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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 as threatened 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 salmon recovery plan. The resulting Puget Sound Salmon Recovery Plan (hereinafter called 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 toward recovery.

This technical memorandum was developed by the Puget Sound Recovery Implementation Technical Team (PS RITT) to provide a formal monitoring and adaptive management framework (hereinafter called 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, test assumptions across chapters, or 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, identify uncertainties, and 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 (hereinafter called 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 KEAs.
- **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 Miradi software 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 these 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, provided as an example, is neither prescriptive nor all inclusive. However, we do recommend that 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 these salmon use 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 hierarchical watershed-, reach-, and habitat unit–scale classifications. These classifications are intended to include all habitats utilized by Chinook salmon across their life history or contributing to the formation and maintenance of their 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 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 evolutionarily significant unit 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

This document draws on the insights and inputs of many people. In particular, Bob Warinner, Washington Dept. Fish and Wildlife, helped apply the framework described here to Chinook salmon recovery planning using data and information from the Skagit River watershed, and helped improve it through constructive feedback. Members of three lead entity watershed groups—Skagit, San Juan, and Hood Canal—provided their time, data, knowledge, and comments throughout document development. From the Skagit group, we thank Shirley Solomon and Mary Raines; from the San Juan group, Barbara Rosenkotter, Laura Arnold, and the WRIA 2 Technical Advisory Team; and from the Hood Canal group, Richard Brocksmith and Scott Brewer. We also thank Aundrea McBride and Greg Hood, Skagit River System Cooperative, for help in developing the nearshore marine sections of this technical memorandum. We acknowledge Phil Roni, George Pess, Tim Beechie, and Sandie O'Neill, Northwest Fisheries Science Center (NWFSC); and Dave Beauchamp, University of Washington, for valuable suggestions during development of the manuscript. We thank Bruce Crawford and Scott Redman, Puget Sound Partnership; and Abby Hook, Hook Knauer LLP, for cross-referencing and incorporating the developing concepts into other ongoing projects; and we are grateful to Elisabeth Babcock and Alison Agness, National Marine Fisheries Service Northwest Region (now West Coast Region), for their continuing review and support. We also thank our peer reviewers, Tim Beechie, Mike Ford, Kurt Fresh, Correigh Green, George Pess, and Casey Rice, NWFSC; Dave Beauchamp; Jeff Duda, U.S. Geological Survey; and Nick Salafski, Foundations of Success. And lastly, we thank Stacey Vynne, Puget Sound Partnership, for helping finalize the draft for submission to the technical memorandum series, and Ed Quimby, NWFSC, for editing and formatting this publication.

Framework Structure

Introduction

Chinook salmon (*Oncorhynchus tshawytscha*) were listed as threatened in the Puget Sound evolutionarily significant unit (ESU) 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 nonprofit organizations—the Shared Strategy for Puget Sound—in coordination with the Puget Sound Technical Recovery Team (PS TRT) appointed by the National Marine Fisheries Service (NMFS), established a process to develop a salmon recovery plan. Volume I of the resulting Puget Sound Salmon Recovery Plan (hereinafter called the Recovery Plan) (SSDC 2007) provides a regional-scale overview of recovery. Volume II of the Recovery Plan consists of individual chapters that describe information specific to each of the 14 Chinook salmon watersheds the TRT identified 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, 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).

The Puget Sound Recovery Implementation Technical Team (PS RITT) was convened in 2006 and consists of a team of independent volunteer scientists from the Northwest Fisheries Science Center (NWFSC), Northwest Indian Fisheries Commission (NWIFC), Washington Department of Fish and Wildlife (WDFW), Seattle City Light, and several consultants. This occurred after the PS TRT completed their work to define the populations of salmon listed under the ESA in the Puget Sound ESU and subsequently disbanded. The mission of the PS RITT is to "support the recovery of Pacific salmon [*Oncorhynchus* spp.] in Puget Sound to robust and harvestable levels by providing scientific support (e.g., original design and analyses, project review, literature review, and the scientific interpretation of independent studies) to the Puget Sound Salmon Recovery Council, watershed recovery groups, state and federal agencies, tribes, and other organizations and governments that are working to implement salmon recovery plans within the Puget Sound domain." The technical aspects of this framework for recovery planning and development of monitoring and adaptive management plans for the Puget Sound Chinook Salmon ESU were developed by the PS RITT, while the policy and strategic aspects were adapted from the Conservation Measures Partnership's Open Standards for the Practice of Conservation (hereinafter called Open Standards) (CMP 2007) by staff in the Puget Sound Partnership (PSP). In developing this framework, the authors relied on expert knowledge, published literature, informational reports, and unpublished data made available by state, tribal, and federal agencies.

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[1] The document is online at http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Recovery-Plan.cfm.

The PS RITT currently consists of Kirk Lakey (Chair, WDFW, Issaquah, WA), Kenneth P. Currens (Vice Chair, NWIFC, Olympia, WA), Greg Blair (ICF International, Seattle, WA), Ed Connor (Seattle City Light), Mike Parton (Environ Corporation, Olympia), and Melinda L. Rowse (NWFSC, Seattle). Past members of the PS RITT include Norma Jean Sands (past Chair, NWFSC, retired), Kit Rawson (past Chair, Tulalip Tribes, present affiliation Swan Ridge Consulting, Mount Vernon, WA), Krista Bartz (NWFSC, present affiliation National Park Service, Anchorage, AK), Eric Beamer (Skagit River System Cooperative, LaConnor, WA), Michael Blanton (WDFW, present affiliation PSP, Tacoma, WA), and Bill Graeber (Cardno Entrix, Seattle). In addition, PSP staff including Rebecca Ponzio (present affiliation Washington Environmental Council, Seattle) and Kari A. Stiles assisted the PS RITT and contributed to this technical memorandum.

Despite the lack of a formal framework from 2006 to 2013, 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 comanagers, 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 (SSDC 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 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 (hereinafter called the framework) 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 report, we define parameters important to Chinook salmon and the ecosystems that support them. We also define linkages of anthropogenic impacts (social and economic) to Chinook salmon and the ecosystems on which they depend. The process can be applied via eight steps to develop monitoring and adaptive management actions and plans within each watershed (see the companion guidance document produced by Long Live the Kings and PSP, titled Chinook Monitoring and Adaptive Management Project Toolkit (hereinafter called the Toolkit) (LLTK and PSP 2014). 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). The framework is currently developed for Chinook salmon, but can be adapted to other salmonid species such as summer chum salmon (*O. keta*) and steelhead (*O. mykiss*), both of which are also listed as threatened in Puget Sound.

The Open Standards Approach

We designed the framework to be consistent with the Open Standards document (CMP 2007). 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. 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, then ultimately to adapt actions.

Open Standards encompasses five main steps commonly applied to conservation projects: 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 that can be refined and adapted over time as new information is developed and shared—a true adaptive management process.

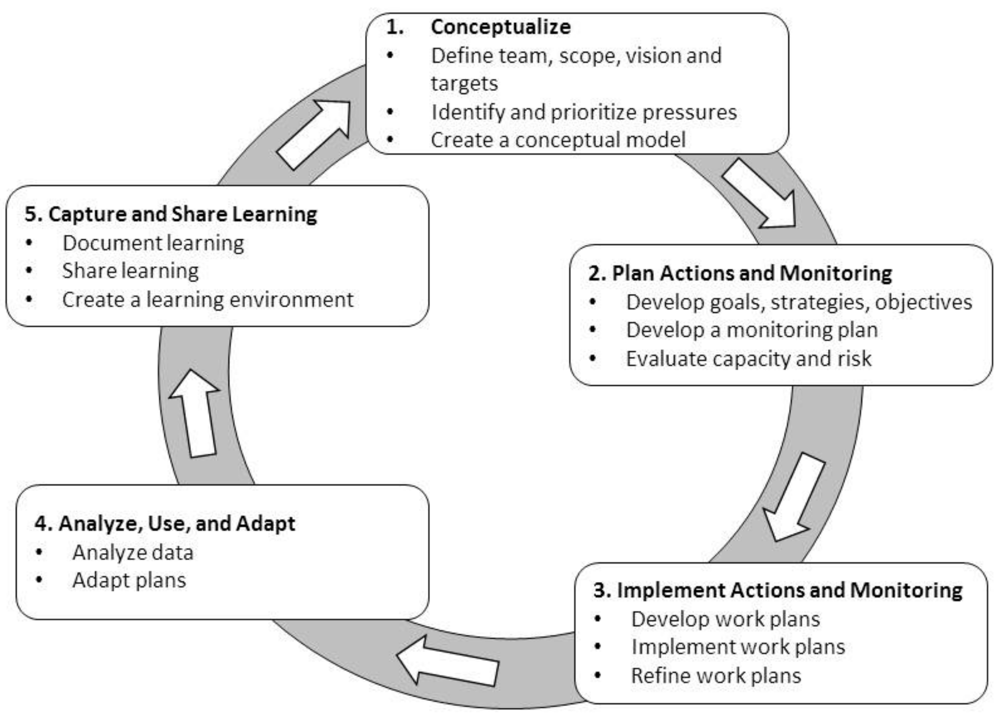


Figure 1. Five general steps used to organize the Open Standards system. (Adapted from CMP 2007.)

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. Monitoring plans will then be developed and implemented by applying Step 2 and Step 3 of the Open Standards approach. 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, Step 5, the critical step 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 this 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 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. Miradi, an open source software package, is available for free (https://miradi.org/download). We used this software to create a template containing 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 (KEAs), indicators, pressures, stresses, contributing factors and drivers, and strategies and 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 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*). These 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. These attributes 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*). These are the proximate human activities or processes that have caused, are causing, or may cause the destruction, degradation, 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 tide gates in estuary habitats.

5. Stresses. Stresses are attributes of an ecosystem component's ecology that are impaired directly or indirectly by human activities. They 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*). These 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). Furthermore, drivers differ from contributing factors in that they also include nonhuman 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 the Ecosystem Components section of this document, where we have identified 14 ecosystem components associated with Chinook salmon recovery in the Puget Sound region, and defined KEAs 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 the Framework Process section of this document, 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. Further development of these elements and this process are available in the Toolkit (LLTK and PSP 2014) during the first implementation phase (June 2013 to June 2014) in applying the framework to recovery planning in the local watersheds.

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, as well as across multiple watersheds. For example, we can have greater confidence and better understand regional priority pressures by evaluating the key pressures from all 14 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 14 watersheds. 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, 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 (Stem et al. 2005, CMP 2007). A monitoring plan defines which information needs to be collected, 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 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 logjams? Were the objectives of a management action met?
- Validation monitoring. This 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 logjams are installed? Effectiveness and validation monitoring are related and complementary, since it is necessary to know that 1) actions are being achieved (effectiveness monitoring) and 2) 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), 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 below, and also in the Toolkit guidance document.

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," 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).

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) their freshwater habitats, 3) their 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 Recovery Plan (SSDC 2007) 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 them, 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 life cycle segment or event is associated with habitat types (Table 2 and see also the Glossary). 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:

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

Category	**Ecosystem component**
Chinook salmon	Chinook salmon
Freshwater habitat	Upland Channel >50 m bankfull width Channel <50 m bankfull width Side channel Nonchannel lakes and wetlands
Estuarine and marine habitat (including nearshore and offshore marine)	Natal Chinook estuary Coastal landform Bluff-backed beach Pocket estuary (embayment) Rocky pocket estuary Rocky beach Offshore marine system
Species and food webs	Species and food webs

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 the Glossary.

Life cycle		**Freshwater habitat**			**Nearshore marine habitat**		
Segment	**Event**	**Channel**	**Nonchannel lakes and wetlands**	**Estuarine habitat (natal Chinook)**	**Drift cell system**	**Rocky shoreline**	**Offshore marine habitat (offshore system)**
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, subadult
	Open water rearing	—	—	—	—	—	Subadult
Maturation	Coastal migration	—	—	—	Adult	Adult	Adult
Spawning migration	Migration to spawning location	Adult	Adult	Adult			

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

Background

McElhany et al. (2000) listed four parameters for evaluating Pacific salmonid populations that fit the definition of KEAs: abundance, productivity or population growth rate, diversity, and spatial structure. Because the topic of the document was the criteria for a population to be viable, these four have become known in the salmon recovery community as viable salmonid population (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).

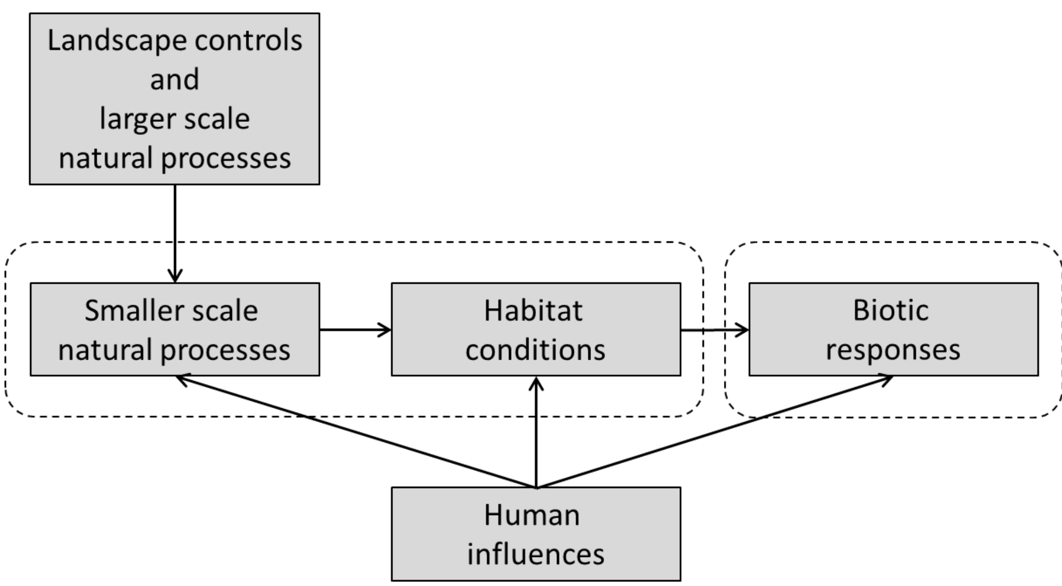


Figure 2. Conceptual diagram of linkages between landscape controls, habitat characteristics, and biotic responses. Dashed lines indicate overlap with the habitat-related and species-related ecosystem subcomponents. (Adapted from Beechie et al. 2003b.)

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, Figure 4, and Figure 5 depict the relationship between these segments/events and various freshwater, estuarine, and nearshore marine habitat types.

KEAs and Indicators

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 (Table 3 and Table 4).

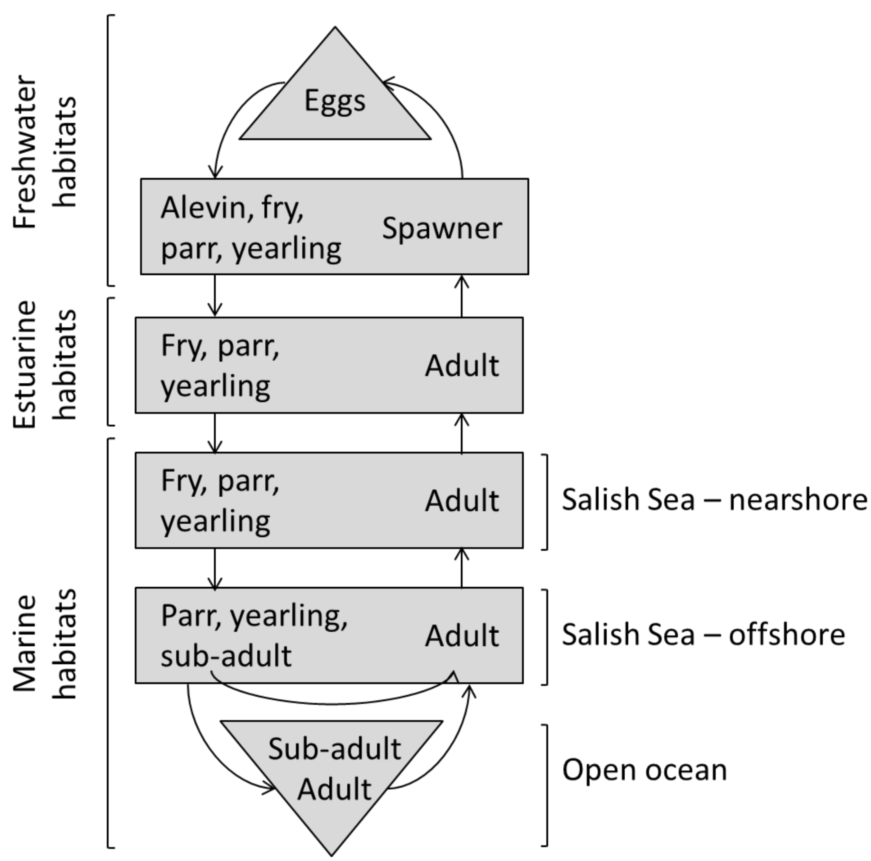


Figure 3. Schematic diagram of the life cycle of Puget Sound Chinook salmon and the freshwater, estuarine, and marine habitats associated with each life stage.

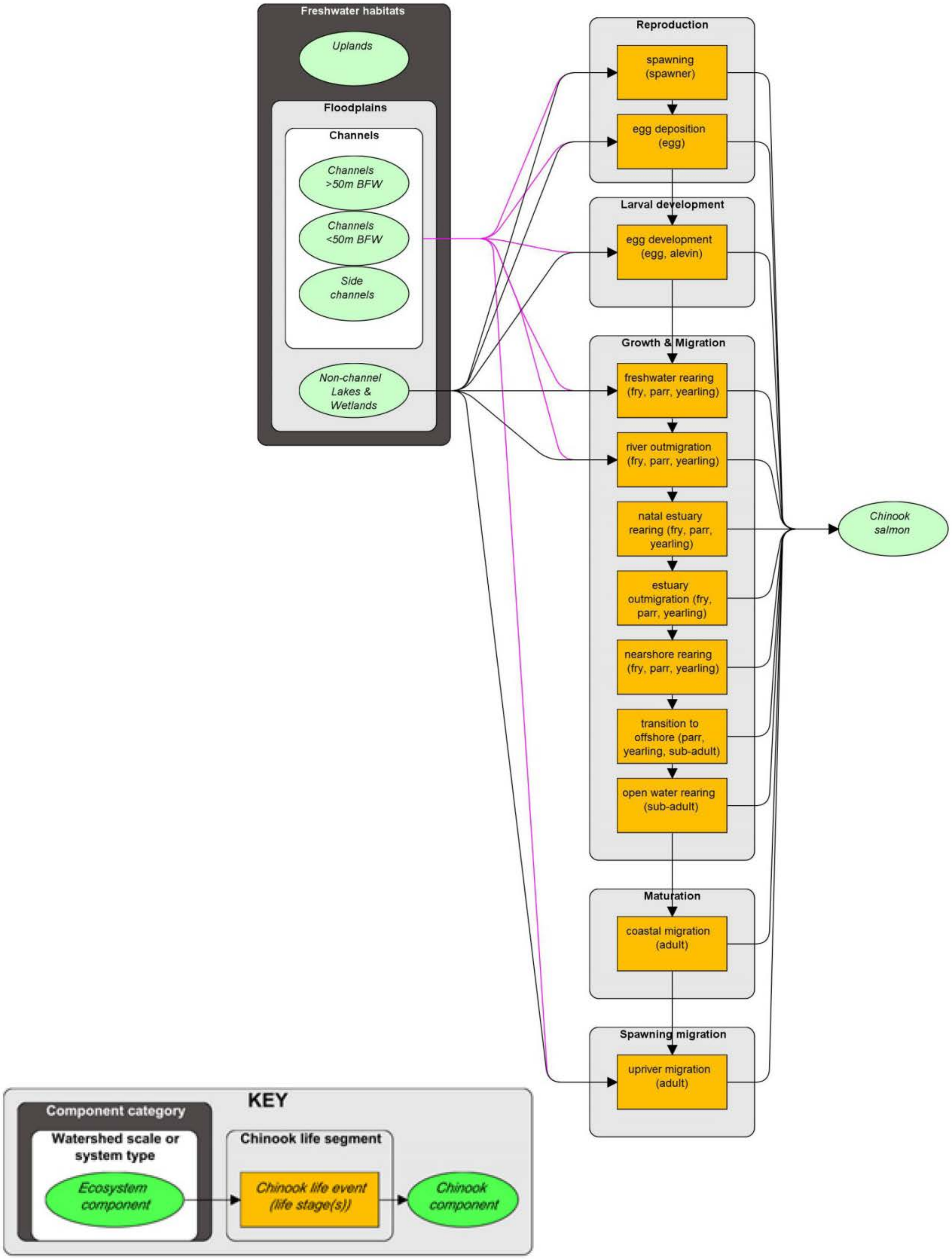


Figure 4. Relationships between freshwater habitat ecosystem components and Chinook salmon life stages, as described in the framework and depicted in Miradi. Also see Table 2 for a description of relationships between habitats and Chinook salmon life stages.

