predators, 2) competitors, 3) prey, or 4) symbiotically as pathogens, facilitators, etc. (Table 16). Which species fit best into each category depends on the Chinook life stage and habitat type of interest. For example, predators of adult Chinook spawning in freshwater habitats (e.g., black bears (*Ursus americanus*)) differ from predators of the eggs that the spawners release (e.g., torrent sculpins (*Cottus rhotheus*)). Predation by humans is excluded from this section, because it is included elsewhere (e.g., as a pressure; Appendix B). Interactions with hatchery fish (e.g., as potential predators, competitors, and pathogen vectors) are included both here and in Appendix B, Table B-2b.

<u>Key Ecological Attributes and Indicators</u>

Levin et al. (2010) identify four KEAs applicable to species and food webs. Two of the KEAs—population size and population condition—pertain to species; the other two—community composition and energy and material flow—relate to food webs. Each of these KEAs can be subdivided further. The rationale against doing so is to keep the framework as simple as possible, so that multiple indicators can apply to a single KEA and excessive data gaps can be avoided (Levin et al. 2010). In support of this rationale and in the interest of maintaining consistency, our framework uses identical KEAs with minor changes to their definitions.

<u>Species KEAs</u>

Population size is defined as the abundance of a population, measured as a number of individuals or total biomass (Levin et al. 2010). Changes in abundance over time are also included, measured as productivity or population dynamics like rates of birth, death, immigration and emigration. Population condition includes various measures of population health, such as genetic diversity, phenotypic diversity, age structure, size structure and spatial structure (Levin et al. 2010). It also incorporates two measures of health at the organismal level: physiological status (i.e., individual size and growth) and disease status (i.e., incidence of infection).

Population size and condition, thus defined, encompass the three types of KEAs often used by Open Standard practitioners (size, condition, landscape context; TNC 2007). Population size and condition also include all four parameters used to describe viable populations of Chinook salmon (abundance, productivity, diversity, and spatial structure; McElhany et al. 2000). Here, these parameters are applied to other species. Some of these species have no delineated population structure, or are rarely identified past the family or genus level, making groupings like "population" and "species" irrelevant. Still other species are both ESA-listed and directly responsible for Chinook mortality (e.g., orcas (*Orcinus orca*) and steelhead (*Oncorhynchus mykiss*)). As a result, trade-offs might occur between improvements in the status of these species and Chinook.

<u>Food Webs KEAs</u>

While the species KEAs characterize single species or guilds, the food webs KEAs integrate multiple species at various trophic levels, or they refer to ecological processes rather than species (Table 16). For example, community composition encompasses various measures of biodiversity, such as species diversity, trophic diversity, response diversity and functional redundancy (Levin et al. 2010). Functional redundancy refers to the number of species that perform the same functional role in a food web (Lawton and Brown 1993). Response diversity represents the number of reactions functionally similar species exhibit when confronted with disturbance (Elmqvist et al. 2003).

Energy and material flows (i.e., via consumption) consist of processes such as primary production and nutrient cycling, as well as, flows of organic and inorganic matter within food webs (Levin et al. 2010). Consumption is another key process—between trophic levels, along different energy pathways, and within and among habitats. The relative importance of food production, temporal food supply, and competition to growth (and thus size-selective survival)

and the importance of predation within or beyond the Puget Sound region should be fundamental to our understanding of what limits production of Chinook salmon and other salmonids.

Where anadromous salmon are concerned, these flows are not unidirectional, moving only upstream to downstream and eventually to the ocean. It is well documented that salmon subsidize freshwater and terrestrial food webs by redistributing organic matter and nutrients from marine ecosystems (reviewed by Naiman et al. 2009). It is also well documented that salmon transport persistent industrial pollutants (reviewed by ISAB 2011), and that Chinook salmon are particularly laden vectors (Hites et al. 2004, O'Neill and West 2009). Note that this KEA is also incorporated in the habitat-related sections of the framework, either directly (e.g., KEA V, Nutrient Supply, of the freshwater ecosystem component) or indirectly (e.g., KEA VIII-29, Water Quality, of the estuarine and marine ecosystem component).

Indicators

Potential indicators for the species and food webs KEAs are listed in Table 17. As in Tables 5 and 6, some indicators are directly measurable, whereas others are derived. Unlike Tables 5 and 6, Table 17 does not target specific species. Instead, examples of specific species that interact with Chinook according to the literature are provided in Table 18. This is not an exhaustive list of relevant species, nor is Table 17 a complete list of potential indicators. Moreover, we do not suggest that every indicator and species in these tables be monitored in all watersheds. Each watershed group will need to tailor their monitoring plan to include indicators deemed important at the local scale.

CHAPTER III: Framework Process

General Application of the Framework

In Chapter I we introduced the framework, its context in Puget Sound salmon recovery implementation, and its basis in the Open Standards approach. In Chapter I we also outlined the elements of the framework (ecosystem components, key ecological attributes, indicators, pressures, stresses, contributing factors, drivers, and strategies and their associated actions), and described the first three in detail in Chapter II. The following section describes the Open Standards tools and eight steps to apply the framework by practitioners to develop watershed-specific monitoring and adaptive management plans (Table 19). The tools include: a portfolio of elements, a conceptual model, results chains, and viability analyses. Miradi software can be used for tracking decisions and linking the elements of the framework, but this framework process is not contingent on any specific software package.

Open Standard Tools for Applying the Framework

Open Standards provides a common and systematic method for selecting the subset of key ecological attributes and *indicators* that are best suited for the purposes of monitoring and that can support adaptive management within a given watershed. This method starts by using the best available data on Chinook populations to assess their status and trends, and then employing the local watershed chapters of the Puget Sound Recovery Plan and other local and regional sources of scientific information to identify the ecosystem components that have the greatest influence on the long-term population viability of Chinook salmon population in each watershed

This process first involves developing and refining a list of *ecosystem components*, which we have defined in Chapter II to include the Chinook salmon populations present in each watershed, as well as the freshwater, estuary and nearshore marine habitats, and other species and foodwebs that are critical to the long-term health and persistence of these populations (Figure 11). Because these *ecosystem components* are much too broad to measure (e.g., estuary ecosystems), a list of *key ecological attributes* (KEAs) is identified for each of the ecosystem components. KEAs are a limited set of the biological characteristics, habitat characteristics, and ecological processes that shape the natural variability of an ecosystem component over time and space (TNC 2007). KEAs are linked to ecosystem components through cause-and-effect relationships. KEAs are still typically too broad to measure in a cost-effective manner over time, so it is necessary to identify *indicators* that can be effectively measured over time that can be used to document changes in KEAs. Indicators are important because they inform managers of the status and changes in KEAs over time. In addition to the list of ecosystem components, KEAs, and associated indicators, we next list all possible elements (Pressures, Stresses, Drivers, and Strategies and Actions) in the framework as described above in Chapter I and in Figures 12 and 13. In addition, Figures 14 -- 16 provide a detailed construct of the defined pressures (Figure 14) and stresses to both Chinook salmon (Figure 15) and their habitats (Figure 16). This entire list is defined as the *Portfolio of Elements* for the watershed (Figures 11--16).

Next, the process involves completing a *viability assessment* for each ecosystem component. *Viability assessment* is an Open Standards tool for defining current conditions and desired future healthy conditions for each of the KEAs, and then setting appropriate and measurable goals for these healthy conditions. Viability assessments involve determining whether the current status of ecosystem components and their KEAs are in "poor", "fair", "good", or "very good" condition (Table 20). This is accomplished by establishing specific ranges of values for each of these ratings for each indicator. It is desirable to have established scientifically defined thresholds, but this will not be possible for all indicators. When such information does not exist, best professional judgment must suffice for the near-term so the process is not stalled, and effectively, this informs watershed partners and planners of gaps in data and knowledge. These indicator ratings are used to develop a simple viability assessment table (Table 21) for all of the KEAs, which can then be used to identify of the KEAs. This process should be iterative, and through successive trials can be used to further refine the prospective list of KEAs, their indicators, and values/ratings. The viability assessment will be used to inform the prioritization of recovery actions, the focus of monitoring and adaptive management plans, and the distribution/utilization of limited resources.

A *conceptual model* is completed that develops the linkages between the most important pressures in a watershed, the relationship and impact of these threats to the ecosystem components (Figure 13). Using Miradi software these linkages can be portrayed graphically, and the dynamic and complex nature of these linkages can be tracked more easily. Developing the conceptual model is an important component of the Open Standards process, since it provides the process for linking pressures and ecosystem components. Conceptual models can then be reduced to a simple *results chain(s)* that portray the links between chosen conservation strategies and actions and contributing factors, which cause reductions in pressures and stresses, to produce desired changes in the status of the ecosystem components and their respective KEAs and indicators (Figure 17). This process provides a method for determining the final subset of KEAs and indicators that will be the most useful for monitoring and adaptive management. From the refined list of KEAs and indicators determined in the preceding steps, a final list is determined by selecting those that are most impacted by the pressures present in a watershed. Further, the final subset of KEAs and indicators should be those that are linked through the results chain to feasible strategies and actions that can effectively reduce major threats over time, resulting in measurable improvements in the indicators (and thus KEAs and ecosystem components they represent)(Figure 17).

Each results chain includes *intermediate results*[2], or expected changes, and *objectives*, or quantitative desired outcomes. Results chains also include *goals*, or the desired future condition of an ecosystem component (Figure 17). These goals are expected to change as a result of implementing strategies, completing actions, and achieving intermediate results.

Pressure assessments provide a systematic, transparent, consistent way of describing our best assessment of the relative impacts of different pressures on different ecosystem components. An

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[2] Intermediate results that specifically address changes in pressures and stresses are called pressure- and stress-reduction results, respectively, in our Miradi Template. Intermediate results that address changes in contributing factors are simply called intermediate results.

understanding of the relative impacts of different pressures is important for prioritizing recovery strategies, actions, and monitoring. We presume that pressures that are having the greatest potential impact on salmon and other ecosystem components are the most important to address for recovery. Likewise, understanding how much effort and resources it takes to change the impacts of pressures helps us allocate resources to recovery wisely. Using a systematic, consistent approach not only allows us to identify which pressures may be greatest and where, but it also allows us to identify where the uncertainty about the pressures is greatest. This can help focus monitoring programs on key pressures and help answer key policy questions. A detailed description of the methods for pressure assessment is too much to include in this document. However, the process generally uses published and unpublished scientific information and expert knowledge to estimate the scope, severity, and irreversibility of impacts, and to describe the uncertainty in these estimates.

Process: Eight Steps for Applying the Framework

We can use this framework to develop individual watershed-based, but regionally consistent monitoring and adaptive management plans. The process for applying the framework within each individual watershed is described below (Table 19). These steps can guide the development of monitoring and adaptive management plans and are intended to be applied in an iterative manner.

These steps involve interpreting the technical information present in recovery plans and updated scientific work. The science-related tasks are the focus of this document; however, accomplishing them depends on the participation of policy makers and managers through implementation of the following steps.

1. *Develop preliminary watershed-specific conceptual model*. This first step uses the *Portfolio of Elements* to document the conditions, relationships, and assumptions regarding what would be necessary for Chinook Salmon recovery as stated in Volume II of the Puget Sound Chinook Salmon Recovery Plan (Shared Strategy 2007).the 2005 Recovery Plan. This includes goals, objectives and assumptions identified in the individual watershed chapters. These goals, objectives and assumptions are relative to the Ecosystem Components and threats, stresses, pressures, and contributing factors that exist in the watershed. First, watershed managers identify an initial list of Ecosystem Components present in the watershed. The population(s) of Chinook salmon present in each watershed should be placed on this list first. The other ecosystem components placed on this list should be those that directly influence the long-term viability or health of the Chinook salmon population(s) present in the watershed. Because Chinook salmon use many different ecosystems during their life history, components should be included for each of the major ecosystems present within a watershed.

2. *Update Conceptual Model*: Modify the preliminary conceptual model to include any new information gained since 2005. This includes new scientific studies and completed restoration/recovery projects. Remove elements of the framework that are not relevant to the individual watershed. This step documents the evolution of information associated with the Recovery Plan and sets the work for the rest of the steps.

3. *Conduct Viability Assessment*: Identify the current status, recent trends, and desired future conditions of ecosystem components identified in Steps 1 and 2. Information for this step is derived from individual watershed chapters in Volume II of the Recovery Plan, as well as information gained since the Recovery Plan was submitted. This step helps practitioners document and track the status of the ecosystem components of the Recovery Plan and sequence when and where to focus recovery efforts.

4. *Assess pressures (pressure ratings/rankings)*: Assess the relative impact of each pressure on each of the ecosystem components. This helps practitioners understand which pressures should be the focus of the work for implementing the Recovery Plan. It is also a critical step for developing monitoring and adaptive management plans.

5. *Create results chains*: Using the conceptual model, viability assessment, and pressure ratings/rankings identify the key pressures which have the largest impact on the ecosystem components to create results chains that define the goals, objectives and assumptions delineated in the Conceptual Model.

6. *Link Results Chains to Monitoring:* Identify objectives and indicators for the intermediate results which are included in the results chains. This step identifies the types of monitoring (implementation, status and trends, effectiveness, and validation) needed to appropriately address Chinook salmon recovery.

7. *Develop Monitoring Plan:* Use the conceptual model, results chains, and viability and pressure ratings/rankings to develop a monitoring plan for salmon recovery. The types of monitoring included will depend on the results chains, i.e., indicators of intermediate results pertain to implementation monitoring while indicators of ecosystem components pertain to both status and trends and effectiveness monitoring. The focus of monitoring in the plan will depend on the prioritization determined in the viability and pressure ratings/rankings. The monitoring plan will also include specific methodology for measuring indicators.

8. *Develop Adaptive Management plan:* Develop an adaptive management plan that describes the interval, participation and approach used to evaluate and make decisions based on the monitoring results. The adaptive management plan can then be used to amend recovery implementation actions, the monitoring plan and the watershed chapter Recovery Plan.

Regional Scale Application

The application of this framework supports key decisions made at both the regional and watershed scales by using the same hierarchical structure as the recovery criteria for Puget Sound Chinook salmon, and adopted by the National Marine Fisheries Service. Although recovery criteria apply to the regional scale of the Puget Sound Chinook salmon evolutionarily significant unit (ESU), the criteria demand knowledge of the status of *all* the independent populations that occur in the watersheds and across different biogeographical sub-regions of Puget Sound (NMFS 2006). For example, two of the recovery criteria are: 1) "viability status of *all* populations in the

ESU is improved from current conditions" and, 2) "two to four Chinook salmon populations in each of five biogeographical regions within the ESU achieve viability." Population and watershed-based monitoring of Chinook salmon viability documented by this framework specifically allows assessment of the status of Chinook salmon at the sub-regional and regional (Puget Sound) scales, i.e., consistent with the recovery criteria.

This framework also provides the information to assess threats to recovery at the watershed scale as well as across the ESU. For example, as part of recovery planning the Endangered Species Act identifies factors that have to be evaluated in addition to the status of the species. These include:

1) the present or threatened destruction, modification, or curtailment of Chinook salmon habitat
2) over-utilization for commercial, recreational, scientific or educational purposes
3) disease or predation
4) inadequacy of existing regulatory mechanisms, and
5) other natural or human-derived factors affecting continued existence of Chinook salmon.

The *Final Supplement to the Shared Strategy's Puget Sound Salmon Recovery Plan* (NMFS 2006) provides additional descriptions of the evaluation of threats to habitat needed at both the watershed and Puget Sound scales. A variety of ecosystem functions (channel function and complexity, natural substrate and sediment processes, flows, floodplain functions, connectivity, nearshore processes, prey availability) and pressures (stormwater runoff, agricultural practices, urban and rural development, toxic contaminants, obstructions to fish migration, dredging, bank hardening, and forestry practices) are listed and need to be considered. The Final Supplement leaves the scientific and logistic questions of how, when, and where to do this unanswered. However, it specifically identifies the requirement to use technical tools that accurately assess the impacts of habitat management actions. This framework includes a detailed list of KEAs and pressures, and a systematic process for evaluating these, and is consistent with the *Final Supplement*. Information from the watersheds applied within the context of this framework will provide detailed insights into what factors are most important in a given watershed, as well as across multiple watersheds.

Analysis of information developed from this kind of hierarchical framework also will help identify both shared and unique policy needs for addressing key pressures and allocating scarce resources. Because monitoring can be explicitly linked to where these questions occur, it allows monitoring to be designed to contribute information to policy solutions that advance salmon recovery more efficiently than either watershed scale or regional monitoring can provide independently. For example, this information provides the basis for describing, prioritizing, and designing monitoring that might be needed across watersheds. It also identifies monitoring needs within single watersheds that are also important to the Puget Sound ESU because those populations contribute to achieving the population-based regional recovery criteria. This latter circumstance is not easily addressed by monitoring frameworks based only on the regional scale.

Monitoring and Adaptive Management

The framework developed here provides a standard way of organizing and depicting the key relationships underlying the diverse recovery strategies in the 14 watershed chapters of Volume II of the Recovery Plan. Monitoring of the indicators (i.e., for KEA's or other ecosystem components) will provide information regarding both the logic of the chapters' recovery strategies, as well as the success of implementing of those strategies. In response to the information gained from monitoring, adaptive management will then consist of: 1) modification of the specified recovery actions to implement within the watershed chapters; and thus 2) modification of the Volume II Recovery Plan chapters themselves.

The first type of adaptation—modification of watershed chapter recovery actions—will occur when either research or monitoring provides new information which alters prior assumptions. For example, if monitoring data revealed that an exploitation rate target is repeatedly not attained, then harvest management implementation might be adjusted by altering annual fishing plans, thus improving preseason abundance forecasts or better enforcing regulations. This framework provides an organized systematic process to determine the indicator(s) that will best evaluate actions implemented with the intent of achieving recovery goals.

The second kind of adaptation—modification of a watershed chapter—will occur when it becomes clear that the assumptions underlying the chapter's basic strategies are no longer held. For example, if a strategy was based on the assumption that lack of good quality spawning habitat limited production, then that chapter might have emphasized a hatchery supplementation program to provide more incubation capacity than was available in the degraded natural environment. If, subsequently, population life stage validation monitoring suggested that estuarine rearing habitat capacity was a key limiting factor, then the chapter assumptions and goals would need to be revised to emphasize restoration of estuarine habitats.

NMFS offers guidance for applying the adaptive management principles of Anderson et al. (2003) to salmon recovery. The guidance lists the following essential features of an adaptive management plan: 1) revise management strategies regularly; 2) use conceptual or quantitative models to guide hypotheses, strategies, and actions; 3) identify a range of potential management actions; 4) track progress by monitoring and evaluation; 5) make decisions regarding strategies and actions through iterative learning; and 6) use stakeholder participation in adjusting strategies and actions (NMFS 2007). This framework will make it possible to apply these principles to salmon recovery across all 14 Puget Sound watersheds.

Conclusion

We present our framework as a method to systematically organize information and evaluate progress of Chinook salmon recovery across the Puget Sound ESU. It may be used to monitor and adapt recovery strategies and actions for the multiple populations of Chinook salmon. Chinook salmon have a very complex and diverse life history—they are migratory, depend on freshwater, estuarine, and marine habitats, and disperse widely. In addition, they are highly adaptable and can form metapopulations from which individuals stray to newly available habitats (and populations) or alternately, away from lost or damaged habitats. Actions affecting the recovery of Chinook salmon in the Puget Sound region likewise occur across a heterogeneous landscape and at multiple geographic scales. These actions are driven by human behaviors that reflect differences in local, regional, and national economies, community values, and available resources. Authorities who make decisions at multiple levels of government (e.g., local, regional, and national) and in multiple contexts (e.g., political, regulatory, and enforcement) influence the effectiveness of Chinook salmon recovery actions taken at each land use scale, whether local or regional.

A successful approach to collect information, evaluate actions, and inform decisions made at all land use scales needs to provide consistency across these multiple scales and geographies, while also retaining flexibility to capture unique differences. No such approach to monitoring, adapting, and improving salmon recovery efforts across multiple scales currently exists. Recognizing this, the National Marine Fisheries Service (NMFS) specifically identified the development and implementation of such an approach as a requirement for approval of the Puget Sound Salmon Recovery Plan under the Endangered Species Act (NMFS 2006). Our framework was developed in response to the NMFS requirement. Successful implementation of the framework will require commitment from both technical experts and policy decision-makers.

Our framework builds on a general strategic planning system called the Open Standards for the Practice of Conservation. Open Standards provides a common vocabulary for organizing descriptions of conservation strategies and actions, direct and indirect threats to the environment and species, and the attributes of a sustainable ecosystem. Lack of a common vocabulary hampers the communication and coordination that must occur if a monitoring approach is to include both local and regional recovery efforts (Hamm 2012). Open Standards also provides a hierarchical structure so that actions can be shared and coordinated between recovery plans and across different spatial and organizational levels. Despite the theoretical and practical advantages of Open Standards for conservation planning, applying Open Standards or similar systems to a problem as large and complex as Pacific salmon recovery at the scale of Puget Sound has not been done.

The process to incorporate information stated in the 2005 recovery plan chapter, and the incorporation of information produced since 2005 provides the basis for development of the watershed-scale monitoring and adaptive management plans. Ultimately the RITT framework will be applied across all watersheds in the Puget Sound region as applicable to Chinook salmon. The resulting monitoring and adaptive management plans will stand alone for each watershed and be the road map for local entities to pursue funding, engage in activities for salmon recovery, and maintain the ability to measure change (progress) and adapt management actions to support these changes. Also, given the consistent structure of the RITT framework, it will also be possible to evaluate the plans, recovery objectives and goals, and strategies across watersheds and across the region.

Once the monitoring and adaptive management plans are developed, managers can use the information to observe: 1) how the plan is designed to achieve the desired goals for Chinook salmon recovery in the watershed, 2) where integration of various salmon recovery strategies may occur (i.e., within and across watersheds, and across the Puget Sound region), or 3) where potential gaps, lack of integration, or conflict between watershed strategies exist. The key to success of this process includes identifying indicators, both for ecosystem components and for intermediate results of strategies and actions that are linked to ecosystem components. Commonality between watersheds regarding choice of indicators will help to make cross-watershed and regional evaluations. Thus, use of this framework should allow plan implementers to track success or lack thereof. In the latter case, the objective would be to determine the cause of a problem so that it can be corrected. This reflects what we define as adaptive management.

