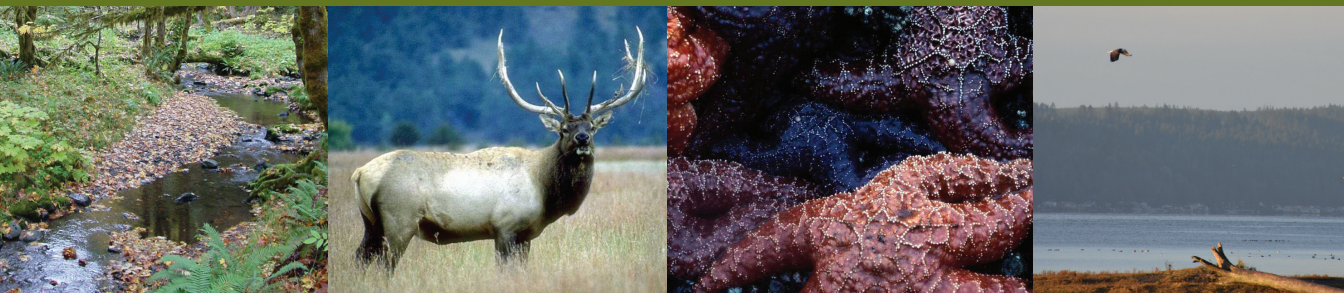


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## SOUND INDICATORS:

A REVIEW FOR THE PUGET SOUND PARTNERSHIP



An assessment of the Puget Sound Partnership's  
progress in developing the scientific basis for  
monitoring and assessing progress toward achieving  
a vibrant Puget Sound

August 2012

Washington State Academy of Sciences Committee on  
Puget Sound Indicators

# Sound Indicators: A Review for the Puget Sound Partnership

## About the Washington State Academy of Sciences

The Washington State Academy of Sciences (WSAS) is an organization of Washington State's leading scientists and engineers dedicated to serving the state with scientific counsel. Formed as a working academy, not an honorary society, WSAS is modeled on the National Research Council. Its mission is two-fold:

To provide expert scientific and engineering analysis to inform public policy making in Washington State, and

To increase the role and visibility of science in the state.

WSAS was formed in response to authorizing legislation signed by Governor Gregoire in 2005. Its 12-member Founding Board of Directors was recommended to the governor by the presidents of Washington State University and the University of Washington and duly appointed by the governor. In April 2007, WSAS was constituted by the Secretary of State as a private, independent 501(c)(3).

Washington State Academy of Sciences  
410 11th Avenue SE, Suite 205  
Olympia, WA 98501  
programs@washacad.org  
<http://www.washacad.org>  
(360) 534-2336

# Sound Indicators: A Review for the Puget Sound Partnership

## Review Committee

**Gordon Orians, Chair**

University of Washington

**Megan Dethier**

University of Washington

**Charles Hirschman**

University of Washington

**Alan Kohn**

University of Washington

**Duncan Patten**

Montana State University

**Terry Young**

Environmental Science Consultant



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A review and evaluation of a final draft of the report was overseen by the WSAS Report Review Committee, chaired by Anjan Bose. Five independent reviewers (Robert T. Paine, University of Washington; Jennifer Ruesink, University of Washington; Ronald Thom, Pacific Northwest National Laboratory; Stewart Tolnay, University of Washington; and Phillip Wandschneider, Washington State University) provided useful suggestions that the Committee incorporated into the final report.

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## SOUND INDICATORS: A REVIEW FOR THE PUGET SOUND PARTNERSHIP

## EXECUTIVE SUMMARY

The enabling legislation (Engrossed Substitute Senate Bill 5372) that created the Puget Sound Partnership (PSP) directed the PSP to develop an Action Agenda that is a “comprehensive schedule of projects, programs, and other activities designed to achieve a healthy Puget Sound ecosystem.” The Action Agenda was to “include near-term and long-term benchmarks designed to ensure continuous progress needed to reach the goals, objectives, and designated outcomes by 2020.” The Science Panel of the PSP was charged by PSP’s Leadership Council with identifying an appropriate set of environmental indicators that would help efforts to accomplish the goal of restoring and maintaining a vibrant and productive Puget Sound ecosystem.