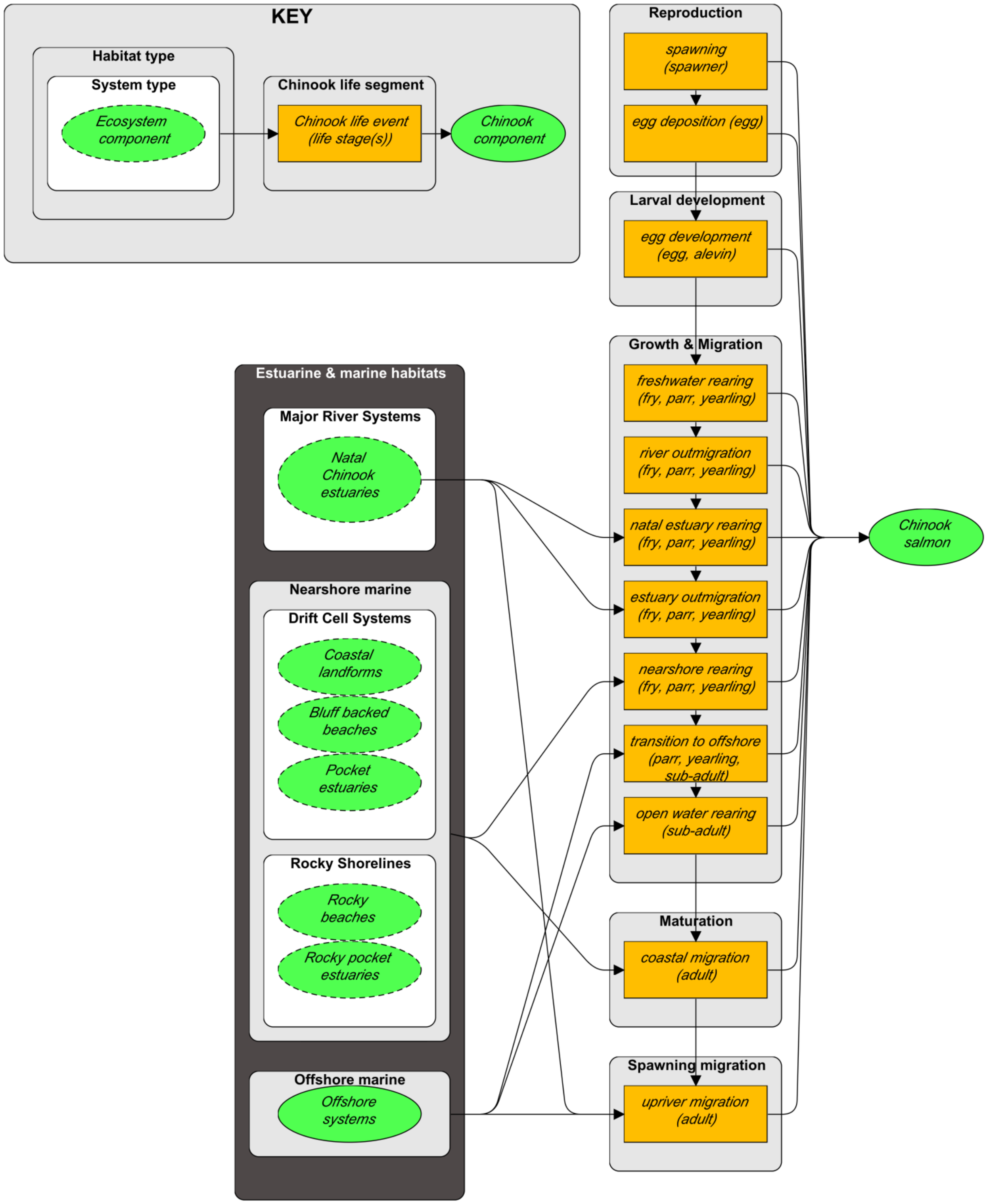


Figure 5. Relationships between estuarine and marine habitat ecosystem components and Chinook salmon life stages, as described in the framework and depicted in Miradi software. Also see Table 2 for a description of relationships between habitats and Chinook salmon life stages.

Table 3. 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.

	Reproduction			**Growth and migration**		
KEA	**Spawning**	**Egg deposition**	**Larval development (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 (including hatchery)	No. of river outmigrants by life history type (inclu. 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 broodyear spawner Intrinsic spawners per broodyear spawners	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)

Table 4. 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.

	Growth and migration					
KEA	**Estuary outmigration**	**Nearshore rearing**	**Transition to offshore**	**Open water rearing**	**Maturation (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	—	Interannual 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	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)	—	—	—	—

Indicators for each KEA (i.e., VSP parameter) and relevant life cycle segment and event are listed in Table 3 and Table 4. Indicators are not designated in all table cells because some are problematic to measure (e.g., abundance of subadults) 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 (Table 3 and Table 4). We considered both feasibility of measurement and possible relationships between the KEAs. A 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 (Table 5 and Table 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 (a productivity indicator). 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 diversity and spatial structure 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-3).

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 water bodies (lacustrine and palustrine habitats) (Table 1, Table 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 kilometers and meters, respectively) for this framework (Figure 6, Table 7). At the watershed scale, we utilize habitat classification systems described by Beechie et al. (2003a, 2003b, 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 deep water habitats. Each

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 method
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. and adult)
	Ocean survival rate (smolt-to-adult returns)	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 or otolith back-calculations for size at circuli)	Trapping studies (in freshwater, estuarine, and nearshore habitats)
	Estuary residence time	DM (scale or otolith back-calculations for size at circuli)	Marking studies
	Avg. size at age	DM(scale or otolith back-calculations for size at circuli)	Escapement samples, terminal fishery samples
Productivity—population growth	Spawners per broodyear 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 method
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, tow net)
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

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 deep water 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 (Table 8 and Table 9). For convenience, we follow Beechie et al. (2003a) in organizing these KEAs into

Table 7. Classification of freshwater habitats within Puget Sound watersheds. Ecosystem components (in italics) representing habitat types important to Chinook salmon recovery are defined at various scales; see the Glossary for more information. (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].)

Watershed scale		**Reach scale**	**Habitat unit scale**
Upland	Upland	Not described in this document	Not described in this document
Floodplain	Channel	*Channel >50 m BFW*	Mid channel
		Confined	Pool
		Straight	Glide
		Unconfined	Riffle (boulder/cobble or cobble/gravel)
		Meandering	
		Island-braided	Edge
		Braided	Bar
			Bank (natural or hardened)
			Backwater (alcove)
		Channel <50 m BFW	Pool
		Confined	Glide
		Bedrock	Riffle
		Colluvial	Rapids
		Unconfined	Run
		Alluvial	Cascades
		Cascades	
		Step pool	
		Plane bed	
		Pool riffle	
		Dune ripple	
		Side channel	Pool
		Unconfined	Glide
		Alluvial	Riffle
		Step pool	Rapids
		Plane bed	Run
		Pool riffle	
		Dune ripple	
	Nonchannel lakes and wetlands	Lake	Littoral
		Pond	Limnetic
		Reservoir (i.e., lacustrine habitat)	
		Wetland (i.e., palustrine habitat)	Emergent wetland
			Scrub-shrub wetland
			Forested wetland

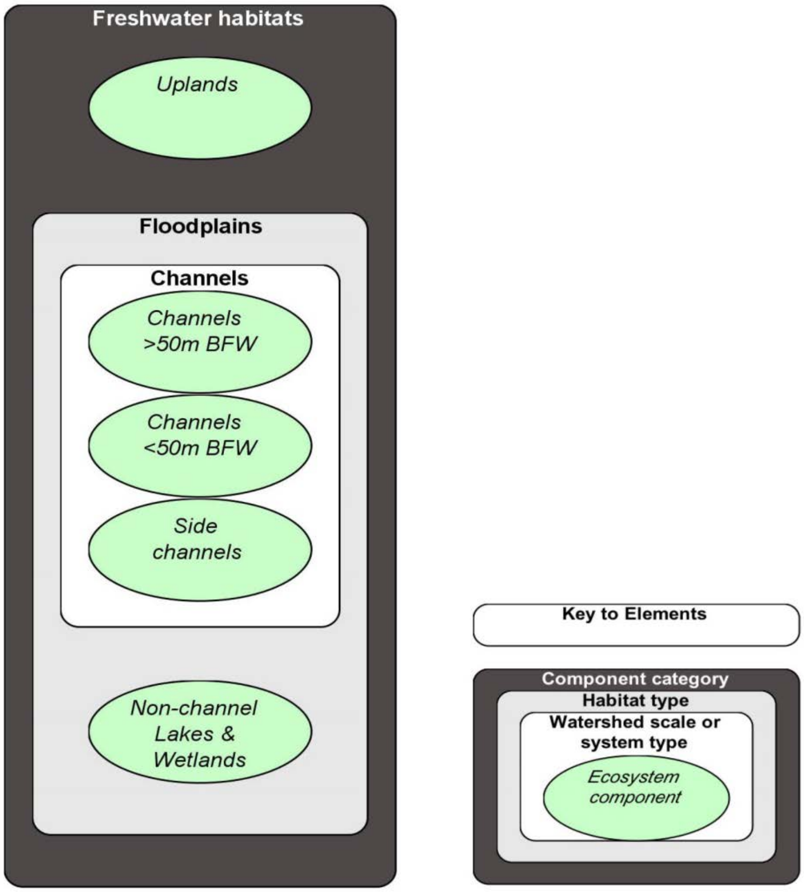


Figure 6. Freshwater habitat ecosystem components (italicized) organized by habitat type and watershed scale or system type, as described in the framework and depicted in Miradi software.

watershed-scale 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-scale 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-scale 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-4).

Table 8. Priority KEAs for 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 matter	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 here need to be adapted to specific components. Examples of component-specific KEAs and indicators are in Table 9 and Table 10.

I. Sediment dynamics

Sediment dynamics include the processes that supply, transport, and deposit sediment within freshwater watersheds. Upland and riparian hillslopes and streambanks 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 water and groundwater rerouting);

Table 9. Freshwater 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.

		Floodplain										
		Channel										
		Channel >50 m bankfull width					***Channel <50 m bankfull width***			***Side channel***	***Nonchannel lakes and wetlands***	
Ecosystem process	***Upland***	Straight	Meander-ing	Island-braided	Braided	Lake, pond, reservoir	Bedrock	Colluvial	Alluvial	Alluvial	Lake, pond, reservoir	Wetland
Sediment dynamics	I-1	*	I-1, 2	I-1, 2	I-1, 2	I-1, 2	*	I-1, 2	I-1, 2	I-1, 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-3, 4	II-4	II-3, 4
Organic matter	III-5, 6	III-5, 6	III-5, 6	III-5, 6	III-5, 6	III-5, 6	III-5, 6	III-5, 6	III-5, 6	III-5, 6	III-5, 6	III-5, 6
Riparian	—	IV-7, 8, 9	*	*	*	IV-7, 8	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	V-10, 11, 12
Floodplain/ channel interactions	—	VI-13	VI-13, 14	VI-13, 14	VI-13, 14	VI-13	—	—	VI-13, 14	VI-13, 14	—	VI-13, 14
Habitat connectivity	—	VII-15	—	—	—	VII-15	VII-15	—	—	VII-15	VII-15	VII-15

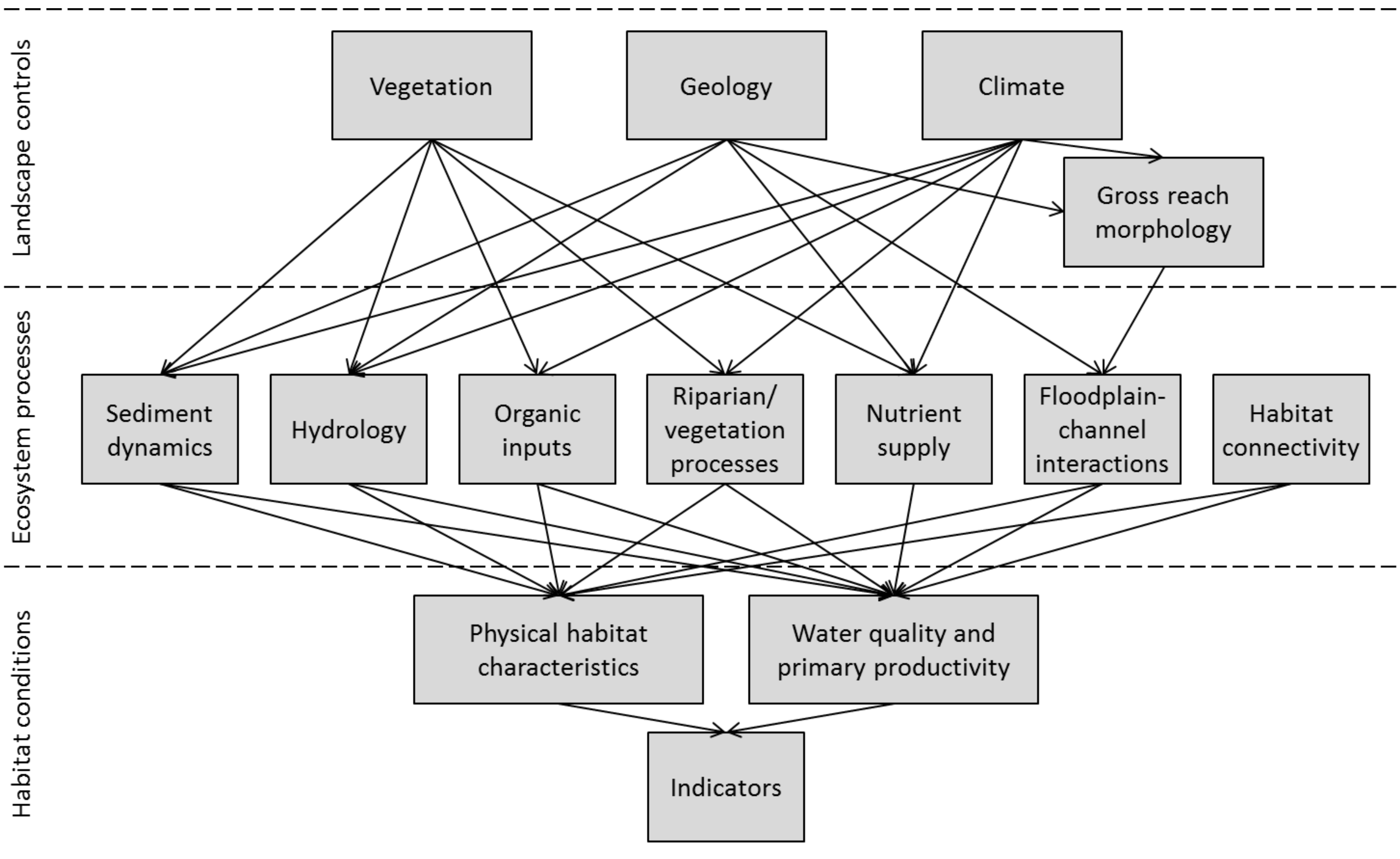


Figure 7. Conceptual diagram of linkages between landscape controls, ecosystem processes, and freshwater habitat conditions. The KEAs in our framework match the processes in this model. (Adapted from Roni et al. 2002.)

Table 10. Freshwater ecosystem processes, KEAs, and examples of KEA and pressure indicators at watershed and reach scales.

Ecosystem process	Scale	KEA	Example of KEA indicator*	Example of pressure indicator
I. Sediment dynamics	Watershed	1. Sediment delivery 2. Sediment transport and storage	Sediment budget and transport/storage regime (Madej 1992, Reid and Dunne 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 streambanks, 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

Table 10 continued. Freshwater ecosystem processes, KEAs, and examples of KEA and pressure indicators at watershed and reach scales.

Ecosystem process	Scale	KEA	Example of KEA indicator*	Example of pressure indicator
II. Hydrology	Watershed	3. High-flow hydrology regime 4. Low-flow hydrology 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 and 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 water and groundwater flow patterns)
	Reach	3. High-flow hydrology regime 4. Low-flow hydrology 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

Table 10 continued. Freshwater ecosystem processes, KEAs, and examples of KEA and pressure indicators at watershed and reach scales.

Ecosystem process	Scale	KEA	Example of KEA indicator*	Example of pressure indicator
III. Organic matter	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 process (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 large woody debris (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, Plotnikof 1994, Kleindl 1995, Karr and Chu 1997) 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
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)

Table 10 continued. Freshwater ecosystem processes, KEAs, and examples of KEA and pressure indicators at watershed and reach scales.

Ecosystem process	Scale	KEA	Example of KEA indicator*	Example of pressure indicator
IV. Riparian (continued)	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 upslope 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 upslope vegetation 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. Nutient 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 (DO), 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 exceedance Contaminants
	Reach	10. Nutrient concentrations (high, low) 11. Water quality 12. Nutrient cycling/flux	Nutrient concentrations, including total N, organic N, NH_4, NO_3, NO_x, total P, organic P, particulate P, and ortho-PO_4 (Levin et al. 2010) Benthic community structure (Karr 1991, Plotnikoff 1994, Karr and Chu 1997)	Toxics in water, freshwater fish, shellfish, and juvenile salmon (from point and nonpoint sources) (Beechie et al. 2003a, Levin et al. 2010) Biological water quality index (including toxics, fecal bacteria) (Levin et al. 2010)

Table 10 continued. Freshwater ecosystem processes, KEAs, and examples of KEA and pressure indicators at watershed and reach scales.

Ecosystem process	Scale	KEA	Example of KEA indicator*	Example of pressure indicator
VI. Floodplain/ channel interactions	Watershed	13. Floodplain—connectivity 14. Floodplain—structure and function	Length 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 prespawn holding (deep pools) and spawning (gravel riffles in main stem, 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)	Type and location of limits to juvenile and adult fish passage Area of lost natural floodplain area (historical vs. current)
	Reach	13. Floodplain—connectivity 14. 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)

Table 10 continued. Freshwater ecosystem processes, KEAs, and examples of KEA and pressure indicators at watershed and reach scales.

Ecosystem process	Scale	KEA	Example of KEA indicator*	Example of pressure indicator
VII. Habitat connectivity	Watershed	15. 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, Bélisle 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 nonindigenous species, pathogens, or contaminants Location and duration of low-flow barrier
	Reach	15. 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 channel

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

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 were 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 (high and low) provides 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 prespawning 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 episodic 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 were identified for hydrology:

- KEA II-3. High-flow hydrological regime, and
- KEA II-4. Low-flow hydrological regime.

III. Organic matter

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 (Frissel et al. 1986, Gregory et al. 1991, Gregory and Bisson 1997, Montgomery and Buffington 1997). Vegetation removal and bank armoring, along with floodplain development, can impede recruitment and processing of detritus (Pess et al. 2005).

Two KEAs were 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 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 KEA 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 on the width of forest buffer adjacent to stream; that is, 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 were 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, 2003b). 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 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 stormwater, 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). Furthermore, 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, Oregon (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 Chinook salmon growth, survival, or distribution. Water quality and contaminants are complex mechanisms that 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, affecting Chinook salmon directly or indirectly via their habitat or food supply.

Three KEAs were 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 Shellberg 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 10% 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 Shellberg 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), groundwater connections, or both (Gregory and Bisson 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 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, levees, revetments, and roads (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, 2003b, Collins et al. 2003).

Two KEAs were 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 that are required by each Chinook life history stage. Furthermore, 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 Chinook salmon use 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 was identified for habitat connectivity:

- KEA VII-15. Habitat connectivity.

Key Ecological Attributes and Indicators for Estuarine and Marine Habitats

Background

The need for a regionally consistent classification of estuarine and marine habitats is apparent when the individual chapters in Volume II of the Recovery 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. Also, 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.

Estuarine and Marine Habitat Components

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) 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-scale and small-scale landscape controls, natural processes, and biological responses based on a general

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 the Glossary.

Broad habitat	System type	System subtype	Shoreline type	Habitat zone
Estuarine	Major river system	*Natal Chinook estuary*	Drowned channel River-dominated (fan) delta Tidal delta Delta lagoon	Alluvial floodplain Tidal channel (e.g., distributary and blind tidal channels, lagoon inlet/outlet) Impoundment (e.g., lagoon, pond, lake) Tidally influenced wetland (e.g., salt marsh, scrub-shrub, forested) Tide flat, low tide terrace, subtidal flat All other zones possible along delta margin
Nearshore marine	Drift cell system	*Coastal landform*	Barrier beach (spit, cusp, tombolo)	Backshore, beach face, tide flat, low-tide terrace, subtidal flat
		Bluff-backed beach	Sediment source beach Depositional beach Beach seep Plunging sediment bluff	Marine riparian zone Bluff face Backshore, berm, beach face, tide flat, low-tide terrace
		Pocket estuary (embayment)	Drowned channel lagoon Tidal delta lagoon Longshore lagoon Tidal channel lagoon or marsh Closed lagoon or marsh Open coastal inlet	Marine riparian zone Tidal channel (e.g., distributary and blind tidal channels, lagoon inlet/outlet) Impoundment (e.g., lagoon, pond, lake) Tidally influenced wetland (e.g., salt marsh, scrub-shrub, forested) Backshore, berm, beach face, tide flat, low-tide terrace
	Rocky shoreline	*Rocky pocket estuary*	Pocket beach lagoon Pocket beach estuary Pocket beach closed lagoon or marsh	Marine riparian zone Tidal channel (e.g., distributary and blind tidal channels, lagoon inlet/outlet) Impoundment (e.g., lagoon, pond, lake) Tidally influenced wetland (e.g., salt marsh, scrub-shrub, forested) Backshore, berm, beach face, tide flat, low-tide terrace
		Rocky beach	Veneered rock platform Rocky shoreline Plunging rocky shoreline Pocket beach	Marine riparian zone Plunging rocky cliff, cliff Rocky platform, backshore, berm, beach face, low-tide terrace

Table 11 continued. 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 the Glossary.