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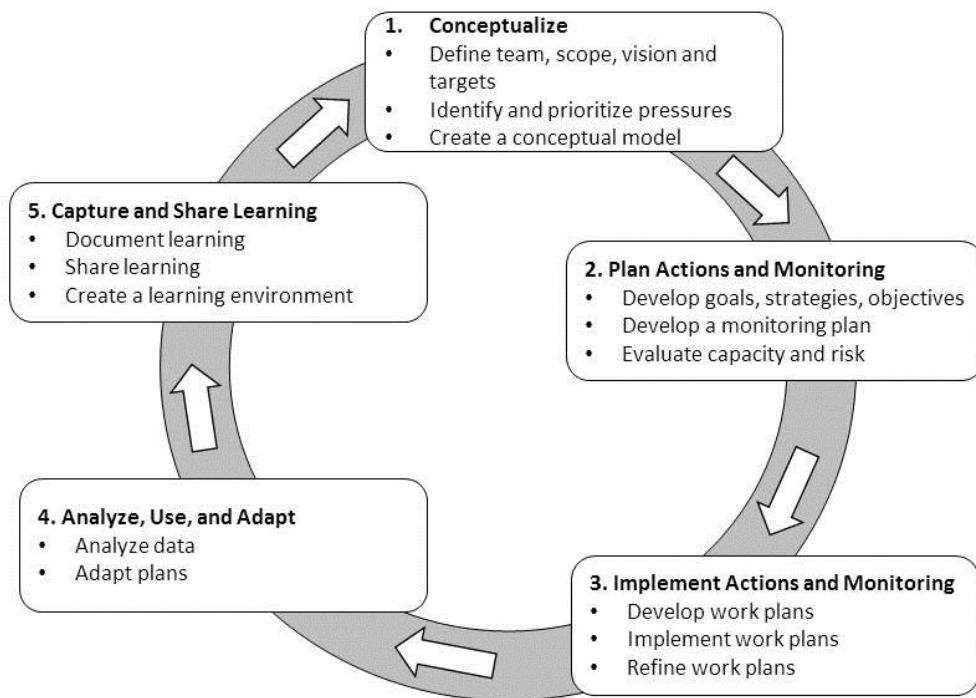
Figures

Figure 1. Five general steps used to organize the Open Standards system (adapted from CMP 2007).
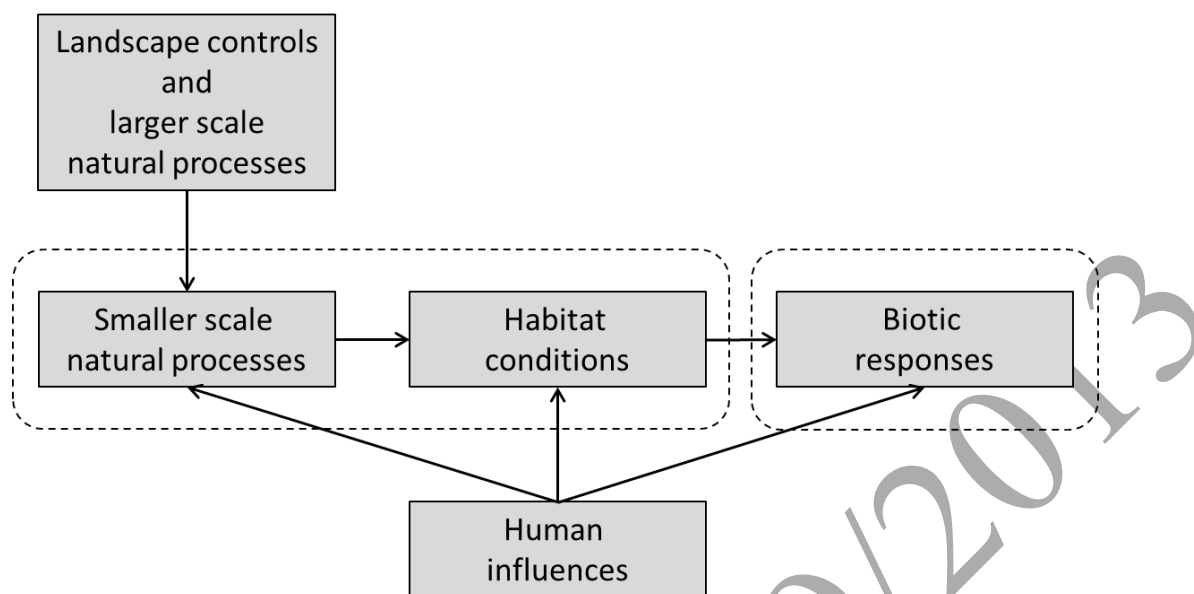
Figure 2. Conceptual diagram of linkages between landscape controls, habitat characteristics, and biotic responses (adapted from Beechie et al. 2003b). Dashed lines indicate overlap with the habitat- and species-related ecosystem subcomponents.
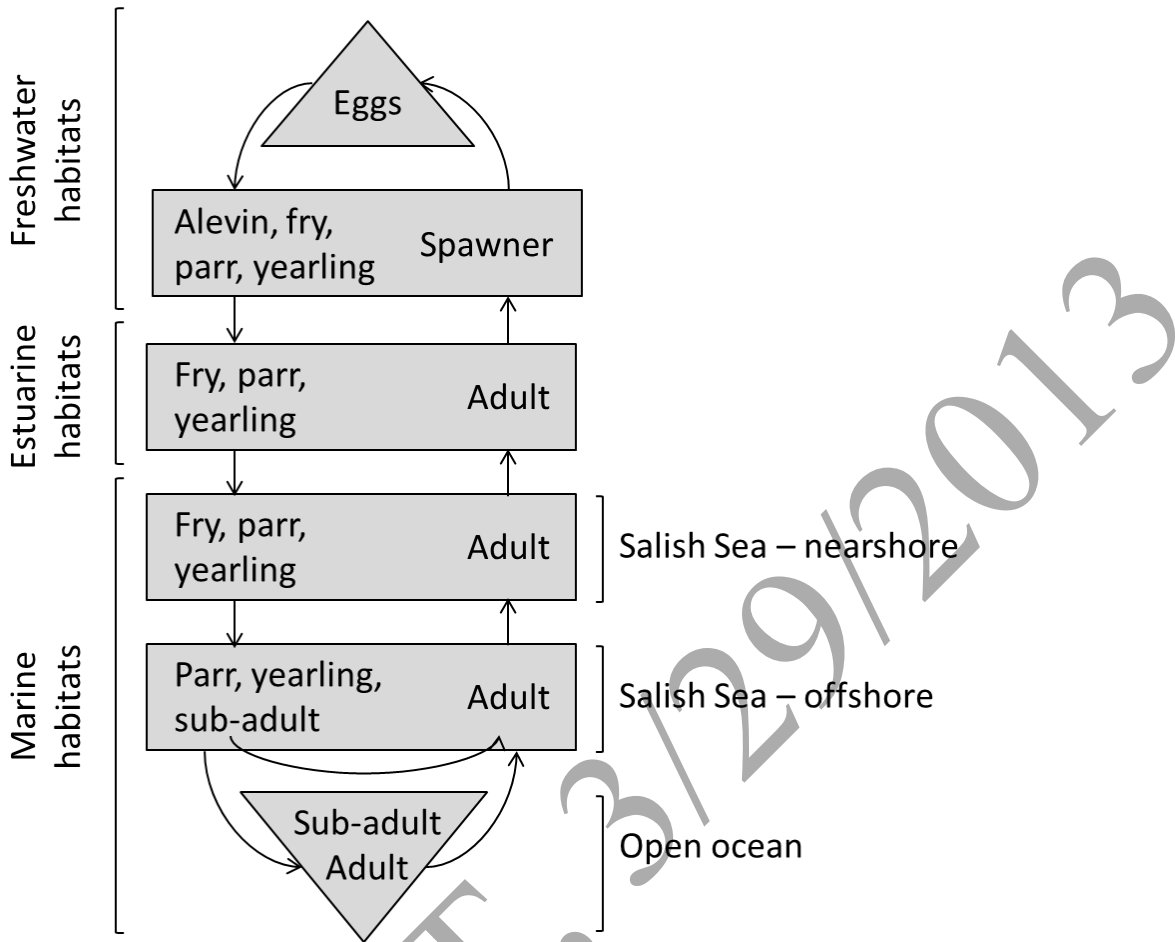
Figure 3. Schematic diagram of the life cycle of Puget Sound Chinook salmon, and the freshwater, estuarine, and marine habitats associated with each life stage.
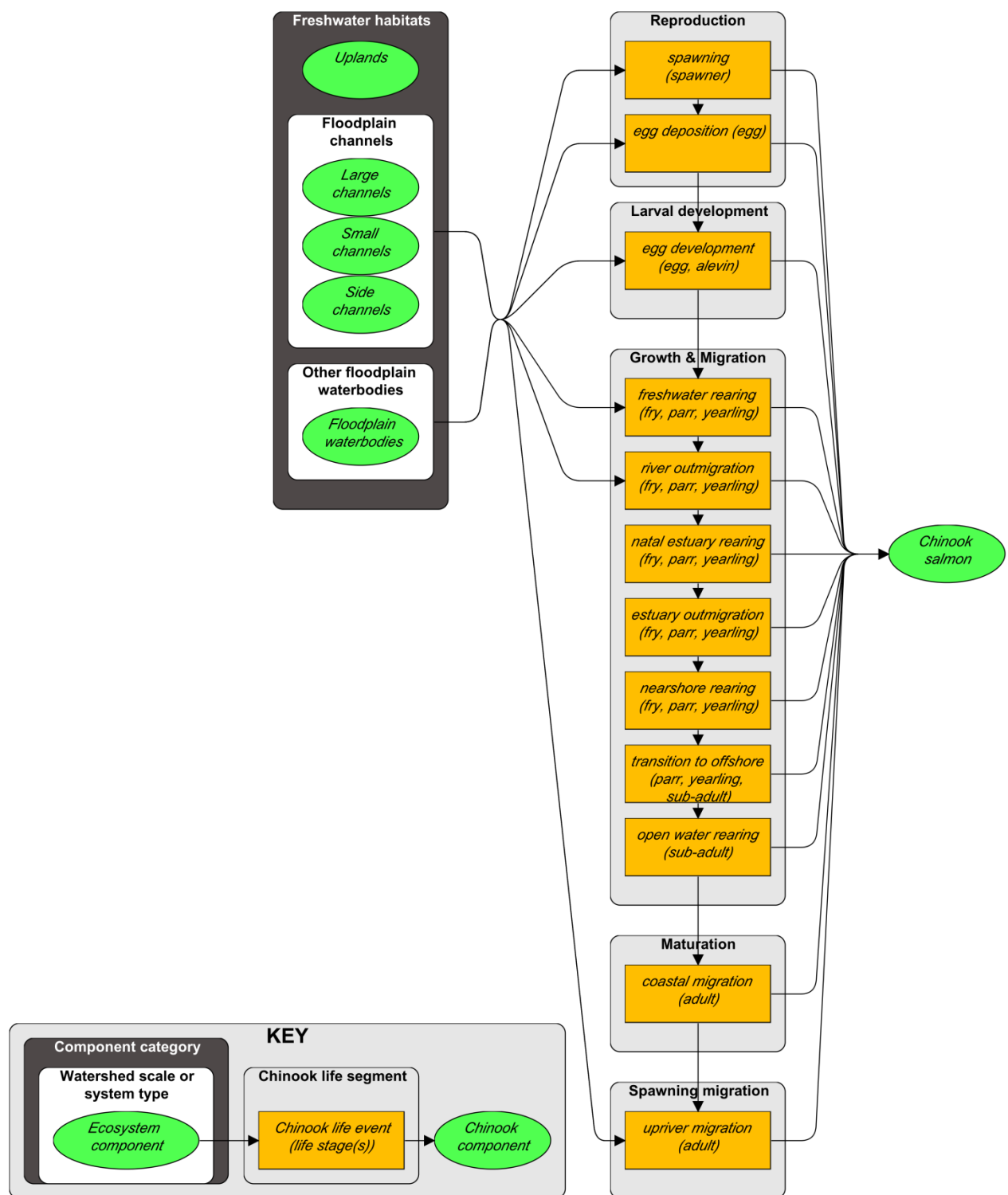
Figure 4. Relationships between freshwater habitat ecosystem components and Chinook salmon life stages as described in the framework and depicted in Miradi. See Table 2 also for a description of relationships between habitats and Chinook salmon life stages.
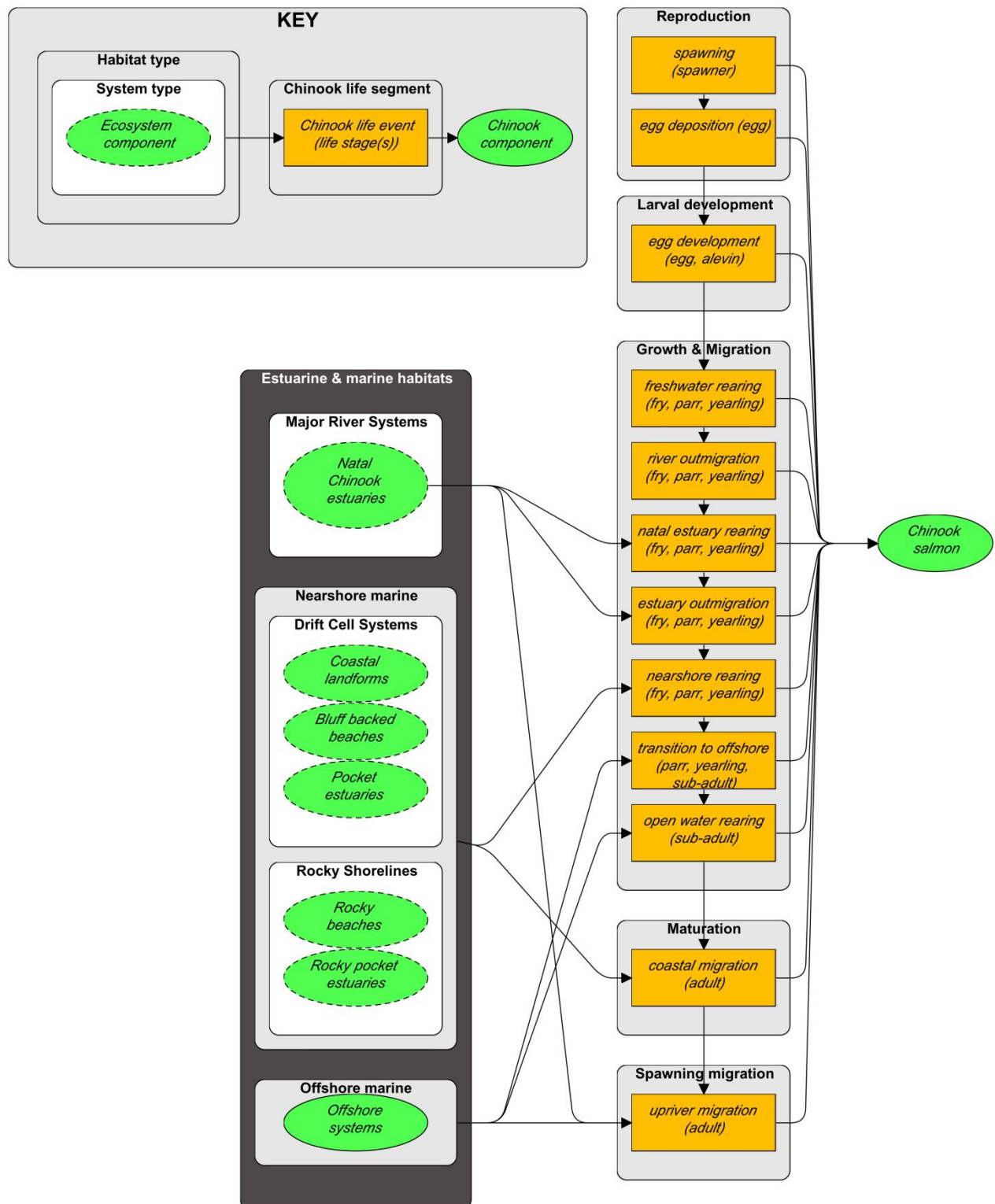
Figure 5. Relationships between estuarine and marine habitat ecosystem components and Chinook salmon life stages as described in the framework and depicted in Miradi. See Table 2 also for a description of relationships between habitats and Chinook salmon life stages.

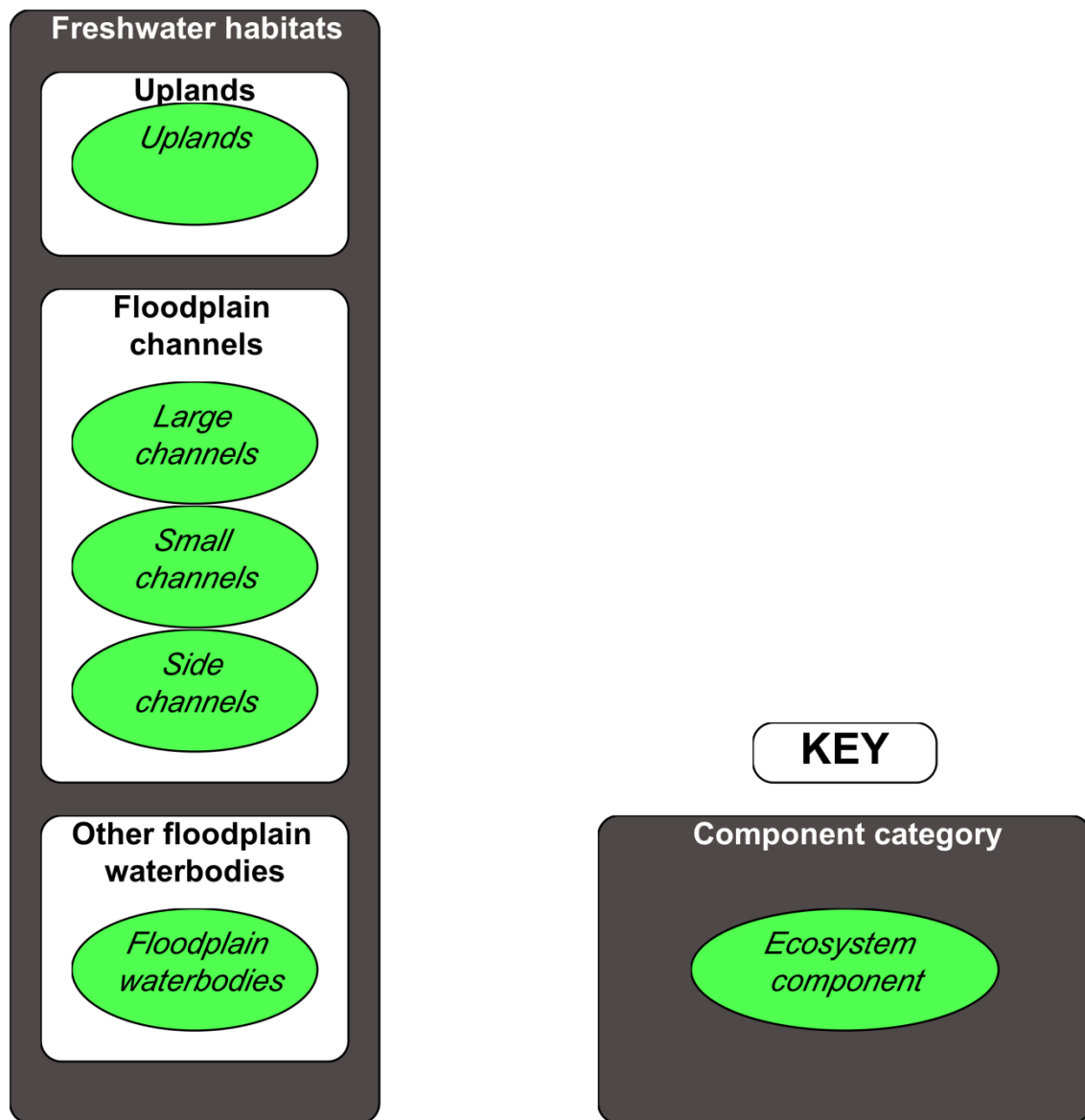Figure 6. Freshwater habitat ecosystem components (italicized) organized by habitat type and watershed scale or system type as described in the framework and depicted in Miradi.
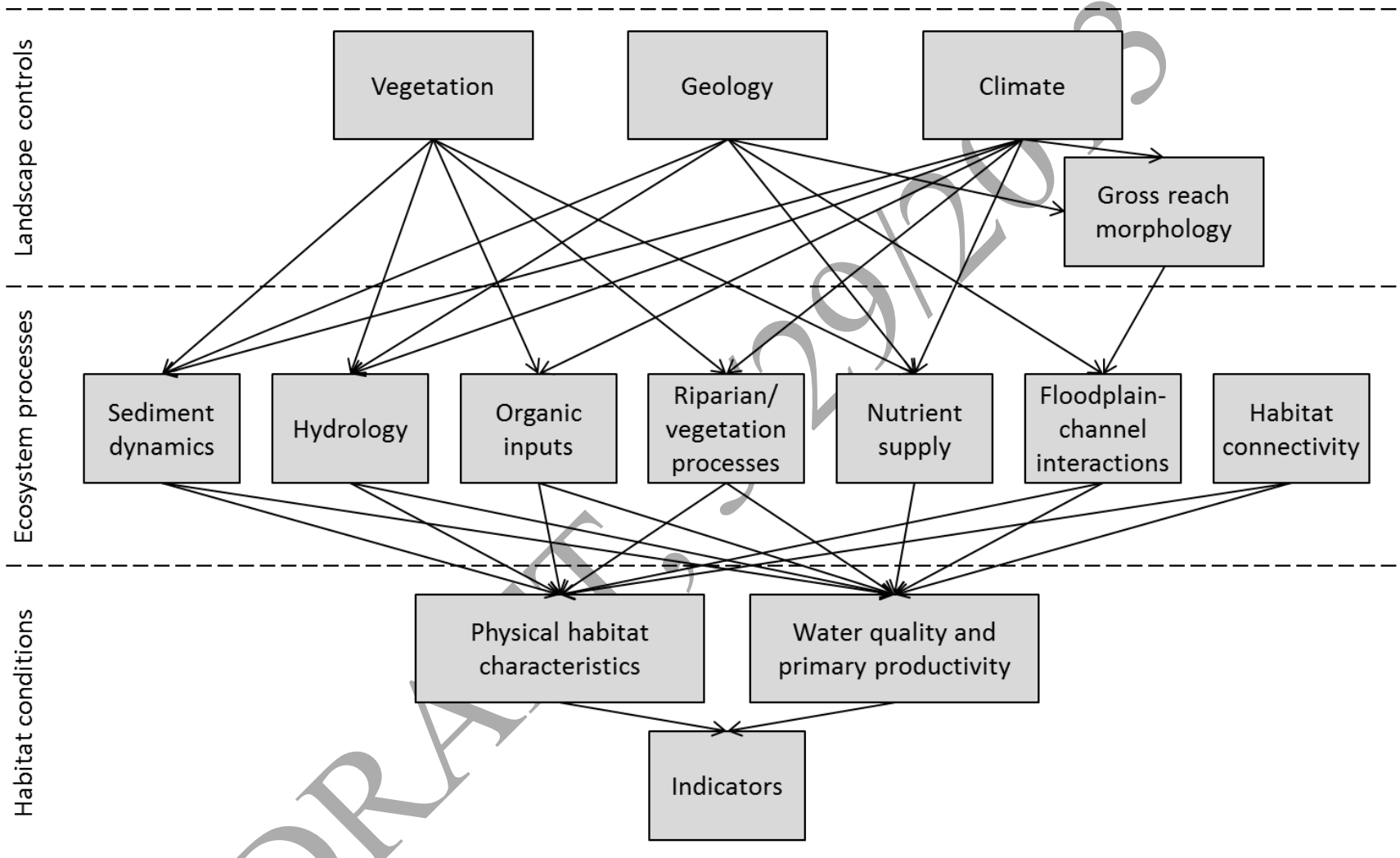
Figure 7. Conceptual diagram of linkages between landscape controls, ecosystem processes, and freshwater habitat conditions (adapted from Roni et al. 2002). The key ecological attributes (KEAs) in our framework match the processes in this model.

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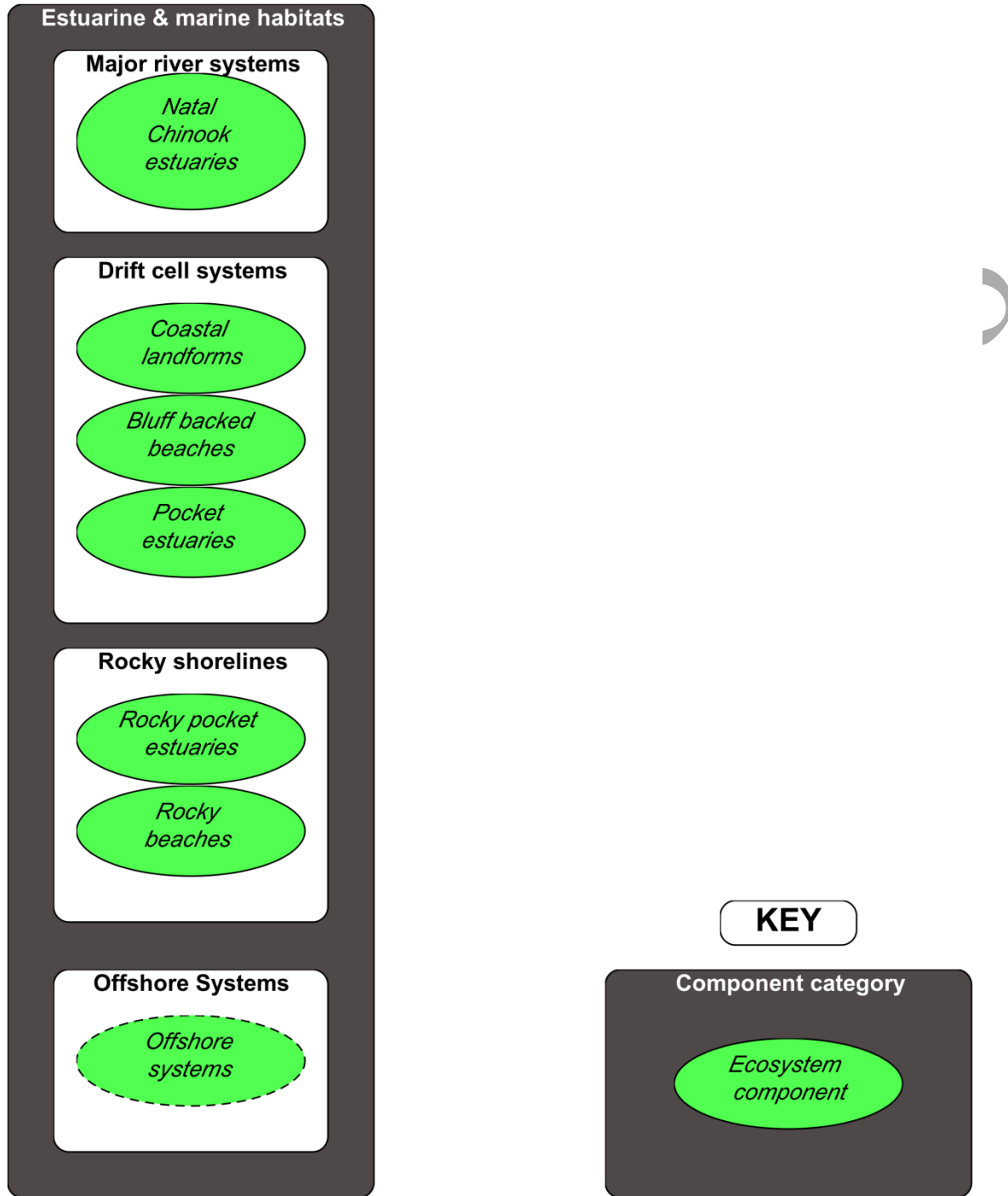
Figure 8. Estuarine and marine habitats (italicized), as described in the framework and depicted in Miradi.
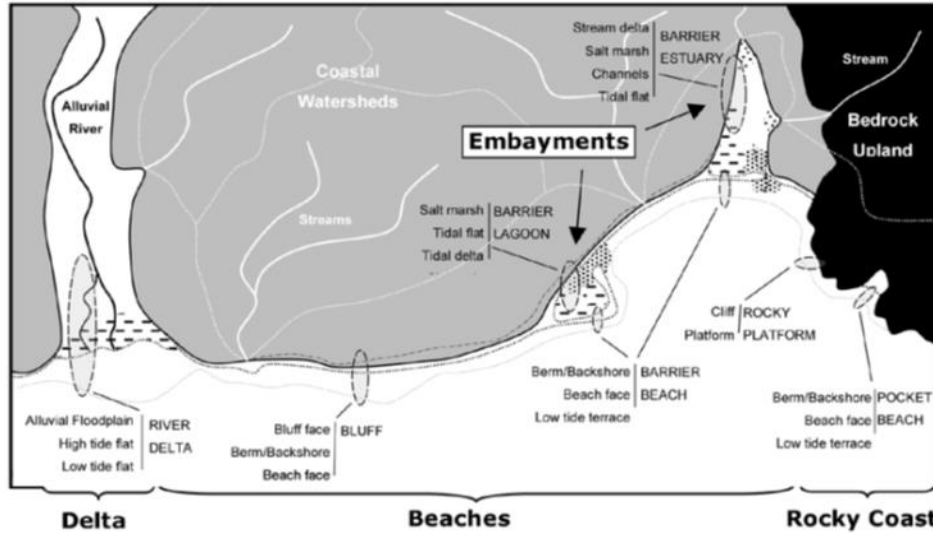
Figure 9. Shoreline habitats typical to Puget Sound (reproduced from Shipman 2008). The illustration demonstrates the hierarchical relationships listed in Table 10, columns 3-5, specifically among system subtypes (e.g., Natal Chinook estuaries, bluff backed beaches, rocky beaches, and pocket estuaries), shoreline types (e.g., barrier beach, pocket beach lagoons), and habitat zones (e.g., alluvial floodplains, backshores, marine riparian zones).
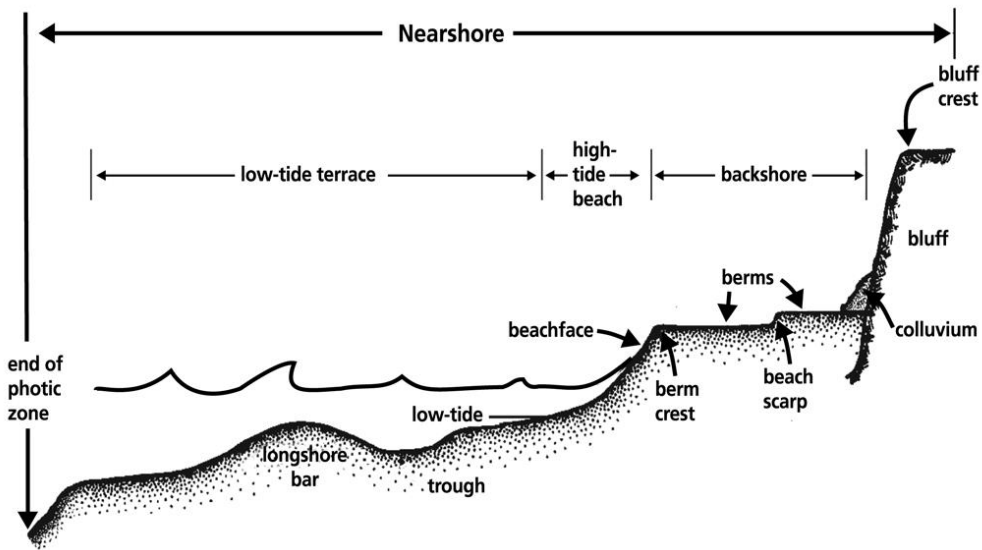
Figure 10. Cross-section of a beach showing typical nearshore marine habitat zones in the Puget Sound region (reproduced from Johannessen and MacLennan 2007). Habitat zones by system subtype are also listed in Table 10.