The enabling legislation that created the Washington State Academy of Sciences (Engrossed Senate Bill 5381) directed the WSAS to conduct ongoing independent reviews and assessments of the Puget Sound Partnership’s progress in developing the scientific basis for achieving a vibrant Puget Sound. By the end of 2010, the PSP Science Panel’s efforts had reached the stage where an independent review by the WSAS was timely and useful to help guide its future indicator development efforts. The PSP Science Panel asked the WSAS to evaluate the processes it used to develop a system of indicators of ecosystem condition, and human health and well-being. The WSAS was also asked to assess how well the individual indicators and the full set of indicators could function as the basis for guiding the PSP’s future management efforts and for monitoring progress in improving the ecological condition of Puget Sound. This report is the response of the Committee convened by the WSAS to meet that request. The Committee’s analysis is based on documents supplied to it by PSP on or before September 30, 2011.

Specifically, the WSAS was asked to evaluate whether the Puget Sound Partnership’s current choice of indicators of ecosystem status, and of human health and well-being, meet the objectives defined by the Leadership Council, to evaluate the process by which individual indicators and the set of indicators were selected, and to recommend how the PSP might most effectively continue the process of refining and selecting indicators.

Indicators need to detect and report on changes at appropriate spatial and temporal scales without being overwhelmed by natural environmental variability. They need to yield reliable and useful numbers in the face of inevitable external perturbations. They should be able to accommodate technological changes so that meaningful status and trends can be identified even though measurement technologies change. The value of indicators increases with the time span over which they are maintained because it is difficult to detect and interpret trends in components of the environment and to know whether variations fall outside the “normal” range without long-term data.

Due perhaps to the challenging timeframes imposed by legislative mandates, the PSP's efforts overlapped in time and were not always internally consistent. No document exists that describes the development of the Dashboard indicator set and/or the criteria that were used to evaluate indicator characteristics. ***The Committee recommends that the PSP use a stepwise procedure to improve its set of indicators: 1) develop a conceptual framework of the ecosystem that summarizes its major attributes, both structural elements and processes; 2) identify indicators that accurately represent each attribute, using an appropriate conceptual model or empirical association; 3) develop an appropriate metric for each indicator; 4) evaluate reliability of each indicator and metric; 5) avoid duplication of indicators; 6) and finally, reassess the resulting indicators to ensure that they represent all major attributes.***

An effective indicator set should comprehensively but concisely represent current understanding of the condition and key functional processes of the focal system. Such an understanding can best be formed and expressed using a conceptual framework that includes the system's components and their dynamical interactions. This framework can guide the selection of indicators so that every key ecosystem attribute is represented by an indicator. O'Neill et al. (2008) categorized existing indicators and identified important ecological attributes for which no indicators were available and recommended the development of conceptual models to refine the process for choosing indicators. Later, Levin et al. (2011) provided a draft conceptual framework that again attempted to incorporate ecological science into the interpretation of the legislative goals. The Dashboard indicators, however, were selected with inadequate reference to this ecosystem-based conceptual framework. Failure to utilize a comprehensive conceptual framework led to many of the problems with the Dashboard indicator set. Following steps 1-6 outlined above could have avoided these problems. An unfortunate outcome of using a combination of flawed processes is that some important attributes are missing, some of the Dashboard indicators do not match the attributes they are supposed to represent, and the set of Dashboard indicators as a whole is skewed toward some attributes at the expense of others. In addition, insufficient attention was given to evaluating the specific metrics to be used for each indicator.

Due perhaps to the challenging timeframes imposed by legislative mandates, many of the efforts overlapped in time and took slightly different directions, resulting in a disjointed progression toward the ultimate choice of indicators. Nonetheless, significant progress has been achieved in a relatively short time.

***The Committee recommends that future refinement of the Dashboard indicator list be based on development and use of a comprehensive conceptual framework that describes the Puget Sound system and clearly identifies the key processes that determine its properties.*** The PSP focused on indicators of the "state" (condition) of the

ecosystem, which the Committee defines as indicators that reflect the structural, compositional, and functional elements of the system and that collectively provide a window into the condition of the system as a whole. The Committee supports this approach.