Broad habitat	**System type**	**System subtype**	**Shoreline type**	**Habitat zone**
Offshore marine	*Offshore marine*	Bay/inlet	—	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 predators and competitors, and a much different zooplankton community use the deeper stratum during daylight, with some species migrating into the shallower layer during twilight-night periods) Epibenthic habitat Benthic habitat
		Open basin	—	Water column habitat Epibenthic habitat Benthic habitat

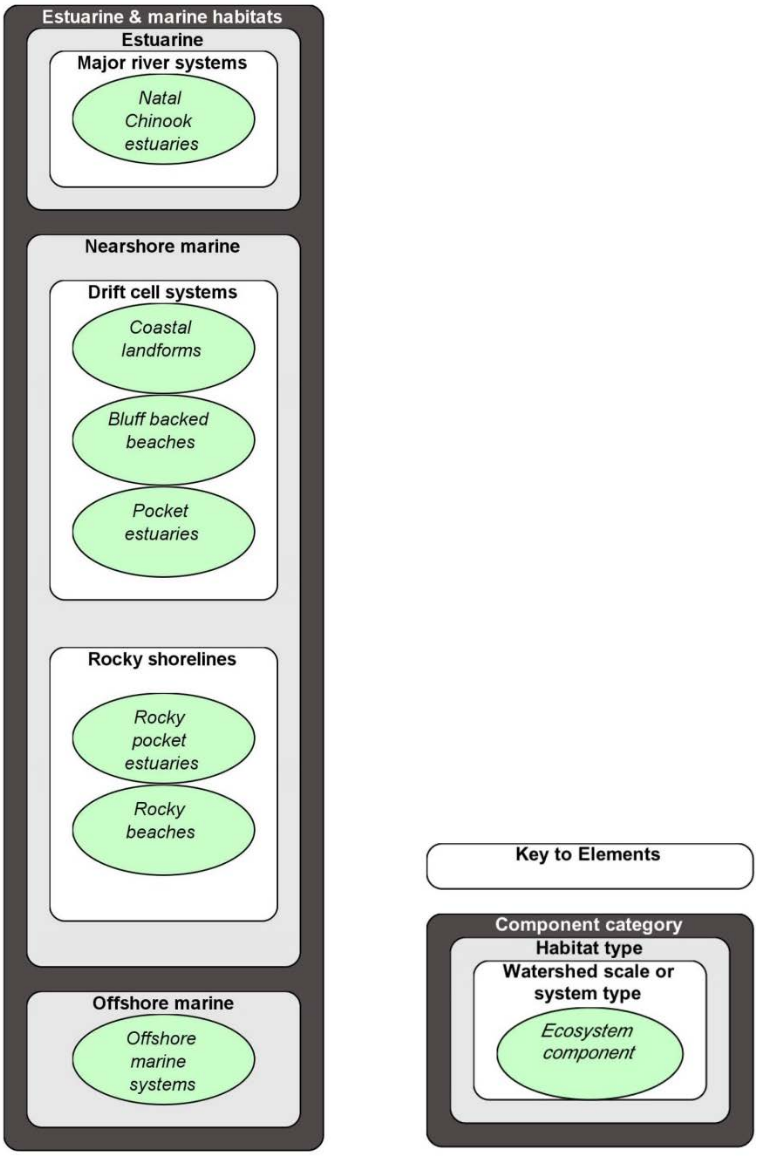


Figure 8. Estuarine and marine habitats (italicized), as described in the framework and depicted in Miradi software.

conceptual diagram that is applicable region-wide (Figure 2, Figure 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 (see the map in the Glossary); 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 KEAs, 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, 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 (Figure 9 and Figure 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 vegetation [MRV], salt marsh, and submerged aquatic vegetation [SAV], including kelp, eelgrass [*Zostera marina*], 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, MRV is associated only with habitat zones higher in elevation than extreme high tide. SAV 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., MRV, salt marsh, and SAV) are also biotic response variables in the conceptual diagram (Figure 2) and are a result of multiple ecosystem processes.

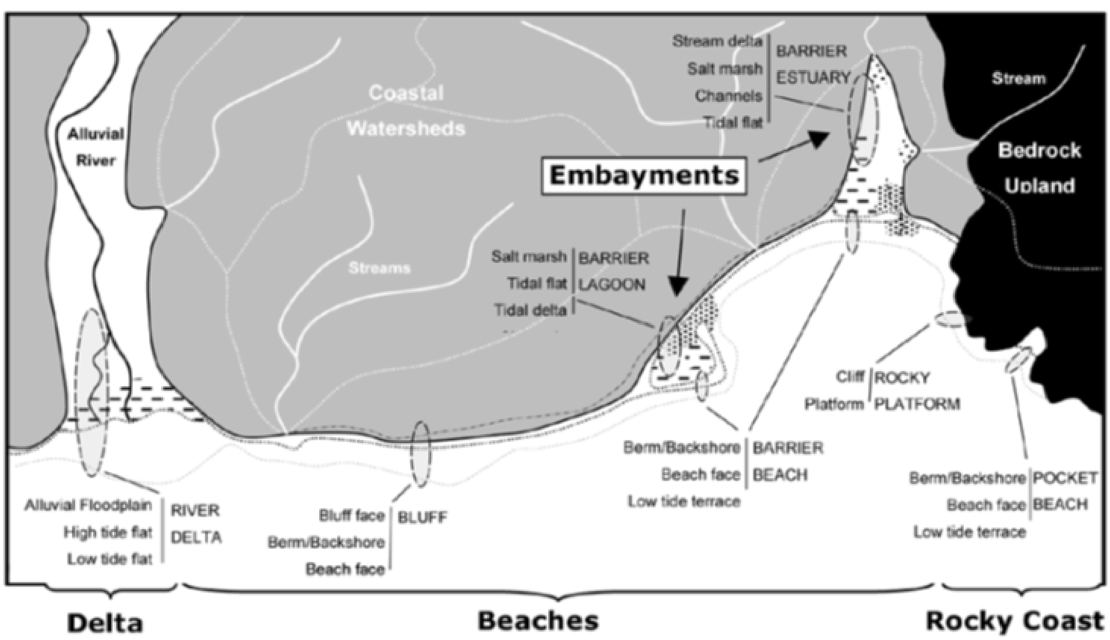


Figure 9. Shoreline habitats typical to Puget Sound. The illustration demonstrates the hierarchical relationships listed in Table 10, columns 3 through 5, specifically among system subtypes (e.g., natal Chinook estuary, bluff-backed beach, rocky beach, and pocket estuary), shoreline types (e.g., barrier beach, pocket beach lagoon), and habitat zones (e.g., alluvial floodplain, backshore, marine riparian zone). (Reprinted from Shipman 2008.)

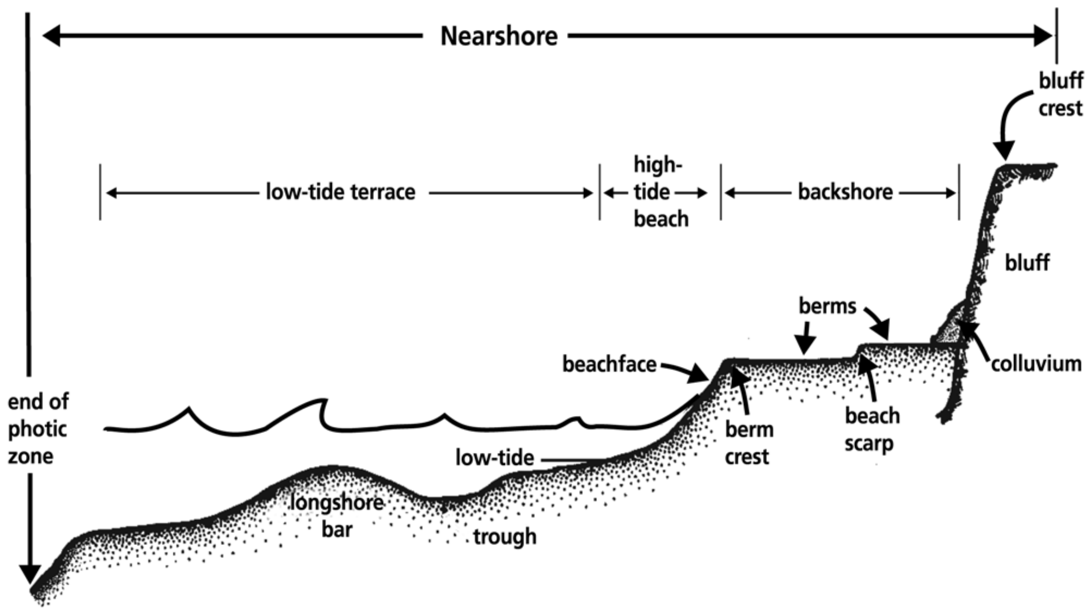


Figure 10. Cross section of a beach showing typical nearshore marine habitat zones in the Puget Sound region. Habitat zones by system subtype are also listed in Table 10. (Reprinted from Johannessen and MacLennan 2007.)

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 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 Puget Sound Nearshore Ecosystem Restoration Project 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 watershed and hypothetical examples for each component that illustrate how component-specific indicators and KEAs are derived from the generic KEAs listed in Table 12 and Table 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-4).

Table 12. 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 features
	I-9	Coastal sediment dynamics—condition of wind and wave features
II. Sediment dynamics—fluvial	II-10	Fluvial sediment dynamics—condition
III. Hydrological dynamics—tidal	III-11	Tidal circulation—extent of biological activity
	III-12	Tidal circulation—water condition
IV. Hydrological dynamics—freshwater	IV-13	Freshwater hydrology—water condition (relative to physical and chemical parameters)
	IV-14	Freshwater hydrology—condition (relative to freshwater input, stream discharge and flow)
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
	VIII-30	MRV—spatial extent and continuity
	VIII-31	MRV—community structure
	VIII-32	MRV—function

* To be used in development of adaptive management and monitoring plans, the KEAs included here need to be adapted to specific components. Examples of component-specific KEAs and indicators are in Table 13 and Table 14.

Table 13. Estuarine and marine 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 cell containing an asterisk (*) is considered a potential KEA.

		Drift cell system			**Rocky shoreline**		
Ecosystem process	***Natal Chinook estuary***	***Coastal landform***	***Bluff-backed beach***	***Pocket estuary***	***Rocky pocket estuary***	***Rocky beach***	***Offshore marine system***
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 & maintenance	V-15, 16	—	—	V-15, 16	V-15, 16	—	—
VI. Detritus recruitment & 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, 30, 31, 32	VIII-21, 25, 26, 29, 30, 31, 32	VIII-20, 21, 25, 26, 29, 30, 31, 32	VIII-20, 21, 22, 23, 24, 27, 28, 29, 30, 31, 32	VIII-20, 21, 22, 23, 24, 27, 28, 29, 30, 31, 32	VIII-20, 21, 25, 26, 29, 30, 31, 32	VIII-20, 21, 29

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

KEA	Example indicator of KEA status or condition
<u>Major river system: Natal Chinook estuary</u>	
II-10. Fluvial sediment dynamics—condition	Sediment loading Sediment accretion
III-11. Tidal circulation—extent of biological activity	Primary productivity Secondary productivity No. and species of organisms present (zooplankton, macrobiota, etc.)
III-12. Tidal circulation—water condition	Temperature, salinity, dissolved oxygen (DO), pH Sediment load Nutrient load
IV-13. Freshwater hydrology—water condition	Temperature, salinity, DO, pH Sediment load Nutrient load
IV-14. Freshwater hydrology—condition	River or stream discharge rate and hydrograph (flow gauges and precipitation)
V-15. Tidal channel formation and maintenance—extent of channels	Extent (area, length, width) of blind or distributary channels
V-16. Tidal channel formation and maintenance—connectivity of channels	Connectivity of blind or distributary channels. Metrics should address connectivity within and between habitat types
VI-17. Detritus recruitment and retention—extent	Amount (quantity, size, volume, type) of detritus recruited or retained in the habitat zones. Measure in tidally influenced wetlands
VI-18. Detritus recruitment and retention—extent of supply	Recruitment of detritus from marine riparian vegetation (MRV)
VII-19. Habitat connectivity condition	Extent (area, length, width) of bluff retreat Extent (number, volume) of landslides Extent (area, length) of coastal landforms over time Distance between suitable habitats Indicators should address connectivity within habitat types and between habitat types
VIII-20. SAV beds—condition	Community structure (species composition) Density (no. shoots/m^2) Spatial extent and continuity (i.e., patchiness) Function of submerged aquatic vegetation (SAV) Substrate composition of SAV beds Elevation of SAV beds
VIII-21. SAV beds—extent	Amount (area, length, width in acres) of any SAV, either eelgrass or kelp species
VIII-22. Estuarine habitats—extent	Amount (area in acres) of estuarine habitat (intertidal and subtidal) zones Number of accessible (to Chinook salmon) pocket estuaries
VIII-23. Estuarine habitats—condition	Elevation of estuarine habitats Vegetation community composition

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

KEA	Example indicator of KEA status or condition
Major river system: Natal Chinook estuary (continued)	
VIII-24. Estuarine habitats—distribution	Spatial distribution of defined estuarine habitats Distance of pocket estuary from natal Chinook estuary Distance between pocket estuaries or other estuarine habitats
VIII-27. Tidally influenced wetlands—extent	Amount (area in acres) of tidal wetland habitat Number of pocket estuaries, and distance between them
VIII-28. Tidally influenced wetlands—condition	Vegetation community composition Elevation of wetlands Changes in tidal wetland accretion
VIII-29. Water quality	River discharge rate and hydrograph Temperature, salinity, DO, pH Nutrient load Detritus load Turbidity (sediment load—suspended)
VIII-30. MRV—spatial extent and continuity	Amount (area in acres, length, width) of MRV Spatial extent and continuity (i.e., patchiness)
VIII-31. MRV—community structure	Community structure (species composition) Density (no. shoots/m^2) Seral stage
VIII-32. MRV—function	Function of MRV (e.g., recruitment, canopy closure, etc.)
Drift cell system: Bluff-backed beach	
I-1. Coastal sediment dynamics in drift cells—condition	Number of drift cells with functional sediment dynamics Percent of drift cells with functional sediment dynamics Percent feeder bluff Rocky beach embeddedness Rocky beach profile Drift cell beach profile
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	Amount (area, volume) of sediment deposition or accretion (relative to historic) on coastal landform
I-6. Coastal sediment supply—extent	Rate of sediment supply (e.g., landslide area on a bluff-backed beach over time) Extent (length, expressed as % or count) of sediment source bluffs and transport zones that are functioning 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 features	Amount (area, length, width) of bluff retreat Amount (number, volume) of landslides Amount (area, length) of coastal landforms over time Extent and distribution of uninterrupted transport zones

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

KEA	Example indicator of KEA status or condition
Drift cell system: Bluff-backed beach (continued)	
I-9. Coastal sediment dynamics—condition of wind and wave features	Composition of SAV bed substrate
III-11. Tidal circulation—extent of biological activity	Primary productivity Secondary productivity Number and species of organisms present (zooplankton, macrobiota, etc.)
III-12. Tidal circulation—water condition	Temperature, salinity, DO, pH Sediment load Nutrient load
IV-13. Freshwater hydrology—water condition	Temperature, salinity, DO, pH Sediment load Nutrient load
VI-17. Detritus recruitment and retention—extent	Amount (quantity, size, volume, type) of detritus recruited or retained in the habitat zones. Measure in tidally influenced wetlands
VI-18. Detritus recruitment and retention—extent of supply	Recruitment of detritus from MRV
VIII-20. SAV beds—condition	Community structure (species composition) Density (no. shoots/m^2) Spatial extent and continuity (i.e., patchiness) Function of SAV Substrate composition of SAV beds Elevation of SAV beds
VIII-21. SAV beds—extent	Amount (area, length, width in acres) of any SAV, either eelgrass or kelp species
VIII-25. Intertidal habitat zone—extent	Amount (area in acres, length) of intertidal and subtidal habitat zones Number of accessible pocket estuaries
VIII-26. Intertidal habitat zone—condition	Profile (slope and elevation) of intertidal zones (see Figure 10). Note: This is an indicator of tidal hydrology
VIII-29. Water quality	River discharge rate and hydrograph Temperature, salinity, DO, pH Nutrient load Detritus load Turbidity (sediment load—suspended)
VIII-30. MRV—spatial extent and continuity	Amount (area in acres, length, width) of MRV Spatial extent and continuity (i.e., patchiness)
VIII-31. MRV—community structure	Community structure (species composition) Density (no. shoots/m^2) Seral stage
VIII-32. MRV—function	Function of MRV (e.g., recruitment, canopy closure, etc.)

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

KEA	Example indicator of KEA status or condition
<u>Drift cell system: Coastal landform</u>	
I-1. Coastal sediment dynamics in drift cells—condition	Number of drift cells with functional sediment dynamics Percent of drift cells with functional sediment dynamics Percent feeder bluff Rocky beach embeddedness Rocky beach profile Drift cell beach profile
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	Amount (area, volume) of sediment deposition or accretion (relative to historic) 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 features	Amount (area, length) of coastal landforms over time Extent and distribution of uninterrupted transport zones
III-11. Tidal circulation—extent of biological activity	Primary productivity Secondary productivity Number and species of organisms present (zooplankton, macrobiota, etc.)
III-12. Tidal circulation—water condition	Temperature, salinity, DO, pH Sediment load Nutrient load
IV-13. Freshwater hydrology—water condition	Temperature, salinity, DO, pH Sediment load Nutrient load
VI-17. Detritus recruitment and retention—extent	Amount (quantity, size, volume, type) of detritus recruited or retained in the habitat zones. Measure in tidally influenced wetlands
VI-18. Detritus recruitment and retention—extent of supply	Recruitment of detritus from MRV
VIII-20. SAV beds—condition	Community structure (species composition) Density (no. shoots/m^2) Spatial extent and continuity (i.e., patchiness) Function of SAV Substrate composition of SAV beds Elevation of SAV beds
VIII-21. SAV beds—extent	Amount (area, length, width in acres) of any SAV, either eelgrass or kelp species
VIII-25. Intertidal habitat zone—extent	Amount (area in acres, length) of intertidal and subtidal habitat zones Number of accessible pocket estuaries
VIII-26. Intertidal habitat zone—condition	Profile (slope and elevation) of intertidal zones (see Figure 10). Note: This is an indicator of tidal hydrology

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

KEA	Example indicator of KEA status or condition
Drift cell system: Coastal landform (continued)	
VIII-29. Water quality	River discharge rate and hydrograph Temperature, salinity, DO, pH Nutrient load Detritus load Turbidity (sediment load—suspended)
VIII-30. MRV—spatial extent and continuity	Amount (area in acres, length, width) of MRV Spatial extent and continuity (i.e., patchiness)
VIII-31. MRV—community structure	Community structure (species composition) Density (No. shoots/m^2) Seral stage
VIII-32. MRV—function	Function of MRV (e.g., recruitment, canopy closure, etc.)
Drift cell system: Pocket estuary	
I-1. Coastal sediment dynamics in drift cells—condition	Number of drift cells with functional sediment dynamics Percent of drift cells with functional sediment dynamics Percent feeder bluff Rocky beach embeddedness Rocky beach profile Drift cell beach profile
I-2. Coastal sediment dynamics in drift cells—landscape context	Distribution of functional drift cells across landscape
II-10. Fluvial sediment dynamics—condition	Sediment loading Sediment accretion
III-11. Tidal circulation—extent of biological activity	Primary productivity Secondary productivity Number and species of organisms present (zooplankton, macrobiota, etc.)
III-12. Tidal circulation—water condition	Temperature, salinity, DO, pH Sediment load Nutrient load
IV-13. Freshwater hydrology—water condition	Temperature, salinity, DO, pH Sediment load Nutrient load
IV-14. Freshwater hydrology—condition	River or stream discharge rate and hydrograph Presence/absence of freshwater input (pocket estuaries)
V-15. Tidal channel formation and maintenance—extent of channels	Extent (area, length, width) of blind or distributary channels
V-16. Tidal channel formation and maintenance—connectivity of channels	Connectivity of blind or distributary channels. Metrics should address connectivity within and between habitat types
VI-17. Detritus recruitment and retention—extent	Amount (quantity, size, volume, type) of detritus recruited or retained in the habitat zones. Measure in tidally influenced wetlands

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

KEA	Example indicator of KEA status or condition
<u>Drift cell system: Pocket estuary (continued)</u>	
VI-18. Detritus recruitment and retention—extent of supply	Recruitment of detritus from MRV
VII-19. Habitat connectivity condition	Extent (area, length, width) of bluff retreat Extent (number, volume) of landslides Extent (area, length) of coastal landforms over time Distance between suitable habitats Indicators should address connectivity within habitat types and between habitat types
VIII-20. SAV beds—condition	Community structure (species composition) Density (no. shoots/m^2) Spatial extent and continuity (i.e., patchiness) Function of SAV Substrate composition of SAV beds Elevation of SAV beds
VIII-21. SAV beds—extent	Amount (area, length, width in acres) of any SAV, either eelgrass or kelp species
VIII-22. Estuarine habitats—extent	Amount (area in acres) of estuarine habitat (intertidal and subtidal) zones Number of accessible (to Chinook salmon) pocket estuaries
VIII-23. Estuarine habitats—condition	Elevation of estuarine habitats Vegetation community composition
VIII-24. Estuarine habitats—distribution	Spatial distribution of defined estuarine habitats Distance of pocket estuary from natal Chinook estuary Distance between pocket estuaries, or other estuarine habitats
VIII-27. Tidally influenced wetlands—extent	Amount (area in acres) of tidal wetland habitat Number of pocket estuaries, and distance between them
VIII-28. Tidally influenced wetland—condition	Vegetation community composition Elevation of wetlands Changes in tidal wetland accretion
VIII-29. Water quality	River discharge rate and hydrograph Temperature, salinity, DO, pH Nutrient load Detritus load Turbidity (sediment load—suspended)
VIII-30. MRV—spatial extent and continuity	Amount (area in acres, length, width) of MRV Spatial extent and continuity (i.e., patchiness)
VIII-31. MRV—community structure	Community structure (species composition) Density (no. shoots/m^2) Seral stage
VIII-32. MRV—function	Function of MRV (e.g., recruitment, canopy closure, etc.)