Figure 11. Ecosystem components (italicized) and system types, for component categories of freshwater habitats, estuarine and marine habitats, species and food webs, and salmonids as described in the framework and depicted in Miradi.

Driver

Strategy type
Strategy

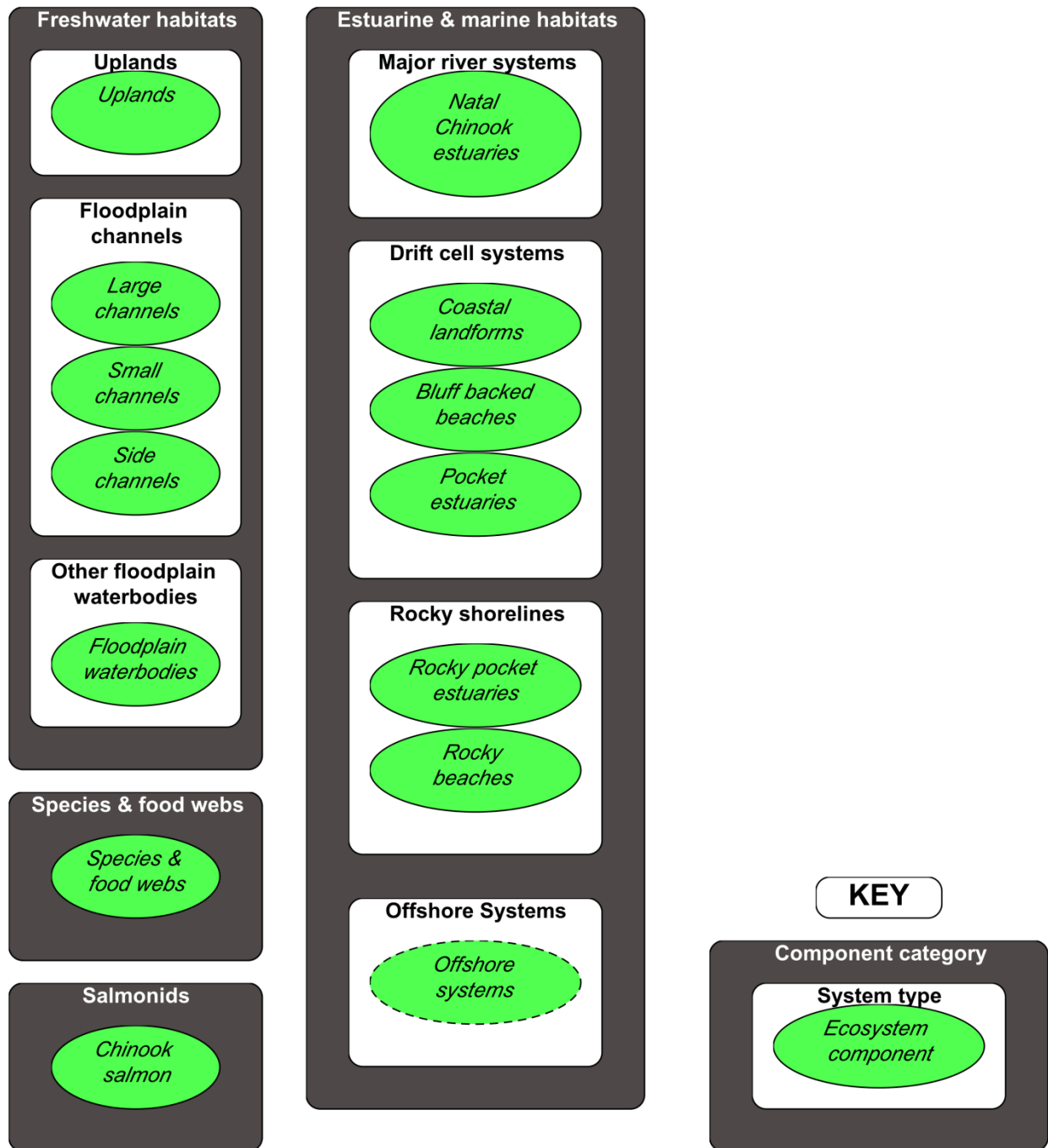**Factor type**
Contributing factor

Pressure category
Pressure

Stress type (habitat, species, food web)
"Non-Chinook" stress

Component category
Habitat type
Watershed scale or system type
Ecosystem component

Life cycle segment
Stress type (life cycle event)
Chinook stress

Chinook component

Protection strategies

Restoration strategies

Harvest management strategies

Hatchery management strategies

Outreach & education strategies

Analysis strategies

Social factors

Technical factors

Funding factors

Institutional factors

Legal factors

Agriculture & aquaculture

Biological resource use

Energy production & mining

Natural systems modification

Human intrusions & disturbance

Development

Transportation & service corridors

Pollution

Invasive & problematic species

Water withdrawals & diversions

Disrupted sediment regime

Disrupted hydro regime

Disrupted organic regime

Altered riparian condition

Altered nutrient supply & cycling

Disrupted floodplain & habitat connectivity

Disrupted tidal & freshwater hydrology & circulation

Disrupted freshwater hydrology & mixing

Altered channel formation & maintenance

Reduced detritus recruitment & retention

Reduced solar radiation & SAV

Altered ecological relationships

Freshwater habitats
Uplands

Floodplain channels

Other floodplain waterbodies

Estuarine & marine habitats
Major river systems

Nearshore marine
Drift cell systems

Rocky shorelines

Offshore systems

Species & food webs

Reproduction
Spawning success reduced

Egg deposition success reduced

Larval development
Egg development success reduced

Growth & migration
Freshwater rearing success reduced

River outmigration success reduced

Natal estuary rearing success reduced

Estuary outmigration success reduced

Nearshore rearing success reduced

Transition to offshore success reduced

Open water rearing success reduced

Maturation
Coastal migration success reduced

Migration to spawning location
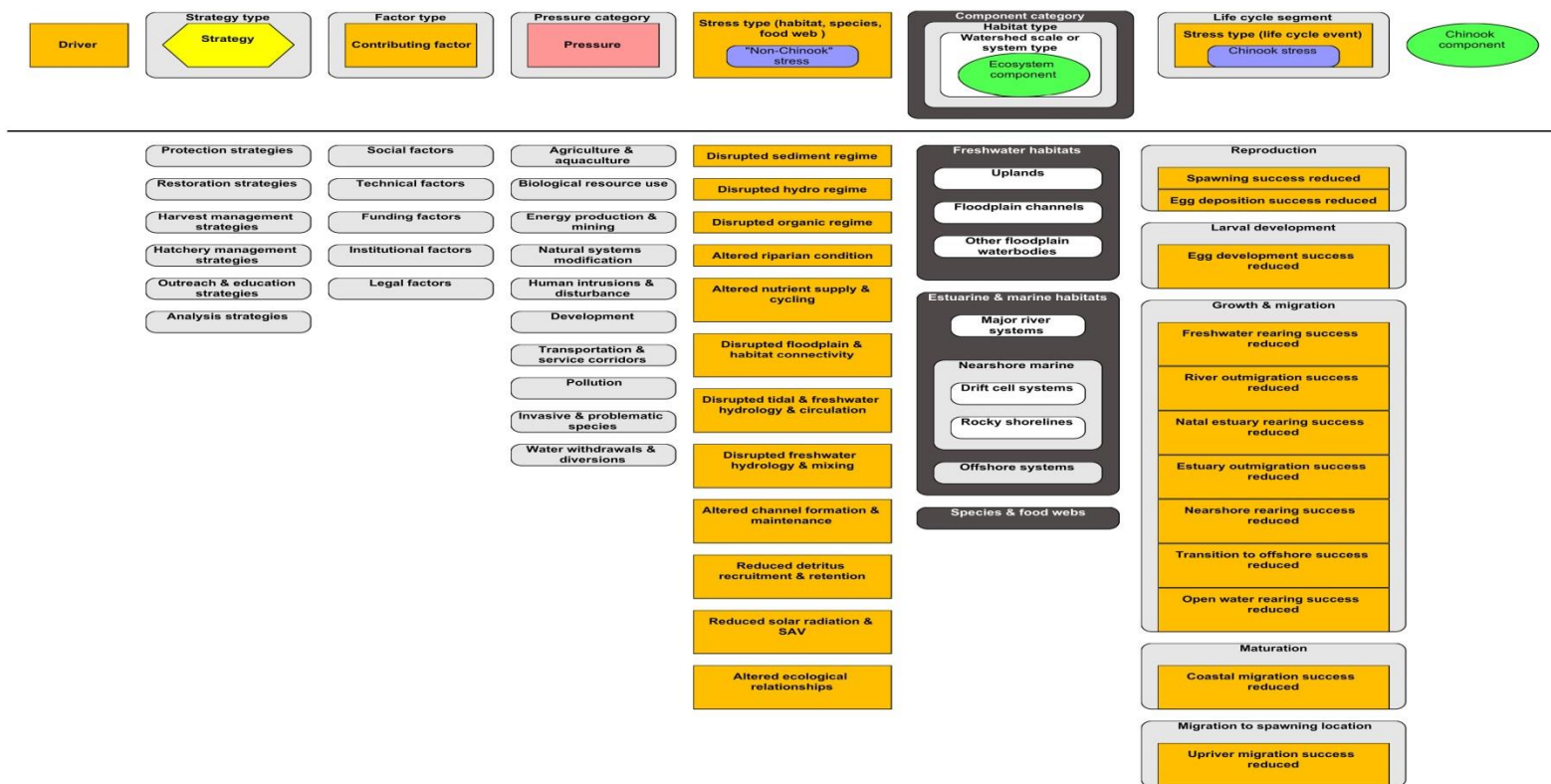Upriver migration success reduced

Figure 12. Generic portfolio of elements, as described in the framework and depicted in Miradi. See Appendix B for examples of the specific elements within each category. See also Figure 11 and Figures 14-16 for more detailed lists of components, pressures, and stresses. See Figure 13 for a key that illustrates the relationships between the elements within an individual conceptual model.
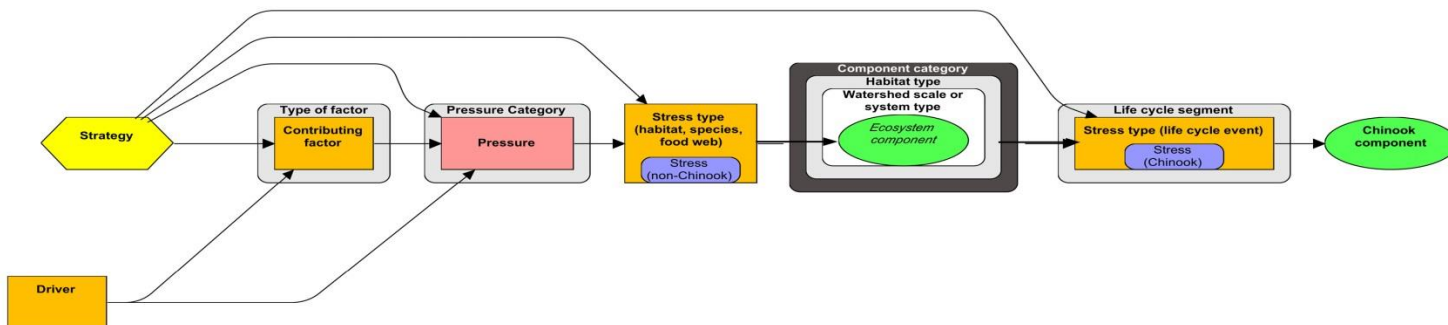
Figure 13. Key to relationships between the portfolio of elements within a watershed conceptual model as described in the framework and depicted in Miradi. Strategies can address contributing factors, pressures or stresses. Contributing factors underlie the existence and persistence of pressures and are within the scope of the project. Drivers (e.g. climate change; population growth) underlie problems in the ecosystem but are beyond the scope of the project. Drivers can be addressed through adaptation and mitigation strategies focused on their impacts (e.g. sea level rise; development patterns).
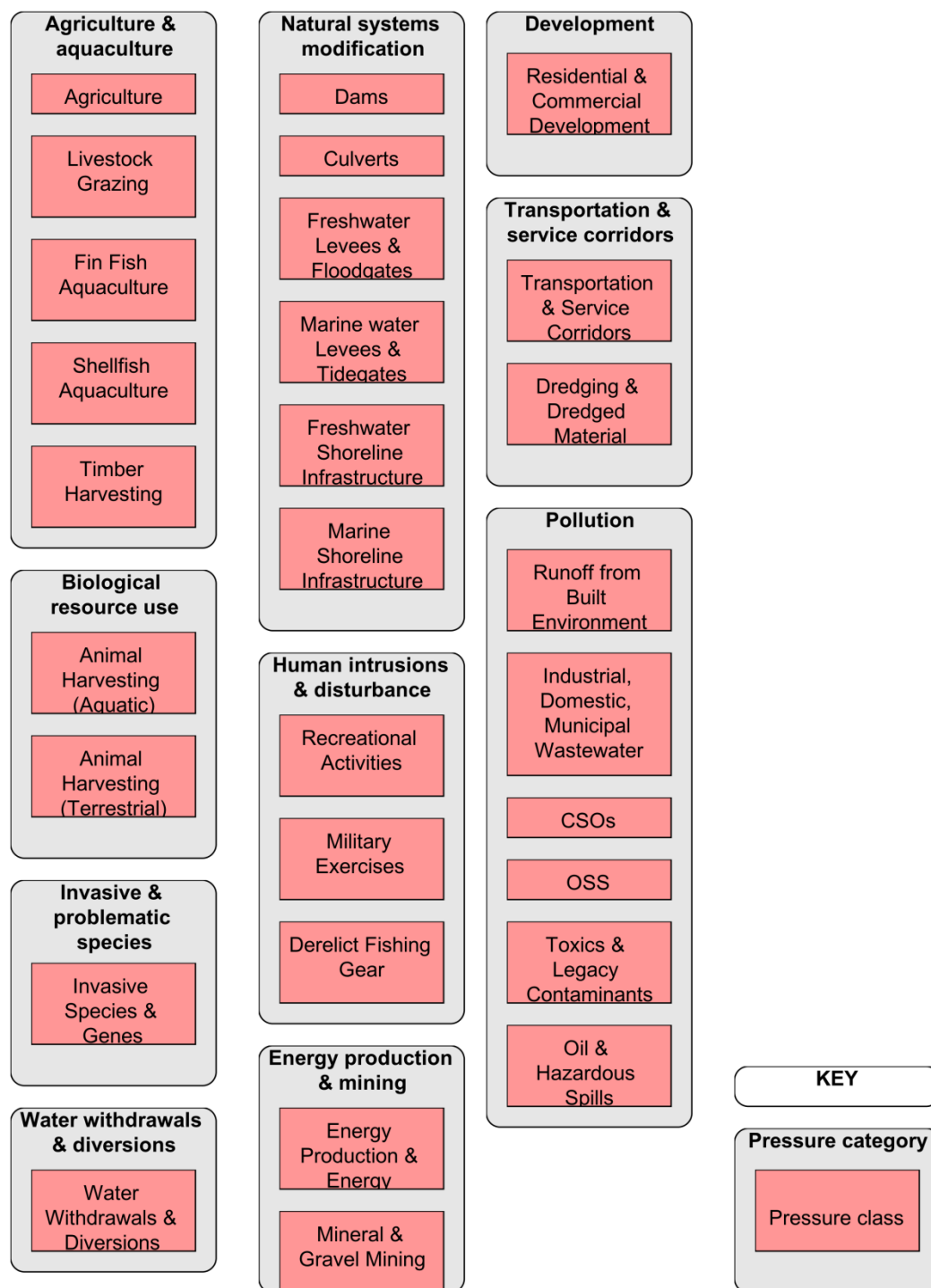
Agriculture & aquaculture

- Agriculture
- Livestock Grazing
- Fin Fish Aquaculture
- Shellfish Aquaculture
- Timber Harvesting

Biological resource use

- Animal Harvesting (Aquatic)
- Animal Harvesting (Terrestrial)

Invasive & problematic species

- Invasive Species & Genes

Water withdrawals & diversions

- Water Withdrawals & Diversions

Natural systems modification

- Dams
- Culverts
- Freshwater Levees & Floodgates
- Marine water Levees & Tidegates
- Freshwater Shoreline Infrastructure
- Marine Shoreline Infrastructure

Human intrusions & disturbance

- Recreational Activities
- Military Exercises
- Derelict Fishing Gear

Energy production & mining

- Energy Production & Energy
- Mineral & Gravel Mining

Development

- Residential & Commercial Development

Transportation & service corridors

- Transportation & Service Corridors
- Dredging & Dredged Material

Pollution

- Runoff from Built Environment
- Industrial, Domestic, Municipal Wastewater
- CSOs
- OSS
- Toxics & Legacy Contaminants
- Oil & Hazardous Spills

KEY

Pressure category

- Pressure class

Figure 14. Taxonomy of pressures as described in the framework and depicted in Miradi. See also Appendix Table B-1 for definitions of pressures.
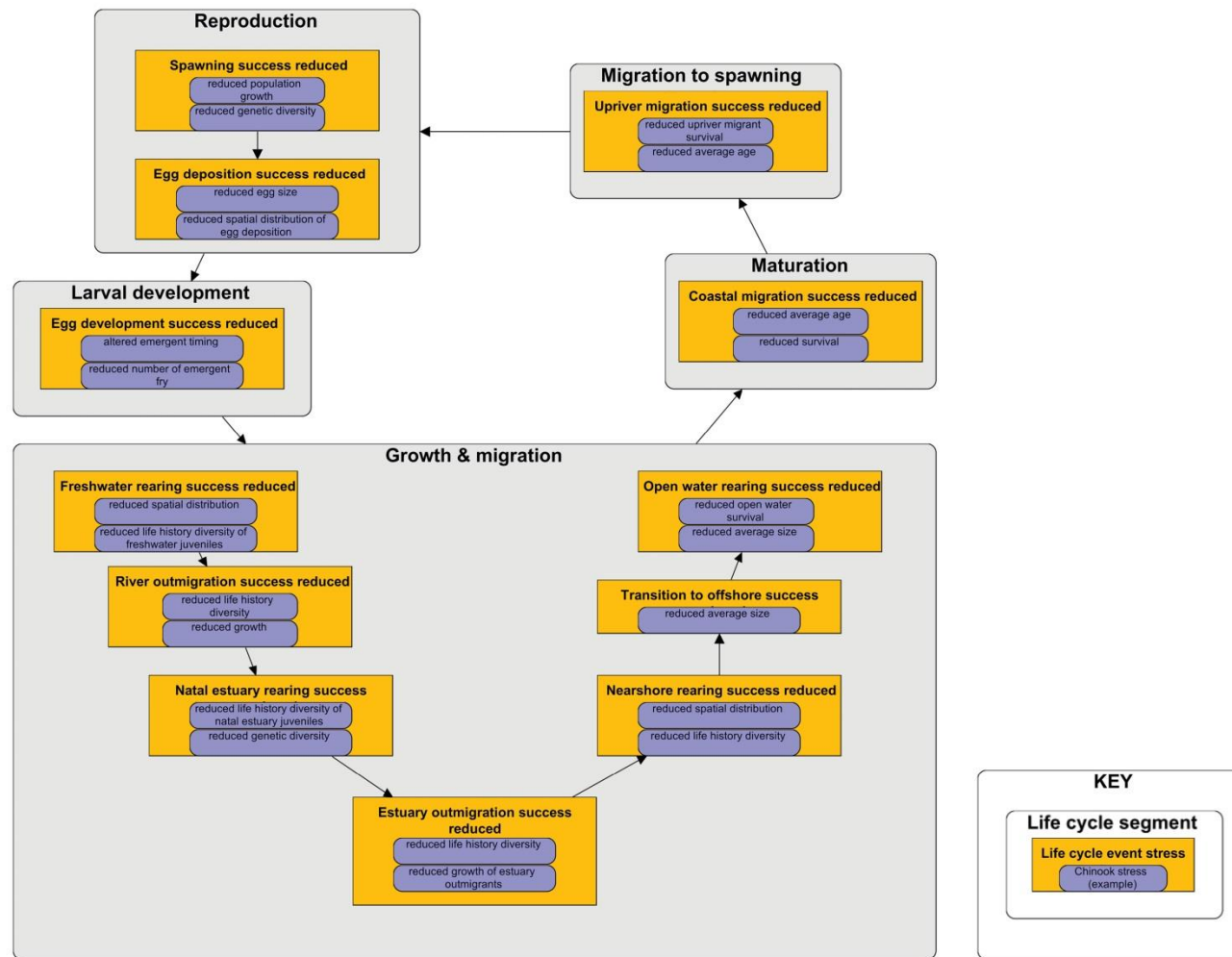
Figure 15. Taxonomy of Chinook salmon stresses, organized by Chinook life cycle, as described in the framework and depicted in Miradi. See also Appendix Table B-2a for a list of stresses related to the Chinook salmon ecosystem component.

altered coastal sediment dynamics
altered fluvial sediment dynamics

circulation
altered tidal hydrology

Disrupted hydrological regime
altered hydrological dynamics

Disrupted freshwater hydrology & mixing
altered freshwater hydrology

Disrupted organic regime
altered organic dynamics

Altered channel formation & maintenance
reduced blind channels
reduced distributary channel

Altered riparian condition
degraded riparian integrity

Reduced detritus recruitment & retention
reduced detritus recruitment

Altered nutrient supply & cycling
altered nutrient supply

Reduced solar radiation & SAV
reduced SAV bed extent

Disrupted floodplain & habitat connectivity
degraded floodplain integrity
degraded habitat connectivity

Altered ecological relationships
altered population abundance
altered population condition
altered energy flow
altered community composition

KEY

Stress categories:

Stress type
component-specific stress

Example of complete suite of component-specific stresses:

Large channels

altered sediment dynamics
altered organic inputs
degraded riparian integrity
altered nutrient dynamics
degraded floodplain integrity
degraded habitat connectivity
altered hydrological dynamics

Figure 16. Taxonomy of habitat stresses, organized by stress type, as described in the framework and depicted in Miradi. An example of a complete suite of habitat stresses for a single ecosystem component, *Large Channels*, is included. See also Appendix Table B-2b for a list of stresses related habitat and species and food web ecosystem components.
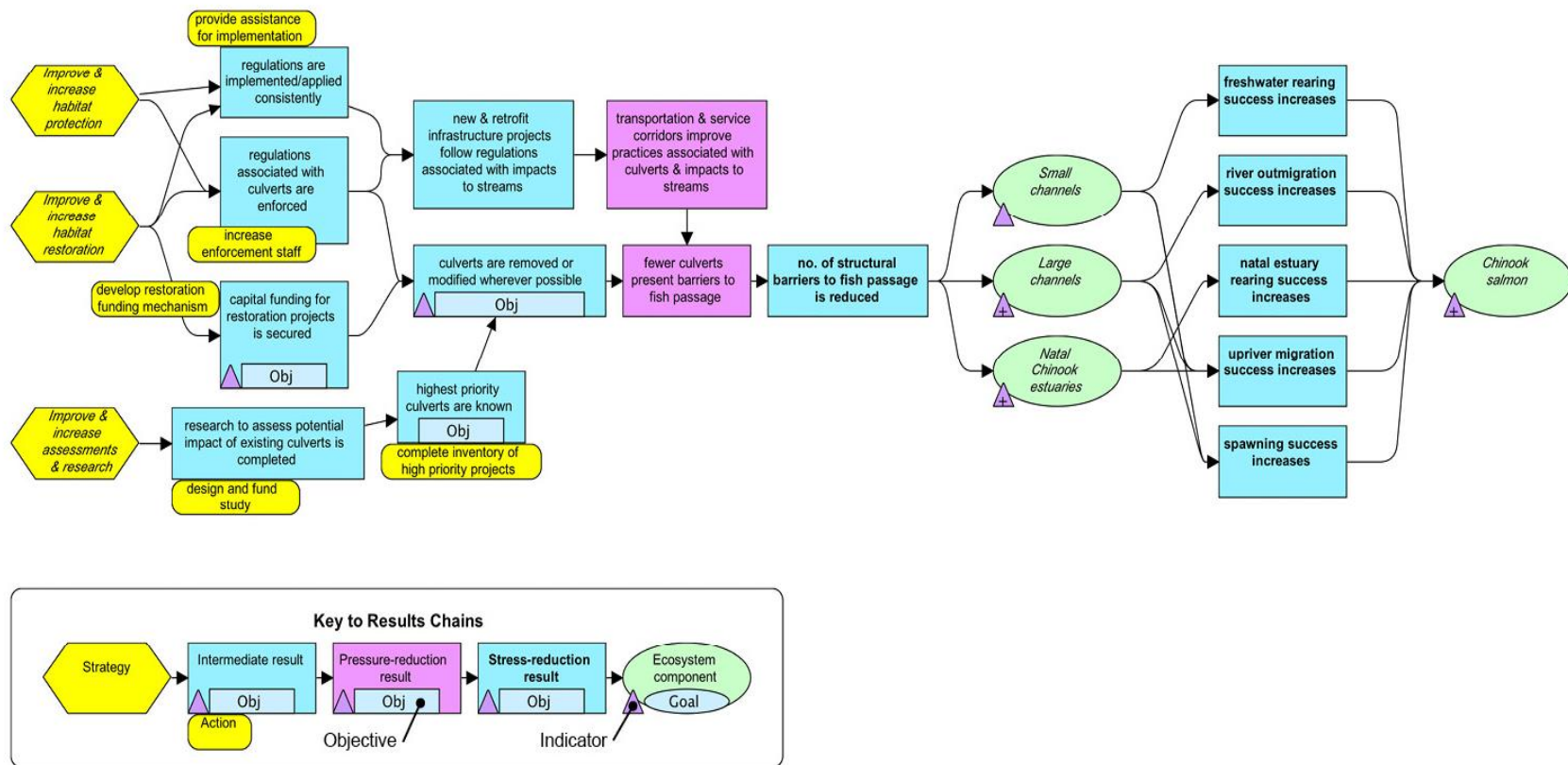
Figure 17. Example of a results chain addressing issues associated with culverts in salmon-bearing streams.