The PSP indicator-selection process initially used two approaches for deriving appropriate indicator categories. One came from the legislative goals; the other employed “targets” developed using the Open Standards methodology. However, neither approach covered the range of attributes necessary to adequately describe the system. Despite the analysis of Levin et al. (2011), which attempted to address some of these flaws, the Dashboard indicator list failed to include some ecologically significant attributes. Nevertheless, most of the Dashboard indicators would be appropriate if they were further refined. ***The Committee offers the following recommendations to the PSP as it continues to refine the Dashboard:***

- ▷ ***To help implement the recommendation regarding the use of a conceptual model, we suggest that the PSP fine-tune the framework created by Levin et al. (2011), using their “key attributes” and “relevant measures.” This framework can be evaluated with reference to existing conceptual models of the Puget Sound ecosystem. The criteria used to evaluate individual indicators should be adjusted; gaps should be identified and filled.***
- ▷ ***All documents describing indicator sets should contain language that clearly describes the purpose served by each indicator, its role in the total set, and how to interpret any changes it reports.***

The development of indicators for human health and well-being has lagged behind efforts to develop ecological indicators. None of the current human dimension indicators relates clearly to quantifiable aspects of the state of the Sound. ***The Committee recommends that:***

- 1. The PSP use the conceptual model that we suggested and revise it appropriately to clearly show functional linkages between human actions, the condition of the Sound, and human well-being.***
- 2. Indicators chosen to represent human well-being include only concrete, measurable parameters that are clearly linked to resources provided by Puget Sound.***
- 3. The importance to human well-being be given a more central and unified focus in the development of Dashboard indicators.***
- 4. Although subjective elements (e.g., aesthetics, “existence value” of an ecosystem) are important parts of the connection between human well-being and***

***Puget Sound, measuring subjective perceptions with a high degree of scientific reliability is problematic. We recommend use of established social science methods, such as willingness to pay higher taxes to ensure that Puget Sound is maintained for future generations, for this appraisal.***

The Committee found the documented process for selecting and evaluating the Dashboard indicators difficult to understand. Criteria were binned into “primary considerations,” “data considerations,” and “other,” the latter including being readily understood by the public. Some of these criteria are inappropriate or are inappropriately weighted. For example, favoring currently popular indicators or indicators for which data are immediately available resulted in missing important parts of the functioning of the system. Some of the Dashboard indicators do not match the attributes they are supposed to represent. Although the PSP claimed to focus on indicators of the “state” of the ecosystem, the selection criteria used do not match that objective. For example, only indicators for which data were available survived the first cut; potentially valuable indicators were eliminated simply because no data were available to populate them. The weights given to the different criteria and then used to sum the scores for ranking indicators do not match their importance.

The Dashboard authors judged that the Dashboard should include indicators from each of four combinations of “sensitivity” (lagging versus leading) and “specificity” (diagnostic versus broadly informative). The four categories do not correspond to any key ecosystem attributes. ***To rectify these problems the Committee, recommends that:***

- ▷ ***The criterion of “theoretically sound” has the highest weighting in choosing indicators.***
- ▷ ***The PSP adopt an approach that focuses on condition indicators that describe the state of the ecosystem, rather than on management-driven indicators.***
- ▷ ***The PSP reassess the pool of indicators from which the final list was selected, using only “primary” considerations as the basis for the initial screening.***
- ▷ ***The finally selected indicators be ones that can be disaggregated to characterize geographical subunits of Puget Sound as well as the ecosystem as a whole.***
- ▷ ***Most indicators not be selected for their communication role. An education program must be part of the development and use of an indicator system, but it should play only a minor role in the selection of indicators.***

The Puget Sound Science Update (PSSU) and the Dashboard currently provide neither criteria for evaluating the metrics to be used for each indicator nor criteria for evaluating the performance of the indicators over time. Therefore, the Committee is unable to determine the adequacy of the proposed indicators to monitor progress toward meeting goals and objectives.

- ▷ ***We recommend that priority be given to monitoring and reporting trends in the ecological indicators to allow “adaptive management” of the indicator set, i.e. changing the set if some initially selected indicators turn out to be ineffective.***

The Committee evaluated the PSP’s provisional list of Dashboard indicators and categorized them as follows:

- **Refine and use in the Dashboard.**
  - **Marine Water Quality**, if PSP adopts the Washington State Department of Ecology (DOE) measurement parameters cited by the Committee, and omits “monitoring to the bottom” and coastal bays outside the Puget Sound basin
  - **Toxics in Fish**
  - **Toxics in Sediment**
  - **Water Quantity**
  - **Salmon**
  - **Eelgrass**
- **Continue to develop for possible use in the Dashboard.**
  - **For Freshwater Quality, we recommend expansion of the list of monitored parameters beyond “conventional pollutants.”**
  - **The Shoreline Armoring** indicator is appropriate as one part of a marine habitat “extent” attribute but needs to be complemented by other habitat extent data.
  - **The Land Use/Land Cover** indicator is important in recognizing tradeoffs inherent in different types of land use. ***We recommend that it be modified so that the metrics are independent of policy and goal statements, and that further development of this indicator be accomplished expeditiously.***
- **Do not use in its current form.**
  - ▷ ***We recommend that PSP reconsider its decision to include herring spawning biomass as a metric of the “Pacific Herring” indicator. We suggest that PSP either use its influence or funding to encourage the Washington Department of Fish and Wildlife (WDFW) to return to monitoring herring standing stock, or give additional consideration to investigating jellyfish populations as a Food Web indicator.***



- ▷ *Because terrestrial bird populations relate only weakly to the condition of Puget Sound, we recommend that this indicator be eliminated from the Dashboard, although some metrics relating to terrestrial birds may be relevant as indicators of terrestrial condition.*
- **Add as potential indicators.**
  - ▷ *We recommend inclusion of indicators of key ecosystem attributes that currently have little to no representation in the indicator set. These include:*
    - **Extent** of the range of marine habitat types in Puget Sound, to parallel the terrestrial land use/land cover indicator. Data already exist to begin creating such an indicator. The data gathered for this indicator are essential for understanding the status of other indicators such as eelgrass, shoreline armoring, and biodiversity.
    - **Primary productivity.** Data may already be available from the Ocean Climate Laboratory of NOAA.
    - **Freshwater quality in lakes as well as streams,** and primary organic productivity in freshwater habitats.
    - **Biodiversity** of selected types of organisms and/or selected habitat types.
    - **Sediment delivery and transport** along beaches, as a key process that affects ecosystem condition in the nearshore areas of Puget Sound.

In conclusion, the Committee has identified and described significant flaws and inconsistencies in the processes the PSP used to select a set of indicators to monitor trends in the condition of the Puget Sound ecosystem and to assess the consequences of management interventions. We recognize the complexity of the task that confronted the Science Panel and the Leadership Council, however, and judge that its efforts, although at times uncoordinated and contradictory, have laid a solid foundation on which the PSP can build as it refines its procedures and outcomes. Again we stress the importance of developing and using a conceptual model of the Puget Sound system to identify the key attributes for which indicators need to be developed. We have suggested a stepwise procedure that, if adopted, would help the PSP select, describe, and provide the rationale for the indicators that it needs to develop and refine. The Washington State Academy of Sciences looks forward to continuing to be of service to the Puget Sound Partnership as it builds on its valuable efforts to provide a solid scientific basis for maintaining and improving the ability of the Puget Sound ecosystem to enrich the lives of the people who live near it.

# I. INTRODUCTION

The enabling legislation (Engrossed Substitute Senate Bill 5372) that created the Puget Sound Partnership (PSP) directed the PSP to develop an Action Agenda that is a “comprehensive schedule of projects, programs, and other activities designed to achieve a healthy Puget Sound ecosystem.” The Action Agenda was to “include near-term and long-term benchmarks designed to ensure continuous progress needed to reach the goals, objectives, and designated outcomes by 2020.”

The legislation defines benchmarks as “measurable interim milestones or achievements established to demonstrate progress toward a goal, objective, or outcome.” The legislation also defines an environmental indicator as “a physical, biological, or chemical measurement, statistic, or value that provides a proximate gauge, or evidence of, the state or condition of Puget Sound.” Guided by these definitions, the Science Panel of the PSP was charged by PSP’s Leadership Council with identifying an appropriate set of environmental indicators that would help efforts to accomplish the goal of restoring and maintaining a thriving and productive Puget Sound ecosystem. The PSP Science Panel developed and used the PSSU as the primary way to assess and synthesize the scientific theories, concepts, and information available to inform its selection of the set of indicators. The legislature clearly intended that the PSP would develop and use a set of indicators that provided both the scientific justification for management interventions and a solid basis for evaluating the consequences of those interventions.