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

KEA	Example indicator of KEA status or condition
<u>Rocky shoreline: Rocky beach</u>	
I-4. Coastal sediment deposition and accretion—condition of sediment	Composition (size and type) of sediment Beach face and back shore width and area
I-6. Coastal sediment supply—extent	Rate of sediment supply (e.g., landslide area on a bluff-backed beach over time) Extent (length, expressed as % or count) of sediment source bluffs and transport zones that are functioning 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 features	Amount (area, length) of coastal landforms over time Extent and distribution of uninterrupted transport zones
I-9. Coastal sediment dynamics—condition of wind and wave features	Composition of SAV bed substrate
III-11. Tidal circulation—extent of biological activity	Primary productivity Secondary productivity Number and species of organisms present (zooplankton, macrobiota, etc.)
III-12. Tidal circulation—water condition	Temperature, salinity, DO, pH Sediment load Nutrient load
IV-13. Freshwater hydrology—water condition	Temperature, salinity, DO, pH Sediment load Nutrient load
VI-18. Detritus recruitment and retention—extent of supply	Recruitment of detritus from MRV
VII-19. Habitat connectivity condition	Extent (area, length, width) of bluff retreat Extent (number, volume) of landslides Extent (area, length) of coastal landforms over time Distance between suitable habitats Indicators should address connectivity within habitat types and between habitat types
VIII-20. SAV beds—condition	Community structure (species composition) Density (no. shoots/m^2) Spatial extent and continuity (i.e., patchiness) Function of SAV Substrate composition of SAV beds Elevation of SAV beds
VIII-21. SAV beds—extent	Amount (area, length, width in acres) of any SAV, either eelgrass or kelp species
VIII-25. Intertidal habitat zone—extent	Amount (area in acres, length) of intertidal and subtidal habitat zones Number of accessible pocket estuaries
VIII-26. Intertidal habitat zone—condition	Profile (slope and elevation) of intertidal zones (see Figure 10). Note: This is an indicator of tidal hydrology

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

KEA	Example indicator of KEA status or condition
Rocky shoreline: Rocky beach (continued)	
VIII-29. Water quality	River discharge rate and hydrograph Temperature, salinity, DO, pH Nutrient load Detritus load Turbidity (sediment load—suspended)
VIII-30. MRV—spatial extent and continuity	Amount (area in acres, length, width) of MRV Spatial extent and continuity (i.e., patchiness)
VIII-31. MRV—community structure	Community structure (species composition) Density (no. shoots/m^2) Seral stage
VIII-32. MRV—function	Function of MRV (e.g., recruitment, canopy closure, etc.)
Rocky shoreline: Rocky pocket estuary	
I-4. Coastal sediment deposition and accretion—condition of sediment	Composition (size and type) of sediment Beach face and back shore width and area
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-6. Coastal sediment supply—extent	Rate of sediment supply (e.g., landslide area on a bluff-backed beach over time) Extent (length, expressed as % or count) of sediment source bluffs and transport zones that are functioning 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 features	Amount (area, length) of coastal landforms over time Extent and distribution of uninterrupted transport zones
I-9. Coastal sediment dynamics—condition of wind and wave features	Composition of SAV bed substrate
II-10. Fluvial sediment dynamics—condition	Sediment loading
III-11. Tidal circulation—extent of biological activity	Primary productivity Secondary productivity Number and species of organisms present (zooplankton, macrobiota, etc.)
III-12. Tidal circulation—water condition	Temperature, salinity, DO, pH Sediment load Nutrient load
IV-13. Freshwater hydrology—water condition	Temperature, salinity, DO, pH Sediment load Nutrient load
IV-14. Freshwater hydrology—condition	River or stream discharge rate and hydrograph (flow gauges and precipitation) Presence/absence of freshwater input (pocket estuaries)

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

KEA	Example indicator of KEA status or condition
Rocky shoreline: Rocky pocket estuary (continued)	
V-15. Tidal channel formation and maintenance—extent of channels	Extent (area, length, width) of blind or distributary channels
V-16. Tidal channel formation and maintenance—connectivity of channels	Connectivity of blind or distributary channels. Metrics should address connectivity within and between habitat types
VI-17. Detritus recruitment and retention—extent	Amount (quantity, size, volume, type) of detritus recruited or retained in the habitat zones. Measure in tidally influenced wetlands
VI-18. Detritus recruitment and retention—extent of supply	Recruitment of detritus from MRV
VII-19. Habitat connectivity condition	Extent (area, length, width) of bluff retreat Extent (number, volume) of landslides Extent (area, length) of coastal landforms over time Distance between suitable habitats
VIII-20. SAV beds—condition	Community structure (species composition) Density (no. shoots/m^2) Spatial extent and continuity (i.e., patchiness) Function of SAV Substrate composition of SAV beds Elevation of SAV beds
VIII-21. SAV beds—extent	Amount (area, length, width in acres) of any SAV, either eelgrass or kelp species
VIII-22. Estuarine habitats—extent	Amount (area in acres) of estuarine habitat (intertidal and subtidal) zones Number of accessible (to Chinook salmon) pocket estuaries
VIII-23. Estuarine habitats—condition	Elevation of estuarine habitats Vegetation community composition
VIII-24. Estuarine habitats—distribution	Spatial distribution of defined estuarine habitats Distance of pocket estuary from natal Chinook estuary Distance between pocket estuaries or other estuarine habitats
VIII-27. Tidally influenced wetlands—extent	Amount (area in acres) of tidal wetland habitat Number of pocket estuaries, and distance between them
VIII-28. Tidally influenced wetlands—condition	Vegetation community composition Elevation of wetlands Changes in tidal wetland accretion
VIII-29. Water quality	River discharge rate and hydrograph Temperature, salinity, DO, pH Nutrient load Detritus load Turbidity (sediment load—suspended)
VIII-30. MRV—spatial extent and continuity	Amount (area in acres, length, width) of MRV Spatial extent and continuity (i.e., patchiness)

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

KEA	Example indicator of KEA status or condition
Rocky shoreline: Rocky pocket estuary (continued)	
VIII-31. MRV—community structure	Community structure (species composition) Density (no. shoots/m^2) Seral stage
VIII-32. MRV—function	Function of MRV (e.g., recruitment, canopy closure, etc.)
Offshore marine system	
III-11. Tidal circulation—extent of biological activity	Primary productivity Secondary productivity Number and species of organisms present (zooplankton, macrobiota, etc.)
III-12. Tidal circulation—water condition	Temperature, salinity, DO, pH Sediment load Nutrient load
IV-13. Freshwater hydrology—water condition	Temperature, salinity, DO, pH Sediment load Nutrient load
VI-18. Detritus recruitment and retention—extent of supply	Recruitment of detritus from MRV
VIII-20. SAV beds—condition	Community structure (species composition) Density (no. shoots/m^2) Spatial extent and continuity (i.e., patchiness) Function of SAV Substrate composition of SAV beds Elevation of SAV beds
VIII-21. SAV beds—extent	Amount (area, length, width in acres) of any SAV, either eelgrass or kelp species
VIII-29. Water quality	River discharge rate and hydrograph Temperature, salinity, DO, pH Nutrient load Detritus load Turbidity (sediment load—suspended)

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

KEA	Indicator	Current status	Desired future status	Historical condition	Indicator description and method
Pocket estuary component					
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 ha	311.5 ha	340.7 ha	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	3.49 km	Not specified	1.26 km	Median distance along shoreline at mean of lower low water (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 estuary component					
VIII-22. Estuarine habitat extent	Accessible* tidally influenced wetlands within the Skagit estuary	3,118.0 ha	4,232.6 ha	11,483.0 ha	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 ha	895.8 ha	1,223.8 ha	Sum of area of accessible* distributary channels in the Skagit estuary, remote-sensed methods
VIII-22. Estuarine habitat extent	Accessible* blind channel tidal area within the Skagit estuary	62.7 ha	110.8 ha	1,158.0 ha	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 and natal estuarine habitat are sufficiently exposed to tidal hydrology to allow access to and use of habitat by juveniles.

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 shore forms (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) shore forms where there is a net gain and storage of sediment (Shipman 2008). Pocket estuaries with lagoon habitat formed behind coastal landforms 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. Oversupplied sediment caused by a) an increase in bluff erosion (due to sea level rise or an uptick in storm frequency), b) loss of stabilizing bluff vegetation, or c) rerouting of surface water or groundwater such that slope failure and erosion increase; or
2. Undersupplied 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 were identified:

- KEA I-1. Coastal sediment dynamics in drift cells—condition, and
- 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., a beach in a small rocky embayment). Sediment for the pocket beach is locally derived rather than delivered via longshore sediment dynamics. Variable erodibility 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 upslope.

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 offshore. 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, and
- 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 KEA II). Localized impediments to wave energy (e.g., jetties) will change local sediment dynamics, causing the silting in of enclosed areas and the scouring of 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 features, and
- KEA I-9. Coastal sediment dynamics—condition of wind and wave 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, a function of watershed conditions upstream, is covered in the subsection 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 and 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, tide gates, 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 biological activity (relative to primary and secondary productivity), and
- KEA III-12. Tidal circulation—water condition (relative to physical and chemical parameters).

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 silt deposition in the estuary (see KEA VIII-23) 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—water condition (relative to physical and chemical parameters), and
- KEA IV-14. Freshwater hydrology—condition (relative to freshwater input, stream discharge, and flow).

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 tide gates 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, and
- 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 microhabitat for invertebrates (Tonnes 2008), and nurse logs that 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, and
- 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 that are required by each 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 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, synonymous with the concept of habitat opportunity proposed by Simenstad (2000) and Simenstad and Cordell (2000), 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 tide-gated estuarine channel systems, additional data are needed to determine local connectivity, such as the percentage of time tide gate 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, and other ecosystem processes. SAV beds provide direct habitat for juvenile Chinook salmon and many other species important to salmonid food webs. SAV distribution is limited by desiccation stress, salinity patterns, and water clarity. Likewise, spawning locations of forage fish (e.g., surf smelt [*Hypomesus pretiosus*], sand lance [*Ammodytes hexapterus*], and Pacific herring [*Clupea pallasii*]) in intertidal habitat zones 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 types and tidal elevations. Tidal inundation and energy can be affected by shoreline armoring and constrictions on tidal flows such as tide gates and other marine engineering.

Marine riparian vegetation (MRV) is also a factor that affects the quality of estuarine and nearshore marine intertidal, and wetland habitats. The relationships of MRV that directly affect Chinook salmon in estuarine and nearshore marine habitats are not well studied to date. We provide the context for work to be connected on this topic in KEAs VIII-30, VIII-31, and VIII-

32, but leave prioritization to the watersheds if this is an aspect stated in their recovery plan goals and thus their monitoring and adaptive management plans. For example, marine riparian areas have largely not been mapped and should be done to establish baseline. And it may be difficult to evaluate/rank MRV indicators now in the viability assessment, as benchmarks have yet to determined. See Brennan et. al. (2009) for additional guidance and references.

Thirteen 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,
- KEA VIII-30. MRV—spatial extent and continuity,
- KEA VIII-31. MRV—community structure (e.g., species composition and seral stage), and
- KEA VIII-32. MRV—function (e.g., recruitment, canopy closure, etc.).

Key Ecological Attributes and Indicators for Species and Food Webs

Background

Nonnative 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, they are often overlooked in the practice of recovery planning and implementation. 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., Arkoosh et al. 2004, Ruggerone and Goetz 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 subsection of the framework, like the habitat-related subsections above, relies on a simple conceptual diagram in which large-scale 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 salmon and other species in all the life stages and habitats described above (Figure 4, Table 5, and Table 2). The intent of this subsection 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 monitoring and adaptive management plans.

This subsection of the framework is based on Chapter 1A of the 2010 Puget Sound Science Update. In this chapter, Levin et al. (2010) 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 salmon 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 here and in appendix Table B-4.

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	KEA
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 web	Community composition Energy and material flow

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

Key Ecological Attributes and Indicators

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.

Species KEAs

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 Standards practitioners: size, condition, and landscape context (TNC 2007). Population size and condition also include all four parameters (abundance, productivity, diversity, and spatial structure) used to describe viable populations of Chinook salmon (McElhany et al. 2000). Here those 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 salmon.

Food web KEAs

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), as well as 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 Table 5 and Table 6, some indicators are directly measurable, whereas others are derived. Unlike Table 5 and Table 6, Table 17 does not target specific species. Instead, examples of specific species that interact with Chinook salmon 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 its monitoring plan to include indicators deemed important at the local scale.

Table 17. Examples of species and food webs indicators, grouped by KEA and relationship to Chinook salmon.

	Ecological relationship to Chinook salmon				
KEA	**Predator species**	**Competitor species**	**Prey species**	**Other species**	**Food web**
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 salmon spawning naturally[a] Abundance of other salmonid populations spawning concurrently with Chinook salmon[a]	Abundance, biomass, or density of preferred prey populations	Abundance, biomass, or density of key facilitators	—
Population condition	Spatiotemporal distribution of key predator populations Size structure of key predator populations Proportion (by weight) of Chinook salmon in the diets of key predator populations	Spatiotemporal 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 salmon Individual body mass, fork length, and marine growth for key competitor populations[b]	Spatiotemporal distribution of key prey populations Proportion (by weight) of key prey types in the diet of juvenile Chinook salmon Energy contribution of key prey types in juvenile Chinook salmon[c]	Prevalence of key pathogens in Chinook salmon	—

Table 17 continued. Examples of species and food webs indicators, grouped by KEA and relationship to Chinook salmon.

	Ecological relationship to Chinook salmon				
KEA	Predator species	Competitor species	Prey species	Other species	Food web
Community composition	—	—	—	—	Diversity of nonnative predator species Response diversity of prey species Benthic index of biological integrity[a] Ephemeroptera, Plecoptera, and Trichoptera species richness[a] Species diversity and trophic diversity of catches by beach seine, tow net, 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).
[b] Indicator is specific to marine habitats (see Table 10).
[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	Example and literature source
Freshwater	Predator species	Piscivorous mammals
		Piscivorous birds
		Gulls (*Larus* spp.), Weitkamp and Ruggerone 2000[a]
		Piscivorous fish
		Salmonids
		Rainbow trout (*Oncorhynchus mykiss*), Tabor et al. 2004[a]
		Brook trout (*Salvelinus fontinalis*), Levin et al. 2002[b]
		Cutthroat trout (*O. clarkii*), Nowak et al. 2004,[a] Beauchamp et al. 2007[a]
		Nonsalmonids
		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 salmon, Peery and Bjornn 2004,[b] Weber and Fausch 2005[b]
		Other salmonid species, Stein et al. 1972,[b] Hearn 1987[b]
		Nonsalmonids
	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 et al.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
Estuarine	Predator species	Piscivorous mammals
		Harbor seal (*Phoca vitulina*), NMFS 1997,[a, c] London et al. 2002[a]
		Piscivorous birds
		Caspian tern (*Hydroprogne caspia*), Collis et al. 2001[b]
		Piscivorous fish
		Salmonids
		Cutthroat trout, Simenstad et al. 1982,[a] Footen 2001,[a] Duffy and Beauchamp 2008[a]
		Steelhead, Simenstad et al. 1982[a]
		Nonsalmonids
		Staghorn sculpin (*Leptocottus armatus*), Footen 2001[a]
		River lamprey (*Lampetra ayresi*), Ruggerone et al. 2004[a]

Table 18 continued. 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	Example and literature source
Estuarine (continued)	Competitor species	Salmonids
		Hatchery Chinook salmon, Levings et al. 1986[b]
		Other salmonid species
		Nonsalmonids
		Threespine stickleback (*Gasterosteus aculeatus*), Spilseth 2008[b]
	Prey species	Aquatic and terrestrial insects
		Dipterans, Dunford 1975,[b] Fresh et al. 1978,[a] Shreffler et al. 1992,[a] Duffy 2003[a]
		Chironomids, Dunford 1975,[b] Shreffler et al. 1992,[a] Duffy 2003[a]
		Hymenopterans, Duffy 2003[a]
		Small crustaceans
		Cladocera, Dunford 1975,[b] Shreffler et al. 1992,[a] Simenstad et al. 2003[a]
		Euphausiids, Fresh et al. 1978,[a] Duffy 2003[a]
		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
		Chum salmon (*O. keta*), Bax et al. 1978[a]
	Other species	Pathogens
		Nanophyetus salmincola, Arkoosh et al. 2004[a]
		Facilitators
		Beaver (*Castor canadensis*), Pess et al. 2002,[a] Hood 2012[a]
Marine	Predator species	Piscivorous mammals
		Orca, Hanson et al. 2010,[a]
		Sea lion (*Zalophus californianus*), NMFS 1997[a, c]
		Piscivorous birds
		Gulls, 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, Duffy and Beauchamp 2008[a]
		Nonsalmonids
		River lamprey, Beamish and Neville 1995[b]
		Spiny dogfish (*Squalus acanthias*), Beamish et al. 1992[b]
	Competitor species	Salmonids
		Hatchery Chinook salmon, Levings et al. 1986,[b] Duffy 2009,[a] Rice et al. 2011[a]
		Other salmonid species
		Pink salmon (*O. gorbuscha*), Ruggerone and Goetz 2004[a]
		Nonsalmonids
		Pacific herring, Beauchamp and Duffy 2011[a]

Table 18 continued. 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	Example and literature source
Marine (continued)	Prey species	Aquatic and terrestrial insects and arachnids
		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, Fresh et al. 1981,[a] Duffy et al. 2010[a]
		Pacific sand lance, 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, 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.

Framework Process

General Application of the Framework

We have introduced the framework structure above, its context in Puget Sound salmon recovery implementation, and its basis in the Open Standards approach. 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 the Ecosystem Components section. The current section describes the Open Standards tools and eight steps to apply the framework for practitioners to develop watershed-specific monitoring and adaptive management plans (Table 19). Implementation of the framework is further elaborated upon in the Toolkit (LLTK and PSP 2014). 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 Standards 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 salmon populations to assess their status and trends, then employing the local watershed chapters of the 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 in each watershed.

This process first involves developing and refining a list of ecosystem components, which we have defined in the previous section to include the Chinook salmon populations present in each watershed, as well as the freshwater, estuary, and nearshore marine habitats, and other species and food webs 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 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 and used to document changes in KEAs. Indicators are important because they inform managers of the status and changes in KEAs. 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 the first section and in Figure 12 and Figure 13. In addition, Figure 14 through Figure 16 provide a detailed construct of the defined pressures

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

Step	Summary	Resource	Product
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 Vol. II of the Recovery 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 Vol. II of the Recovery 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 Vol. II of the Recovery 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 Vol. II of the Recovery 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 Recovery Plan Final watershed-specific conceptual model Viability analysis Pressure rating and ranking	Results chains
6	Link results chains to monitoring: Identify objectives and indicators for intermediate results in the results chains.	Results chains This document	Indicators and objectives for 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 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.

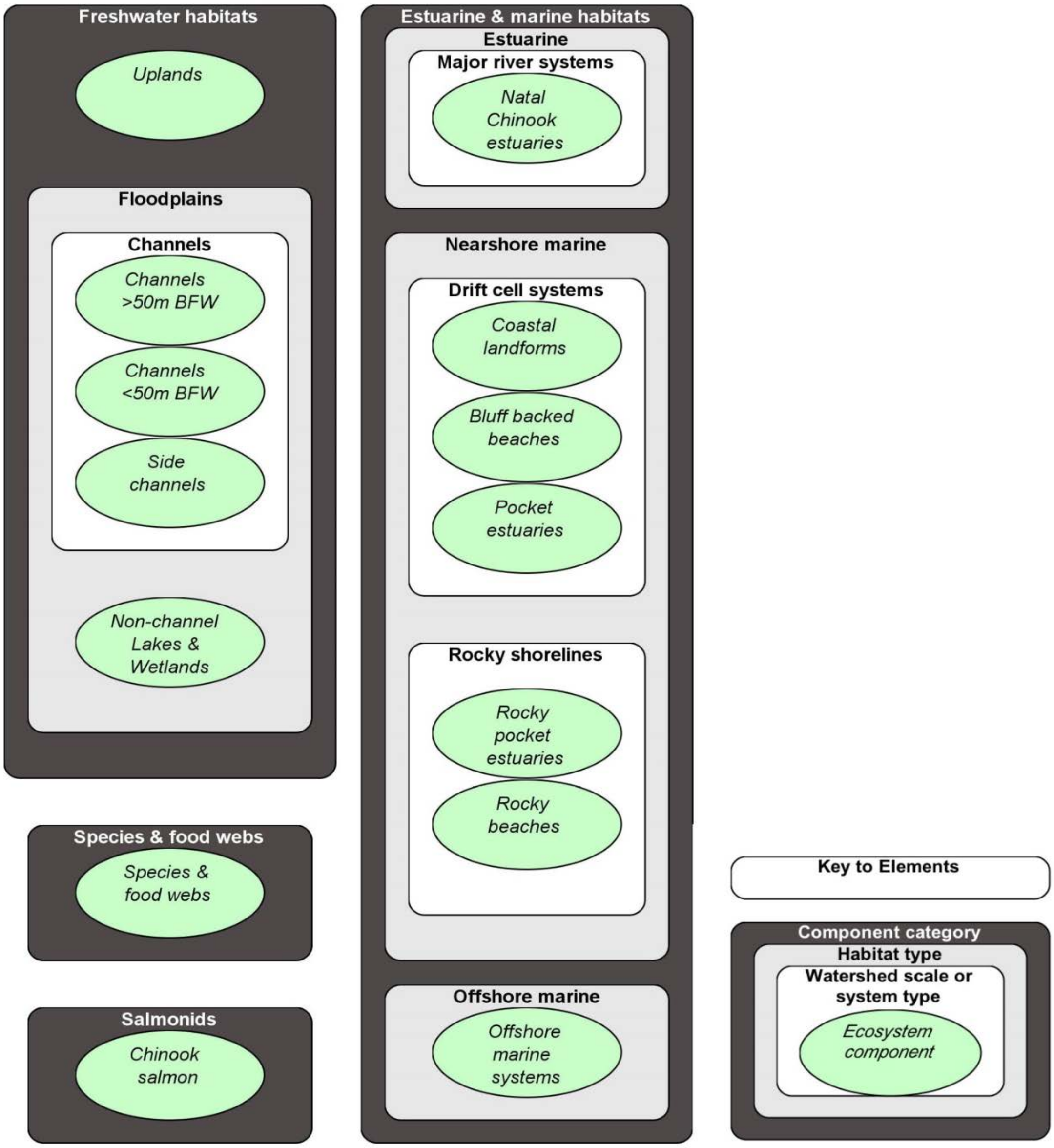


Figure 11. Ecosystem components (italicized) and system types for component categories of freshwater habitats, estuarine and marine habitats, species and food webs, and salmonids, as described in the framework and depicted in Miradi software.

(Figure 14) and stresses (Figure 15) to Chinook salmon and their habitats (Figure 16). This entire list is defined as the Portfolio of Elements for the watershed (Figure 11 through Figure 16).