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Tables

Table 1. Fourteen ecosystem components associated with Chinook salmon recovery in the Puget Sound
region. Components are divided into four broad categories.

Ecosystem Component Categories	Ecosystem components
Chinook salmon	Chinook salmon
Freshwater habitats	Uplands
	Large channels
	Small channels
	Side channels
	Other floodplain waterbodies
Estuarine and marine habitats	Natal Chinook estuaries
	Coastal landforms
	Bluff backed beaches
	Pocket estuaries
	Rocky pocket estuaries
	Rocky beaches
	Offshore marine systems
Species and food webs	Species and food webs

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Table 2. Chinook salmon life stages and their relationship to broad types of freshwater, estuarine, and marine habitats. The table entries show which life stages use each habitat type, during particular life cycle segments and events. Detailed definitions of life stages are provided in Appendix D.

Life cycle segments	Life cycle events	Freshwater habitats		Estuarine habitats	Nearshore marine habitats		Offshore marine habitats
		Floodplain channels	Other floodplain waterbodies	Natal Chinook estuaries	Drift cell systems	Rocky shorelines	Offshore systems
Reproduction	Spawning	Spawner	Spawner				
	Egg deposition	Egg	Egg				
Larval development	Egg development	Egg, alevin	Egg, alevin				
Growth and migration	Freshwater rearing	Fry, parr, yearling	Fry, parr, yearling				
	River outmigration	Fry, parr, yearling	Fry, parr, yearling				
	Natal estuary rearing			Fry, parr, yearling			
	Estuary outmigration			Fry, parr, yearling			
	Nearshore rearing				Fry, parr, yearling	Fry, parr, yearling	
	Transition to offshore						Parr, yearling, sub-adult
	Open water rearing						Sub-adult
Maturation	Coastal migration				Adult	Adult	Adult
Spawning migration	Migration to spawning location	Adult	Adult	Adult			

Table 3. Key ecological attributes (KEAs) and potential indicators for the Chinook salmon ecosystem component, organized by life cycle segments and events (first and second rows, respectively). Half of the life cycle events—"spawning" to "natal estuary rearing"—are shown in this table; the rest are in Table 4. The cell entries under each life cycle event are indicators.

KEA	Reproduction		Larval development	Growth and migration		
	Spawning	Egg deposition	Egg development	Freshwater rearing	River outmigration	Natal estuary rearing
Abundance	No. of spawners No. of female spawners Hatchery contribution to spawning population	No. of redds; No. of eggs; Biomass of eggs	No. of emergent fry	No. of juveniles by life history type (incl. hatchery)	No. of river outmigrants by life history type (incl. hatchery)	No. of fry, parr Hatchery contribution to estuary population
Productivity— survival rate		Size of eggs	Emergent fry per spawner	Stream survival rate	Outmigrants per spawner	
Productivity— fish growth	Avg. size at age		Avg. size of emergent fry	River residence time	Avg. size of fry, parr, yearlings	Estuary growth rate; Estuary residence time
Productivity— population growth	Spawners per brood year spawner	Eggs per female			Outmigrants per spawner	
Spatial structure	Distribution of spawners within/among subbasins	No. of subbasins with high redd density		Distribution of rearing within/among freshwater habitats		Distribution of rearing within/among estuary habitats
Life history diversity	Age structure of spawners; Timing of spawning		Timing and size at emergence	No. and frequency of freshwater life history types	Age structure of outmigrants; Outmigration timing	Estuary residence time
Genetic diversity	Effective population size; Alleles per locus; Gene flow					No. of populations using estuary habitats (based on genetic stock identification)

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Table 4. Key ecological attributes (KEAs) and potential indicators for the Chinook salmon ecosystem component, organized by life cycle segments and events (first and second rows, respectively). Half of the life cycle events―"estuary outmigration" to "migration to spawning location"―are shown in this table; the rest are in Table 3. The cell entries under each life cycle event are indicators.

KEA	Growth and migration				Maturation	Spawning migration
	Estuary outmigration	Nearshore rearing	Transition to offshore	Open water rearing	Coastal migration	Migration to spawning location
Abundance	No. of estuary outmigrants Hatchery contribution to estuary outmigrants	Density of fry, parr, yearlings Hatchery contribution to nearshore	Density of parr, yearlings		No. of recruits; Terminal run no.	No. of upriver Migrants Hatchery contribution to upriver migrants
Productivity— survival rate		Nearshore survival rate		Inter-annual survival rate	Ocean survival rate; Recruits per outmigrant; Maturation rate by age	Spawners per upriver migrant
Productivity— fish growth	Size distribution of fry, parr, yearlings	Size distribution of fry, parr, yearlings; Nearshore growth rate; Nearshore residence time	Size distribution of parr, yearlings	Avg. size at age; Annual growth rate	Avg. size at age	Avg. size at age
Productivity— population growth					Recruits per spawner	Upriver migrants per spawner
Spatial structure		Distribution of rearing within/ among nearshore habitats; No. of drift cells with rearing		Distribution of rearing in the ocean Distributions among offshore regions within Puget Sound (e.g., SPS, CPS, NPS, etc	No. of coastal migration routes	
Life history diversity	Outmigration timing	Nearshore residence time Timing of nearshore residence			Age structure of fishery recruits; Timing of return to terminal areas	Age structure of upriver migrants; Timing of upriver migration

Genetic diversity	No. of populations using nearshore habitats (based on genetic stock identification)

Table 5. Examples of ways in which abundance and productivity indicators for the Chinook salmon ecosystem component might be determined, either through direct measurements (DM) or calculations using other indicators. Potential methods for obtaining some indicators are provided.

KEA	Indicator	Computed from	Potential methods
Abundance	No. of spawners	DM; Dam or weir counts; No. of female spawners; No. of redds	Full census (for DM) Counts reduced for in-river mortality Redd surveys expanded for fish per redd
	No. of river outmigrants by life history type	DM; Smolt trap or weir counts	Full census (for DM); Mark-recapture studies (trap efficiency studies)
	No. of fry, parr (in estuaries)	Density of fry, parr by habitat type; Total area by habitat type	
	No. of recruits	No. of (natural-origin) spawners; Coded-wire tag recoveries; Fishery contribution by stock	Cohort reconstruction models
	Terminal run no.	Terminal area harvest; No. of spawners	
Productivity— survival rate	Stream survival rate	No. of spawners; Eggs per female spawner; No. of river outmigrants	
	Nearshore survival rate	DM	Acoustic tagging studies Size-selective % of total mortality est. by comparison of scale size-at-circuli distributions at this life stage to subsequent life stages (offshore juv & adult)
	Ocean survival Rate(SARs)	No. of river outmigrants; No. of recruits	Size-selective % of total mortality est. by comparison of scale size-at-circuli distributions at this life stage to subsequent life stages (adults)
	Spawners per upriver migrant	DM; No. of spawners ; No. of upriver migrants	Tagging studies (for DM)
Productivity— fish growth	Avg. size of fry, parr, yearlings	DM (Scale and/or otolith back-calculations for size-at circuli)	Trapping studies (in freshwater, estuarine, and nearshore habitats)
	Estuary residence time	DM, (Scale and/or otolith back-calculations for size-at circuli)	Marking studies
	Avg. size at age	DM(Scale and/or otolith back-calculations for size-at circuli	Escapement samples; Terminal fishery samples
Productivity— population growth	Spawners per brood year spawner	No. of spawners; Age structure of spawners	
	Eggs per female	Avg. spawner size at age; Fecundity by size from hatcheries	
	Outmigrants per spawner	No. of river outmigrants; No. of spawners	

Recruits per spawner	No. of recruits; No. of spawners

Table 6. Examples of ways in which spatial structure and diversity indicators for the Chinook salmon ecosystem component might be determined, either through direct measurements (DM) or calculations using other indicators. Potential methods for obtaining indicators are provided.

KEA	Indicator	Computed from	Potential methods
Spatial structure	Distribution of spawners within/among subbasins	DM; No. of redds (by location)	Full census (for DM); Inferred from redd surveys
	Distribution of rearing within/among freshwater habitats	No. of juveniles by life history type (per freshwater habitat type)	Snorkel surveys or electrofishing in freshwater habitats
	Distribution of rearing among/within nearshore habitats	Density of fry, parr, yearlings (per nearshore habitat type)	Trapping studies (via beach seine, purse seine, townet)
Life history diversity	Age structure of spawners	DM	Analysis of scales sampled from spawners
	Timing of spawning	DM	Redd surveys
	No. and frequency of freshwater life history types	DM	Analysis of scales or otoliths from spawners
	Outmigration timing	DM; Smolt trap or weir counts	Full census (for DM); Mark-recapture studies
	Estuary residence time	DM	Trapping studies in representative habitats
	Age structure of fishery recruits	DM	Analysis of scales sampled from terminal fisheries
	Timing of return to terminal areas	DM	Records of terminal fishery catch
Genetic diversity	Effective population size	Genotypes of spawners; No. of spawners	Genetic analysis of tissue samples

Table 7. Classification of freshwater habitats within Puget Sound watersheds, modified from Beechie et al. 2003b (all scales); Cowardin et al. 1979 and Beechie et al. 2005 (reach and habitat unit scale); Montgomery and Buffington 1997 and Beechie et al. 2006a (reach scale); and Bisson et al. 1988 (habitat unit scale). Ecosystem components (in italics) representing habitat types important to Chinook salmon recovery are defined at various scales (see Appendix D for more information).

Watershed scale	Reach scale	Habitat unit scale
Uplands	Not described in this document	Not described in this document

Floodplain channels	• *Large channels* (main channels >50 m BFW)
	  o Confined
	    ▪ Straight
	  o Unconfined
	    ▪ Meandering
	    ▪ Island-braided
	    ▪ Braided
		• Mid-channel
		  o Pools
		  o Glides
		  o Riffles (boulder/cobble or cobble/gravel)
		• Edge
		  o Bars
		  o Banks (natural or hardened)
		  o Backwaters (alcoves)

	• *Small channels* (main channels <50 m BFW)
	  o Confined
	    ▪ Bedrock
	    ▪ Colluvial
	  o Unconfined
	    ▪ Alluvial
	      □ Cascades
	      □ Step pools
	      □ Plane beds
	      □ Pool riffles
	      □ Dune ripples
		• Pools
		• Glides
		• Riffles
		• Rapids
		• Runs
		• Cascades

	• *Side channels*
	  o Unconfined
	    ▪ Alluvial
	      □ Step pools
	      □ Plane beds
	      □ Pool riffles
	      □ Dune ripples
		• Pools
		• Glides
		• Riffles
		• Rapids
		• Runs

Other floodplain waterbodies	• Lacustrine habitats (i.e., lakes, ponds, reservoirs)
	  o Connected to channels [a]
	  o Isolated from channels [b]
		• Littoral
		• Limnetic

	• Palustrine habitats (i.e., wetlands)
	  o Connected to channels [a]
	  o Isolated from channels [b]
		• Emergent wetland
		• Scrub-shrub wetland
		• Forested wetland

[a] Waterbodies in which Chinook could live directly due to their connectivity with channels.
[b] Waterbodies inaccessible to Chinook.

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Table 8. Priority KEAs freshwater habitat components, organized by ecosystem process.

Ecosystem process		KEA (generic)*
I. Sediment dynamics	I-1	Sediment delivery
	I-2	Sediment transport and storage
II. Hydrology	II-3	High flow hydrological regime
	II-4	Low flow hydrological regime
III. Organic Inputs	III-5	Organic matter – inputs
	III-6	Organic matter – retention/processing
IV. Riparian	IV-7	Spatial extent and continuity of riparian area
	IV-8	Riparian community structure
	IV-9	Riparian function
V. Nutrient Supply	V-10	Nutrient concentrations (high, low)
	V-11	Water quality
	V-12	Nutrient cycling/flux
VI. Floodplain-channel interactions	VI-13	Floodplain-connectivity
	VI-14	Floodplain-structure and function
VII. Habitat connectivity	VII-15	Habitat connectivity

* To be used in development of adaptive management and monitoring plans, the KEAs included in this column need to be adapted to specific components. Examples of component-specific KEAs and indicators can be found in Tables 9 and 10.

Table 9. Freshwater key ecological attributes (KEAs), organized by ecosystem process and ecosystem component (italicized). Roman numerals correspond to ecosystem processes in the text; Arabic numbers refer to the associated KEAs. Table cells containing these numerals and numbers (e.g., I-2) are considered priority KEAs for monitoring and adaptive management of Puget Sound salmon recovery. Table cells containing an asterisk (*) are considered potential KEAs.

Ecosystem processes	Uplands	Floodplain channels							Side channels	Other floodplain waterbodies	
		Large channels (>50 m bankfull width)				Small channels (<50 m bankfull width)				Lacustrine habitats	Palustrine habitats
		Straight	Meandering	Island-braided	Braided	Bedrock	Colluvial	Alluvial	Alluvial		
Sediment dynamics	I-1	*	I-1	I-1	I-2	*	I-1	I-2	I-2	I-2	I-2
Hydrology		II-3,4	II-3,4	II-3,4	II-3,4	II-3,4	II-3,4	II-3,4	II-3,4	II-4	II-3,4
Organic inputs	III-5	III-5	III-5	III-5	III-5	III-5	III-5	III-5	III-5,6	III-5,6	III-5,6
Riparian		IV-7,8,9	*	*	*	IV-7,8,9			IV-7,8,9	IV-7,8,9	IV-7,8,9
Nutrient supply		V-10,11,12	V-10,11,12	V-10,11,12	V-10,11,12	V-10,11,12	V-10,11,12	V-10,11,12	V-10,11,12	V-10,11,12	V-10,11,12
Floodplain/channel interactions	VI-13	VI-13,14	VI-13,14	VI-13,14	VI-13,14			VI-13,14	VI-13,14		VI-13,14
Habitat connectivity		VII-15				VII-15			VII-15	VII-15	VII-15

Table 10. Freshwater ecosystem processes, key ecological attributes (KEAs), and examples of KEA and pressure indicators at watershed and reach scales. Merged cells suggest that the rationale or ecological correlation is the same for both geographic scales.

Ecosystem processes	Scales	KEAs	Examples of KEA indicators [a]	Examples of pressure indicators
I. Sediment dynamics	Watershed	1. Sediment delivery 2. Sediment transport and storage	• Sediment budget and transport/storage regime (Madej 1992, Reid and 1996) • Sediment loading (rate) (Reid and Dunne 1996) • Substrate composition (relevant to Chinook spawning, egg incubation, and juvenile overwintering requirements) (Schuett-Hames and Pleus 1996, McHugh and Budy 2005) • Current frequency and volume of mass wasting (inventory) (Reid and Dunne 1996)	• Road density (e.g., index of sediment loading) • Loss of substrate area suitable for Chinook spawning, egg incubation, juvenile overwintering • Historical frequency and volume of mass wasting (inventory) (Reid and Dunne 1996) (i.e., measured loss)
	Reach	1. Sediment delivery 2. Sediment transport and storage	• Substrate composition (relevant to Chinook spawning, egg incubation, and juvenile overwintering requirements) (Schuett-Hames and Pleus 1996, McHugh and Budy 2005) • Sediment input (adjacent hillslopes and stream banks, and/or upstream sediment supply) (Reid and Dunne 1996) • Patterns of sediment deposition (aggrading, degrading) (Madej 1992) • Total suspended sediment (weight/volume)	• Length and percentage of armored channel bank, including riprap, bulkheads, docks/boat ramps, and marina areas • Amount of in-channel dredging • Length, area, and percentage of log storage areas
II. Hydrology	Watershed	3. High flow hydrological regime 4. Low flow hydrological regime	• Area/basin discharge, (e.g.,T_{QMean}, $T_{0.5\,Yr}$), threshold discharge, point discharge, groundwater recharge/discharge (Booth et al. 2004) • Land cover including percentages of impervious surface area and vegetative cover • Hydrographic patterns unique to each watershed will determine specific measures and the seasonal patterns most affecting Chinook (e.g., 7-day low flow; peak flow frequency, magnitude, and duration) (Dunne and Leopold 1978, Booth et al. 2004, Beechie et al. 2006b) • Groundwater elevation/flows	• Regulated instream flow hydrograph • Volume of in-basin storage • Withdrawals and consumption • Volume of out-of-basin transfer • Volume and location of stormwater discharge and related alteration of natural hydrologic processes (e.g., infiltration; surface and groundwater flow patterns)

Ecosystem processes	Scales	KEAs	Examples of KEA indicators [a]	Examples of pressure indicators
	Reach	3. High flow hydrological regime 4. Low flow hydrological regime	Seasonal hydrological patterns: • Water depth and velocity • Area and type of habitat units (including seasonal variation) (Schuett-Hames et al. 1994, Johnson et al. 2001) • Residual pool depth (Lisle 1987) • Stage/discharge/habitat relationships (e.g., low flow resulting in isolated habitats; high velocities resulting in redd scouring)	• Scour depth in incubation habitats • Area of redd stranding due to natural or regulated flows • Area and connectivity of floodplain channels leading to stranding of juveniles during low flow time periods • Rapid decreases in flow stage (e.g., ramping of regulated flows) that isolate pools in floodplain channels and wetlands
III. Organic inputs	Watershed	5. Organic matter—input 6. Organic matter—retention/ processing	• Structure (species composition and seral stage), continuity (width and length), and extent (area) of riparian systems; also see the Riparian Processes (IV) below • Allocthonous recruitment from riparian vegetation • Carbon and nitrogen cycling (flow); amount and sources of inputs; also see Nutrient Process (V) below • Recruitment and transport rates of instream LWD	• Reduction of riparian forest cover • Changes in delivery of organic inputs from upslope areas • Changes in delivery of organic inputs from upstream areas • Type and concentration of exogenous organic inputs
	Reach	5. Organic matter—input 6. Organic matter—retention/ processing	• Primary productivity and water chemistry (e.g., biological oxygen demand; total nitrogen concentration) • Macroinvertebrate community structure (e.g., Index of Biological Integrity) (Karr 1991, Kleindl 1995, Karr and Chu 1997; Plotnikof 1994) • Allocthonous recruitment from riparian vegetation • Recruitment and retention of instream LWD	• Reduction of organic matter input or retention related to changes in area, community, and seral stage of riparian forest • Type and concentration of exogenous organic inputs

Ecosystem processes	Scales	KEAs	Examples of KEA indicators [a]	Examples of pressure indicators
IV. Riparian	Watershed	7. Spatial extent and continuity of riparian area 8. Riparian community structure 9. Riparian function	• Structure (species composition and seral stage), continuity (width and length), and extent (area) of riparian vegetation (species composition and seral stage) • Distribution of LWD concentrations and complexes (Wohl et al. 2010) • Wood budget (Martin and Benda 2001, Abbe et al. 2003) • Recruitment rate of LWD	• Area of lost depositional/floodplain areas that historically or potentially supported riparian forests (Collins et al. 2003) • Length and area of hydromodified bank (e.g., erosion, bank hardening, diking) • Area and percentage of lost riparian forest cover • Limits and interruptions of LWD transport (Naiman et al. 2002)
	Reach	7. Spatial extent and continuity of riparian area 8. Riparian community structure 9. Riparian function	• Riparian area (extent) • Riparian community species composition and structure (WFPB 1997, Johnson et. al 2001, Booth et al 2002, Bowen and Waltermire 2002, May 2003, Wohl et al 2010) • Size, species, and decay state of downed wood • Area, condition, and seral stage of up-slope LWD recruitment areas • Canopy closure (Schuett-Hames et al. 1994, Korhonen et al 2006) • Recruitment rate of LWD (Van Sickle and Gregory 1990, Naiman et al. 2002)	• Length and area of hydromodified bank (e.g., erosion, bank hardening, diking) • Loss of riparian vegetation area • Change and reduction in riparian and upslopevegetation community structure • Loss of late seral stage component for LWD recruitment to salmon habitats • Conversion of riparian area for human uses (e.g., transportation, residential, and commercial structures)
V. Nutrient supply	Watershed	10. Nutrient concentrations (high, low) 11. Water quality 12. Nutrient cycling/flux	• Baseline levels of nutrients (primarily nitrogen (N), phosphorus (P), and potassium (K)) • Water quality metrics, including temperature, dissolved oxygen, pH, conductivity/salinity • Nutrient budget (types and sources of nutrient inputs)	• Inventory of anthropogenic nutrient sources (locations and load levels) • Natural or artificial abundance of salmon carcasses • Clean Water Act, 303d status • Water quality standards excedance • Contaminants

Ecosystem processes	Scales	KEAs	Examples of KEA indicators [a]	Examples of pressure indicators
	Reach	10. Nutrient concentrations (high, low) 11. Water quality, incl. contaminants 12. Nutrient cycling/flux	• Nutrient concentrations, including total N, organic N, NH_4, NO_3, NO_x; and total P, organic P, particulate P, and ortho-PO_4 (Levin et al. 2010) • Benthic community structure (Karr 1991, Plotnikoff 1994, Karr and Chu 1998)	• Toxics in water, freshwater fish, shellfish, and juvenile salmon (from point and non-point sources) (Beechie et al. 2003, Levin et al. 2010) • Biological water quality index (including toxics, fecal bacteria) (Levin et al. 2010)
VI. Floodplain/ channel interactions	Watershed	13. Floodplain—connectivity 14. Floodplain—structure and function	• Length and/or area of potential floodplain development (gradient/confinement metrics) • Hyporheic connection intact (groundwater, lakes, ponds, wetlands) • Historical and current distribution of utilized habitats for holding, spawning and rearing • Distribution of habitats for rearing juveniles • Distribution of habitats for pre-spawn holding (deep pools) and spawning (gravel riffles in mainstem, side-channel and large tributaries) • Location, area, and elevation/topography of floodplain features over time (Montgomery and Buffington 1998, Collins et al. 2003, Rapp and Abbe 2003, Downs and Gregory 2006)	• The type and location of limits to juvenile and adult fish passage • Area of lost natural floodplain area (historical vs. current)
	Reach	11. Floodplain—connectivity 12. Floodplain—structure and function	• Length of natural bank • Depositional/transport state (aggradation/degradation rates)	• Length of hydromodified bank • Depth of historical conditions (i.e., for comparison and planning)

Ecosystem processes	Scales	KEAs	Examples of KEA indicators [a]	Examples of pressure indicators
VII. Habitat connectivity	Watershed	13. Habitat connectivity	• Availability and use of habitat patches for Chinook salmon (by life stage) • Pathways (landscape) and movements (behavior) of Chinook salmon between habitat patches (i.e., for migration, rearing, feeding, etc.)(Kocik and Ferreri 1998, Belisle 2005) • Temporal (future short- and long-term) accessibility (Price et al. 2010) • Historical vs. current connectivity patterns (Fullerton et al. 2010) • Correlation between abundance of Chinook salmon (by life stage) and size of required habitat types (Romero et al. 2009)	• Adult and juvenile salmon passage barriers that limit distribution (inventory and passage assessment by life stage) • Access/limitations of non-indigenous species, pathogens, and/or contaminants • Location and duration of low flow barrier
	Reach	13. Habitat connectivity	• Local network connections (i.e., pathways), in which fish can access preferred habitat patches (Kocik and Ferreri 1998) • Distribution of suitable habitat patches (Benda et al. 2004a, 2004b, Ganio et al 2005, Fullerton et al. 2010) • Thalweg profiles and metrics (Mossop and Bradford 2006) • Size of habitat patches for specific life stages of Chinook salmon	• Frequency and duration of floodplain inundation • Restriction of access to floodplain channels

[a] The suite of KEA indicators listed exemplifies what can be measured. Exclusion or apparent endorsement of any specific approach is unintentional.