The enabling legislation that created the Washington State Academy of Sciences (Engrossed Senate Bill 5381) directed the WSAS to conduct ongoing independent reviews and assessments as requested by the governor or the legislature. As part of this mission, WSAS was commissioned to examine and report on the Puget Sound Partnership’s progress in developing the scientific bases for monitoring and assessing progress toward achieving a vibrant Puget Sound. By the end of 2010, the PSP’s Science Panel’s efforts had reached the stage where the first independent review by the WSAS was judged to be timely and useful to help guide its future indicator development efforts. Accordingly, the Science Panel asked the WSAS (a) to evaluate the processes it used to develop a system of indicators of ecosystem condition, and human health and well-being, and (b) to assess how well the individual indicators and the full set of indicators could function as the basis for guiding the PSP’s future management efforts and for monitoring progress in improving the ecological condition of Puget Sound and the lives of the people whose health and welfare depend on the goods and services provided by it. To respond to that request, the WSAS convened the Committee on Puget Sound Indicators (hereafter referred to as the “Committee”). The Committee met four times between July 2011 and January 2012. This review is the WSAS response to that request.

The PSP has made considerable progress in identifying a set of ecological condition indicators but much more remains to be accomplished. Indicators of human health and well-being are currently less fully developed. These works-in-progress—the ecological condition indicators and the indicators of human health and well-being—are the subject of this review. The Science Panel intends to develop additional indicators related to specific management interventions and designed to assess whether the interventions are achieving their intended effects. Those efforts have yet to produce documents that the Committee is able to assess.

## **I. A. What Are Indicators and Why Do We Need Them?**

Indicators serve as clues that something more fundamental or complicated is happening than what is actually measured by them. Properly designed indicators are good surrogates for the underlying complex economic, sociological, or scientific data that are too expensive to measure directly or too difficult to explain to broad audiences. Abnormal blood pressure signals that some physiological process is not functioning properly, but it does not tell a doctor which process is malfunctioning or why. The gross national product (GNP) measures something about the performance of the national economy, but it provides little information on performances of specific economic sectors. Blooms of cyanobacteria (*Oscillatoria*) in a temperate zone lake indicate that serious pollution problems are developing. People often want indicators to do more than they are capable of accomplishing. Indicators serve a valuable function, which is to inform us of trends in some entity of interest, but in general they should not be designed to be “diagnosticators.” Their role is to warn us and inform us of changes that warrant attention. To assess the causes of the trends reported by indicators, we need and use other tools.

Indicators are important because we use them to guide our behavior. We fill the tank when the gauge indicates a low fuel level. When the Dow Jones index rises or falls, thousands of people reconsider their financial decisions. Indicators are needed because “... of a very practical problem: too many needs, too few funds.” (Jarvinen, 1985). Although we could measure many interesting and useful things, we are unlikely to have sufficient funds to measure more than a few of them over time. Moreover, people will pay attention to only a few indicators. Difficult choices are inevitable!

Indicators are used for a variety of purposes; no single indicator can serve all of them. Indicators may inform us about processes at local, regional, national, or international scales. They may be designed to tell us about long-term changes or about changes that are likely to happen in the immediate future. The difficulty of matching indicators to the temporal and spatial scales over which they are expected to inform us is generally unappreciated. Ecological condition indicators—designed to inform us about long-term

status and trends in the fundamental dynamic properties of ecosystems—are an important component of a set of indicators because what people value, and how they use the goods and services provided by ecosystems, change over time. For example, the major concern of people participating in the first Stockholm conference on the environment in 1972 was exhaustion of non-renewable natural resources. Ten years later, the primary concern was the consequences of over-use of renewable resources. Similarly, a decade ago, the major conflict over Puget Sound was about who had legal rights to harvest how many fish and where they could set their nets. Today, the primary concerns focus on habitat loss and discharge of toxic materials into the Sound. Ten years from now, concerns are certain to differ to some degree from those that preoccupy us today. We need indicators that will inform us about processes and properties of the Puget Sound ecosystem that will help us deal with matters that may be important to future inhabitants of the region. Some of those concerns are certain to be ones that we cannot imagine today.

We also need indicators that are designed to tell us whether interventions we have made are yielding the desired results. Scientists predicted that Lake Washington's waters would respond rapidly if discharges of sewage into the lake ceased. Use of a simple water quality indicator confirmed the prediction (Edmondson, 1991). We also need indicators that report on progress toward achieving a desired target or goal, both in cases of a specific management intervention initiated to achieve that target (e.g., expanding a specific habitat type), and in cases lacking specific targets (e.g., population size of iconic species, such as herring). Ecological condition indicators serve each of these functions because they track the functioning and structural elements of the ecosystem. Additional indicators designed to track the direct results of interventions, often called management indicators, complement the condition indicators but cannot replace them.