Next the process involves completing a viability assessment for each ecosystem component. The assessment is an Open Standards tool for defining current conditions and desired future healthy conditions for each of the KEAs, 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

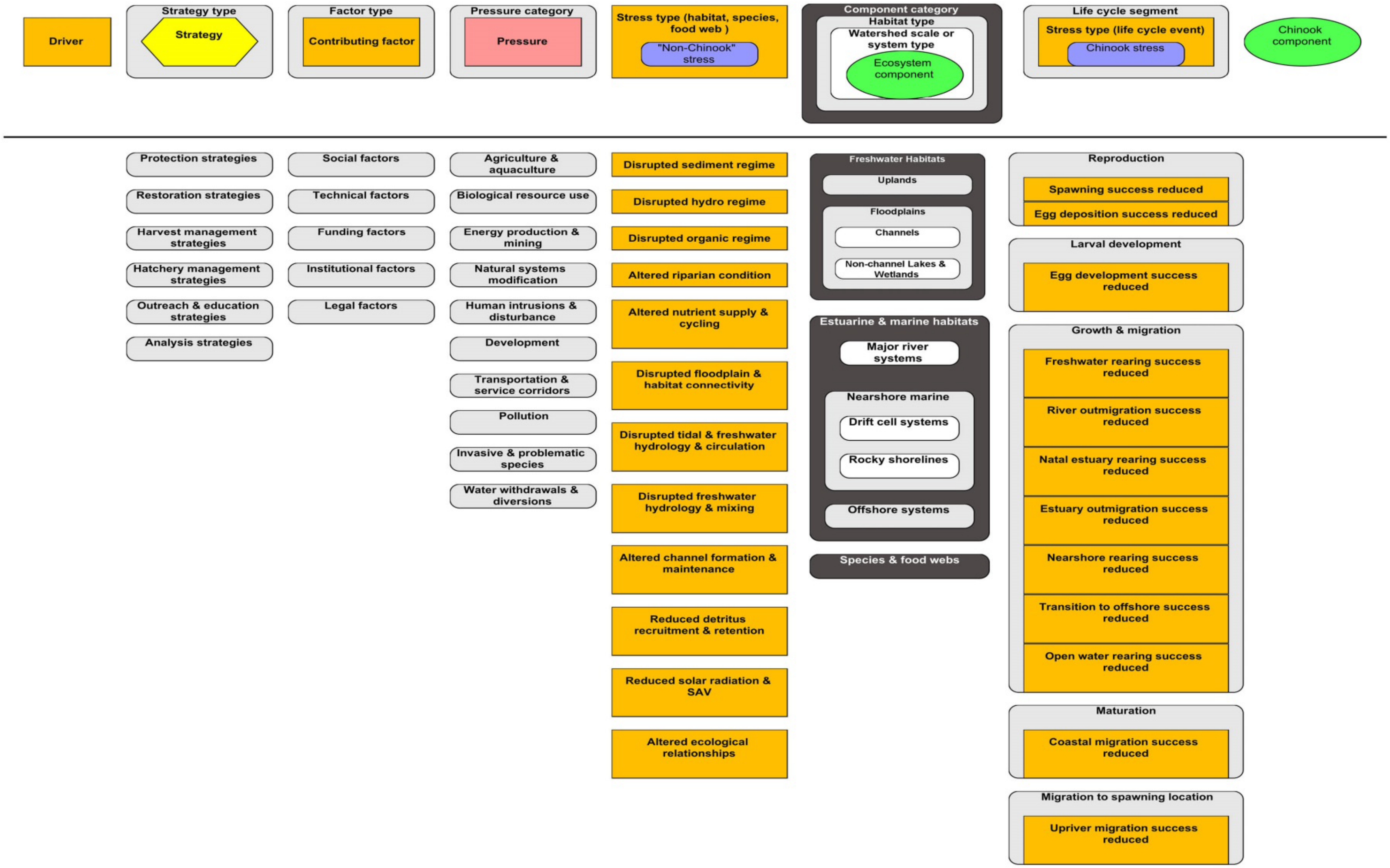


Figure 12. Generic portfolio of elements, as described in the framework and depicted in Miradi. See Appendix B for examples of the specific elements within each category. Also see Figure 11 and Figure 14 through Figure 16 for more detailed lists of components, pressures, and stresses. See Figure 13 for a key that illustrates the relationships between the elements within an individual conceptual model.

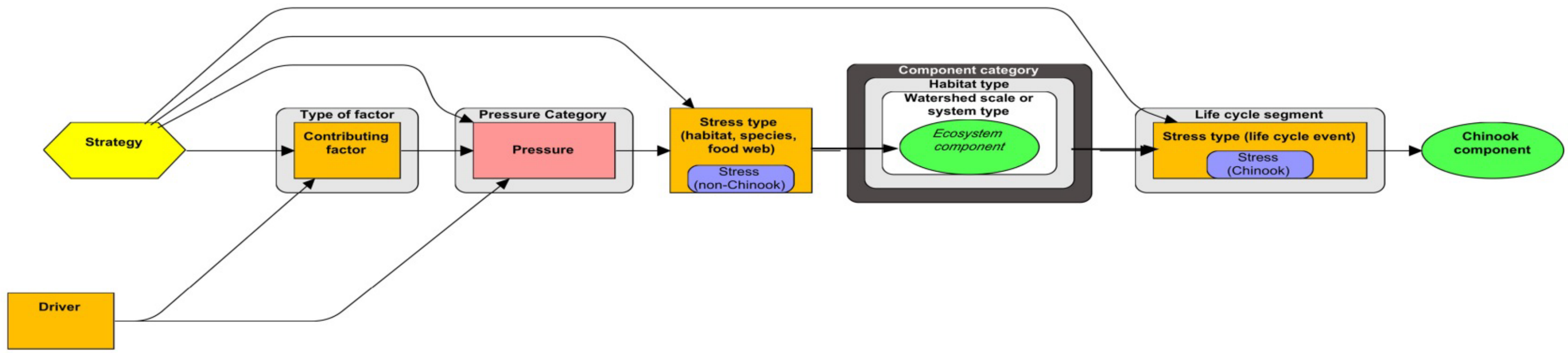


Figure 13. Key to relationships between the portfolio of elements within a watershed conceptual model, as described in the framework and depicted in Miradi. Strategies can address contributing factors, pressures, or stresses. Contributing factors underlie the existence and persistence of pressures and 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).

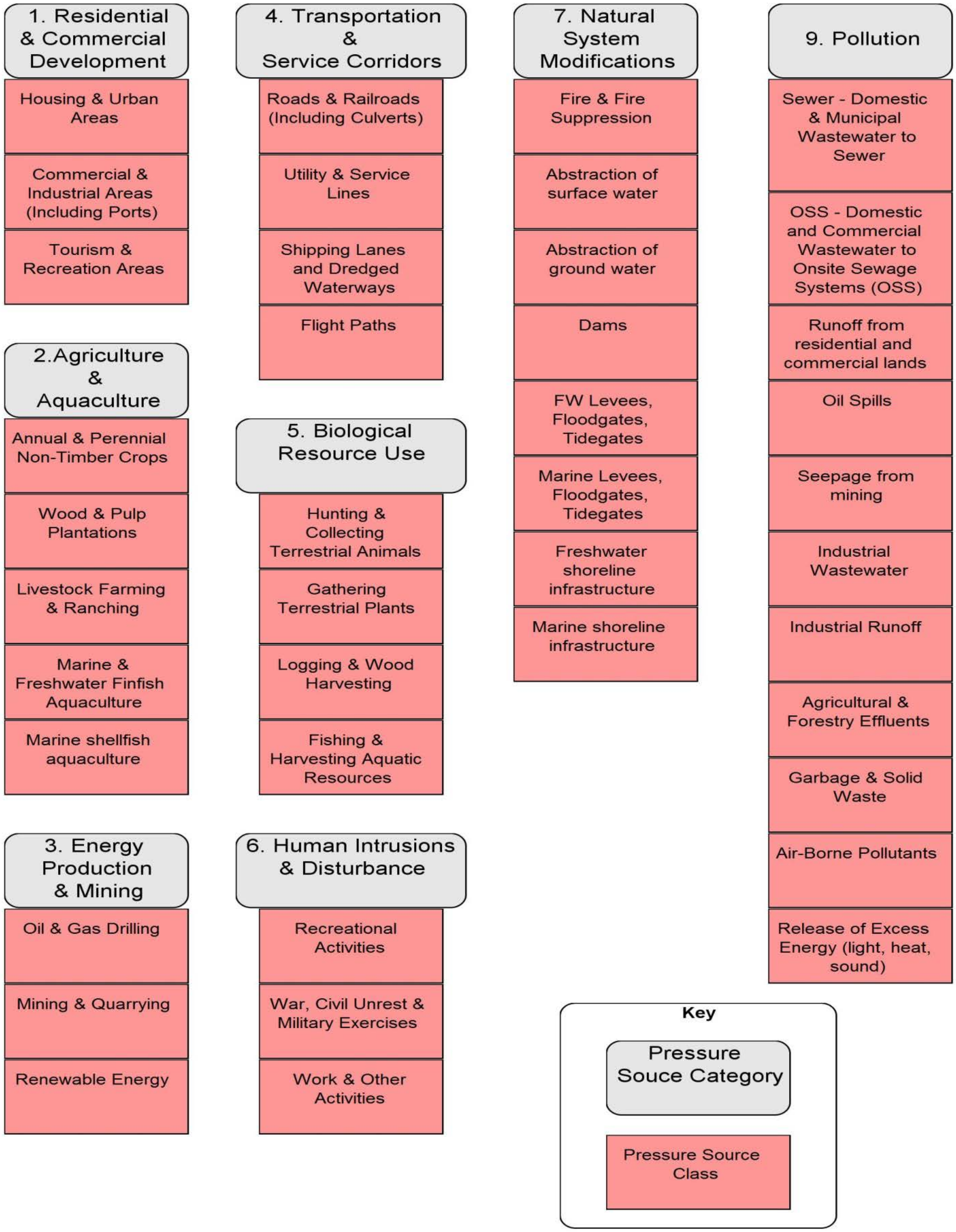


Figure 14. Taxonomy of sources of pressures developed by the Puget Sound Partnership and as described in the framework and depicted in Miradi. Also see appendix Table B-1 for definitions of pressures.

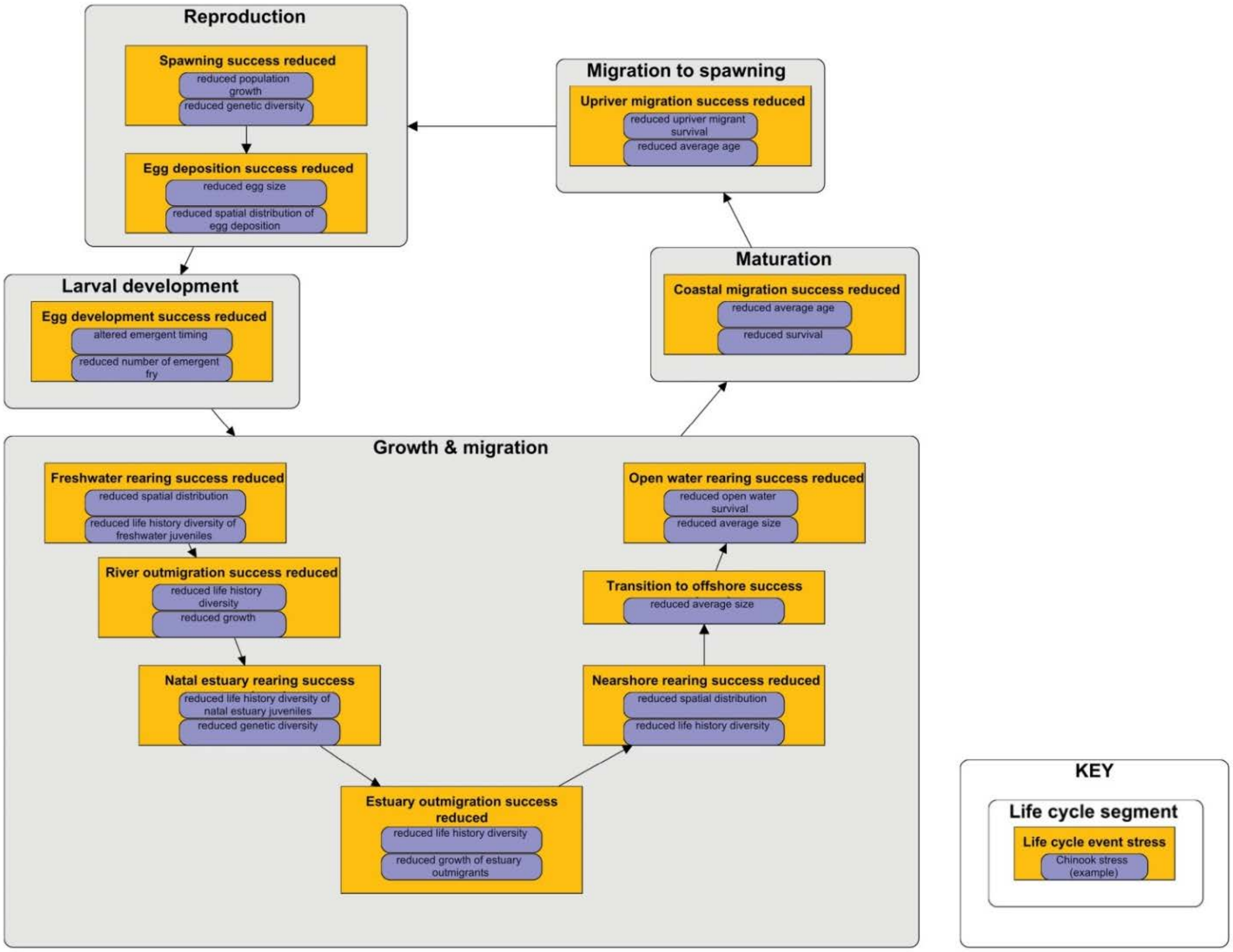


Figure 15. Taxonomy of Chinook salmon stresses organized by Chinook salmon life cycle, as described in the framework and depicted in Miradi. Also see appendix Table B-3 for a list of stresses related to the Chinook salmon ecosystem component.

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 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/use of limited resources.

A conceptual model is completed that develops the linkages between the most important pressures in a watershed and the relationship and impact of these threats to the ecosystem components (Figure 13). Using Miradi software, these linkages can be portrayed graphically and

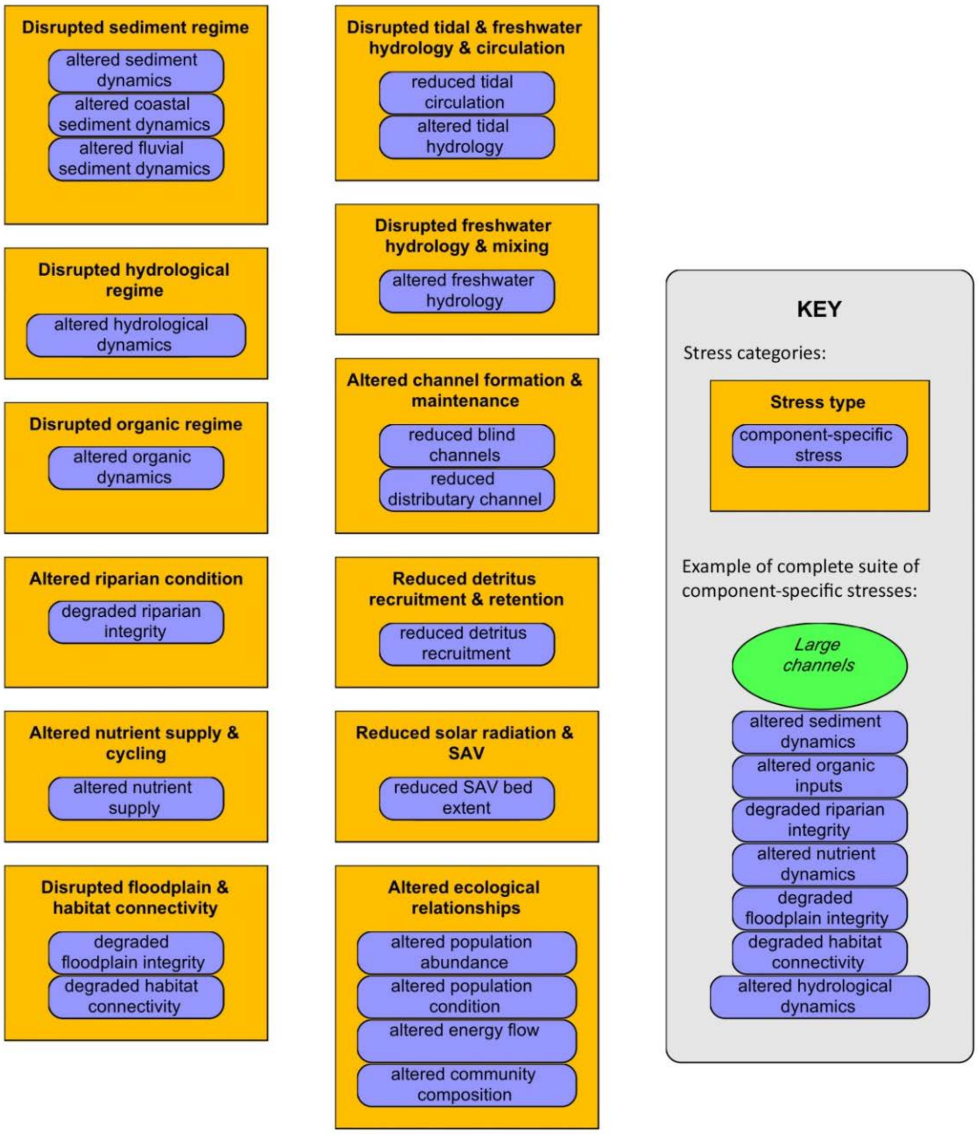


Figure 16. Taxonomy of habitat stresses organized by stress type, as described in the framework and depicted in Miradi. An example of a complete suite of habitat stresses for a single ecosystem component, Large channels, is included. Also see appendix Table B-4 for a list of stresses related habitat and species and food web ecosystem components.

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 simple results chains 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

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

				Current condition		**Desired future condition**[a]		**Location in Skagit Vol. II**
KEA	**Life cycle event**	**Indicator**	**Population**	Value	Status	Value	Status	
Abundance	Natal estuary rearing	No. of parr in the Skagit natal estuary	All	2,250,000	Fair	3,600,000	Good	Chap. 16, p. 284
	Spawning	No. of populations meeting “no. of spawners” recovery goals	All	NC[b]	ND[c]	6 out of 6	Very good	Chap. 4, p. 21
			Lower Skagit	NC	ND	3,900–7,400[d]	Very good	
			Upper Skagit	NC	ND	5,380–9,400[d]	Very good	
			Lower Sauk	NC	ND	1,400–2,700[d]	Very good	
			Upper Sauk	NC	ND	750–1,340[d]	Very good	
			Suiattle	NC	ND	160–270[d]	Very good	
			Upper Cascade	NC	ND	290–510[d]	Very good	
Productivity–survival rate	Coastal migration	No. of populations meeting “no. of recruits per spawner” recovery goals	All	NC	ND	6 out of 6	Very good	Chap. 4, p. 21
			Lower Skagit	NC	ND	3.0–5.4[e]	Very good	
			Upper Skagit	NC	ND	3.8–6.6[e]	Very good	
			Lower Sauk	NC	ND	3.0–4.8[e]	Very good	
			Upper Sauk	NC	ND	3.0–4.1[e]	Very good	
			Suiattle	NC	ND	2.8–4.2[e]	Very good	
			Upper Cascade	NC	ND	3.0–4.6[e]	Very good	

[a] Desired future conditions for population-specific indicators reflect population-specific recovery goals in the Skagit chapter.
[b] NC = Not calculated.
[c] ND = Not determined.
[d] Number of spawners by population.
[e] Number of recruits per spawner by population.

Table 21. Example of a viability table for four indicators associated with four 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 condition**		**Desired future condition**		**Reference**
				Measure	Status	Measure	Status	
Channels >50 m BFW (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	SSDC 2007, Chap. 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	Chap. 10, p. 98, 113–114
		Size	Floodplain side channel area	560 ha	Fair	628 ha	Good	Chap. 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	Beamer et al. 2005, App. 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	—	App. D, p. 15[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, the historical condition of this indicator was 1,158.0 ha (very good).
[e] According to Appendix D, the historical condition of this indicator was 1.26 km (very good).