Table 11. Classification of estuarine and marine habitats, showing the five largest hierarchical scales with ecosystem components at various scales depicted in italics. Detailed definitions of select habitats are provided in Appendix D.

Broad habitats	System types	System subtypes	Shoreline types	Habitat zones
Estuarine	Major river systems	*Natal Chinook estuaries*	• Drowned channels • River-dominated (fan) deltas • Tidal deltas • Delta lagoons	• Alluvial floodplains • Tidal channels (e.g., distributary and blind tidal channels, lagoon inlets/outlets) • Impoundments (e.g., lagoons, ponds, lakes) • Tidally influenced wetlands (e.g. saltmarsh, scrub-shrub, forested) • Tide flats, low tide terraces, subtidal flats • All other zones possible along delta margins
Nearshore marine	Drift cell systems	*Coastal landforms*	• Barrier beaches (spits, cusps, tombolos)	• Backshores, beach faces, tide flats, low tide terraces, subtidal flats
		Bluff backed beaches	• Sediment source beaches • Depositional beaches • Beach seeps • Plunging sediment bluffs	• Marine riparian zones • Bluff faces • Backshores, berms, beach faces, tide flats, low tide terraces
		Pocket estuaries (embayments)	• Drowned channel lagoons • Tidal delta lagoons • Longshore lagoons • Tidal channel lagoons (or marshes) • Closed lagoons and marshes • Open coastal inlets	• Marine riparian zones • Tidal channels (e.g., distributary and blind tidal channels, lagoon inlets/outlets) • Impoundments (e.g., lagoons, ponds, lakes) • Tidally influenced wetlands (e.g., saltmarsh, scrub-shrub, forested) • Backshores, berms, beach faces, tide flats, low tide terraces
	Rocky shorelines	*Rocky pocket estuaries*	• Pocket beach lagoons • Pocket beach estuaries • Pocket beach closed lagoons and marshes	• Marine riparian zones • Tidal channels (e.g., distributary and blind tidal channels, lagoon inlets/outlets) • Impoundments (e.g., lagoons, ponds, lakes) • Tidally influenced wetlands (e.g., saltmarsh, scrub-shrub, forested) • Backshores, berms, beach faces, tide flats, low tide terraces
		Rocky beaches	• Veneered rock platforms • Rocky shorelines • Plunging rocky shorelines • Pocket beaches	• Marine riparian zones • Plunging rocky cliffs, cliffs • Rocky platforms, backshores, berms, beach faces, low tide terraces
Offshore marine	*Offshore marine systems*	Bays/inlets		• Water column habitat(At a minimum, stratify into shallow mixed layer vs deeper waters. Juvenile salmon use the shallow mixed layer whereas larger salmon, other potential (fish) predators and competitors, and a much different zooplankton community use the deeper stratum during daylight with some spp migrating into the shallower layer during twilight-night periods)

Broad habitats	System types	System subtypes	Shoreline types	Habitat zones
				• Epibenthic habitat • Benthic habitat
		Open basins		• Water column habitat • Epibenthic habitat • Benthic habitat

Table 12. Priority KEAs for estuarine and marine ecosystem components, organized by ecosystem process.

Ecosystem process	KEA (generic)*	
I. Sediment dynamics - coastal	I-1	Coastal sediment dynamics in drift cells - condition
	I-2	Coastal sediment dynamics in drift cells - landscape context
	I-3	Coastal sediment deposition and accretion - extent
	I-4	Coastal sediment deposition and accretion - condition of sediment
	I-5	Coastal sediment deposition and accretion - condition of impoundment
	I-6	Coastal sediment supply - extent
	I-7	Coastal sediment supply - distribution
	I-8	Coastal sediment dynamics - extent (size or volume) of wind and wave dependent features
	I-9	Coastal sediment dynamics - condition of wind and wave dependent features
II. Sediment dynamics - fluvial	II-10	Fluvial sediment dynamics - condition
III. Hydrological dynamics - tidal	III-11	Tidal circulation - extent of dependent biological activity
	III-12	Tidal circulation - dependent water condition
IV. Hydrological dynamics - freshwater	IV-13	Freshwater hydrology - dependent water condition
	IV-14	Freshwater hydrology - condition
V. Tidal channel formation and maintenance	V-15	Tidal channel formation and maintenance - extent of channels
	V-16	Tidal channel formation and maintenance - connectivity of channels
VI. Detritus recruitment and retention	VI-17	Detritus recruitment and retention - extent
	VI-18	Detritus recruitment and retention - extent of supply
VII. Habitat connectivity	VII-19	Habitat connectivity condition
VIII. Multiple ecosystem processes	VIII-20	SAV beds - condition
	VIII-21	SAV beds - extent
	VIII-22	Estuarine habitats - extent
	VIII-23	Estuarine habitats - condition
	VIII-24	Estuarine habitats – distribution
	VIII-25	Intertidal habitat zone - extent
	VIII-26	Intertidal habitat zone - condition
	VIII-27	Tidally influenced wetlands - extent
	VIII-28	Tidally influenced wetlands - condition
	VIII-29	Water quality

* To be used in development of adaptive management and monitoring plans, the KEAs included in this column need to be adapted to specific components. Examples of component-specific KEAs and indicators can be found in Tables 13 and 14.

Table 13. Estuarine and marine key ecological attributes (KEAs), organized by ecosystem process and ecosystem component (italicized). Roman numerals correspond to ecosystem processes in the text; Arabic numbers refer to the associated KEAs. The table cells containing these numerals and numbers (e.g., I-2) are considered priority KEAs for monitoring and adaptive management of Puget Sound salmon recovery. The table cells containing an asterisk (*) are considered potential KEAs.

| Ecosystem processes | System types: Major river systems | Drift cell systems | | | Rocky shorelines | | Offshore marine systems |
	System subtypes: *Natal Chinook estuaries*	*Coastal landforms*	*Bluff backed beaches*	*Pocket estuaries*	*Rocky pocket estuaries*	*Rocky beaches*	
I. Sediment dynamics - coastal	*	I-1,2,3, 5,8	I-1,2,3, 6,7,8,9	I-1,2	I-4,5,6,7,8,9	I-4,6,7,8,9	
II. Sediment dynamics - fluvial	II-10			II-10	II-10		
III. Hydrological dynamics - tidal	III-11,12	III-11,12	III-12	III-11,12	III-11,12	III-11,12	III-11,12
IV. Hydrological dynamics - freshwater	IV-13,14	IV-13	IV-13	IV-13,14	IV-13,14	IV-13	IV-13
V. Tidal channel formation and maintenance	V-15,16			V-15,16	V-15,16		
VI. Detritus recruitment and retention	VI-17,18	VI-17,18	VI-17, 18	VI-17,18	VI-17,18	VI-18	VI-18
VII. Habitat connectivity	VII-19			VII-19	VII-19	VII-19	
VIII. Multiple ecosystem processes	VIII-20,21,22,23, 24,27,28,29	VIII-21,25,26,29	VIII-20,21,25, 26,29	VIII-20,21,22,23, 24,27,28,29	VIII-20,21,22,23,24,27,28,29	VIII-20,21,25, 26,29	VIII-20, 21,29

Table 14. Priority KEAs and example indicators for estuarine and marine ecosystem components, organized by component.

Bluff backed beach KEAs	Example indicators of KEA status or condition
I-1 Coastal sediment dynamics in drift cells - condition	• Number of drift cells with functional sediment dynamic • % of drift cells with functional sediment dynamics
I-2 Coastal sediment dynamics in drift cells - landscape context	• Distribution of functional drift cells across landscape
I-3 Coastal sediment deposition and accretion - extent	•
I-6 Coastal sediment supply - extent	• Extent (length)(expressed as % or count) of sediment source bluffs that are functioning
I-7 Coastal sediment supply - distribution	• Distribution of functioning sediment source bluffs
I-8 Coastal sediment dynamics - extent (size or volume) of wind and wave dependent features	• Extent (area, length, width) of bluff retreat • Extent (number, volume) of landslides
I-9 Coastal sediment dynamics - condition of wind and wave dependent features	• Composition of SAV bed substrate
III-11 Tidal circulation - extent of dependent biological activity	• Primary productivity
III-12 Tidal circulation - dependent water condition	•
IV-13 Freshwater hydrology - dependent water condition	•
VI-17 Detritus recruitment and retention - extent	•
VI-18 Detritus recruitment and retention - extent of supply	• Recruitment from MRV
VIII-20 SAV beds - condition	•
VIII-21 SAV beds - extent	• Area (acres) of SAV habitat
VIII-25 Intertidal habitat zone - extent	• Area (acres) of intertidal habitat
VIII-26 Intertidal habitat zone - condition	• Elevation of intertidal habitat (indicator of tidal hydrology)
VIII-29 Water quality	• Salinity • Nutrient load • Sediment load
Coastal landform KEAs	Example indicators of KEA status or condition
I-1 Coastal sediment dynamics in drift cells - condition	• Number of drift cells with functional sediment dynamics; • % of drift cells with functional sediment dynamics
I-2 Coastal sediment dynamics in drift cells - landscape context	• Distribution of functional drift cells across landscape

Bluff backed beach KEAs	Example indicators of KEA status or condition
I-3 Coastal sediment deposition and accretion - extent	• Amount (or extent) of sediment accretion (relative to historic values) on coastal landform
I-5 Coastal sediment deposition and accretion - condition of impoundment	• Width of tidal inlets for lagoons at or near equilibrium; • Proportion of spits with overwash deposits
I-8 Coastal sediment dynamics - extent (size or volume) of wind and wave dependent features	• Extent (area, length) of coastal landforms over time
III-11 Tidal circulation - extent of dependent biological activity	• Primary productivity
III-12 Tidal circulation - dependent water condition	•
IV-13 Freshwater hydrology - dependent water condition	•
VI-17 Detritus recruitment and retention - extent	•
VI-18 Detritus recruitment and retention - extent of supply	• Recruitment from MRV
VIII-20 SAV beds - condition	•
VIII-21 SAV beds - extent	• Area (acres) of habitat
VIII-25 Intertidal habitat zone - extent	• Area (acres) of habitat
VIII-26 Intertidal habitat zone - condition	• Elevation (indicator of tidal hydrology)
VIII-29 Water quality	• Salinity • Nutrient load • Sediment load

Natal Chinook estuary KEAs	Example indicators of KEA status or condition
II-10 Fluvial sediment dynamics - condition	•
III-11 Tidal circulation - extent of dependent biological activity	• Primary productivity
III-12 Tidal circulation - dependent water condition	•
IV-13 Freshwater hydrology - dependent water condition	•
IV-14 Freshwater hydrology - condition	• River or stream discharge rate and hydrograph
V-15 Tidal channel formation and maintenance - extent of channels	• Distributary channel extent
V-15 Tidal channel formation and maintenance - extent of channels	• Blind channel extent
V-16 Tidal channel formation and maintenance - connectivity of channels	• Distributary channel extent
V-16 Tidal channel formation and maintenance - connectivity of channels	• Blind channel extent
VI-17 Detritus recruitment and retention - extent	•

Natal Chinook estuary KEAs	Example indicators of KEA status or condition
VI-18 Detritus recruitment and retention - extent of supply	• Recruitment from MRV
VII-19 Habitat connectivity condition	• Indicators should address connectivity within habitat types and between habitat types
VIII-20 SAV beds - condition	•
VIII-21 SAV beds - extent	• Area (acres) of habitat
VIII-22 Estuarine habitats - extent	• Area (acres) of habitat
VIII-23 Estuarine habitats - condition	• Extent (acres, proportion) exposed to tidal inundation; elevation of estuarine habitat
VIII-24 Estuarine habitats - distribution	• Distribution of estuarine habitats
VIII-27 Tidally influenced wetlands - extent	• Area (acres) of tidal channel and marsh habitats
VIII-28 Tidally influenced wetlands - condition	• Elevation
VIII-29 Water quality	• Salinity • Nutrient load • Detritus load • Sediment load

Offshore marine system KEAs	Example indicators of KEA status or condition
III-11 Tidal circulation - extent of dependent biological activity	• Primary productivity
III-12 Tidal circulation - dependent water condition	•
IV-13 Freshwater hydrology - dependent water condition	•
VI-18 Detritus recruitment and retention - extent of supply	• Recruitment from MRV
VIII-20 SAV beds - condition	•
VIII-21 SAV beds - extent	• Area (acres) of habitat
VIII-29 Water quality	• Salinity • Nutrient load • Sediment load

Pocket estuary KEAs	Example indicators of KEA status or condition
I-1 Coastal sediment dynamics in drift cells - condition	• Number of drift cells with functional sediment dynamics • % of drift cells with functional sediment dynamics
I-2 Coastal sediment dynamics in drift cells - landscape context	• distribution of functional drift cells across landscape
II-10 Fluvial sediment dynamics - condition	•
III-11 Tidal circulation - extent of dependent biological activity	• Primary productivity

Pocket estuary KEAs	Example indicators of KEA status or condition
III-12 Tidal circulation - dependent water condition	•
IV-13 Freshwater hydrology - dependent water condition	•
IV-14 Freshwater hydrology - condition	• River or stream discharge rate and hydrograph
V-15 Tidal channel formation and maintenance - extent of channels	• Blind channel extent
V-16 Tidal channel formation and maintenance - connectivity of channels	• Blind channel extent
VI-17 Detritus recruitment and retention - extent	• Measure in tidally influenced wetlands
VI-18 Detritus recruitment and retention - extent of supply	• Recruitment from MRV
VII-19 Habitat connectivity condition	• Indicators should address connectivity within habitat types and between habitat types
VIII-20 SAV beds - condition	•
VIII-21 SAV beds - extent	• Area (acres) of habitat
VIII-22 Estuarine habitats - extent	• Area (acres) of habitat
VIII-23 Estuarine habitats - condition	• Extent (acres, proportion) exposed to tidal inundation; elevation of estuarine habitat
VIII-24 Estuarine habitats - distribution	• Distribution of estuarine habitats
VIII-27 Tidally influenced wetlands - extent	• Area (acres) of tidal channel and marsh habitats
VIII-28 Tidally influenced wetlands - condition	• Elevation
VIII-29 Water quality	• Salinity • Nutrient load • Detritus load • Sediment load

Rocky beach KEAs	Example indicators of KEA status or condition
I-4 Coastal sediment deposition and accretion - condition of sediment	• Grain size distribution
I-6 Coastal sediment supply - extent	• Extent (length) (expressed as % or count) of functioning sediment source bluffs and transport zones within drift cells
I-7 Coastal sediment supply - distribution	• Distribution of functioning sediment source bluffs and transport zones within drift cells
I-8 Coastal sediment dynamics - extent (size or volume) of wind and wave dependent features	• Extent (area, length, width) of bluff retreat • Extent (number, volume) of landslides measure of sediment recruitment
I-9 Coastal sediment dynamics - condition of wind and wave dependent features	• Composition of SAV bed substrate

Rocky beach KEAs	Example indicators of KEA status or condition
III-11 Tidal circulation - extent of dependent biological activity	• Primary productivity
III-12 Tidal circulation - dependent water condition	•
IV-13 Freshwater hydrology - dependent water condition	•
VI-18 Detritus recruitment and retention - extent of supply	• Recruitment from MRV
VII-19 Habitat connectivity condition	• Indicators should address connectivity within habitat types and between habitat types
VIII-20 SAV beds - condition	•
VIII-21 SAV beds - extent	• Area (acres) of habitat
VIII-25 Intertidal habitat zone - extent	• Area (acres) of habitat
VIII-26 Intertidal habitat zone - condition	• Elevation (indicator of tidal hydrology)
VIII-29 Water quality	• Salinity • Nutrient load • Sediment load

Rocky pocket estuary KEAs	Example indicators of KEA status or condition
I-4 Coastal sediment deposition and accretion - condition of sediment	• Beach face and back shore width and area
I-5 Coastal sediment deposition and accretion - condition of impoundment	•
I-6 Coastal sediment supply - extent	•
I-7 Coastal sediment supply - distribution	•
I-8 Coastal sediment dynamics - extent (size or volume) of wind and wave dependent features	• Extent (area, length, width) of bluff retreat • Extent (number, volume) of landslides measure of sediment recruitment
I-9 Coastal sediment dynamics - condition of wind and wave dependent features	• Composition of SAV bed substrate
II-10 Fluvial sediment dynamics - condition	•
III-11 Tidal circulation - extent of dependent biological activity	• Primary productivity
III-12 Tidal circulation - dependent water condition	•
IV-13 Freshwater hydrology - dependent water condition	•
IV-14 Freshwater hydrology - condition	• River or stream discharge rate and hydrograph
V-15 Tidal channel formation and maintenance - extent of channels	• Blind channel extent
V-16 Tidal channel formation and maintenance - connectivity of channels	• Blind channel extent
VI-17 Detritus recruitment and retention - extent	• Measure in tidally influenced wetlands

Rocky pocket estuary KEAs	Example indicators of KEA status or condition
VI-18 Detritus recruitment and retention - extent of supply	• Recruitment from MRV
VII-19 Habitat connectivity condition	• Indicators should address connectivity within habitat types and between habitat types
VIII-20 SAV beds - condition	•
VIII-21 SAV beds - extent	• Area (acres) of habitat
VIII-22 Estuarine habitats - extent	• Area (acres) of habitat
VIII-23 Estuarine habitats - condition	• Extent (acres, proportion) exposed to tidal inundation; elevation of estuarine habitat
VIII-24 Estuarine habitats - distribution	• Distribution of estuarine habitats
VIII-27 Tidally influenced wetlands - extent	• Area (acres) of tidal channel and marsh habitats
VIII-28 Tidally influenced wetlands - condition	• Elevation
VIII-29 Water quality	• Salinity • Nutrient load • Detritus load • Sediment load

Table 15. KEAs and indicators for estuarine and marine components in the Skagit Watershed.

Component	KEA	Indicator	Current Status	Desired Future Status	Historic conditions	Indicator description and methods
Pocket estuaries	VIII-22 Estuarine habitat extent	Count of accessible* pocket estuaries within Skagit Bay	8	12	22	Count of accessible* pocket estuaries of Skagit Bay; GIS methods
	VIII-22 Estuarine habitat extent	Extent of accessible* pocket estuary habitat within Skagit Bay	47.5 hectares	311.5 hectares	340.7 hectares	Sum of area of accessible* intertidal and subtidal habitat within pocket estuaries of Skagit Bay; GIS methods
	VII-19 Habitat connectivity condition	Median distance between pocket estuaries	3.49km	not specified	1.26km	Median distance along shoreline at MLLW between accessible* pocket estuaries within the Whidbey Basin; GIS methods
	VII-19 Habitat connectivity condition	Median landscape connectivity of pocket estuaries within Skagit Bay	0.14	0.14		Median landscape connectivity index (distance and complexity of fish migration pathways to accessible* pocket estuaries within Skagit Bay; methods described in Beamer et al 2005
Natal Chinook estuaries	VIII-22 Estuarine habitat extent	Accessible* tidally influenced wetlands within the Skagit estuary	3,118.0 hectares	4,232.6 hectares	11,483.0 hectares	Sum of area of tidally influenced wetlands in the Skagit estuary; Remote sensed methods
	VIII-22 Estuarine habitat extent	Accessible* distributary channel area within the Skagit estuary	851.7 hectares	895.8 hectares	1,223.8 hectares	Sum of area of accessible*distributary channelsin the Skagit estuary; Remote sensed methods
	VIII-22 Estuarine habitat extent	Accessible* blind channel tidal area within the Skagit estuary	62.7 hectares	110.8 hectares	1,158 hectares	Sum of area of accessible*blind tidal channels in the Skagit estuary; Remote sensed methods with subsample of channels field measured
	VII-19 Habitat connectivity condition	Median landscape connectivity of blind channels within the Skagit estuary	0.0190	0.0246		Median landscape connectivity index (distance and complexity of fish migration pathways to accessible* blind channels within the Skagit estuary; methods described in Beamer et al 2005

*Accessible = accessible to juvenile Chinook salmon rearing; pocket estuaries or natal estuarine habitat is sufficiently exposed to tidal hydrology to allow access to and use of habitat by juvenile Chinook

Table 16. Key ecological attributes, as related to Chinook salmon, for the species and food webs ecosystem component. The identity of the appropriate predator, competitor, prey or other species depends on the Chinook life stage and habitat type of interest.

Ecological relationship to Chinook salmon	Key ecological attributes (KEAs)

Predator species	Population size
	Population condition
Competitor species	Population size
	Population condition
Prey species	Population size
	Population condition
Other species*	Population size
	Population condition
Food webs	Community composition
	Energy and material flow

* Pathogens or facilitators (e.g., species that provide habitat for Chinook salmon)

Table 17. Examples of species and food webs indicators, grouped by key ecological attribute (KEA) and relationship to Chinook salmon.

KEA	Ecological relationship to Chinook salmon				
	Predator species	Competitor species	Prey species	Other species	Food webs
Population size	• Abundance, biomass, or density of key predator populations • Productivity of key predator populations	• Abundance, biomass, or density of key competitor populations • Annual releases of hatchery salmonids • Smolt-to-adult returns of hatchery salmonids • Abundance of hatchery Chinook spawning naturally [a] • Abundance of other salmonid populations spawning concurrently with Chinook [a]	• Abundance, biomass, or density of preferred prey populations	• Abundance, biomass, or density of key facilitators	
Population condition	• Spatio-temporal distribution of key predator populations • Size structure of key predator populations • Proportion (by weight) of Chinook in the diets of key predator populations •	• Spatio-temporal distribution of key competitor populations • Size structure of key competitor populations • Consumption demand of key competitor populations (in space and time), relative to that of juvenile Chinook • Individual body mass, fork length and marine growth for key competitor populations [b]	• Spatio-temporal distribution of key prey populations • Proportion (by weight) of key prey types in the diet of juvenile Chinook • Energy contribution of key prey types in juvenile Chinook [c]	• Prevalence of key pathogens in Chinook	
Community composition					• Diversity of non-native predator species • Response diversity of prey species • Benthic index of biological integrity (B-IBI) [a] • Ephemeroptera, Plecoptera, and Trichoptera (EPT) species richness [a] • Species diversity and trophic diversity of catches by beach seine, townet, etc. [b] • Average trophic level of fish caught by fisheries [b]

| Energy and material flow | • Chlorophyll a concentration
• Stable isotope or fatty acid signatures of key species
• Consumption demand on key prey by key predator guilds
• Pollutant concentrations of key species |

[a] Indicator is specific to freshwater habitats (see Table 7 of this document).
[b] Indicator is specific to marine habitats (see Table 10 of this document).
[c] Energy contribution is calculated as the percentage of total joules consumed to support observed growth.

Table 18. Examples of specific species or guilds that interact with Chinook salmon as predators, competitors, prey, etc., according to the literature.