Thus, the full set of indicators chosen to provide the public, decision makers, and managers with the best information to guide interventions, to assess their effects (positive and negative), and to allow us to learn adaptively as we move forward, will need to serve a variety of purposes. Clearly specifying the purpose served by each indicator and its role in the total picture is a vital component of communicating the rationale for the design of an indicator set.

In recent years, affordable methods to generate the data needed for development and computing of indicators of the state and functioning of ecosystems have become increasingly available. Impressive technological developments, particularly in aerial and remote sensing capabilities, now make it possible to develop, report, and use a variety of environmental indicators that have relevance at many different spatial scales.

The value of indicators, whatever their relevant spatial scale, increases with the time span over which they are measured. It is generally difficult to detect and interpret trends in components of the environment and to know whether variations fall outside the “normal” range without long-term data records.

## **I. B. Developing a Good Set of Indicators Is Genuinely Difficult**

The Committee is fully aware of the complexity and difficulty of the task undertaken by the Science Panel and Leadership Council. Difficulties occur at every stage in the process of indicator development. Because financial resources are inevitably less than necessary to meet all needs, only a few of the many possible indicators are likely to be funded over long enough time to provide useful information about status and trends. Deciding which of the fundamental ecological processes that drive the dynamic properties of the Puget Sound ecosystem are the most important to measure is not easy.

Once the key processes have been selected, it may still be difficult to determine which indicators would provide the best clues to the underlying processes. For example, environmental scientists agree that loss of habitat and fragmentation of remaining habitats cause extermination of species. Measuring the extent of remaining habitats is not difficult; devising an indicator of fragmentation, however, is extremely difficult. Recognizing this problem, The H. John Heinz Center established a special committee to design a good indicator of fragmentation for its second report on “The State of the Nation’s Ecosystems” (Heinz Center, 2008). Despite major efforts, the scientists were unable to devise an indicator of fragmentation that was adequate, yet not too complicated. Good indicators of biodiversity are also very difficult to devise.

Once an appropriate indicator has been selected, a suitable metric still must be determined. It is easy to devise an appropriate metric for some indicators. In terrestrial ecosystems, soil organic matter—the single most important indicator of soil quality and productivity—is relatively easy to measure. However, because soil is very heterogeneous, a large number of samples must be taken even within a limited area to determine soil organic matter status. In marked contrast, it is easy to recognize that an important property of the nation’s ecosystems is their productivity—that is the rate at which they use solar energy to convert atmospheric carbon dioxide to organic compounds—but deciding on the best metric for measuring productivity is difficult. Finally, assessing and communicating the significance of changes in the chosen metrics encounters additional problems. What does a trend in the measure mean? How easy is it to distinguish a real signal against the background “noise” that characterizes all natural ecosystems? Are changes in the metric within the normal range of variation or do they signal a potentially important deviation that deserves attention?

To answer the last question, it is usually necessary to compare status and trends measured by an indicator against a reference state, that is, the value of its metric at some time in the past that can serve as an appropriate baseline. Without a baseline, it is hard to assess the significance of the magnitude of changes, determine whether directions and magnitudes of changes are important, or if efforts to deal with them are succeeding. Baselines for some indicators, such as water and air quality standards, are established by legislation. They often deal primarily with human health issues. Baselines established by legislation or by regulation are likely to be changed when new information dictates new standards. Indicators based on such regulations may lack long-term value.

Selecting baselines for many ecological indicators may be difficult. Few or no data may be available to characterize environmental states in the distant past. Many ecosystems and habitats are so poorly known that even current natural states and processes can be characterized only within broad ranges. Abundances of many species change dramatically seasonally and at longer intervals. Ecosystem productivity may vary greatly in response to changes in temperature, precipitation, and concentrations of nutrients and toxins. The greater the range of normal variability, the harder it is to detect abnormal variation.

Thus, although this report suggests ways PSP can improve processes for selecting individual indicators and recommends changes in the full indicator set, we fully recognize the enormity and complexity of the task undertaken by the Science Panel and the Leadership Council. Making full use of the set of indicators in the complex social and political environment in which they must function is a task that will continue to confront the PSP. Devising, interpreting, and using a good set of indicators of the status and trends in the Puget Sound ecosystem, and of the health and well-being of people living in the region, is not rocket science. It is much more difficult!