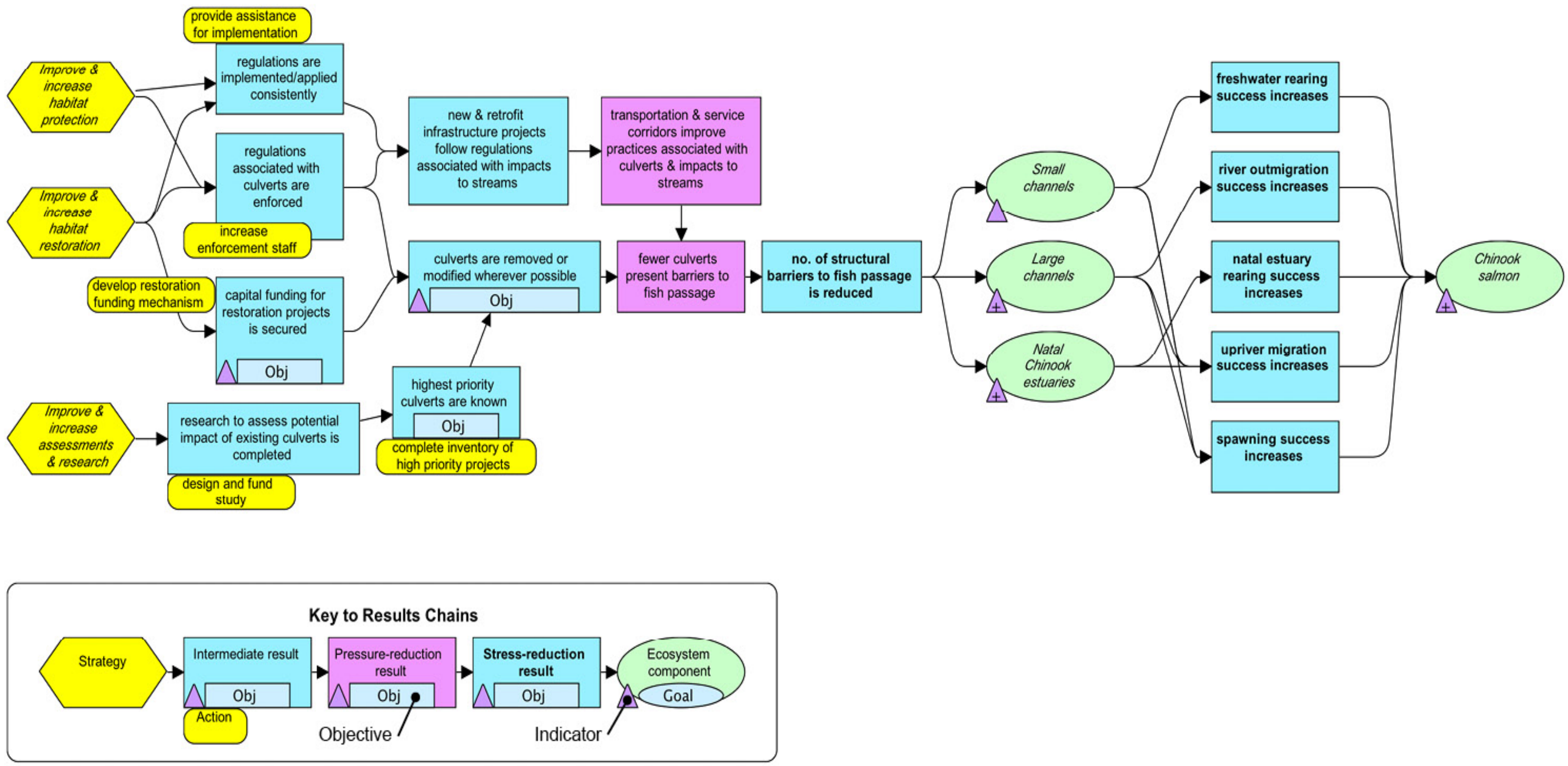


Figure 17. Example of a results chain addressing issues associated with culverts in salmon-bearing streams.

by selecting those that are most impacted by the pressures present in a watershed. Furthermore, 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 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 monitoring and adaptive management plans that are watershed-based and regionally consistent. 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. This process is further developed in the Toolkit document (LLTK and PSP 2014).

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 Recovery Plan (SSDC 2007). This includes goals, objectives, and assumptions

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

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. Initially, watershed managers identify a 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 Step 1 and Step 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 that 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, that is, 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 the 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 adopted by NMFS. Although recovery criteria apply to the regional scale of the Puget Sound Chinook Salmon ESU, the criteria demand knowledge of the status of all the independent populations that occur in the watersheds and across different biogeographical subregions 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-based and watershed-based monitoring of Chinook salmon viability documented by this framework specifically allows assessment of the status of Chinook salmon at the subregional and regional (Puget Sound) scales, that is, 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 ESA 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. Overutilization 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, consistent with the Final Supplement, includes a detailed list of KEAs and pressures and a systematic process for evaluating these. 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 furnishes the basis for describing, prioritizing, and designing monitoring that might be needed across watersheds. It also identifies monitoring needs within single watersheds that are 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 KEAs or other ecosystem components) will provide information regarding 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 Chinook populations. 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, NMFS specifically identified the development and implementation of such an approach as a requirement for approval of the Recovery Plan under the ESA (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 Open Standards for the Practice of Conservation (CMP 2007). 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 it 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 provide 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 a potential gap, lack of integration, or conflict between watershed strategies exists. The key to success of this process includes identifying indicators for ecosystem components and indicators 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 it can be corrected. This reflects what we define as adaptive management.

Glossary

This glossary has two subsections, one listing abbreviations and another listing terms related to ecosystem components. The latter list has terms grouped into three components: Chinook salmon life stages, freshwater habitats, and estuarine and marine habitats.

Abbreviations

BFW. For *bankfull width*. Channel width between the tops of banks on either side of a stream; tops of banks are the points at which water overflows its channel at bankfull discharge.

DO. For *dissolved oxygen*. The amount of oxygen that is present in the water, measured in milligrams per liter.

ESA. For *U.S. Endangered Species Act of 1973*. Passed by Congress, its purpose is to provide a means to conserve the ecosystems on which threatened and endangered species depend.

ESU. For *evolutionarily significant unit*. A population or group of populations that 1) is substantially reproductively isolated from other populations, and 2) represents an important component of the evolutionary legacy of the species.

GIS. For *Geographic Information System*. A computer system for assembling, storing, manipulating, and displaying geographically referenced information.

KEA. For *key ecological attribute*. The characteristic 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.

LWD. For *large woody debris*. A large piece of woody material such as a log or stump that intrudes into a stream channel.

MRV. For *marine riparian vegetation*.

NMFS. For *National Marine Fisheries Service*.

Open Standards. For *Open Standards for the Practice of Conservation* (CMP 2007).

PSP. For *Puget Sound Partnership*.

PS RITT. For *Puget Sound Recovery Implementation Technical Team*.

PS TRT. For *Puget Sound Technical Recovery Team*.

Recovery Plan. For *Puget Sound Salmon Recovery Plan*.

SAV. For *submerged aquatic vegetation*.

Toolkit. For *Chinook Monitoring and Adaptive Management Project Toolkit*.

TRT. For *Technical Recovery Team*.

VSP. For *viable salmonid population*. An independent population of any Pacific salmonid (genus *Oncorhynchus*) that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a long time frame.

WDFW. For *Washington Department of Fish and Wildlife*.

WDNR. For *Washington Department of Natural Resources*.

Terms Related to Ecosystem Components

Chinook Salmon Life Stages

Spawner. Sexually mature salmon at or very near locations where it 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 streambed 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 streambed 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 subadult 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 greater than 90 mm fork length (Beamer et al. 2005).

Subadult. 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, subadults are sometimes called blackmouth and can range from 2 to 6 years old.

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

Freshwater Habitats

Upland. Geomorphic surface with no defined channel. This surface may include isolated wetland.

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

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

Channel <50 m BFW. Mainstem and tributary channel (i.e., riverine habitat) with bankfull width less than 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-scale and habitat unit–scale classes follow Bisson et al. (1988), Montgomery and Buffington (1997), and Beechie et al. (2003a, 2003b, 2005).

Side channel. Active channel that is separated by stable islands from the main channel (i.e., large or small channel, 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).

Nonchannel lakes and wetlands. Deep-water or shallow-water, nonriverine habitats located in floodplains. These habitats may be lacustrine (lake, pond, or reservoir) or palustrine (wetland). 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. (1979), the defining characteristics of these habitats are as follows:

- Lacustrine habitats include deep-water and shallow-water bodies (i.e., lake, reservoir, pond, wetland) that are 1) located in topographic depressions or dammed channels and 2) not dominated by vegetation (areal coverage <30%), and c) larger than 8 ha in total area. Water bodies less than 8 ha in total area may be counted as lacustrine if they meet the first two criteria (1 and 2 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 water body boundary.
- Palustrine habitats include shallow water bodies (i.e., wetlands) that are either dominated by vegetation (i.e., areal coverage >30%) or lacking such vegetation but having 1) total areas less than 8 ha, 2) no active wave-formed or bedrock shoreline features, and 3) maximum water depths less than 2 m at low water.

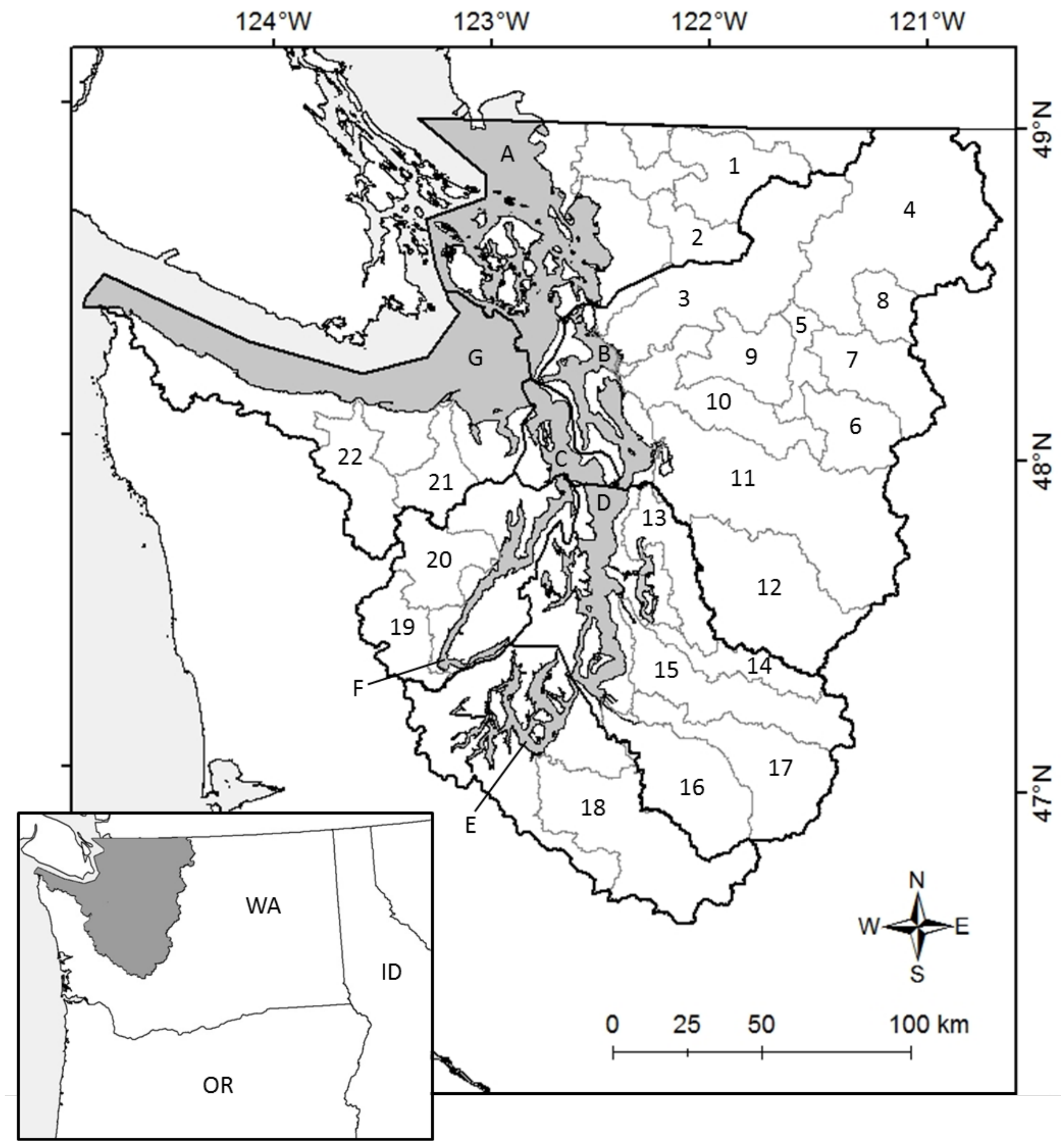
Estuarine and Marine Habitats

Geographic basin. 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 (see map of marine basins below). 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 (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 salmon estuaries. For the purposes of this framework, natal Chinook estuaries correspond to the "large river deltas" in PSNERP's Change Analysis data set (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 salmon populations (Ruckelshaus et al. 2006) (see map of marine basins and crosswalk table below). 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 (see classification systems table below).

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 2 system types, 5 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 (see classification systems table below).

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).



Marine basins (A−G) and Chinook salmon populations (1−22) within the Puget Sound region. Abbreviations (A−G and 1−22) are explained in the crosswalk table below.

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 the map above.

Marine basin*	**Large river delta name**	**Natal Chinook estuary?**	**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 the map (C, North Central Puget Sound) is not included, as no deltas/estuaries drain into this basin. Likewise, 2 of the 22 Chinook salmon populations depicted in the map (13, Sammamish River and 14, Cedar River) are not included because they currently have no large river deltas for their natal estuarine habitat.

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

Framework classification			**Other classification**		
System type	**System subtype**	**Shoreline type**	**Johannessen and MacLennan 2007**	**Shipman 2008**	**McBride et al. 2009**
Major river system	Natal Chinook estuary	Drowned channel	Not addressed	Open coastal inlet	Drowned channel
		River-dominated (fan) delta	Not addressed	Fan delta, river-dominated delta	Fan delta, river-dominated delta
		Tidal delta	Not addressed	Tide-dominated delta	Tide-dominated delta
		Delta lagoon	Not addressed	Barrier estuary, wave-dominated delta	Delta lagoon, drowned channel lagoon, tidal delta lagoon
Drift cell system	Coastal landform	Barrier beach (spit, cusp, tombolo)	Accretion shoreform	Barrier	Barrier beach
	Bluff-backed beach	Sediment source beach	Feeder bluff, feeder bluff (exceptional)	Bluff	Sediment source beach
		Depositional beach	Accretion shoreform	Bluff	Depositional beach
		Beach seep	Not addressed	Not addressed	Beach seep
		Plunging sediment bluff	Not addressed	Not addressed	Plunging sediment bluff
	Pocket estuary (embayment)	Drowned channel lagoon	Not addressed	Barrier estuary	Drowned channel lagoon
		Tidal delta lagoon	Not addressed	Barrier estuary	Tidal delta lagoon
		Longshore lagoon	Not addressed	Barrier lagoon	Longshore lagoon
		Tidal channel lagoon (or marsh)	Not addressed	Barrier lagoon	Tidal channel lagoon
		Closed lagoon and marsh	Not addressed	Closed lagoon and marsh	Closed lagoon and marsh
		Open coastal inlet	Not addressed	Open coastal inlet	Drowned channel

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

Framework classification			**Other classification**		
System type	**System subtype**	**Shoreline type**	**Johannessen and MacLennan 2007**	**Shipman 2008**	**McBride et al. 2009**
Rocky shoreline	Rocky pocket estuary	Pocket beach lagoon	Not addressed	Barrier estuary	Pocket beach lagoon
		Pocket beach estuary	Not addressed	Barrier estuary	Pocket beach estuary
		Pocket beach closed lagoon and marsh	Not addressed	Pocket beach closed lagoon and marsh	Pocket beach closed lagoon and marsh
	Rocky beach	Veneered rock platform	Not addressed	Platform	Veneered rock platform
		Rocky shoreline	Not addressed	Platform	Rocky shoreline
		Plunging rocky shoreline	Not addressed	Plunging	Plunging rocky shoreline
		Pocket beach	Not addressed	Pocket beach	Pocket beach

* 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 comanaged by the Western Washington Treaty Indian Tribes and WDFW.

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Appendix A: Terminology Crosswalk

Table A-1. Crosswalk of terminology common to our framework, the Puget Sound Partnership (PSP), Open Standards for the Practice of Conservation (CMP 2007), and the Miradi software package. Framework terms are ordered alphabetically. (Definitions adapted from CMP 2007.)

Framework/PSP term	Open Standards/ Mirandi term	Definition
Action	Activity	Activity that is 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 factor	Factor	Human-induced action or event that contributes 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.
Driver	Indirect threat	Human-induced action, event, or natural process that contributes 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 component	Conservation target	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.
Goal/target (framework and PSP terms, respectively)	Goal	A measure of an ecosystem component or pressure, representing the desired future condition of the component or pressure.
Indicator (for an ecosystem component)	Indicator	A measure of condition or status—in this case, of an ecosystem component.
Indicator (for intermediate results)	Indicator	A measure of effectiveness or progress toward the objectives of intermediate results.
Indicator (for pressure)	Indicator	A measure of condition or status—in this case, of a pressure.

Table A-1 continued. Crosswalk of terminology common to our framework, the Puget Sound Partnership (PSP), Open Standards for the Practice of Conservation (CMP 2007), and the Miradi software package. Framework terms are ordered alphabetically. (Definitions adapted from CMP 2007.)

Framework/PSP term	Open Standards/ Mirandi term	Definition
Intermediate results	Results or outcomes	The desired or expected results (aka, changes to contributing factors) that would follow from the implementation of strategies and the completion of actions.
Key ecological attribute (KEA)	KEA	Aspect of an ecosystem component's biology that, if missing or altered, would lead to the loss of the component or its ecological integrity.
Objective (for intermediate results)	Objective	A quantitative, time-bound measure associated with intermediate results, reflecting the desired future outcome.
Objective (for pressures)	Objective	A quantitative, time-bound measure associated with the status of a pressure, representing 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 their contribution to specific stresses associated with KEAs of components.
Pressure	Direct threat	Pressures are primarily human activities that directly affect ecosystem components or alter key ecological processes (e.g., hydrological dynamics) common to multiple ecosystem components. They 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 that 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).
Stress	Stress	A stress is equivalent to an altered or degraded KEA of an ecosystem component. It is an impaired aspect of the ecosystem and results directly from human activities or natural pressures on the ecosystem.
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.

Appendix B: Supporting Information for Select Elements

The five selected elements in this appendix are pressures (Table B-1 and Table B-2), stresses (Table B-3 and Table B-4), contributing factors (Table B-5), drivers (Table B-6), and strategies (Table B-7).

Pressures

A pressure taxonomy has been developed by the Puget sound Partnership (PSP) to support assessment of threats to Puget Sound ecosystems and identification of priority actions to reduce those threats. Pressures are defined as human activities or processes that have caused, are causing, or may cause the destruction, degradation, or impairment of ecosystem components. Pressures include both stressors, the most proximate agents of change to the ecosystem, and the sources of stressors. Table B-1 and Table B-2 identify the pressure–source and pressure–stressor classifications, respectively. These classifications represent a modest revision to the Pressure Taxonomy that was included in the 2012/2013 action agenda for Puget Sound (PSP 2012). They were revised through the Puget Sound Pressure Assessment Project (https://sites.google.com/site/pressureassessment) to better capture sources of stress in Puget Sound and for better alignment with the International Union for Conservation of Nature threat taxonomy.

Table B-1. Taxonomy of Puget Sound pressure sources based on previous classifications (IUCN 2001, Salafsky et al. 2008). Minor modifications by the PSP resulted in eight source categories. Sources are the cause of stressors that in turn are the causes of stressed conditions in the ecosystem.

Source class	Definition and exposition	Puget Sound examples
1. Residential and commercial development	*Human settlements or other nonagricultural land uses with a substantial footprint.* These sources of stress are tied to a defined and relatively compact area, which distinguishes them from those in 4, Transportation and service corridors, which have a long narrow footprint, and 6, Human intrusions and disturbance, which do not have an explicit footprint.	—
1.1. Housing and urban areas	*Human cities, towns, and settlements including nonhousing development typically integrated with housing.* This class dovetails with 1.2, Commercial and industrial areas (including ports). As a general rule, however, if people live in the development, it should fall into this source class. This class does not include transportation and utility infrastructure, water use, shoreline armoring and overwater structures, or runoff and other pollution associated with any developed areas (see 4, 7, and 9).	Urban areas, suburbs, villages, ranchettes, vacation homes, shopping areas, offices, schools, hospitals, land reclamation, or expanding human habitation that causes habitat conversion or degradation in riverine, estuary, and coastal areas, etc.
1.2. Commercial and industrial areas (including ports)	*Factories and other commercial centers.* Shipyards and airports fall into this class, whereas shipping lanes and flight paths fall under 4, Transportation and service corridors. Overwater structures and shoreline armoring associated with marinas and ports full under 7, Natural system modifications. Water use and dams are also covered under 7. For runoff and other pollution associated with commercial and industrial areas, see 9, Pollution.	Military bases, factories, stand-alone shopping centers, office parks, power plants, train yards, shipyards, ports, airports, landfills, etc.
1.3. Tourism and recreation areas	*Tourism and recreation sites with a substantial footprint.* This class includes vacation housing/resorts and associated habitat effects of recreation areas. However, disturbance effects posed by recreational activities outside the footprint of developed areas are included in 6.1, Recreational activities.	Ski areas, golf courses, resorts, ball fields, county parks, campgrounds, coastal and estuarine tourist resorts, etc.
2. Agriculture and aquaculture	*Farming and ranching practices, expansion and intensification, including silviculture, mariculture and aquaculture (includes the impacts of any fencing around farmed areas).* The use of agrochemicals, rather than the direct conversion of land to agricultural use, should be included under 9.3, Agricultural and forestry effluents. Likewise in cases where conversion to agriculture causes increased runoff and hence sedimentation of rivers and lakes, that is also best treated under 9.3.	—

Table B-1 continued. Taxonomy of Puget Sound pressure sources based on previous classifications (IUCN 2001, Salafsky et al. 2008). Minor modifications by the PSP resulted in eight source categories. Sources are the cause of stressors that in turn are the causes of stressed conditions in the ecosystem.

Source class	Definition and exposition	Puget Sound examples
2.1. Annual and perennial nontimber crops	*Crops planted for food, fodder, fiber, fuel, or other uses.* This class includes small-holder farming, agro-industry farming, and rotating agriculture.	—
2.2. Wood and pulp plantations	*Stands of trees planted for timber or fiber outside of natural forests, often with nonnative species.* If it is one or a couple of timber species that are planted on a rotation cycle, it belongs here. If it is multiple species or enrichment plantings in a quasi-natural system, it belongs in 5.3, Logging and wood harvesting. This class includes small-holder and agro-industry plantations.	—
2.3. Livestock farming and ranching	*Domestic terrestrial animals raised in one location on farmed or nonlocal resources (farming); also domestic or semidomesticated animals allowed to roam in the wild and supported by natural habitats (ranching).* This class includes small-holder grazing, ranching, or farming, and agro-industry grazing, ranching, or farming, and nomadic grazing. In farming, animals are kept in captivity; in ranching they are allowed to roam in wild habitats. Forage of wild resources for stall-fed animals falls under 5.2, Gathering terrestrial plants. If a few animals are mixed in a subsistence cropping system, it belongs in 2.1, Annual and perennial nontimber crops.	—
2.4. Marine and freshwater finfish aquaculture	*Finfish raised in one location on farmed or nonlocal resources; also hatchery fish allowed to roam in the wild.* This class includes pressures associated with the location, intensification, or practice of finfish aquaculture. Farmed animals are kept in captivity; hatchery fish are put into wild habitats and are the aquatic equivalent of terrestrial ranching.	—
2.5. Marine shellfish aquaculture	*Marine shellfish raised in one location on farmed or nonlocal resources.* This class includes pressures associated with the location, intensification, or practice of shellfish aquaculture.	—
3. Energy production and mining	*Production of nonbiological resources.* Various forms of water use (for example, dams for hydro power) that involve alterations to hydrologic regimes should go in 7.2, Dams and water management/use.	—

Table B-1 continued. Taxonomy of Puget Sound pressure sources based on previous classifications (IUCN 2001, Salafsky et al. 2008). Minor modifications by the PSP resulted in eight source categories. Sources are the cause of stressors that in turn are the causes of stressed conditions in the ecosystem.