Associated habitat	Ecological relationship to Chinook salmon	Examples and literature sources

Freshwater habitat	Predator species	• Piscivorous mammals
		• Piscivorous birds
		  ○ Gulls (*Larus* spp.); Weitkamp and Ruggerone 2000 [a]
		• Piscivorous fish
		  ○ Salmonids
		    ▪ Rainbow trout (*O. mykiss*); Tabor et al. 2004 [a]
		    ▪ Brook trout (*Salvelinus frontinalis*); Levin et al. 2002 [b]
		    ▪ Cutthroat trout (*O. clarki clarki*); Nowak et al. 2004[a], Beauchamp et al. 2007[a]
		  ○ Non-salmonids
		    ▪ Northern pikeminnow (*Ptychocheilus oregonensis*); Rieman et al. 1991 [b], Tabor et al. 2004 [a]
		    ▪ Smallmouth bass (*Micropterus dolomieu*); Rieman et al. 1991 [b], Tabor et al. 2004 [a]

	Competitor species	• Salmonids
		  ○ Hatchery Chinook (*O. tshawytscha*); Peery and Bjornn 2004 [b], Weber and Fausch 2005 [b]
		  ○ Other salmonid species; Stein et al. 1972 [b], Hearn 1987 [b]
		• Non-salmonids

	Prey species	• Aquatic and terrestrial insects
		  ○ Diptera; Becker 1973 [b]; Loftus and Lenon 1977 [b]; Merz 2002 [b], Koehler et al. 2006[a]
		• Small crustaceans
		  ○ Cladocera; Craddock et al. 1976 [b], Kjelson 1982 [b], Koehler et al. 2006[a]
		  ○ Gammarid amphipods; Muir and Emmett 1988 [b]

	Other species	• Pathogens ○ *Renibacterium salmoninarum*; Arkoosh et al. 2004 [a], Rhodes et al. 2006 [a], Rhodes et al. 2011 [a] • Facilitators

Associated habitat	Ecological relationship to Chinook salmon	Examples and literature sources

Estuarine habitat	Predator species	• Piscivorous mammals
		 o Harbor seals (*Phoca vitulina*); NMFS 1997 [a, c], London et al. 2002 [a]
		• Piscivorous birds
		 o Caspian terns (*Hydroprogne caspia*); Collis et al. 2001 [b]
		• Piscivorous fish
		 o Salmonids
		  ▪ Cutthroat trout (*O. clarki clarki*); Simenstad et al. 1982[a], Footen 2001[a], Duffy and Beauchamp 2008[a]
		  ▪ Steelhead (*O. mykiss*); Simenstad et al. 1982[a]
		 o Non-salmonids
		  ▪ Staghorn sculpin (*Leptocottus armatus*); Footen 2001 [a]
		  ▪ River lamprey (*Lampetra ayresi*); Ruggerone et al. 2004 [a]

	Competitor species	• Salmonids o Hatchery Chinook (*O. tshawytscha*); Levings et al. 1986 [b] o Other salmonid species • Non-salmonids o Threespine stickleback (*Gasterosteus aculeatus*); Spilseth 2008 [b]
	Prey species	• Aquatic and terrestrial insects o Dipterans; Dunford 1975 [b], Fresh et al. 1978 [a], Shreffler et al. 1992 [a], Duffy 2003 [a] o Chironomids; Dunford 1975 [b], Shreffler et al. 1992 [a], Duffy 2003 [a] o Hymenopterans; Duffy 2003 [a] • Small crustaceans o Cladocera; Dunford 1975 [b], Shreffler et al. 1992 [a], Simenstad et al. 2003 [a] o Euphausiids; Fresh et al. 1978 [a], Duffy 2003 [a] o Gammarid amphipods; Dunford 1975 [b], Fresh et al. 1978 [a], Shreffler et al. 1992 [a], Duffy 2003 [a] • Polychaetes; Duffy 2003 [a] • Larval/juvenile fish o Chum salmon (*O. keta*); Bax et al. 1978 [a]
	Other species	• Pathogens o *Nanophyetus salmincola*; Arkoosh et al. 2004 [a] • Facilitators o Beaver (*Castor canadensis*); Pess et al. 2002 [a], Hood 2012 [a]

Associated habitat	Ecological relationship to Chinook salmon	Examples and literature sources
Marine habitat	Predator species	• Piscivorous mammals 　○ Orcas (*Orcinus orca*); Hanson et al. 2010 [a] 　○ Sea lions (*Zalophus californianus*); NMFS 1997 [a, c] • Piscivorous birds 　○ Gulls (*Larus* spp.); Ruggerone 1986 [b, c] 　○ Common merganser (*Mergus merganser*); Wood 1987 [b] • Piscivorous fish 　• Salmonids 　　▪ Coho salmon (*O. kisutch*); Fresh et al. 1981 [a] 　　▪ Cutthroat trout (*O. clarki clarki*); Duffy and Beauchamp 2008 [a] 　• Non-salmonids 　　▪ River lamprey (*Lampetra ayresi*); Beamish and Neville 1995 [b] 　　▪ Spiny dogfish (*Squalus acanthias*); Beamish et al. 1992 [b]
	Competitor species	• Salmonids 　○ Hatchery Chinook (*O. tshawytscha*); Levings et al. 1986 [b], Duffy 2009 [a], Rice et al. 2011 [a] 　○ Other salmonid species 　　▪ Pink salmon (*O. gorbuscha*); Ruggerone and Goetz 1994 [a] • Non-salmonids 　○ Pacific herring (*Clupea pallasii*); Beauchamp and Duffy 2011 [a]
	Prey species	• Aquatic and terrestrial insects 　○ Insecta; Fresh et al. 1981 [a], Duffy 2003 [a], Duffy et al. 2010 [a] 　○ Arachnida; Duffy 2003 [a] • Small crustaceans 　○ Gammarid amphipods; Duffy 2003 [a], Duffy et al. 2010 [a] 　○ Decapods; Fresh et al. 1981 [a], Duffy 2003 [a], Duffy et al. 2010 [a] • Larval/juvenile fish 　○ Pacific herring (*Clupea pallasii*); Fresh et al. 1981 [a], Duffy et al. 2010 [a] 　○ Pacific sand lance (*Ammodytes hexapterus*); Fresh et al. 1981 [a], Duffy 2003 [a], Duffy et al. 2010 [a]
	Other species	• Pathogens 　○ *Lepeophtheirus salmonis*; Waknitz et al. 2002 [a], Gardner and Peterson 2003 [b] 　○ *Vibrio anguillarum*; Arkoosh et al. 1998 [a] • Facilitators 　○ Common eelgrass (*Zostera marina*); Thayer and Phillips 1977 [a, c], Phillips 1984 [b]

[a] Source describes relationships observed in the Puget Sound region.
[b] Source describes relationships observed outside the Puget Sound region.
[c] Source does not identify salmon to the species level.

Table 19. Eight-step outline for using the framework to develop a watershed-specific monitoring and adaptive management plan.

Step	Summary	Resources	Products
1	*Develop a preliminary conceptual model* by defining watershed-specific relationships between the elements from the generic portfolio of elements (Figure 12)	• Generic portfolio of elements • Chapter of interest in Volume II of the Plan	Preliminary watershed-specific conceptual model
2	*Update the conceptual model* to include new information gained since 2005, and remove elements that are not relevant to the watershed.	• Preliminary watershed-specific conceptual model • Chapter of interest in Volume II of the Plan • Habitat Work Schedule [a] • Relevant information gained since 2005 [b] • Three-Year Work Plans [c]	Final watershed-specific conceptual model

3	_Conduct viability assessment:_ Identify current status, recent trends, and desired future conditions of ecosystem components	• Chapter of interest in Volume II of the Plan • Habitat Work Schedule [a] • Relevant information gained since 2005 [b] • Three-Year Work Plans [c]	Viability analysis, including indicators for ecosystem components
4	_Assess pressures (pressure ratings/rankings):_ Assess the relative impact of each pressure on each ecosystem component.	• Chapter of interest in Volume II of the Plan • Habitat Work Schedule [a] • Relevant information gained since 2005 [b]	Pressure rating and ranking
5	_Create results chains:_ Identify the key pressures that have the largest impact on the ecosystem components.	• Chapter of interest in Volume II of the Plan • Final watershed-specific conceptual model • Viability analysis • Pressure rating and ranking • "Skagit Case Study" section of this document	Results chains
6	_Link results chains to monitoring:_ Identify objectives and indicators for intermediate results in the results chains (Figure 20).	• Results chains • This document	Indicators and objectives for various types of monitoring (i.e., implementation and effectiveness monitoring)
7	_Develop monitoring plan:_ Use the conceptual model, results chains, and viability and pressure ratings/rankings, including indicators and objectives to develop a monitoring plan	• Conceptual model • Viability analysis • Pressure rating and ranking • Results chains	Monitoring plan
8	_Develop adaptive management plan:_ The adaptive management plan will describe the interval, participation and approach used to evaluate and make resource management decisions based on monitoring results. It may be used to update recovery implementation actions, the monitoring plan, and the watershed chapter recovery plan.	• Conceptual model • Results chains • Monitoring plan	Adaptive management plan

[a] Availability of this resource (see http://hws.ekosystem.us/) will vary from watershed to watershed.
[b] Availability of this resource (which includes monitoring, assessments, etc.) will vary from watershed to watershed.
[c] Availability of this resource (see http://psp.wa.gov) will vary from watershed to watershed.

Table 20. Example of a viability table for three indicators associated with two key ecological attributes (KEAs) for Chinook salmon. Current conditions and desired future conditions (i.e., Skagit Chinook salmon recovery goals) are shown, at both the watershed- and population-scales.

KEAs	Life cycle events	Indicators	Populations	Current conditions Value	Current conditions Status	Desired future conditions[a] Value	Desired future conditions[a] Status	Location in the Skagit Volume II chapter
Abundance	Natal estuary rearing	No. of parr in the Skagit natal estuary	All	2,250,000	Fair	3,600,000	Good	Chapter 16 (p. 284)
	Spawning	No. of populations meeting "No. of spawners" recovery goals	All	Not calculated	Not determined	6 out of 6	Very good	Chapter 4 (p. 21)
			Lower Skagit	"	"	3,900−7,400 [b]	Very good	
			Upper Skagit	"	"	5,380−9,400 [b]	Very good	
			Lower Sauk	"	"	1,400−2,700 [b]	Very good	
			Upper Sauk	"	"	750−1,340 [b]	Very good	
			Suiattle	"	"	160−270 [b]	Very good	
			Upper Cascade	"	"	290−510 [b]	Very good	
Productivity— survival rate	Coastal migration	No. of populations meeting "No. of recruits per spawner" recovery goals	All	Not calculated	Not determined	6 out of 6	Very good	Chapter 4 (p. 21)
			Lower Skagit	"	"	3.0−5.4 [c]	Very good	
			Upper Skagit	"	"	3.8−6.6 [c]	Very good	
			Lower Sauk	"	"	3.0−4.8 [c]	Very good	
			Upper Sauk	"	"	3.0−4.1 [c]	Very good	
			Suiattle	"	"	2.8−4.2 [c]	Very good	
			Upper Cascade	"	"	3.0−4.6 [c]	Very good	

[a] Desired future conditions for population-specific indicators reflect population-specific recovery goals in the Skagit chapter.
[b] Number of spawners by population.
[c] Number of recruits per spawner by population.

Table 21. Example of a viability table for four indicators associated with four key ecological attributes (KEAs) for ecosystem components of freshwater, estuarine, and nearshore marine habitats. Current and desired future conditions are shown, with status rated on a scale of Poor–Fair–Good–Very Good.

Ecosystem component	KEA [a]	KEA type	Indicator	Current conditions Measure	Current conditions Status	Desired future conditions Measure	Desired future conditions Status	Location in the Skagit Volume II chapter
Large channels (freshwater)	VII-14: Habitat connectivity—condition of connected habitat	Condition	Fragmentation of areas with high density of backwater and floodplain channels (i.e., high diversity floodplain habitat)	Fragmented; 20 gaps across total high diversity area	Poor	Not fragmented; no gaps across total high diversity area	Very good	Chapter 10 (p. 117- 118)
Side channels (freshwater)	VI-12: Floodplain connectivity—extent of floodplain/channel interactions	Size	Floodplain side channel length	371.1 km	Fair	442.6 km	Good	Chapter 10 (p. 98, 113-114)
	VI-12: Floodplain connectivity—extent of floodplain/channel interactions	Size	Floodplain side channel area	560 ha	Fair	628 ha	Good	Chapter 10 [b]
Natal Chinook estuaries (estuarine)	VII-16: Tidal hydrology—extent of blind channel exposed to natural processes [c]	Size	Blind tidal channel area accessible to juvenile Chinook salmon	62.7 ha	Poor	110.8 ha	Good	Appendix D (p. 12, 41) [d]
Pocket estuaries (nearshore marine)	XVI-37: Habitat connectivity—distribution (accessibility) of pocket estuary habitat for fish migration	Landscape context	Mean distance between pocket estuaries	Not specified; could be calculated		Not specified; could be calculated		Appendix D (p. 15) of the Skagit plan [e]

[a] KEAs are adapted from Table 9, for freshwater KEAs, and Table 12, for estuarine and nearshore marine KEAs (this document).

[b] Updated information about habitat area was derived from Table 3 in Beamer et al. 2010. This report is based on data collected in 2006.

[c] The indicator associated with this KEA (Blind tidal channel area accessible to juvenile Chinook salmon) could instead be included as an indicator of a related KEA (XIII-26: Nearshore marine—blind tidal channel formation). Although the indicator provides information about multiple KEAs associated with *Natal Chinook Estuaries*, it should be associated with only one KEA per ecosystem component.

[d] According to Appendix D of the Skagit chapter, the historical condition of this indicator was 1,158.0 ha (Very Good).

[e] According to Appendix D of the Skagit chapter, the historical condition of this indicator was 1.26 km (Very Good).

Appendix A: Terminology Crosswalk

Table A. Crosswalk of terminology common to our framework, the Puget Sound Partnership (PSP), Open Standards, and Miradi. Framework terms are ordered alphabetically. Definitions adapted from CMP 2007.

Framework/PSP term	Open Standards/Miradi term	Definition
Actions	Activities	Activities that are associated with a particular strategy and designed to achieve desired intermediate results.
Conceptual model	Conceptual model	A box-and-arrow diagram that portrays the cause-and-effect relationships between strategies, drivers, contributing factors, pressures, stresses, and ecosystem components.
Contributing factors	Factors	Human-induced actions or events that contribute to the persistence of one or more pressures. They can be indirect threats, existing conditions, underlying or root causes, or opportunities, and thus can be negative or positive in nature. They include social, cultural, political, institutional, and economic factors.
Drivers	Indirect threats	Human-induced actions, events, or natural processes that contribute to the existence or persistence of one or more pressures. For the purposes of our framework, drivers are similar to contributing factors, but they are beyond the scope of that which can be addressed directly by salmon recovery plans. For example, drivers might include population growth, climate change, or global market forces. Recovery strategies and actions might address adaptation responses or mitigation of impacts (e.g. adaptation to sea level rise or altered precipitation patterns; mitigation of impacts of population growth; adaptation to altered economic base) but are unlikely to address drivers directly.
Ecosystem components	Conservation targets	Ecosystem components *represent* the focus of a protection, conservation or recovery effort. They can be specific species, habitats, ecosystems, ecological processes, or aspects of human well-being and they are selected to represent the breadth of focus of a project or program.
Goals/targets*	Goals	Measures of an ecosystem component or pressure, representing the desired future condition of the component or pressure.
Indicators (for ecosystem components)	Indicators	Measures of condition or status—in this case, of an ecosystem component.
Indicators (for intermediate results)	Indicators	Measures of effectiveness or progress toward the objectives of intermediate results.

Indicators (for pressures)	Indicators	Measures of condition or status—in this case, of a pressure.
Intermediate results	Results or outcomes	The desired or expected results (a.k.a., changes to contributing factors) that would follow from the implementation of strategies and the completion of actions.
Key ecological attributes (KEAs)	Key ecological attributes (KEAs)	Aspects of an ecosystem component's biology that, if missing or altered, would lead to the loss of the component or its ecological integrity.
Objectives (for intermediate results)	Objectives	Quantitative, time-bound measures associated with intermediate results, reflecting the desired future outcome.
Objectives (for pressures)	Objectives	Quantitative, time-bound measures associated with the status of a pressure. They represent the desired future condition of the pressure.
Pressure rating and ranking	Threat rating and ranking	A method used to rate and rank (prioritize) highest risk or highest priority pressures to ecosystem components. This method helps focus conservation efforts on the highest priority issues. Pressures can be rated based on the risk posed to an ecosystem component or based on their contribution to specific stresses associated with key ecological attributes of components.
Pressures	Direct threats	Pressures are primarily human activities that directly affect ecosystem components or alter key ecological processes (e.g. hydrological dynamics) common to multiple ecosystem components. Pressures include sources of stress (e.g. Residential and Commercial Development) and associated stressors (e.g. habitat conversion due to development).
Results chain	Results chain	A diagram which portrays the logic of how and why individual strategies and actions are expected to affect contributing factors and pressures, thereby reducing stresses and producing desired changes in the status of ecosystem components. Building a results chain requires us to define how we would like the system to change—including desired outcomes and hypothesized theories of change (i.e. the "if-then" relationships)—and how we are going to measure progress toward objectives and goals.
Strategies	Strategies or conservation actions	A group of conservation actions with a common focus designed to achieve specific objectives and goals (e.g., reducing pressures, exploiting opportunities, restoring natural systems).
Stresses	Stresses	Stresses are equivalent to altered or degraded key ecological attributes (KEAs) of ecosystem components. Stresses represent the ultimate ecological effect of pressures.
Viability analysis	Viability assessment	Viability assessment is a systematic method used to describe the current health and desired future health (aka. Goals) of ecosystem components using metrics specified by scientific research, or best professional judgment when research does not exist One or more indicators are identified for each KEA. Information about the current status and desired future status of each indicator is then used to determine which KEAs and which ecosystem components are in greatest need of attention.

* Goals and targets are the framework and PSP terms, respectively.

Appendix B: Supporting Information for Select Elements

Pressures

Pressures are defined as human activities or processes that have caused, are causing, or may cause the destruction, degradation, and/or impairment of ecosystem components. Pressures include both stressors and the sources of stressors. Essentially, pressures deliver stresses directly to ecosystem components.

Table B-1. Taxonomy of pressures based on previous classifications (IUCN 2001, Salafsky et al. 2008), with minor modifications reflecting the work of the Puget Sound Partnership (PSP). Under this taxonomy, pressure categories aggregate stressors and their sources, which often need to be disaggregated for managing and analyzing pressures (e.g., Balmford et. al. 2009).

PSP pressure category	PSP pressure class	IUCN second-level threat classes*	Definition	Common related stressors
2. Agriculture and aquaculture	2.1 Agriculture	2.1 Agriculture and aquaculture – annual and perennial nontimber crops 9.3 Pollution – agricultural and forestry effluents 7.2 Natural system modifications - dams and water management/use	Pressures on ecosystem processes and human well-being due to methods or location of farming. This includes non-timber crops planted for food, fiber, and other uses, nurseries and their physical impacts to the soil, vegetation, associated surface water resources (i.e. runoff or effluent from agricultural lands), and ditching in support of agriculture and hobby farms. This does not include pressures associated with livestock grazing or water withdrawals in support of agriculture (see related pressures)	• habitat conversion – human land use change • hydromodification – ditching • pollution – toxics, nutrients, sediment, pathogens in water • soil compaction

2.1	Livestock Grazing	2.3 Agriculture and aquaculture – livestock farming and ranching 9.3 Pollution – agricultural and forestry effluents 7.2 Natural system modifications - dams and water management/use	Pressures on ecosystem processes and human well-being due to methods or location of livestock grazing activities. This includes domestic animals raised in one location and their physical impacts to the soil, vegetation, associated surface water resources (i.e. runoff or effluent from livestock grazing lands) and ditching. This does not include water withdrawals in support of livestock grazing (see related pressures)	- habitat conversion – human land use change - hydromodification - ditching - pollution – air pollution - pollution – toxics, nutrients, sediment, pathogens in water - soil compaction
2.3	Fin fish aquaculture	2.4 Agriculture and aquaculture – marine and freshwater aquaculture	Pressures put on ecosystem processes and human well-being due to the location, intensification, or practice of aquaculture. This includes both hatchery and farm approaches and it includes pressures associated with permanent and temporary structures.	• disease introduction • habitat conversion - human land use change • increased competition - due to increased native species? • increased predation - from native or introduced species? • pollution - toxics, nutrients, sediment, pathogens in water
2.4	Shellfish aquaculture	2.4 Agriculture and aquaculture – marine and freshwater aquaculture	Pressures on ecosystem processes and human well-being due to the location, intensification, or activities of shellfish aquaculture.	• habitat conversion - human land-use change • increased predation - from native or introduced species? • pollution - nutrients, sediment, pathogens in water
2.5	Timber harvesting	5.3 Biological resource use – logging and wood harvesting 2.2 Agriculture and aquaculture – wood and pulp plantations 9.3 Pollution – agricultural and forestry effluents	Pressures from consumptive uses of biological resources including deliberate and unintentional harvesting effects of timber practices and harvesting. This includes pollution carried in runoff from managed forest lands. This does not include infrastructure associated with forest practices or water withdrawals associated with timber practices (see related pressures)	• habitat conversion - human land use change • pollution - pesticide application • hydromodification - storage, delivery, transport

3. Energy production and mining	3.1	Energy production and energy emissions	9.5 Pollution – air-borne pollutants 9.6 Pollution – excess energy	Pressures on ecosystem processes and human well-being due to the production and use of biological and non-biological sources for energy consumption. This includes industrial and residential (e.g. smoke from wood stoves) sources of airborne pollutants.	• pollution - air pollution • pollution - atmospheric deposition
	3.2	Mineral and gravel mining	3.2 Energy production and mining – mining and quarrying 9.2,5 Pollution – industrial and military effluents; air-borne pollutants	Pressures associated with the extraction of non-biological resources. This includes air and water pollution associated with mining and related activities. This does not include extraction of gravel from river or streambeds. (see related pressures)	• habitat conversion - human land use change • pollution - toxics, nutrients, sediment, pathogens in water • pollution – air pollution
7. Natural system modifications	7.1	Dams	7.2 Natural system modifications - dams and water management/use	Pressures from actions that convert or degrade habitat or alter hydrology via putting in dams to manage how and when water flows through a system, often to improve human welfare.	• fish passage barriers • habitat destruction - altered hydrology • hydromodification - flow regulation • hydromodification - structural barriers to water, sediment, debris flow
	7.2	Culverts	7.2 Natural system modifications - dams and water management/use	Pressures from actions that convert or degrade habitat or alter hydrology via putting in culverts to manage the flow and passage of water, sediment, and species.	• fish passage barriers • hydromodification - structural barriers to water, sediment, debris flow
	7.3	Freshwater levees and floodgates	7.2 Natural system modifications - dams and water management/use	Pressures from actions that convert or degrade habitat or alter hydrology via establishing levees & floodgates along freshwater systems to manage the hydrologic flow in a system, often to improve human welfare	• fish passage barriers • habitat destruction - altered hydrology • hydromodification - structural barriers to water, sediment, debris flow
	7.4	Marine water levees and tidegates	7.2 Natural system modifications - dams and water management/use	Pressures from actions that convert or degrade habitat or alter hydrology via establishing levees & tidegates along marine water systems to manage or exclude marine water into the freshwater system, often to improve human welfare.	• altered hydrological processes • altered sediment dynamics • altered nutrient/organic dynamics • flood intensification • species passage limitations • reduced habitat connectivity

	7.5	Freshwater shoreline infrastructure	7.2 Natural system modifications – other ecosystem modifications 1.1,2,3 Residential and commercial development – housing and urban areas; commercial and industrial areas (train and shipyards); tourism and recreation areas (beach resorts) 9.5 Pollution – air-borne pollutants	Pressures from the armoring of freshwater shorelines and overwater structures that alter, destroy, and disturb habitats and species via a nonconsumptive use, including industrial, commercial, and recreational marinas, ports and shipyards. This includes air pollution from shoreline facilities. This does not include runoff from impervious surfaces or other water pollution (see related pressures). If useful for development of pathways of effect in a given region, this pressure class could be divided into two subclasses addressing infrastructure associated with residential development (7.5.1) and infrastructure associated with non-residential development (7.5.2).	• habitat conversion - human land-use change • increased predation - due to OWS and shading • overwater structures • shoreline armoring • pollution – air pollution
	7.6	Marine shoreline infrastructure	7.2 Natural system modifications – other ecosystem modifications 1.1,2,3 Residential and commercial development – housing and urban areas; commercial and industrial areas (train and shipyards); tourism and recreation areas (beach resorts) 9.5 Pollution – air-borne pollutants	Pressures from armoring of marine shorelines and overwater structures that alter, destroy, and disturb habitats and species via a nonconsumptive use, including industrial, commercial and recreational marinas, ports and shipyards. This includes air pollution from shoreline facilities. This does not include runoff from impervious surfaces or other water pollution (see related pressures). If useful for development of pathways of effect in a given region, this pressure class could be divided into two subclasses addressing infrastructure associated with residential development (7.6.1) and infrastructure associated with non-residential development (7.6.2).	• habitat conversion - human land-use change • increased predation - due to OWS and shading • overwater structures • shoreline armoring • pollution – air pollution
5. Biological resource use	5.1	Animal harvesting (aquatic)	5.4 Biological resource use – fishing and harvesting aquatic resources	Pressures from consumptive uses of aquatic biological resources including deliberate and unintentional harvesting effects on wild and cultivated species. This includes both recreational and commercial harvest. This does not include derelict fishing gear or vessels. (see related pressures)	• bycatch • harvest

	5.2	Animal harvesting (terrestrial)	5.1 Biological resource use – hunting and collecting terrestrial animals	Pressures from consumptive uses of terrestrial biological resources including deliberate and unintentional harvesting effects on wild and managed species. This includes both recreational and commercial harvest.	• harvest
6. Human intrusions and disturbance	6.1	Recreational activities	6.1 Human intrusions and disturbance - recreational activities	Pressures from human activities that alter, destroy, and disturb habitats and species associated with non-consumptive uses of biological resources. This includes recreational vessels, off-road vehicles, and associated air and water pollution, but not NPDES-regulated hull-cleaning (see Pollution pressures). This does not include impacts from commercial whale watching vessels (see *Transportation & Service Corridors*), commercial recreational activities, non-recreational boat discharge, marinas or transportation networks associated with recreational activities or derelict gear and vessels (see related pressures).	• habitat degradation - ? • pollution - air pollution • pollution - toxics, nutrients, sediment, pathogens in water • species disturbance
	6.2	Military exercises	6.2 Human intrusions and disturbance – war, civil unrest and military exercises 9.6 Pollution – excess energy (sonar)	Pressures associated with military exercises that alter, destroy, and disturb habitats and species. This does not include development associated with permanent military bases (see related pressures).	• habitat degradation - defoliation? • habitat conversion - human land-use change • habitat degradation - ? • pollution - munitions testing • pollution - underwater bombs & testing
	6.3	Derelict fishing gear	9.4 Pollution – garbage and solid waste (flotsam and jetsam from recreational boats; waste that entangles wildlife) 5.4 Biological resource use – fishing and harvesting aquatic resources	Pressures associated with presence of derelict gear and vessels, both commercial and recreational, including destruction or degradation of habitats and disturbance of species. This does not include spills associated with derelict vessels.	• derelict fishing gear and vessels