## II. CREATING AN INDICATOR SET

### II. A. Getting Started

A set of indicators that comprehensively but concisely monitors the condition and key functional processes of an ecosystem, including its human components, must reflect the best current understanding of the structure and functioning of that ecosystem. Creating an effective indicator set should employ the following stepwise logical progression. We refer to these steps throughout this document:

- Step 1**     Develop a conceptual framework that summarizes the major structural elements and processes of the ecosystem to identify the key attributes (characteristics) that should be tracked.
- Step 2**     For each attribute, identify potential indicator(s), explicitly describing the rationale for determining that the indicator is a valid representation of the attribute through use of a conceptual model or an empirical association with predictive power.
- Step 3**     Develop an appropriate measure (metric) that demonstrates the response of the indicator to changes in the ecosystem.
- Step 4**     Evaluate each potential indicator and its associated measure (metric) for quality, using criteria (detailed below) such as reliability.
- Step 5**     If more than one high-quality indicator is available for an attribute, winnow the set of potential indicators using other appropriate factors, such as response time and cost.
- Step 6**     Reassess the resulting set of indicators to ensure that they capture all of the important attributes identified in Step 1 above. (This check is useful at each step, essential at the end.)

In the real world, of course, this stepwise progression often may include feedback loops. Nonetheless, it is a useful construct for developing an indicator set. Although the above steps reflect the Committee's experience with ecological condition indicators, we suggest that the same process be used to develop additional indicators of human health and well-being.

In the following sections, we provide additional detail about each step in the process and about areas where the PSP process was more and less effective.



## II. B. Conceptual Frameworks for Selecting a Set of Indicators

The indicators envisioned by the legislature are meant to represent the “condition of Puget Sound.” Accordingly, it is important to select both high-quality individual indicators and a set of indicators that represents the ecosystem as a whole, its component parts, how the parts fit together, and its dynamic processes. In short, the indicator set should be based on the best conceptual understanding of the structure and functioning of the ecosystem.

The legislation for the PSP set out clear goals (healthy populations of native species, human well-being supported by a healthy Sound, etc.) that articulate the desired condition of Puget Sound. It is tempting to create an indicator set that corresponds one-to-one with these goals. In our view, that is not the best way to proceed because doing so may omit measurement of important ecological attributes. Rather, tracking the goals requires an understanding of the ecosystem processes and linkages that create those outcomes.

The Committee considers the use of a conceptual framework representative of the ecosystem to be critical so that every key ecosystem attribute is represented by at least one indicator. Selecting restoration actions or indicators without beginning this conceptual step guarantees that key ecosystem attributes will be missed.

The emphasis in the PSP legislation on assessing and improving the quality of human life that is sustained by Puget Sound also necessitates development of a conceptual framework that illustrates the linkages between the Sound and human well-being. Such a framework should guide the selection of attributes and indicators of well-being. ***We recommend that the PSP develop such a model, and we provide guidance for doing so later in the report.***

### II. B. 1. Existing Conceptual Frameworks of Ecosystem Attributes

Fortunately, much work on indicator development has been done already; several broad approaches have been developed to guide the selection of a representative set of ecosystem condition indicators desired by PSP. We briefly describe three examples. In 1999, at the request of the Environmental Protection Agency (EPA), the National Research Council (NRC) developed a set of indicators that could be measured consistently nationwide to assess and compare the condition of different types of ecosystems (National Research Council, 2000). In addition to providing detailed guidance about the selection of high-quality individual indicators, the NRC developed a framework that listed the ecological characteristics that should be represented, and recommended individual indicators for each characteristic (Table 1, second column). These characteristics reflect

the composition and structure of the nation's ecological wealth, as well as the functions or processes that are important to maintain it. In 2002, a committee of the U.S. Environmental Protection Agency's Science Advisory Board (SAB) developed a framework for assessing ecological condition (U.S. Environmental Protection Agency, 2002) that can be used to organize a large number of indicators into a smaller, more manageable set that still reflects an ecosystem as a whole. The basic ecological model that underpins the SAB method recognizes that ecosystems are characterized by both patterns and processes, and that it is important therefore to include elements that represent ecological structure, composition, and functioning at all relevant scales of ecological hierarchy. At its simplest, the SAB framework identifies six overarching ecological attributes. Each should be represented in an indicator set; if a larger set is desired, the 19 subcategories can be used as a guide to the attributes that should be included (Table 1, first column).