Source class	Definition and exposition	Puget Sound examples
3.1. Oil and gas drilling	*Exploring for, developing, and producing petroleum and other liquid hydrocarbons.* Oil and gas pipelines go into 4.2, Utility and service lines. Spills (oil or other hazardous substances) associated with drilling or transportation of oil go in 9.2, Industrial and military effluents.	Oil wells, deep sea natural gas drilling, hydraulic fracking, etc.
3.2. Mining and quarrying	*Exploring for, developing, and producing minerals and rocks.* Deforestation caused by strip mining should be included here if the motivation is access to minerals. It should be included in 5.3, Logging and wood harvesting, if the primary motivation is access to the trees. Sediment or toxic chemical runoff from mining is under 9.2, Industrial and military effluents.	Coal strip mines, alluvial gold panning, gold mines, rock quarries, sand/salt mines, coral mining, deep sea nodules, guano harvesting, dredging outside of shipping lanes, etc.
3.3. Renewable energy	*Exploring, developing, and producing renewable energy.* Hydropower should be put in 7.2, Dams and water management/use.	Geothermal power production, solar farms, wind farms (including birds flying into windmills), tidal farms, etc.
4. Transportation and service corridors	*Long narrow transport corridors and the vehicles that use them.* This includes transportation and utility corridors outside of human settlements and industrial developments in terrestrial and aquatic environments. These corridors are associated with specific stressors including especially fragmentation of habitats and direct species mortality.	—
4.1. Roads and railroads (including culverts)	*Surface transport on roadways and dedicated tracks.* Off-road vehicles are treated in the appropriate category in 6, Human intrusions and disturbance. If there are small roads associated with a major utility line, they belong in 4.2, Utility and service lines.	Highways, secondary roads, primitive roads, logging roads, bridges and causeways, fencing associated with roads, freight/passenger/ mining railroads, etc.
4.2. Utility and service lines	*Transport of energy and resources.* Cell phone and other communication towers connected by small access roads belong here. If there are small utility lines using a road right of way, they belong in 4.1, Roads and railroads. Oil spills from pipelines go in 9.2, Industrial and military effluents.	Electrical and phone wires, aqueducts, oil and gas pipelines, electrocution of wildlife, etc.

Table B-1 continued. Taxonomy of Puget Sound pressure sources based on previous classifications (IUCN 2001, Salafsky et al. 2008). Minor modifications by the PSP resulted in eight source categories. Sources are the cause of stressors that in turn are the causes of stressed conditions in the ecosystem.

Source class	Definition and exposition	Puget Sound examples
4.3. Shipping lanes and dredged waterways	*Transport on and in freshwater and ocean waterways.* This class includes vessel traffic as well as dredging and other activities that maintain shipping lanes. Wastewater discharge from tugs and nonmilitary cargo vessels is also included here. Anchor damage from dive boats belongs in 6.1, Recreational activities. Oil spills from ships go in 9.2, Industrial and military effluents.	Canals, shipping lanes, whale-watching routes, wakes from cargo ships, etc.
4.4. Flight paths	*Air and space transport.* Airports fall into 1.2, Commercial and industrial areas.	Flight paths, jets impacting birds, etc.
5. Biological resource use	*Consumptive use of "wild" biological resources; also persecution or control of specific species.*	—
5.1. Hunting and collecting terrestrial animals	*Killing or trapping terrestrial wild animals or animal products for commercial, recreation, subsistence, research or cultural purposes, or for control/persecution reasons.* This class focuses on animals that primarily live in a terrestrial environment, as well as those that live on the terrestrial/aquatic boundary. Hunting otters, beavers, amphibians, waterfowl, and sea birds belongs here. Hunting seals, whales and other marine mammals, and freshwater and marine turtles goes in 5.4, Fishing and harvesting aquatic resources. This also includes animal products that are traditionally "gathered," such as honey, eggs, or insects or other slow moving targets.	Trophy hunting, beaver trapping, butterfly collecting, honey or bird nest hunting, etc.; pest control, hunting with dogs, wolf control, persecution of snakes because of superstition, etc.
5.2. Gathering terrestrial plants	*Harvesting plants, fungi, and other nontimber/nonanimal products for commercial, recreation, subsistence, research or cultural purposes, or for control reasons.* This class focuses on plants, mushrooms, and other nonanimal terrestrial species except trees, which are treated in 5.3, Logging and wood harvesting. This source can have intentional and unintentional impacts on target and nontarget species.	Wild mushroom collection, forage for stall-fed animals, orchid collection, harvesting of flowers and greens, etc.; control of host plants to combat timber diseases, etc.

Table B-1 continued. Taxonomy of Puget Sound pressure sources based on previous classifications (IUCN 2001, Salafsky et al. 2008). Minor modifications by the PSP resulted in eight source categories. Sources are the cause of stressors that in turn are the causes of stressed conditions in the ecosystem.

Source class	Definition and exposition	Puget Sound examples
5.3. Logging and wood harvesting	*Harvesting trees and other woody vegetation for timber, fiber, or fuel.* This includes subsistence-scale use and large-scale use, both of which can have intentional and unintentional effects on target and nontarget species. Felling trees to clear agricultural land belongs in 2, Agriculture and aquaculture. If it is a few timber species that are planted on a rotation cycle, it belongs in 2.2, Wood and pulp plantations. If it is multiple species or enrichment plantings in a quasi-natural system, it belongs here. Consider the specific product(s) harvested and the method used (e.g., clear cutting of hardwoods, selective commercial logging, pulp or woodchip operations, fuel wood collection, etc.).	—
5.4. Fishing and harvesting aquatic resources	*Harvesting aquatic wild animals or plants for commercial, recreation, subsistence, research, or cultural purposes, or for control/persecution reasons; includes accidental mortality/bycatch.* This category focuses on all kinds of species that are primarily found in an aquatic environment as well as some species that live on the terrestrial/aquatic boundary. Hunting seals, whales and other marine mammals, and freshwater and marine turtles goes here. Hunting otters, beavers (*Castor canadensis*), amphibians, waterfowl, and sea birds belongs in 5.1, Hunting and collecting terrestrial animals. This class includes large-scale harvest and subsistence/small-scale harvest and can be a source of multiple stressors, including harvest (intentional), and discards or bycatch (unintentional). Note that associated stresses can be both ecosystem degradation and species mortality.	Commercial trawling, commercial long-line fisheries, whaling, seal hunting, turtle egg collection, live coral collection, seaweed collection, blast fishing, cyanide fishing, artisinal trawling, shark nets trapping nontarget species, loss of a species' prey base due to overharvesting by humans of their prey, beach protection with shark nets, sharks and seals killed because they eat commercial fish species, etc.
6. Human intrusions and disturbance	*Human activities that alter, destroy, and disturb habitats and species associated with nonconsumptive uses of biological resources.* Nonconsumptive use means that the resource is not removed (i.e., multiple people can use the same resource, e.g., birdwatching). These pressures typically do not permanently destroy habitat except perhaps in extremely severe manifestations.	—

Table B-1 continued. Taxonomy of Puget Sound pressure sources based on previous classifications (IUCN 2001, Salafsky et al. 2008). Minor modifications by the PSP resulted in eight source categories. Sources are the cause of stressors that in turn are the causes of stressed conditions in the ecosystem.

Source class	Definition and exposition	Puget Sound examples
6.1. Recreational activities	*People spending time in nature or traveling in vehicles outside of established transport corridors, usually for recreational reasons.* This class includes wastewater discharged from recreational vessels. It does not include work involving consumptive use of biodiversity. For example, disturbance impacts from loggers or hunters would appropriately be in category 5, Biological resource use. Vehicles in established transport corridors go in 4, Transportation and service corridors. The development of activities at permanent recreational or tourist facilities (such as hotels and resorts) belongs under section 1.3, Tourism and recreation areas, rather than here.	Off-road vehicles, motorboats, motorcycles, jet skis, snowmobiles, ultralight planes, dive boats, whale watching, mountain bikes, hikers, cross-country skiers, hang gliders, birdwatchers, scuba divers, pets brought into recreation areas, temp-orary campsites, caving, rock climbing, etc.
6.2. War, civil unrest, and military exercises	*Actions by formal or paramilitary forces without a permanent footprint.* This class focuses on military activities that have a large impact on natural habitats, but are not permanently restricted to a single area. It also includes wastewater discharged from military vessels. Development and operation of permanent military bases goes under 1.2, Commercial and industrial areas.	Armed conflict, mine fields, tanks and other military vehicles, training exercises and ranges, defoliation, munitions testing, etc.
6.3. Work and other activities	*People spending time in or traveling in natural environments for reasons other than recreation or military activities.*	Law enforcement, drug smugglers, illegal immigrants, species research, vandalism, etc.
7. Natural system modifications	*Actions and structures that convert or degrade habitat in service of "managing" natural or seminatural systems.* This class deals primarily with changes to natural processes such as fire, hydrology, and sedimentation, rather than land use. Thus it does not include pressures relating to agriculture (which should be under 2, Agriculture and aquaculture), or infrastructure (1, Residential and commercial development and 4, Transportation and service corridors).	—
7.1. Fire and fire suppression	*Suppression or increase in fire frequency or intensity outside its natural range of variation.* This class focuses on the human activities that lead to either not enough fire or too much fire in the ecosystem in question. If fire escapes from established agricultural lands, it belongs here, if fire is used to clear new agricultural lands, it belongs in 2, Agriculture and aquaculture. It also includes damaging "natural" fires in systems that have lost their natural resilience.	Inappropriate fire management, escaped agricultural fires, arson, campfires, fires for hunting, fire suppression to protect homes, etc.

Table B-1 continued. Taxonomy of Puget Sound pressure sources based on previous classifications (IUCN 2001, Salafsky et al. 2008). Minor modifications by the PSP resulted in eight source categories. Sources are the cause of stressors that in turn are the causes of stressed conditions in the ecosystem.

Source class	**Definition and exposition**	**Puget Sound examples**
7.2. Dams and water manage-ment/use	*Changing water flow patterns from their natural range of variation, either deliberately or as a result of other activities.* This class focuses on the human activities that lead to either not enough water or too much water in the ecosystem in question. Note that homogenizing flows to a constant level may be outside the "natural range of variation." This includes surface water diversion, channelization, ditching, artificial lakes, groundwater pumping, dam construction, release of too little or cold water from dam operations, sediment control, dikes, levees, floodgates and tide gates, etc. Dredging belongs in 4.3, Shipping lanes.	—
7.2.1. Abstraction of surface water	*Diverting or withdrawing surface water.*	—
7.2.2. Abstraction of ground water	*Pumping or other extraction of groundwater.*	—
7.2.3. Dams	*Construction or operation of dams used to generate hydropower or manage how and when water flows through a system.* Impacts associated with dams include conversion/loss or degradation of habitat, altered hydrology, and altered connectivity.	—
7.2.4. Freshwater levees, floodgates, tide gates	*Levees and floodgates along freshwater systems to manage the hydrologic flow in a system.* Impacts associated with levees and floodgates include conversion/loss or degradation of habitat, altered hydrology, and altered connectivity.	—
7.2.5. Marine levees, floodgates, tide gates	*Levees and tide gates along marine water systems to manage or exclude marine water into the freshwater system.* Impacts associated with levees and tide gates include conversion or degradation of habitat, altered hydrology, and altered connectivity.	—
7.3. Freshwater shoreline infrastructure	*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.* Runoff from impervious surfaces or other water pollution should go in 9.1.	—

Table B-1 continued. Taxonomy of Puget Sound pressure sources based on previous classifications (IUCN 2001, Salafsky et al. 2008). Minor modifications by the PSP resulted in eight source categories. Sources are the cause of stressors that in turn are the causes of stressed conditions in the ecosystem.

Source class	Definition and exposition	Puget Sound examples
7.4. Marine shoreline infrastructure	*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.* Runoff from impervious surfaces or other water pollution should go in 9.1.	—
9. Pollution	*Introduction of exotic or excess materials or energy from point and nonpoint sources.*	—
9.1 Domestic and urban waste water	—	—
9.1.1. Domestic and commercial sewage	—	—
9.1.1.1. Domestic and municipal wastewater to sewer	*Discharges from municipal wastewater treatment plants (WWTPs) into hydrologic systems.* This class includes waterborne sewage that includes nutrients, pathogens, toxic chemicals, and sediments. Discharges from combined sewer overflows (CSOs) are included here. Onsite sewage systems (OSSs) go in 9.1.1.2. This class does not include wastewater discharged from recreational and other vessels (see 4.3, 6.1, and 6.2) or biosolids applied in terrestrial environments (see 9.3).	—
9.1.1.2. Domestic and commercial wastewater to OSSs	*Discharges from OSSs.* This class includes sewage and leachates (nutrients, toxic chemicals or sediment) from residences and commercial facilities not connected to a municipal system (septics, small private systems, and everything with a drain field).	—
9.1.2. Runoff from residential and commercial lands	*Introduction of exotic or excess material into hydrologic system due to surface water loading and runoff from the built environment.* This class includes runoff from commercial and residential lands, transportation facilities and corridors, as well as hull cleaning and other pollution from marina infrastructure and land-based boat maintenance practices (i.e., National Pollutant Discharge Elimination System–regulated activities that occur in marinas and shipyards). Loading from septic systems (OSSs) goes in 9.1.1.2, CSOs go in 9.1.1.1, runoff from other activities (e.g., agriculture, timber harvest) goes in 9.3, and industrial runoff goes in 9.2.4.	—

Table B-1 continued. Taxonomy of Puget Sound pressure sources based on previous classifications (IUCN 2001, Salafsky et al. 2008). Minor modifications by the PSP resulted in eight source categories. Sources are the cause of stressors that in turn are the causes of stressed conditions in the ecosystem.

Source class	**Definition and exposition**	**Puget Sound examples**
9.2. Industrial and military effluents	*Waterborne pollutants from industrial and military sources including mining, energy production, and other resource extraction industries that include nutrients, toxic chemicals, or sediments.* The source of the pollution is often far from the system—an extreme example is the heavy metals that migrating eels bring to the Sargasso Sea. Often the pollutants only become a problem when they bioconcentrate through the food chain.	—
9.2.1. Oil spills	*Accidental, episodic, or potentially catastrophic spill of oil and hazardous waste in aquatic and terrestrial environments.* This class includes oil spills from pipelines, vessels, marine terminals, and industrial facilities. It does not include chronic or other frequent, smaller pollution events related to normal operations of vehicles, vessels, etc. (see 9.1.2).	—
9.2.2. Seepage from mining	*Waterborne pollutants from mining, including nutrients, toxic chemicals, or sediments.*	—
9.2.3. Industrial wastewater	*Discharge from industrial WWTPs into hydrologic systems.* This class includes waterborne sewage that includes nutrients, pathogens, toxic chemicals, and sediments. Loading from municipal and domestic WWTPs goes in 9.1.1.1, septic systems (OSSs) go in 9.1.1.2, CSOs go in 9.1.1.1, runoff from other activities (e.g., agriculture, timber harvest) goes in 9.3, and industrial runoff goes in 9.2.4.	—
9.2.4. Industrial runoff	*Introduction of exotic or excess material into hydrologic system due to surface water loading and runoff from industrial lands.* This class includes runoff from industrial facilities and lands. Runoff from other lands (residential and commercial) goes in 9.1.2, loading from septic systems (OSSs) goes in 9.1.1.2, CSOs go in 9.1.1.1, runoff from other activities (e.g., agriculture, timber harvest) goes in 9.3, and industrial runoff goes in 9.2.4.	—

Table B-1 continued. Taxonomy of Puget Sound pressure sources based on previous classifications (IUCN 2001, Salafsky et al. 2008). Minor modifications by the PSP resulted in eight source categories. Sources are the cause of stressors that in turn are the causes of stressed conditions in the ecosystem.

Source class	Definition and exposition	Puget Sound examples
9.3. Agricultural and forestry effluents	*Waterborne pollutants from agricultural, silvicultural, and aquaculture systems that include nutrients, toxic chemicals, or sediments and the effects of these pollutants on the site where they are applied.* This class also includes pollutants added by biosolids, herbicide, and pesticide application. Wind erosion of agricultural sediments or smoke from forest fires goes in 9.5, Airborne pollutants.	Nutrient loading from fertilizer runoff, manure from feedlots, nutrients from aquaculture, etc.; soil erosion from overgrazing, increased runoff and hence sedimentation due to conversion of forests to agricultural lands, etc.; herbicide runoff from orchards, etc.
9.4. Garbage and solid waste	*Rubbish and other solid materials including those that entangle wildlife.* This class generally is for solid waste outside of designated landfills; landfills themselves should go in 1.2, Commercial and industrial areas. Likewise, toxins leaching from solid waste (e.g., mercury leaking out of a landfill into groundwater) should go in 9.2, Industrial and military effluents.	Municipal waste, litter from cars, flotsam and jetsam from recreational boats, waste that entangles wildlife, construction debris, etc.
9.5. Airborne pollutants	*Atmospheric pollutants from stationary and mobile sources.* This class includes smog and ozone, the specific sources of which can be difficult to determine and difficult to address.	Smog from vehicle emissions, factory smoke emissions, coal burning, wind dispersion of pollutants or sediments, smoke from forest fires or woodstoves, etc. Associated stressors can include acid rain, excess nitrogen deposition, radioactive fallout.
9.6. Release of excess energy (light, heat, sound)	*Inputs of heat, sound, or light that disturb wildlife or ecosystems.* These inputs of energy can have strong effects on some species or ecosystems.	Lamps attracting insects, beach lights disorienting turtles, etc.; heated water from power plants, damaging atmospheric radiation resulting from ozone holes, etc.; noise from highways or airplanes, sonar from submarines that disturbs whales, etc.

Table B-2. Puget Sound stressors, the most proximate agents of change to Puget Sound ecosystems, including both human and natural processes that impair or degrade the system. The 39 stressor classes are grouped into 26 higher level categories.

Code	Name	Description
01	Habitat conversion due to human land use change	—
01.1	Conversion of land cover for residential, commercial, and industrial use	Conversion of land cover to one dominated by residential, commercial, or industrial development. In the terrestrial and nearshore environments, sources include residential and commercial development; in the marine environment, consider conversion for marinas and other marine uses. Agriculture and aquaculture (see 01.2) and dredging (see 01.3) are assessed separately. Stress associated with disturbance due to human activities (including in developed areas) is addressed separately (see 07). Terrestrial habitat fragmentation (see 02), shoreline hardening (see 03), and barriers to terrestrial animal movement and migration (see 06) are addressed as separate stressors. Pollution impacts are assessed through separate stressors (see 22 through 23). Note that conversion can be a step-wise process where, for example, native forest land is converted to managed forests, which are then under stress for further conversion to agriculture or residential and commercial development.
01.2	Conversion of land cover for natural resource production	Conversion of land cover to one dominated by natural resource production, such as through agriculture and timber production in terrestrial environments and aquaculture in marine and nearshore environments. This stressor has to do with the reduction in extent and quality of habitat due to conversion. Stress associated with disturbance due to human activities (including in developed areas) is addressed separately (see 07). Terrestrial habitat fragmentation (see 02), shoreline hardening (see 03), and barriers to terrestrial animal movement and migration (see 06) are addressed as separate stressors. Pollution impacts are assessed through separate stressors (see 22 through 23). Note that conversion can be a step-wise process where, for example, native forest land is converted to managed forests, which are then under stress for further conversion to agriculture or residential and commercial development.
01.3	Conversion of land cover for transportation and utilities	Conversion of land cover to one dominated by transportation and service corridors. This stressor has to do with the reduction in extent and quality of habitat due to conversion, including conversion by dredging. Stress associated with disturbance due to human activities (including in developed areas) is addressed separately (see 07). Terrestrial habitat fragmentation (see 02), shoreline hardening (see 03), and barriers to terrestrial animal movement and migration (see 06) are addressed as separate stressors. Pollution impacts are assessed through separate stressors (see 22 through 23).

Table B-2 continued. Puget Sound stressors, the most proximate agents of change to Puget Sound ecosystems, including both human and natural processes that impair or degrade the system. The 39 stressor classes are grouped into 26 higher level categories.