1. Residential and commercial development	1.1	Residential and commercial development	1.1 1.2 1.3 Residential and commercial development – housing and urban areas; commercial and industrial areas; tourism and recreation areas

9.5 9.6 Pollution – air-borne pollutants; excess energy | Pressures associated with human settlements or other non-agricultural land uses with a substantial footprint, including residential, commercial, and industrial. This includes new and existing development. This does not include shoreline armoring, overwater structures, transportation and utility infrastructure, port and shipyard development, or runoff associated with any developed areas. (see related pressures) | • habitat conversion – human land use change
- pollution – air pollution
• pollution – light and noise pollution |
| 4. Transportation and service corridors | 4.1 | Transportation and service corridors | 4.1, 4.2, 4.3 Transportation and service corridors – roads and railroads; utility and service lines; shipping lanes

9.5 Pollution – air-borne pollutants | Pressures associated with the quantity and location of transportation and service networks, including boats, cars, trains & pipelines, and roads associated with timber harvest. This includes air pollution from vehicles and non-recreational vessels as well as direct discharge and damage from wakes and anchors from non-recreational vessels, including commercial transport and tourist ships in freshwater and marine waterways. This does not include runoff or accidental spills associated with transportation networks, derelict vessels, or pressures associated with recreational vessels. (see related pressures) | • habitat conversion - human land-use change
• pollution - air pollution
• pollution - toxics, nutrients, sediment, pathogens in water
• species disturbance |
| | 4.2 | Dredging and dredged material disposal | 4.3 Transportation and service corridors – shipping lanes | Pressures associated with the dredging and disposal of material from river and harbor systems. | • habitat conversion - human land-use change
• pollution - release of legacy toxics
• pollution - release of legacy toxics |
| 9. Pollution | 9.1 | Runoff from built environment | 9.1 Pollution – household sewage and urban wastewater (oil and sediment from roads, fertilizers and pesticides from lawns and golf-courses, road salt) | Pressures from the introduction of exotic or excess material into hydrologic system due to surface water loading and runoff from the built environment. The "built environment" includes commercial, residential, and industrial lands and transportation facilities and corridors. This includes hull-cleaning and other pollution from marina infrastructure and land-based boat maintenance practices (i.e. NPDES regulated activities that occur in marinas and shipyards). This does not include loading from septic systems (OSS), combined sewer overflows (CSOs), or runoff from other activities (e.g., agriculture, timber harvest). (see related pressures) | • hydromodification - altered volume and timing of runoff
• pollution - toxics, nutrients, sediment, pathogens in water |

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	9.2	Industrial and domestic municipal wastewater	9.1, 9.2 Pollution – household sewage and urban wastewater; industrial and military effluents	Pressures associated with discharge from municipal and industrial WWTPs into hydrologic systems. This includes water-borne sewage that includes nutrients, pathogens, toxic chemicals, and sediments. This does not include discharge from municipal combined sewer overflows (CSOs), onsite sewage systems (OSS), wastewater discharged from recreational and other vessels, or biosolids applied in terrestrial environments. (see related pressures)	• pollution - toxics, nutrients, sediment, pathogens in water
	9.3	Onsite Systems (OSS)	9.1 Pollution – household sewage and urban	Pressures associated with discharges from Onsite Sewage Systems (OSS). This includes sewage and leachates (nutrients, toxic chemicals and/or sediment) from residences not connected to a municipal system (septics, small private systems, and everything with a drain field).	• pollution - toxics, nutrients, sediment, pathogens in water
	9.4	Combined Sewer Overflows) CSOs	9.1 Pollution – household sewage and urban	Pressures associated with discharge from municipal Combined Sewer Overflows (CSOs)	• pollution - toxics, nutrients, sediment, pathogens in water
	9.5	Toxics and legacy contaminants	9.2 Pollution – industrial and military effluents	Pressures associated with the existence of contaminated soils and lands, including sources and pathways of toxic loading from brownfields and superfund sites. This includes legacy contaminants that are already located in hydrologic systems, that reach hydrologic systems via groundwater, or that directly harm terrestrial systems.	• toxics in environment
	9.6	Oil and hazardous material spills	3.1 Energy production and mining – oil and gas drilling 9.2 Pollution – industrial and military effluents	Pressures associated with the accidental, episodic, or potentially catastrophic spill of oil and hazardous waste in aquatic and terrestrial environments. This does not include chronic or other frequent, smaller pollution events related to normal operations of vehicles, vessels, etc. (see related pressures)	• toxic spills
8. Invasive and other problematic species and genes	8.1	Invasive species (aquatic and terrestrial)	8.1 Invasive and other problematic species and genes – invasive non-native/alien species	Pressures associated with the introduction and distribution of non-native species or genes that are capable of aggressively establishing or causing environmental damage.	• increased competition - due to increased non-native species • introduced genetic material
10. Water Withdrawals and Diversions	10.1	Water withdrawals and diversions	7.2 Natural system modifications - dams and water management/use	Pressures associated with modification, extraction, or diversion of water supplies, including water withdrawals and diversions associated with agriculture, forestry practices and exempt wells. This includes changing water flow patterns, such as instream flows, from their natural range of variation either deliberately as a result of water supply or flood management operations.	• hydromodification - water diversion • hydromodification - water extraction

Stresses

Stresses are equivalent to altered key ecological attributes (KEAs) of ecosystem components. Stresses are not pressures, but rather degraded conditions that result from pressures. For example, reduced population size is a stress that might result from the pressure of unsustainable fishing. Tables C-2a and C-2b list stresses related to KEAs of the 14 ecosystem components in the framework.

Table B-2a. Stresses associated with key ecological attributes (KEAs) of the Chinook salmon ecosystem component. Examples of indicators that reflect the health of (or stress to) associated KEAs are also included.

Key ecological attribute (KEA)	Associated stress (altered KEA)	Example indicator
Abundance	Reduced abundance of spawners	No. of subbasins meeting spawner abundance targets
	Reduced abundance of eggs	Redd abundance; Egg biomass
	Reduced abundance of emergent fry	No. of emergent fry
	Reduced abundance of juveniles	No. of parr
	Reduced abundance of river outmigrants	No. of parr outmigrants; No. of river yearling outmigrants
	Reduced abundance of estuary juveniles	No. of parr in natal estuary
	Reduced abundance of estuary outmigrants	No. of estuary outmigrants
	Reduced abundance of nearshore juveniles	No. of parr
	Reduced abundance of coastal migrants	No. of management units meeting targets
	Reduced abundance of upriver migrants	No. migrating upriver
Productivity—survival rate	Reduced egg survival	Egg size
	Reduced emergent fry survival	Emergent fry survival rate
	Reduced river outmigrant survival	River outmigrants per spawner
	Reduced juvenile survival in estuaries	Estuary survival rate of fry, parr, yearling
	Reduced sub-adult survival in open water	Inter-annual survival rate by age
	Reduced coastal migrant survival	Maturation rate by age; Marine survival
	Reduced upriver migrant survival	In-river survival rate
Productivity—	Reduced growth of spawners	Size of spawners at given age

fish growth	Reduced growth of emergent fry	Size of emergent fry
	Reduced growth of freshwater juveniles	River residence time of fry, parr, yearlings
	Reduced growth of river outmigrants	Size of fry, parr, yearlings at outmigration
	Reduced growth of estuary juveniles	Growth rate or residence time of fry, parr
	Reduced growth of estuary outmigrants	Size of fry, parr, yearlings
	Reduced growth of nearshore juveniles	Nearshore rearing size, growth rate, or residence time of fry, parr
	Reduced growth of juveniles transitioning to offshore	Transition to offshore size of parr, yearling
	Reduced growth of open water sub-adults	Size of open water sub-adults; Open water annual growth rate by age
	Reduced growth of coastal migrants	Size of coastal migrant fishery recruits at age
	Reduced growth of upriver migrants	Size of upriver migrants at age
Productivity—population growth	Reduced spawner population	Brood year spawners
	Reduced egg population	No. of eggs per female; Egg biomass per female
	Reduced river outmigrant population	River outmigrants per spawner
	Reduced coastal migrant population	No. of subbasins meeting targets for fishery recruits per spawner
Spatial structure	Reduced spatial distribution of spawners	No. of subbasins occupied by spawners
	Reduced spatial distribution of egg deposition	No. of subbasins with high redd density
	Reduced spatial distribution of freshwater juveniles	Distribution of fry, parr rearing among lowland, mainstem, headwaters
	Reduced spatial distribution of estuary juveniles	Distribution of rearing among natal estuary habitat types
	Reduced spatial distribution of nearshore juveniles	No. of drift cells with rearing; Distribution of nearshore rearing among/within habitat types
	Reduced spatial distribution of open water juveniles	Distribution of rearing in the ocean
	Reduced spatial distribution of coastal migrants	No. of coastal migration routes
Life history diversity	Reduced life history diversity of spawners	Spawning timing; Spawner age
	Reduced life history diversity of emergent fry	Timing and size of emergent fry at emergence (swim-up)
	Reduced life history diversity of freshwater juveniles	Diversity of fry, parr river residence times
	Reduced life history diversity of river outmigrants	Diversity of outmigration timing; Age structure of river outmigrants
	Reduced life history diversity of estuary juveniles	Diversity of estuary residence times
	Reduced life history diversity of estuary outmigrants	Diversity of estuary outmigration timing
	Reduced life history diversity of nearshore juveniles	Diversity of nearshore residence times

	Reduced life history diversity of coastal migrants	Age structure of fishery recruits; Timing of coastal migrant return to terminal areas
	Reduced life history diversity of upriver migrants	Age structure of upriver migrants; Diversity of upriver migration timing
Genetic diversity	Reduced genetic diversity of spawners	Spawner effective population size, alleles per locus, or gene flow rate
	Reduced genetic diversity of nearshore juveniles	No. of populations rearing in nearshore habitats

Table B-2b. Stresses associated with the key ecological attributes (KEAs) of the habitat and species and food web ecosystem components (italicized).

Ecosystem component category	Ecosystem component	Key ecological attribute (KEA)[*]	Associated stress (altered KEA)
Freshwater habitats	*Uplands*	I-1 Sediment dynamics—sediment delivery	Altered sediment delivery
		III-5 Organic matter— inputs	Altered organic inputs
	Large channels	I-1 Sediment dynamics—sediment delivery	Altered sediment delivery, transport, and storage
		I-2 Sediment dynamics—transport and storage	Altered sediment delivery, transport, and storage
		II-3 Hydrology— high flow hydrological regime	Altered low and high flow hydrological regimes
		II-4 Hydrology—low flow hydrological regime	Altered low and high flow hydrological regimes
		III-5 Organic matter— inputs	Altered organic inputs
		IV-7 Riparian—spatial extent and continuity of riparian area	Degraded riparian structure and function
		IV-8 Riparian—community structure	Degraded riparian structure and function
		IV-9 Riparian—function	Degraded riparian structure and function
		V-10 Nutrient supply—nutrient concentrations (high, low)	Altered nutrient concentrations
		V-11 Nutrient supply—water quality	Altered nutrient inputs, cycling, and flux
		V-12 Nutrient supply—nutrient cycling/flux	Altered nutrient inputs, cycling, and flux
		VI-13 Floodplain-channel interactions—connectivity	Degraded floodplain structure and connectivity
		VI-14 Floodplain-channel interactions—structure and function	Degraded floodplain structure and connectivity
		VII-15 Habitat connectivity	Degraded habitat connectivity
	Small channels	I-1 Sediment dynamics—sediment delivery	Altered sediment delivery, transport, and storage
		I-2 Sediment dynamics—transport and storage	Altered sediment delivery, transport, and storage
		II-3 Hydrology—high flow hydrological regime	Altered low and high flow hydrological regimes
		II-4 Hydrology—low flow hydrological regime	Altered low and high flow hydrological regimes
		III-5 Organic matter—inputs	Altered organic inputs
		IV-7 Riparian—spatial extent and continuity of riparian area	Degraded riparian structure and function

		IV-8 Riparian—community structure	Degraded riparian structure and function
		IV-9 Riparian—vegetation, including wetland	Degraded riparian structure and function
		V-10 Nutrient supply—nutrient concentrations (high, low)	Altered nutrient concentrations
		V-11 Nutrient supply—water quality	Altered nutrient inputs, cycling, and flux
		V-12 Nutrient supply—nutrient cycling/flux	Altered nutrient inputs, cycling, and flux
		VI-13 Floodplain-channel interactions—connectivity	Degraded floodplain structure and connectivity
		VI-14 Floodplain-channel interactions—structure and function	Degraded floodplain structure and connectivity
		VII-15 Habitat connectivity	Degraded habitat connectivity
	Side channels	I-2 Sediment dynamics—transport and storage	Altered sediment transport and storage
		II-3 Hydrology—high flow hydrological regime	Altered low and high flow hydrological regimes
		II-4 Hydrology—low flow hydrological regime	Altered low and high flow hydrological regimes
		III-5 Organic matter—inputs	Altered organic inputs, retention, and processing
		III-6 Organic matter—retention/processing	Altered organic inputs, retention, and processing
		IV-7 Riparian—spatial extent and continuity of riparian area	Degraded riparian structure and function
		IV-8 Riparian—community structure	Degraded riparian structure and function
		IV-9 Riparian—vegetation, including wetland	Degraded riparian structure and function
		V-10 Nutrient supply—nutrient concentrations (high, low)	Altered nutrient concentrations
		V-11 Nutrient supply—water quality	Altered nutrient inputs, cycling, and flux
		V-12 Nutrient supply—nutrient cycling/flux	Altered nutrient inputs, cycling, and flux
		VI-13 Floodplain-channel interactions—connectivity	Degraded floodplain structure and connectivity
		VI-14 Floodplain-channel interactions—structure and function	Degraded floodplain structure and connectivity
		VII-15 Habitat connectivity	Degraded habitat connectivity
	Floodplain waterbodies	I-2 Sediment dynamics—sediment transport and storage	Altered sediment transport and storage
		II-3 Hydrology—high flow hydrological regime	Altered high flow regime
		II-4 Hydrology—low flow hydrological regime	Altered low flow regime
		III-5 Organic matter—inputs	Altered organic inputs, retention, and processing

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		III-6 Organic matter—retention/processing	Altered organic inputs, retention, and processing
		IV-7 Spatial extent and continuity of riparian area	Degraded riparian structure and function
		IV-8 Riparian community structure	Degraded riparian structure and function
		IV-9 Riparian function	Degraded riparian structure and function
		V-10 Nutrient supply—nutrient concentrations (high, low)	Altered nutrient concentrations
		V-11 Nutrient supply—water quality	Altered nutrient inputs, cycling, and flux
		V-12 Nutrient supply—nutrient cycling/flux	Altered nutrient inputs, cycling, and flux
		VI-13 Floodplain-channel interactions—connectivity	Degraded floodplain structure and connectivity
		VI-14 Floodplain-channel interactions—structure and function	Degraded floodplain structure and connectivity
		VII-15 Habitat connectivity	Degraded habitat connectivity
Estuarine and marine habitats*	*Natal Chinook estuaries*	II-10 Fluvial sediment dynamics – condition	Altered fluvial sediment dynamics
		III-11 Tidal circulation - extent of dependent biological activity	Reduced tidal circulation
		III-12Tidal circulation - dependent water condition	Reduced tidal circulation
		IV-13 Freshwater hydrology - dependent water condition	Altered freshwater hydrology
		IV-14 Freshwater hydrology - condition	Altered freshwater hydrology
		V-15 Tidal channel formation and maintenance - extent of channels	Reduced distributary channel formation and maintenance
		V-16 Tidal channel formation and maintenance - connectivity of channels	Reduced connectivity of tidal channels
		VI-17 Detritus recruitment and retention - extent	Altered detritus recruitment and retention
		VI-18 Detritus recruitment and retention - extent of supply	Altered detritus recruitment and retention
		VII-19 Habitat connectivity - condition	Altered habitat connectivity
		VIII-20 SAV beds – condition	Altered SAV beds
		VIII-21 SAV beds – extent	Altered SAV beds
		VIII-22 Estuarine habitats - extent	Altered estuarine habitat area
		VIII-23 Estuarine habitats - condition	Altered estuarine habitat
		VIII-24 Estuarine habitats – distribution	Altered estuarine habitat
		VIII-27 Tidally influenced wetlands - extent	Altered tidal hydrology

		VIII-28 Tidally influenced wetlands - condition	Altered tidal hydrology
		VIII-29 Water quality	Altered water quality
	Coastal landforms	I-1 Coastal sediment dynamics in drift cells - condition	Altered coastal sediment dynamics
		I-2 Coastal sediment dynamics in drift cells - landscape context	Altered coastal sediment dynamics
		I-3 Coastal sediment deposition and accretion - extent	Altered coastal sediment dynamics
		I-5 Coastal sediment deposition and accretion - condition of impoundment	Altered coastal sediment dynamics
		I-8 Coastal sediment dynamics - extent (size or volume) of wind and wave dependent features	Altered coastal sediment dynamics
		III-11 Tidal circulation - extent of dependent biological activity	Reduced tidal circulation
		III-12 Tidal circulation - dependent water condition	Reduced tidal circulation
		IV-13 Freshwater hydrology - dependent water condition	Altered freshwater hydrology
		VI-17 Detritus recruitment and retention - extent	Altered detritus recruitment and retention
		VI-18 Detritus recruitment and retention - extent of supply	Altered detritus recruitment and retention
		VIII-21 SAV beds – extent	Altered SAV beds
		VIII-25 Intertidal habitat zone - extent	Altered intertidal habitat
		VIII-26 Intertidal habitat zone - condition	Altered intertidal habitat
		VIII-29 Water quality	Altered water quality
	Bluff backed beaches	I-1 Coastal sediment dynamics in drift cells - condition	Altered coastal sediment dynamics
		I-2 Coastal sediment dynamics in drift cells - landscape context	Altered coastal sediment dynamics
		I-3 Coastal sediment deposition and accretion - extent	Altered coastal sediment dynamics
		I-6 Coastal sediment supply - extent	Altered coastal sediment dynamics
		I-7 Coastal sediment supply - distribution	Altered coastal sediment dynamics
		I-8 Coastal sediment dynamics - extent (size or volume) of wind and wave dependent features	Altered coastal sediment dynamics
		I-9 Coastal sediment dynamics - condition of wind and wave dependent features	Altered coastal sediment dynamics
		III-12 Tidal circulation - dependent water condition	Reduced tidal circulation
		IV-13 Freshwater hydrology - dependent water condition	Altered freshwater hydrology
		VI-17 Detritus recruitment and retention - extent	Reduced detritus recruitment and retention
		VI-18 Detritus recruitment and retention - extent of supply	Reduced detritus recruitment and retention

		VIII-20 SAV beds – condition	Altered SAV beds
		VIII-21 SAV beds – extent	Altered SAV beds
		VIII-25 Intertidal habitat zone - extent	Altered intertidal habitat
		VIII-26 Intertidal habitat zone - condition	Altered intertidal habitat
		VIII-29 Water quality	Altered water quality
	Pocket estuaries	I-1 Coastal sediment dynamics in drift cells - condition	Altered coastal sediment dynamics
		I-2 Coastal sediment dynamics in drift cells - landscape context	Altered coastal sediment dynamics
		II-10 Fluvial sediment dynamics - condition	Altered fluvial sediment dynamics
		III-11 Tidal circulation - extent of dependent biological activity	Reduced tidal circulation
		III-12 Tidal circulation - dependent water condition	Reduced tidal circulation
		IV-13 Freshwater hydrology - dependent water condition	Altered freshwater hydrology
		IV-14 Freshwater hydrology - condition	Altered freshwater hydrology
		V-15 Tidal channel formation and maintenance - extent of channels	Reduced distributary channel formation and maintenance
		V-16 Tidal channel formation and maintenance - connectivity of channels	Reduced connectivity of tidal channels
		VI-17 Detritus recruitment and retention - extent	Reduced detritus recruitment and retention
		VI-18 Detritus recruitment and retention - extent of supply	Reduced detritus recruitment and retention
		VII-19 Habitat connectivity - condition	Degraded habitat connectivity
		VIII-20 SAV beds – condition	Altered SAV beds
		VIII-21 SAV beds – extent	Altered SAV beds
		VIII-22 Estuarine habitats - extent	Altered tidal hydrology
		VIII-23 Estuarine habitats - condition	Altered tidal hydrology
		VIII-24 Estuarine habitats – distribution	Altered tidal hydrology
		VIII-27 Tidally influenced wetlands - extent	Altered tidal hydrology
		VIII-28 Tidally influenced wetlands - condition	Altered tidal hydrology
		VIII-29 Water quality	Altered water quality
	Rocky pocket estuaries	I-4 Coastal sediment deposition and accretion - condition of sediment	Altered coastal sediment dynamics
		I-5 Coastal sediment deposition and accretion - condition of impoundment	Altered coastal sediment dynamics

		I-6 Coastal sediment supply - extent	Altered coastal sediment dynamics
		I-7 Coastal sediment supply - distribution	Altered coastal sediment dynamics
		I-8 Coastal sediment dynamics - extent (size or volume) of wind and wave dependent features	Altered coastal sediment dynamics
		I-9 Coastal sediment dynamics - condition of wind and wave dependent features	Altered coastal sediment dynamics
		II-10 Fluvial sediment dynamics - condition	Altered fluvial sediment dynamics
		III-11 Tidal circulation - extent of dependent biological activity	Reduced tidal circulation
		III-12 Tidal circulation - dependent water condition	Reduced tidal circulation
		IV-13 Freshwater hydrology - dependent water condition	Altered freshwater hydrology
		IV-14 Freshwater hydrology - condition	Altered freshwater hydrology
		V-15 Tidal channel formation and maintenance - extent of channels	Reduced distributary channel formation and maintenance
		V-16 Tidal channel formation and maintenance - connectivity of channels	Reduced connectivity of tidal channels
		VI-17 Detritus recruitment and retention - extent	Reduced detritus recruitment and retention
		VI-18 Detritus recruitment and retention - extent of supply	Reduced detritus recruitment and retention
		VII-19 Habitat connectivity condition	Degraded habitat connectivity
		VIII-20 SAV beds – condition	Altered SAV beds
		VIII-21 SAV beds – extent	Altered SAV beds
		VIII-22 Estuarine habitats - extent	Altered tidal hydrology
		VIII-23 Estuarine habitats - condition	Altered tidal hydrology
		VIII-24 Estuarine habitats – distribution	Altered tidal hydrology
		VIII-27 Tidally influenced wetlands - extent	Altered tidal hydrology
		VIII-28 Tidally influenced wetlands - condition	Altered tidal hydrology
		VIII-29 Water quality	Altered water quality
	Rocky beaches	I-4 Coastal sediment deposition and accretion - condition of sediment	Altered coastal sediment dynamics
		I-6 Coastal sediment supply - extent	Altered coastal sediment dynamics
		I-7 Coastal sediment supply - distribution	Altered coastal sediment dynamics
		I-8 Coastal sediment dynamics - extent (size or volume) of wind and wave dependent features	Altered coastal sediment dynamics
		I-9 Coastal sediment dynamics - condition of wind and wave dependent features	Altered coastal sediment dynamics

		III-11 Tidal circulation - extent of dependent biological activity	Reduced tidal circulation
		III-12 Tidal circulation - dependent water condition	Reduced tidal circulation
		IV-13 Freshwater hydrology - dependent water condition	Altered freshwater hydrology
		VI-18 Detritus recruitment and retention - extent of supply	Reduced detritus recruitment and retention
		VII-19 Habitat connectivity condition	Degraded habitat connectivity
		VIII-20 SAV beds – condition	Altered SAV beds
		VIII-21 SAV beds – extent	Altered SAV beds
		VIII-25 Intertidal habitat zone - extent	Altered intertidal habitat
		VIII-26 Intertidal habitat zone - condition	Altered intertidal habitat
		VIII-29 Water quality	Altered water quality
	Offshore systems	III-11 Tidal circulation - extent of dependent biological activity	Reduced tidal circulation
		III-12 Tidal circulation - dependent water condition	Reduced tidal circulation
		IV-13 Freshwater hydrology - dependent water condition	Altered freshwater hydrology
		VI-18 Detritus recruitment and retention - extent of supply	Reduced detritus recruitment and retention
		VIII-20 SAV beds – condition	Altered SAV beds
		VIII-21 SAV beds – extent	Altered SAV beds
		VIII-29 Water quality	Altered water quality
Species and food webs	*Species and food webs*	Population size—predators	Increased predator abundance
		Population size—competitors	Increased competitor abundance
		Population size—prey	Decreased prey abundance
		Population size—other species	Increased abundance of other species
		Predator population condition—predators	Altered predator population condition
		Competitor population condition—competitors	Altered competitor population condition
		Prey population condition—prey	Decreased prey population condition
		Other species population condition—other species	Altered population condition of other species
		Energy and material flow	Altered energy and material flow
		Community composition	Altered community composition

* KEA numbers for habitat ecosystem components (e.g., I-2) correspond to those in Tables 8, 9, 10, 12, 13, and 14. Species KEAs specify the ecological relationship to Chinook salmon.

Contributing Factors

Contributing factors are the underlying, human-induced actions or events that enable or otherwise add to the occurrence or persistence of pressures. They are used, primarily, to identify the expected intermediate results in results chains. Table B-3 lists broad categories of contributing factors and some examples of how these categories may manifest in watersheds. The list of categories and examples is intended as a starting point for watershed groups to consider why pressures are problematic to Chinook salmon recovery.

Table B-3. Broad categories and examples of contributing factors that may exist in watersheds.

Contributing factor category	Contributing factor examples
Social (expectations and perceptions)	• Public's lack of long-term perspective on the issues • Lack of public and political support for habitat protection and restoration • Education materials that need to be more broadly distributed and used • Outreach programs that need to be more broadly applied
Legal (regulations/policies and enforcement)	• Inconsistencies in and between regulations or policies • Understaffed enforcement programs • Disparate application of regulations • Lack of thorough reviews because regulators are over-burdened • Lack of enforcement
Technical (information and alternatives)	• Lack of data regarding changes over time • Lack of information sharing • Concentration of technical information in few sectors or organizations • Expense of technical experts
Monetary (capital and capacity)	• Expense of work • Limited capacity, given the amount of work • Lack of capital funds
Institutional	• Reliance on historical actions and approaches • Lack of support for work • Inconsistent decision-making process

Drivers

Drivers are similar to contributing factors in that both elements represent the conditions underlying the occurrence or persistence of a pressure. For the purposes of this framework, we distinguish between drivers and contributing factors by defining drivers as conditions that tend to be outside the scope of strategies and actions in the local scale chapters of Volume II of the Plan (Table B-4). Therefore, most chapters do not include drivers; however, they may be incorporated into results chains to identify intermediate results.

Table B-4. Broad categories and examples of drivers that may exist in watersheds.

Driver category	Driver examples
Climate change	• Changes in air temperature and precipitation • Sea level rise • Ocean acidification • Extreme weather events (e.g., storms, droughts, heat waves)
Market forces	• Trade balance (import/export) • State and federal budget forecasts
Human population growth	• Immigration to Puget Sound • Distribution of human population
Human preferences	• Driving patterns • Consumption patterns

Strategies

A strategy is set of conservation actions with a common focus. When such actions are combined they result in reduction of threats, developed capacity, and/or restoration of natural systems (FOS 2009). A well-designed strategy meets several criteria, including 1) linked between one or more ecosystem components; 2) focused―i.e., it outlines specific courses of action to be executed; 3) feasible―i.e., it can be accomplished given existing resources and constraints, and 4) appropriate―i.e., it is consistent with site-specific social, cultural, and biological norms. Table B-5 lists categories and associated definitions of strategies found in both Volumes I and II of the Puget Sound Salmon Recovery Plan.

Table B-5. Categories of strategies common to both volumes of the Plan. Definitions are derived from various sources.

Strategy	Strategy category	Definition	Source
Improve and increase habitat protection	Habitat protection	Safeguarding existing physical habitat and habitat forming processes through voluntary approaches (incentives or technical assistance), regulatory mechanisms, and/or acquisition.	[a]
Improve and increase habitat restoration	Habitat restoration	Enhancing degraded or restoring lost habitat through on-the-ground action, sometimes preceded by acquisition.	[b]
Manage hatcheries to support wild Chinook salmon populations	Hatchery management	Artificially producing Chinook salmon to harvest and/or rebuild natural-origin stocks, without impeding the rebuilding of those stocks (via other strategies) to levels that will sustain fisheries, enable ecological functions, and support treaty-reserved fishing rights.	[c]
Manage harvest to support recovery of wild Chinook populations	Harvest management	Allowing some mortality of listed Chinook salmon so that fisheries directed at harvestable runs of other species or hatchery-produced Chinook are possible. The overall rate of fishery-related mortality to listed Chinook is kept at or below an amount that does not impede the rebuilding of these stocks to levels that are consistent with the capacity of properly functioning habitat and that will sustain fisheries, enable ecological functions, and support treaty-reserved fishing rights.	[d]
Improve and increase assessments and research	Assessment	Filling data gaps and improving strategies as new data and information are acquired.	[e]
	Research	Gaining fuller scientific knowledge or understanding of a subject through basic or applied study.	[f]
Improve and increase education and outreach	Education	Increasing public awareness and knowledge about environmental issues, and providing the skills necessary to make informed environmental decisions and to take responsible actions.	[g]
	Outreach	Disseminating information about an issue and, in some cases, requesting that specific action be taken, without necessarily teaching how to analyze the issue.	[g]

[a] Shared Strategy Development Committee 2007
[b] FOS 2009
[c] WDFW and Puget Sound Treaty Tribes 2004
[d] Puget Sound Indian Tribes and WDFW 2010
[e] San Juan Technical Advisory Team 2005
[f] National Science Board 2010
[g] Environmental Protection Agency 2011

Appendix C: Other Monitoring Projects and Programs

Our framework has been developed alongside other monitoring-related work currently underway in the Puget Sound region. Local scale monitoring projects and programs—too numerous to list here—vary depending on the needs identified within each watershed and the funding available. Regional scale monitoring projects and programs include but are not limited to:

- Salmonid Work Group, Puget Sound Ecosystem Monitoring Program (PSEMP). Led by Bruce Crawford, this group has completed an assessment of current monitoring of salmon and steelhead and is working to define elements of a comprehensive monitoring strategy for salmon habitat. The recently completed VSP assessment examined monitoring of the "viable salmonid population" (VSP) parameters for ESA-listed salmonids in the Puget Sound region (PSEMP 2012). It documented ongoing VSP monitoring efforts in the region, evaluated the quality of the resulting data, and identified key monitoring gaps (Crawford and Rumsey 2011). This assessment was undertaken by the National Marine Fisheries Service (NMFS) and funded by the Environmental Protection Agency (EPA). The proposed habitat monitoring program includes remote sensing, on the ground monitoring of habitat in streams, nearshore, and estuarine areas using a probabilistic design, and intensive habitat monitoring for specific watersheds to complement existing monitoring for salmon and steelhead.

- Intensively Monitored Watersheds Project. This project evaluates salmonid responses to land management and habitat restoration, based on the premise that the complex relationships underlying those responses are best understood by concentrating monitoring efforts in a few locations. Monitoring sites are located in three small stream complexes that focus on coho, steelhead, and cutthroat monitoring and two larger basins that focus on Chinook in the Skagit and Wenatchee. The project is a joint effort of the Washington Departments of Ecology and Fish and Wildlife, NMFS, EPA, Lower Elwha Klallam Tribe, and Weyerhaeuser Company, and is funded by the Washington Salmon Recovery Funding Board. http://www.ecy.wa.gov/programs/eap/imw/index.html.

- WA Department of Ecology's Status and Trends Monitoring for Watershed Health and Salmon Recovery (WSHR). This program uses a probabilistic sampling design to select river and stream sites for monitoring. The rotating panel design divides the state into 8 status and trend regions with 2 sampled each year. The Puget Sound basin was first sampled in 2009, and will be sampled again in 2013. From each of 50 sites, samples will be collected for vertebrates, invertebrates, habitat, and water chemistry. WSHR supports standard protocols for monitoring rivers and streams, training on these protocols, the Washington Master Sample site set, and the STREAM database for managing stream habitat data. http://www.ecy.wa.gov/programs/eap/stsmf/.

- Regional Stormwater Monitoring Program (RSMP). The PSEMP Stormwater Work Group will implement the RSMP with funding from western Washington municipal stormwater permittee contributions. Status and trend monitoring for small streams and nearshore areas in the Puget Sound basin will be collected using a probabilistic sampling design. For streams, 100 randomly selected sites will be sampled during the 4-5 years of the permit cycle; 50 sites will be inside Urban Growth Areas (UGAs) and 50 outside. Water quality, invertebrate, sediment, habitat, and stream flow data will be collected. For nearshore areas, fecal coliform data will be collected monthly at 50 sites in the UGAs, sediment chemistry every five years at 50 sites in UGAs (to compare with PSAMP locations outside UGAs), and Mussel Watch data at 30-50 sites near stormwater outfalls (to be compared with Mussel Watch sites away from outfalls). In addition, a prioritized list of recommended study topics for effectiveness monitoring are being developed. http://www.ecy.wa.gov/programs/wq/stormwater/municipal/rsmp.html.

- US Geological Survey's National Streamflow Information Program (NSIP), Cooperative Water Program (CWP), Groundwater Resources Program (GRP), and National Water Quality Assessment Program (NAWQA). The USGS collects, compiles and publishes hydrologic data from surface-water stations that measure stream discharge and stage for rivers and streams; elevation and storage for lakes and reservoir; groundwater levels in wells; and chemical and physical data for streams, lakes, springs, and wells. Most streamflow data and selected other data are available real-time via satellite-telemetry. Monitoring data from all USGS programs are available through the National Water Information System (NWIS). Konrad and Voss (2012) evaluated the streamflow-gaging network in the Puget Sound basin for its capacity to monitor stormwater in rivers and small streams. http://pubs.usgs.gov/sir/2012/5020/.

Crawford, B. A., and S. M. Rumsey. 2011. Guidance for monitoring recovery of Pacific Northwest salmon and steelhead listed under the Federal Endangered Species Act. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Region

Konrad, C.P., and F. D. Voss. 2012. Analysis of streamflow-gaging network for monitoring stormwater in small streams in the Puget Sound Basin, Washington. U.S. Geological Survey Scientific Investigations Report 2012–5020, 16 p. http://pubs.usgs.gov/sir/2012/5020/.

Puget Sound Ecosystem Monitoring Program Salmonid Workgroup (PSEMP). 2012. Methods and Quality of VSP Monitoring of ESA Listed Puget Sound Salmon and Steelhead. B. A. Crawford (ed.). http://www.psp.wa.gov/downloads/psemp/salmonid_VSP_monitoring_assessment.pdf.

Appendix D: Glossary of Terms Related to Ecosystem Components

Chinook Salmon Life Stages

- Spawner. Sexually mature salmon at or very near locations where they will spawn; or in the act of egg deposition and fertilization.

- Egg. A female gamete from the time of deposition in the substrate to hatching of an alevin.

- Alevin. A juvenile life stage of salmon between hatching from an egg to emergence from the stream bed substrate as a fry. The alevin stage is characterized by the presence of a yolk sac in varying degrees of absorption.

- Fry. A juvenile stage of salmon between the alevin and parr stages. During the fry stage, the yolk sac has been absorbed and the fish has emerged from the stream bed and is actively seeking food. Chinook salmon fry are generally between 30 and 50 mm fork length (Beamer et al. 2005, Fresh 2006).

- Parr. A juvenile life stage of salmon (sometimes called "fingerling") between the fry and yearling stages. Fish at this life stage often have visible parr marks and are actively feeding. Chinook salmon parr are generally between 50 and 90 mm fork length (Beamer et al. 2005, Fresh 2006).

- Yearling. A juvenile life stage of salmon between the parr and sub-adult stages, when fish are at least 1 year but not more than 2 years old. Chinook salmon yearlings outmigrating from the Skagit River are generally >90 mm fork length (Beamer et al. 2005).

- Sub-adult. A developmental life stage of salmon between the yearling and adult stages, when fish exhibit most morphological traits of adults but are not sexually mature. For Chinook salmon, sub-adults are sometimes called "blackmouth" and can range from 2 to 6 years old.

- Adult. Sexually mature or maturing salmon, generally migrating towards natal locations.

Freshwater Habitats

- Uplands. Geomorphic surfaces with no defined channels. These surfaces may include isolated wetlands.

- Floodplains. The bands of relatively level land adjacent to stream channels that may become partly or fully inundated during periods of high flow—on average once every 1.5−2 years (Leopold et al. 1964).

- Large channels. Mainstem channels (i.e., riverine habitats) with bankfull widths >50 m. Habitat formation in these channels is controlled by bank erosion and sediment deposition, leading to lateral movement. Reach and habitat unit scale classes are adapted from Montgomery and Buffington 1997, and Beechie et al. 2003, 2005, and 2006.

- Small channels. Mainstem and tributary channels (i.e., riverine habitats) with bankfull widths <50 m. Habitat formation in these channels is driven by the relative magnitudes of sediment transport and supply, as slope, confinement, and position in the channel network also change. Reach and habitat unit scale classes follow Bisson et al. 1988, Montgomery and Buffington 1997, and Beechie et al. 2003a, b and 2005.

- Side channels. Active channels that are separated by stable islands from main channels (i.e., large or small channels, as defined above). Side channels carry surface water at flows less than bankfull (Lestelle et al. 2005); however, some may become disconnected (dry) at one or both ends during periods of low flow, while others may remain connected (wetted).

- Other floodplain waterbodies. Deep- or shallow-water, non-riverine habitats located in floodplains. These habitats may be lacustrine or palustrine, as defined by Cowardin et al. 1979. Both lacustrine and palustrine habitats may be tidal or nontidal, as long as their ocean-derived salinity is less than 0.5 ‰. According to Cowardin et al., the defining characteristics of these habitats are as follows:

  o Lacustrine habitats include deep and shallow waterbodies (i.e., lakes, reservoirs, ponds, wetlands) that are a) located in topographic depressions or dammed channels; b) not dominated by vegetation (areal coverage ≤30%); and c) larger than 8 ha in total area[3].

  o Palustrine habitats include shallow waterbodies (i.e., wetlands) that are either dominated by vegetation (i.e., areal coverage >30%) or lacking such vegetation but having a) total areas <8 ha; b) no active wave-formed or bedrock shoreline features; and c) maximum water depths <2 m at low water.

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[3] Waterbodies <8 ha in total area may be counted as lacustrine if they meet the first two criteria (a and b, above) and if their maximum water depth exceeds 2 m at low water, or if an active wave-formed or bedrock shoreline feature constitutes all or part of the waterbody boundary.

Estuarine and Marine Habitats

- Geographic Basins. The broad habitat classes in our framework (i.e., estuarine, nearshore marine, and offshore marine habitat) exist within seven geographic basins encompassing the United States portion of the Salish Sea (Figure D-1). Basin boundaries are based on natural breaks in geomorphology and large scale hydrodynamic processes. They are also chosen to be consistent with other classification efforts. The Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) first defined the boundaries (Simenstad et al. 2011) by adapting previous delineations from Ebbesmeyer et al. (1984), Burns (1985), and Redman et al. (2005). The boundaries were used in PSNERP's Strategic Needs Assessment (Schlenger et al. 2011), and they were later adopted by the Northwest Indian Fisheries Commission's Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP; McBride et al. 2009). They differ from the Action Areas adopted by the Puget Sound Partnership (see www.psp.wa.gov/aa_action_areas.php) which are politically, rather than geomorphically or hydrodynamically, defined.

- Estuarine Habitat. This broad habitat class includes only one system subtype: natal Chinook estuaries. For the purposes of this framework, natal Chinook estuaries correspond to the "large river deltas" in PSNERP's Change Analysis dataset (Simenstad et al. 2011). PSNERP's "large river deltas" include 16 deltas, 3 of which do not support natal populations of Chinook salmon in the Puget Sound ESU (Samish, Deschutes, and Quilcene Rivers). The remaining 13 deltas are the natal estuaries for 20 of the 22 ESA-listed Puget Sound Chinook populations (Ruckelshaus et al. 2006) (Figure D-1, Table D-1). Two listed Chinook salmon populations (Cedar and Sammamish Rivers) currently have no large river delta for their natal estuary; they use Salmon Bay and Shilshole Bay along the Lake Washington Ship Canal, both of which are classified as nearshore marine habitat within our hierarchical classification system. As state above, estuarine habitat includes one system subtype (Table 10). This subtype encompasses four shoreline types, selected (in part) to maintain consistency with previously published classifications (Table D-2).

- Nearshore Marine Habitat. The area bounded by the upper limit of tidal influence and the lower limit of the photic zone (Figure 9). The lower limit of the photic zone varies by location and season, but is considered to range from 5 to 20 m in depth (Redman et al. 2005). This definition aligns with that used by PSNERP (after Goetz et al. 2004). Nearshore marine habitat includes two system types, five system subtypes, and 18 shoreline types (Table 10). As with the estuarine shoreline types, the nearshore marine shoreline types were chosen to be consistent with previously published classifications (Table D-2).

- Offshore Marine Habitat. All areas deeper than the lower limit of the photic zone, extending from the water surface to the bottom (Redman et al. 2005). This includes all wet "marine" areas in Puget Sound not captured in the nearshore definition. System subtypes and habitat zones within the offshore marine habitat class (Table 10) were selected to align with Newton et al. 2000.
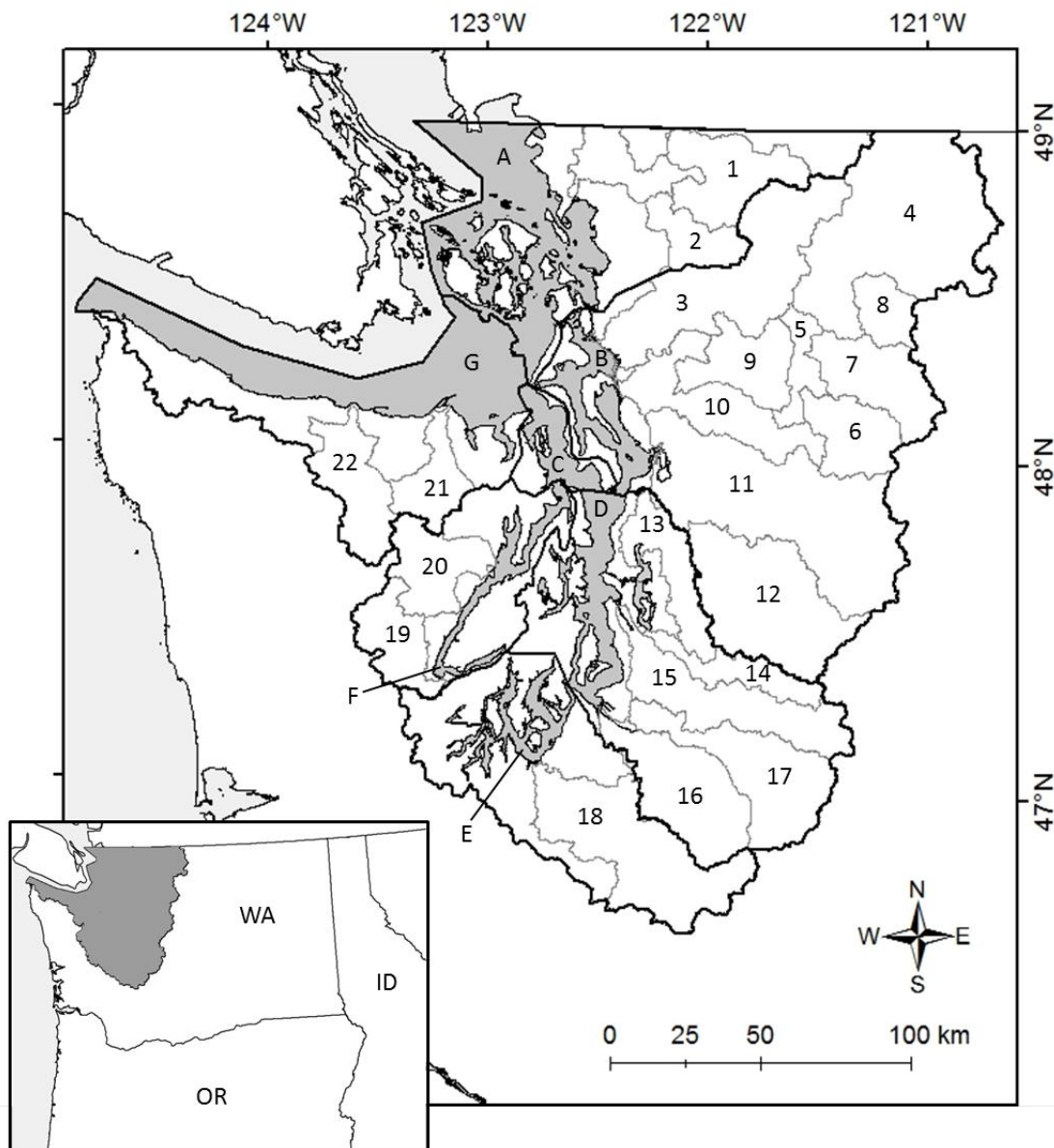
Figure D1. Marine basins (A–G) and Chinook salmon populations (1–22) within the Puget Sound region. Abbreviations (A–G and 1–22) are explained in Table D-1.

Table D1. Crosswalk of the 16 large river deltas, 13 natal Chinook estuaries, and 22 independent populations of Chinook salmon in the Puget Sound region. The marine basin into which each delta/estuary drains is also provided. Abbreviations (A–G and 1–22) match those in Figure D-1.

Marine basin*	Large river delta name	Natal Chinook estuary?	Chinook salmon population in the Puget Sound ESU
San Juan Islands and Georgia Strait (A)	Nooksack	Yes	North Fork Nooksack River (1); South Fork Nooksack River (2)
	Samish	No	
Whidbey Island (B)	Skagit	Yes	Lower Skagit River (3); Upper Skagit River (4); Lower Sauk River (5); Upper Sauk River(6); Suiattle River (7); Cascade River (8)
	Stillaguamish	Yes	North Fork Stillaguamish River (9); South Fork Stillaguamish River (10)
	Snohomish	Yes	Skykomish River (11); Snoqualmie River (12)
South Central Puget Sound (D)	Duwamish	Yes	Duwamish/Green River (15)
	Puyallup	Yes	Puyallup River (16); White River (17)
South Puget Sound (E)	Nisqually	Yes	Nisqually River (18)
	Deschutes	No	
Hood Canal (F)	Skokomish	Yes	Skokomish River (19)
	Hamma Hamma	Yes	Mid-Hood Canal Rivers (20)
	Duckabush	Yes	Mid-Hood Canal Rivers (20)
	Dosewallips	Yes	Mid-Hood Canal Rivers (20)
	Quilcene	No	
Strait of Juan de Fuca (G)	Dungeness	Yes	Dungeness River (21)
	Elwha	Yes	Elwha River (22)

 * One of the seven marine basins depicted in Figure D-1 (C: North Central Puget Sound) is not included. No deltas/estuaries drain into this basin. Likewise, 2 of the 22 Chinook salmon populations depicted in Figure D-1 (13: Sammamish River; 14: Cedar River) are not included because they currently have no large river deltas for their natal estuarine habitat.

Table D2. Classification of estuarine and nearshore marine habitats in the Common Framework (see Table 10), compared with three other classifications specific to Puget Sound (see Figure 8). Many local scale (e.g., watershed- or county-wide) geographic information system (GIS) datasets use the Johannessen and MacLennan 2007 classification to define shoreline features; and at least two regional scale GIS datasets use the Shipman 2008 and McBride et al 2009 classifications.*

Framework classification					
System types	System subtypes	Shoreline Types	Johannessen and MacLennan 2007	Shipman 2008	McBride et al. 2009
Major river systems	Natal Chinook estuaries	Drowned channels	Not addressed	Open coastal inlets	Drowned channels
		River-dominated (fan) deltas	Not addressed	Fan deltas; river dominated deltas	Fan deltas; river dominated deltas
		Tidal deltas	Not addressed	Tide dominated deltas	Tide dominated deltas
		Delta lagoons	Not addressed	Barrier estuaries; wave dominated deltas	Delta lagoons; drowned channel lagoons; tidal delta lagoons
Drift cell systems	Coastal landforms	Barrier beaches (spits, cusps, tombolos)	Accretion shoreforms	Barriers	Barrier beaches
	Bluff backed beaches	Sediment source beaches	Feeder bluffs; feeder bluff s (exceptional)	Bluffs	Sediment source beaches
		Depositional beaches	Accretion shoreforms	Bluffs	Depositional beaches
		Beach seeps	Not addressed	Not addressed	Beach seeps
		Plunging sediment bluffs	Not addressed	Not addressed	Plunging sediment bluffs
	Pocket estuaries (embayments)	Drowned channel lagoons	Not addressed	Barrier estuaries	Drowned channel lagoons
		Tidal delta lagoons	Not addressed	Barrier estuaries	Tidal delta lagoons
		Longshore lagoons	Not addressed	Barrier lagoons	Longshore lagoons
		Tidal channel lagoons (or marshes)	Not addressed	Barrier lagoons	Tidal channel lagoons
		Closed lagoons and marshes	Not addressed	Closed lagoons and marshes	Closed lagoons and marshes
		Open coastal inlets	Not addressed	Open coastal inlets	Drowned channels

Rocky shorelines	Rocky pocket estuaries	Pocket beach lagoons	Not addressed	Barrier estuaries	Pocket beach lagoons
		Pocket beach estuaries	Not addressed	Barrier estuaries	Pocket beach estuaries
		Pocket beach closed lagoons and marshes	Not addressed	Pocket beach closed lagoons and marshes	Pocket beach closed lagoons and marshes
	Rocky beaches	Veneered rock platforms	Not addressed	Platforms	Veneered rock platforms
		Rocky shorelines	Not addressed	Platforms	Rocky shorelines
		Plunging rocky shorelines	Not addressed	Plunging	Plunging rocky shorelines
		Pocket beaches	Not addressed	Pocket beaches	Pocket beaches

* The two regional scale GIS datasets are PSNERP's Puget Sound Nearshore General Investigation (see http://www.nws.usace.army.mil/PublicMenu/Menu.cfm?sitename=PSNERP&pagename=Change_Analysis) and the Salmon and Steelhead Habitat Inventory and Assessment Project (see http://nwifc.org/about-us/habitat/sshiap/), which is co-managed by the western Washington Treaty Indian Tribes and WDFW.