Code	**Name**	**Description**
02	Terrestrial habitat fragmentation	Division of contiguous habitat into smaller, discontiguous patches or different habitat types. Sources of this stressor include development of lands for agriculture, residential, commercial, or industrial uses, or roads and utility corridors. Expressions of this stressor will depend on the endpoint one is assessing. For example, bobcat (*Lynx rufus*) and certain small passerine birds may have minimum patch size requirements on the order of 25 ha and 3 ha, respectively. Landscapes in which habitat patches are predominantly smaller than these minimums are unlikely to support these species. Disturbance due to human activities (see 07) and habitat conversion (see 01) are evaluated as separate stressors.
03	Shoreline hardening	Change of shoreline habitat or features to conditions that reduce habitat extent or disrupt shoreline processes. The primary source of this stressor is the construction of shoreline infrastructure that produces a hard linear surface along the beach or streambank to reduce erosion (e.g., seawalls, revetments, riprap, and rock piles). Habitat conversion for residential, commercial and industrial development, and other uses is evaluated separately (see 01).
04	Shading of shallow water habitat	Decreased light transmitted into shallow waters. This stressor causes species stresses related to productivity or altered predator-prey relationships. The primary source of this stressor is construction of overwater and onshore structures.
05	Fish passage barriers	—
05.1	Dams as fish passage barriers	Dams that block or impede movements and migrations of fish and other aquatic animals. This stressor is intended to evaluate only effects on fish and other aquatic species; effects on flow regulation (see 12) and physical processes (see 13) are evaluated as separate stressors. Fish passage barriers created by culverts and other structures are evaluated as separate stressors (see 05.2).
05.2	Culverts and other fish passage barriers	Structures other than dams that block or impede movements and migrations of fish and other aquatic animals. Includes structures in, alongside, and across water bodies. This stressor is intended to evaluate only effects on fish and other aquatic species; effects on flow regulation (see 12) and physical processes (see 13) are evaluated separately. Fish passage barriers created by dams are evaluated as separate stressors (see 05.1).

Table B-2 continued. Puget Sound stressors, the most proximate agents of change to Puget Sound ecosystems, including both human and natural processes that impair or degrade the system. The 39 stressor classes are grouped into 26 higher level categories.

Code	Name	Description
06	Barriers to terrestrial animal movement and migration	Structures that block or impede movements and migrations of terrestrial animals such as roads and utility infrastructure. Expressions of this stressor will depend on the endpoint one is assessing. For example, for terrestrial species such as elk (*Cervus elaphus*), a strong expression of the stressor may be structures such as multilane roads; for avian species a strong expression of the stressor may be energy infrastructure such as wind turbines. Disturbance due to human activities (see 07) and terrestrial habitat fragmentation (see 02) are evaluated as separate stressors.
07	Species disturbance—terrestrial and freshwater	—
07.1	Terrestrial and freshwater species disturbance in human-dominated areas	Alteration in the feeding, breeding, or resting behaviors of fish or wildlife due to human presence or activities associated with landscapes dominated by man-made structures, such as light and sound disturbances associated with developed areas. Includes artifacts and debris associated with human activities, except pollution impacts are evaluated through separate stressors (see 22 through 23).
07.2	Terrestrial and freshwater species disturbance in natural landscapes	Alteration in the feeding, breeding, or resting behaviors of fish or wildlife and adverse impacts on plant communities due to human presence or activities in more natural landscapes, such as disturbance associated with recreation and vehicle traffic on forest roads. Includes artifacts and debris associated with human activities, except pollution impacts are assessed through separate stressors (see 22 through 23).
08	Species disturbance—marine	Alteration in the feeding, breeding, or resting behaviors of marine birds, fish, or other aquatic species due to human presence or activities (e.g., recreation, vessel traffic, military exercises) or artifacts and debris associated with activities, except pollution impacts (see 22 through 23) and derelict fishing gear (see 09) are assessed through separate stressors.
09	Derelict fishing gear	Mortality associated with entanglement in abandoned nets and other fishing gear.
10	Increased frequency and magnitude of storm flow	—
10.1	Altered peak flows from land cover change	Altered peak flows into and in surface waters related to changes in land cover and the associated surface hardening, and associated impacts, such as changes in sediment and debris delivery. Stress from pollution impacts is evaluated separately (see 22 through 23). Altered peak flow from climate change is evaluated separately (see 10.2).

Table B-2 continued. Puget Sound stressors, the most proximate agents of change to Puget Sound ecosystems, including both human and natural processes that impair or degrade the system. The 39 stressor classes are grouped into 26 higher level categories.

Code	Name	Description
10.2	Altered peak flows from climate change	Altered peak flows into and in surface waters related to changes in precipitation volume and timing due to climate change and associated impacts, such as changes in sediment and debris delivery. Stress from pollution impacts is evaluated separately (see 22 through 23). Altered peak flow from land cover change is evaluated separately (see 10.1).
11	Reduction in base flows	—
11.1	Altered low flows from land cover change	Reduction of low flows in surface waters related to changes in land cover and the associated surface hardening and changes in hydrology. Other reductions of low flows are evaluated separately (see 11.2 and 11.3).
11.2	Altered low flows from climate change	Reduction of low flows in surface water related to changes in precipitation volume and timing due to climate change, resulting in reduced glacial coverage and snowpack or changes in the timing and rate of snowmelt. Other reductions of low flows are evaluated separately (see 11.1 and 11.3).
11.3	Altered low flows from withdrawals	Reduction of low flows in surface waters related to water withdrawals for human use and consumption. Other reductions of low flows are evaluated separately (see 11.1 and 11.3).
12	Flow regulation—prevention of flood flows	Modification of flood flows by flow regulation in river and stream systems. Sources of this stressor are the impoundment of water by dams and the operation of dams for flood control or hydroelectric power production. These structures may also be barriers to movement and migration of fish and aquatic animals, evaluated separately (see 05.1).
13	Structural barriers to water, sediment, debris flow (including flood flows)	—
13.1	In-channel structural barriers to water, sediment, debris flows	Structures that block or restrict movement of water, sediment, or debris flow in the river or stream channel and associated impacts, such as changes in sediment and debris delivery. These structures may also be barriers to movement and migration of fish and aquatic animals, evaluated separately (see 05.2). Impacts associated with dams also are evaluated separately (see 05.1 and 12).
13.2	Other structural barriers to water, sediment, debris flows	Structures that block or restrict movement of water, sediment, or debris flow into the floodplain, such as levees, and associated impacts, such as changes in sediment and debris delivery. These structures may also be barriers to movement and migration of fish and aquatic animals, evaluated separately (see 05.2). Impacts associated with dams also are evaluated separately (see 05.1 and 12).

Table B-2 continued. Puget Sound stressors, the most proximate agents of change to Puget Sound ecosystems, including both human and natural processes that impair or degrade the system. The 39 stressor classes are grouped into 26 higher level categories.

Code	Name	Description
14	Animal harvest	Removal of fish, invertebrates, or wildlife for human use. This stressor includes intentional harvest or removals only and is meant to assess the effect of intentional harvest on species. Sources of this stressor include fishing, hunting, and collections in support of species' management or investigation. Stress from bycatch is evaluated separately (see 15). Stress from disturbance associated with harvest activities also is evaluated separately (see 07.2).
15	Bycatch	Removal of nontarget species of fish, invertebrates, or wildlife caught during commercial or recreational fishing.
16	Plant harvest	—
16.1	Timber harvest	Removal of timber for human use. The strong expression of this stressor is clear cutting. Stress from harvest of other types of plants is evaluated separately (see 16.2). Stress associated with disturbance is evaluated separately (see 07.2).
16.2	Nontimber plant harvest	Removal or harvest of nontimber plants, including mushrooms, floral greens, food plants, algae, and aquatic plants, for human use. Stress from timber harvest is evaluated separately (see 16.1). Stress associated with disturbance is evaluated separately (see 07.2).
17	Increase in native species	—
17.1	Predation from increased native species	Increased predation resulting from the increase/spread of native fish, wildlife, invertebrates, or plants. Includes increased predation from synanthropic species such as corvids (Corvidae), gulls (*Larus* spp.), cowbirds (*Molothrus* spp.), raccoon (*Procyon lotor*), and native species from hatcheries.
17.2	Displacement by increased native species	Displacement or decrease in abundance or decrease in population growth rates resulting from the increase/spread of native fish, wildlife, invertebrates, or plants. Includes displacement by synanthropic species such as corvids, gulls, cowbirds, raccoon, and native fish species released from hatcheries.
18	Introduction of new or increase in nonnative species	—
18.1	Predation from nonnative species	Increased predation resulting from the addition or increase of nonnative fish, wildlife, domestic animals and pets, invertebrates, or plants.
18.2	Displacement by nonnatives	Displacement or decrease in abundance or decrease in population growth rates resulting from the addition or increase of nonnative fish, wildlife, domestic animals and pets, invertebrates, or plants.

Table B-2 continued. Puget Sound stressors, the most proximate agents of change to Puget Sound ecosystems, including both human and natural processes that impair or degrade the system. The 39 stressor classes are grouped into 26 higher level categories.

Code	Name	Description
18.3	Nonnative genetic material	Introduction and spread of extra or new genetic material that includes transgenetic material introduced through a variety of genetic engineering methods and purposes (e.g., genetically modified agricultural crops), intentional or unintentional hybridization of different species because of management actions, and hybridization of introduced, exotic shellfish or fish with native forms through aquaculture.
19	Disease and parasite introduction, spread, or amplification	—
19.1	Spread of disease and parasites to native species	Introduction, spread, or amplification of disease or parasites from human and animal waste, aquaculture, or nonnative species to native species. This is meant to assess the effects of diseases and parasites that affecting species other than humans; diseases affecting humans are evaluated separately (see 19.2).
19.2	Introduction, spread, or amplification of human pathogens	Introduction, spread, or amplification of disease-causing or parasitic organisms to humans. Sources of this stressor include release human and animal waste. This is intended to evaluate effects on humans due to, for example, degradation in water quality and the associated degradation in the quality of aquatic species (e.g., shellfish) consumed by people.
20	Air pollution	—
20.1	Air pollution from mobile sources	Presence or loading of chemicals or particles in the atmosphere that can cause discomfort, disease, or death to humans and harm the natural environment, (including via deposition to land and water) resulting from mobile sources, such as car, truck, and vessel traffic. Noise and light pollution are evaluated separately (see 07.1).
20.2	Air pollution from stationary sources	Presence or loading of chemicals or particles in the atmosphere that can cause discomfort, disease, or death to humans and harm the natural environment, (including via deposition to land and water) resulting from stationary sources, such as industrial and commercial emissions. Noise and light pollution are evaluated separately (see 07.1).
21	Persistent toxic chemicals in aquatic systems	—
21.1	Point source, persistent toxic chemicals in aquatic systems	Presence or loading of persistent toxics from point sources. Sources of this stressor include activities that generate wastewater that is discharged from municipal and industrial sewers and treatment plants. Include stress from persistent chemical cycling here (e.g., PCB and Hg cycling). Stress from nonpoint sources is evaluated separately (see 21.2).

Table B-2 continued. Puget Sound stressors, the most proximate agents of change to Puget Sound ecosystems, including both human and natural processes that impair or degrade the system. The 39 stressor classes are grouped into 26 higher level categories.

Code	Name	Description
21.2	Nonpoint source, persistent toxic chemicals in aquatic systems	Presence or loading of persistent toxics from nonpoint sources, such as runoff from developed areas and roads, including from historic (legacy) sources and small (<10 gallon) spill events. Sources of this stressor include activities that contribute pollutants to surface water runoff, including that discharged through stormwater conveyance systems. Stress from point sources is evaluated separately (see 21.1).
22	Nonpersistent toxic chemicals in aquatic systems	—
22.1	Point source, nonpersistent toxic chemicals in aquatic systems	Presence or loading of nonpersistent toxics from point sources, including historic sources and small spill (<10 gallons) events. Sources of this stressor include activities that generate wastewater that is discharged from municipal and industrial sewers and treatment plants. Stress from nonpoint sources is evaluated separately (see 22.2).
22.2	Nonpoint source, nonpersistent toxic chemicals in aquatic systems	Presence or loading of nonpersistent toxics from nonpoint sources, such as runoff from developed areas and roads, including from historic (legacy) sources and small (<10 gallon) spill events. Sources of this stressor include activities that contribute pollutants to surface water runoff, including that discharged through stormwater conveyance systems. Stress from point sources is evaluated separately (see 22.1).
23	Large spills	Spills of large amounts of oil and hazardous substances (>100 gallon). Sources include large oil spills from large events related to vessels (including derelict vessels), road and rail traffic, pipelines, and industrial facilities. Stress from smaller, more routine spills and releases, such as those that might occur at gas stations and marinas, is evaluated separately (see 21 and 22).
24	Conventional water pollutants	—
24.1	Point source conventional water pollutants	Presence or loading of nutrients, sediment, turbidity, and oxygen demanding substances from point sources. Sources of this stressor include activities that generate wastewater that is discharged from municipal and industrial sewers and treatment plants. Stress from nonpoint sources (see 24.2) and temperature changes (see 24.3) are evaluated separately.
24.2	Nonpoint source conventional water pollutants	Presence or loading of nutrients, sediment, turbidity, and oxygen demanding substances from nonpoint sources. Sources of this stressor include activities that contribute pollutants, including that discharged through stormwater conveyance systems. Stress from point sources (see 24.1) and temperature changes (see 24.3) are evaluated separately.

Table B-2 continued. Puget Sound stressors, the most proximate agents of change to Puget Sound ecosystems, including both human and natural processes that impair or degrade the system. The 39 stressor classes are grouped into 26 higher level categories.

Code	Name	Description
24.3	Changes in water temperature from local causes	Changes in water temperature. Changes in temperature of marine water from human-caused climate change (see 26.4) is evaluated separately.
25	Harmful algal blooms	Presence of biological and chemical agents associated with blooms of algae in marine and freshwater systems.
26	Climate change	Environmental stressors associated with increased gas concentrations in atmosphere.
26.1	Changing air temperature	Changes in air temperature resulting from increased greenhouse gas concentrations in atmosphere. This is a proximate agent on terrestrial species and a source of other stressors. Stress associated with changing water temperature (see 24.3) and changes in air temperature associated with the built environment (see 07.1) are evaluated separately.
26.2	Changing precipitation amounts and patterns	Changes in amount, form, and quantity of precipitation. This is a proximate agent on terrestrial systems and species, but an indirect influence (e.g., via altered flows) on other endpoints and a source of other stressors. Changes in peak (see 10) and base (see 11) flows associated with changing precipitation are evaluated separately.
26.3	Sea level rise	The rise in sea level in Puget Sound related to human-induced climate change.
26.4	Changing ocean condition	Changes in water temperature, patterns and magnitude of upwelling events, nutrient and oxygen levels, and decrease in pH of Puget Sound waters related to increased greenhouse gas concentrations in the atmosphere and human-induced climate change.

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. Table B-3 and Table B-4 list stresses related to KEAs of the 14 ecosystem components in the framework.

Table B-3. Stresses associated with KEAs of the Chinook salmon (*Oncorhynchus tshawytscha*) ecosystem component. Examples of indicators that reflect the health of (or stress to) associated KEAs are also included.

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 subadult survival in open water	Interannual survival rate by age
	Reduced coastal migrant survival	Maturation rate by age, marine survival
	Reduced upriver migrant survival	In-river survival rate
Productivity—fish growth	Reduced growth of spawners	Size of spawners at given age
	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 subadults	Size of open water subadults, 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—pop. growth	Reduced spawner population	Broodyear 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

Table B-3 continued. Stresses associated with KEAs of the Chinook salmon (*Oncorhynchus tshawytscha*) ecosystem component. Examples of indicators that reflect the health of (or stress to) associated KEAs are also included.

KEA	Associated stress (altered KEA)	Example indicator
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-4. Stresses associated with the KEAs of the habitat and species and food web ecosystem components.

Ecosystem component	KEA*	Associated stress (altered KEA)
Freshwater habitats category		
Upland	I-1. Sediment dynamics–sediment delivery	Altered sediment delivery
	III-5. Organic matter–inputs	Altered organic inputs
Channel >50 m BFW	I-1. Sediment dynamics–sediment delivery	Altered sediment delivery
	I-2. Sediment dynamics–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
	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
Channel <50 m BFW	I-1. Sediment dynamics–sediment delivery	Altered sediment delivery
	I-2. Sediment dynamics–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
	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

Table B-4 continued. Stresses associated with the KEAs of the habitat and species and food web ecosystem components.

Ecosystem component	KEA*	Associated stress (altered KEA)
Freshwater habitats category (continued)		
Channel <50 m BFW (continued)	VI-14. Floodplain-channel interactions–structure and function	Degraded floodplain structure and connectivity
	VII-15. Habitat connectivity	Degraded habitat connectivity
Side channel	I-1. Sediment dynamics–sediment delivery	Altered sediment delivery
	I-2. Sediment dynamics–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
	III-6. Organic matter–retention/processing	Altered organic 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
Nonchannel lakes and wetlands	I-1. Sediment dynamics–sediment delivery	Altered sediment delivery
	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
	III-6. Organic matter–retention/processing	Altered organic 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

Table B-4 continued. Stresses associated with the KEAs of the habitat and species and food web ecosystem components.

Ecosystem component	KEA*	Associated stress (altered KEA)
Freshwater habitats category (continued)		
Nonchannel lakes and wetlands (continued)	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 category		
Natal Chinook estuary	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	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. Submerged aquatic vegetation (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 landform	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

Table B-4 continued. Stresses associated with the KEAs of the habitat and species and food web ecosystem components.

Ecosystem component	KEA*	Associated stress (altered KEA)
Estuarine and marine habitats category (continued)		
Coastal landform (continued)	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 beach	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

Table B-4 continued. Stresses associated with the KEAs of the habitat and species and food web ecosystem components.

Ecosystem component	KEA*	Associated stress (altered KEA)
Estuarine and marine habitats category (continued)		
Bluff-backed beach (continued)	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 estuary	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 estuary	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

Table B-4 continued. Stresses associated with the KEAs of the habitat and species and food web ecosystem components.

Ecosystem component	KEA*	Associated stress (altered KEA)
Estuarine and marine habitats category (continued)		
Rocky pocket estuary (continued)	I-8. Coastal sediment dynamics–extent (size or volume) of wind-dependent and wave-dependent features	Altered coastal sediment dynamics
	I-9. Coastal sediment dynamics–condition of wind-dependent 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 beach	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-dependent and wave-dependent features	Altered coastal sediment dynamics
	I-9. Coastal sediment dynamics–condition of wind-dependent and wave-dependent features	Altered coastal sediment dynamics

Table B-4 continued. Stresses associated with the KEAs of the habitat and species and food web ecosystem components.

Ecosystem component	KEA*	Associated stress (altered KEA)
Estuarine and marine habitats category (continued)		
Rocky beach (continued)	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 system	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 category		
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 Table 8 through Table10 and Table 12 through Table 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-5 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.

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 Puget Sound Salmon Recovery Plan (SSDC 2007). Therefore, most chapters do not include drivers (Table B-6); however, they may be incorporated into results chains to identify intermediate results.

Strategies

A strategy is a set of conservation actions with a common focus. When such actions are combined, they result in reduction of threats, developed capacity, 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—that is, it outlines specific courses of action to be executed; 3) feasible— that is, it can be accomplished given existing resources and constraints; and 4) appropriate— that is, it is consistent with site-specific social, cultural, and biological norms. Table B-7 lists categories and associated definitions of strategies found in Volume I and Volume II of the Puget Sound Salmon Recovery Plan (SSDC 2007).

Table B-5. Broad categories and examples of contributing factors that may exist in watersheds.

Category	Example
Social (expectations and perceptions)	The 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 overburdened 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

Table B-6. Broad categories and examples of drivers that may exist in watersheds.

Category	Example
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

Table B-7. Categories of strategies common to both volumes of the Puget Sound Salmon Recovery Plan (SSDC 2007). Definitions are derived from various sources.

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, or acquisition.	SSDC 2007
Improve and increase habitat restoration	Habitat restoration	Enhancing degraded or restoring lost habitat through on-the-ground action, sometimes preceded by acquisition.	FOS 2009
Manage hatcheries to support wild Chinook salmon populations	Hatchery management	Artificially producing Chinook salmon to harvest 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.	WDFW and PSTT 2004
Manage harvest to support recovery of wild Chinook salmon 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.	PSIT and WDFW 2010
Improve and increase assessments	Assessment	Filling data gaps and improving strategies as new data and information are acquired.	SSDC 2007, Vol. II, San Juan chapter
Improve and increase research	Research	Gaining fuller scientific knowledge or understanding of a subject through basic or applied study.	NSB 2010
Improve and increase education	Education	Increasing public awareness and knowledge about environmental issues, and providing the skills necessary to make informed environmental decisions and take responsible actions.	EPA 2011
Improve and increase outreach	Outreach	Disseminating information about an issue and, in some cases, requesting that specific action be taken, without necessarily teaching how to analyze the issue.	EPA 2011

Appendix C: Other Monitoring Projects and Programs

Our framework has been developed alongside other monitoring-related work 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. Current 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 (*Oncorhynchus* spp.) and steelhead (*O. mykiss*) and is working to define elements of a comprehensive monitoring strategy for salmon habitat. The recently completed viable salmonid population (VSP) assessment examined monitoring of the 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. It 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 salmon (*O. kisutch*), steelhead, and cutthroat trout (*O. clarkii*) monitoring and two larger basins that focus on Chinook salmon (*O. tshawytscha*) in the Skagit and Wenatchee rivers. The project, a joint effort of the Washington Department of Ecology, Washington Department of Fish and Wildlife, NMFS, EPA, Lower Elwha Klallam Tribe, and Weyerhaeuser Company, is funded by the Washington Salmon Recovery Funding Board (http://www.ecy.wa.gov/programs/eap/imw/index.html).
- Washington Department of Ecology's Status and Trends Monitoring for Watershed Health and Salmon Recovery (WSHR) program. It uses a probabilistic sampling design to select river and stream sites for monitoring. The rotating panel design divides the state into eight status and trend regions with two sampled each year. The Puget Sound basin, first sampled in 2009, was 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 streamflow data will be collected. For nearshore areas, fecal coliform data will be collected monthly at 50 sites in the UGAs, sediment chemistry every 5 years at 50 sites in UGAs (to compare with PSEMP locations outside UGAs), and Mussel Watch Program data at 30–50 sites near stormwater outfalls (to be compared with Mussel Watch Program sites away from outfalls). In addition, a prioritized list of recommended study topics for effectiveness monitoring is being developed (http://www.ecy.wa.gov/programs/wq/stormwater/municipal/rsmp.html).
- U.S. Geological Survey (USGS) National Streamflow Information Program, Cooperative Water Program, Groundwater Resources Program, and National Water Quality Assessment Program. 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 in real time via satellite telemetry. Monitoring data from all USGS programs are available through the National Water Information System. 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).

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