Each of these ecological attributes can be represented by an indicator or by an index that is created by combining individual indicators. For even larger indicator sets, a third level of disaggregation is presented, along with sample metrics. Using the SAB's nested hierarchy of ecological attributes ensures that important elements of the ecosystem are not omitted. A nested hierarchy can also be used as a guide to aggregating a large set of individual indicators into a few representative categories.

A third systematic method to choose a set of indicators was developed by the Heinz Center (2002; 2008) for the purpose of tracking broad national trends in the condition of the country's major ecosystem types: forests, grasslands and shrublands, farmlands, urban and suburban landscapes, freshwaters, coasts and oceans, and all ecosystems combined. Like the NRC effort, the Heinz Center chose only those indicators that can be measured consistently across the nation. The organizing principle for indicator selection was to represent the same categories of structural or functional attributes for each of the major ecosystem types (Table 1, third column). Tracking these attributes nationwide can provide insight into important changes in the nation's ecological resources that would not be apparent without this national inventory. The addition of goods and services in this framework facilitates consideration of the key PSP goals related to human well-being.

Although each of these frameworks is unique, they overlap considerably. Each includes landscape condition (the extent of habitat or land-use types and their patterns); biological resources; abiotic (chemical and physical) characteristics; and functional characteristics (e.g., ecological productivity). Only the SAB system explicitly lists the dynamic attributes of hydrology and geomorphology, which are critical for understanding ecosystems like Puget Sound, although these ideas are subsumed under "physical characteristics" in the Heinz system.

***These three frameworks illustrate several rules of thumb that the Committee recommends that the PSP use as it develops the final indicator set for Puget Sound.*** First, it is paramount to begin with a conceptual model of the ecosystem being evaluated, and to use this understanding to guide the selection of indicators that represent the important attributes of the system. Second, both structural/compositional elements and dynamic functional properties should be included. ***We also recommend capturing relevant levels of biological and ecological hierarchy. For practical reasons, we recommend choosing indicators that can be disaggregated to characterize geographical subunits of the system as well as the ecosystem as a whole; this is critical in Puget Sound, where both stressors (e.g., toxics in the sediment, land use) and processes (e.g., freshwater input) vary highly among regions.*** Thus, many indicators for Puget Sound will be most relevant at spatial scales smaller than Sound-wide.

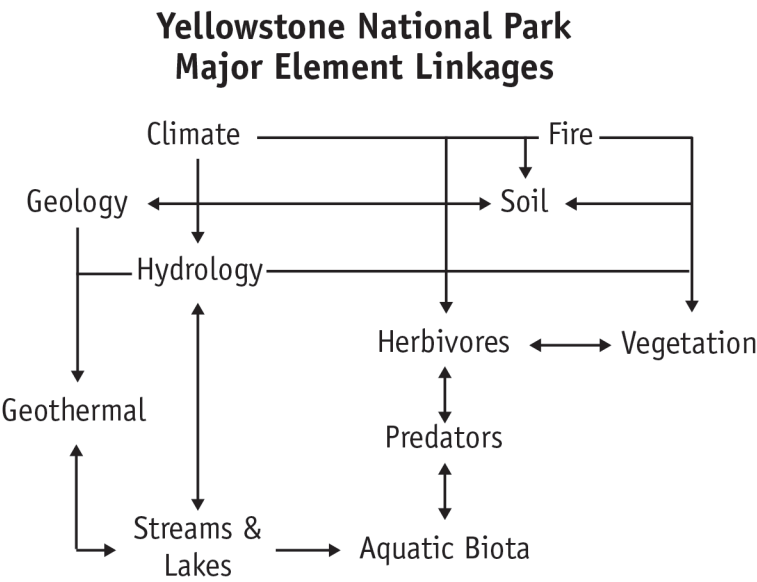
**Table 1. Comparison of three conceptual frameworks of ecosystem structure and functioning:**

<b>SAB FRAMEWORK</b>	<b>NRC (2000)</b>	<b>THE HEINZ CENTER (2008)</b>
<b>LANDSCAPE CONDITION</b>	<b>EXTENT &amp; STATUS OF ECOSYSTEMS</b>	<b>EXTENT AND PATTERN</b>
Extent	Land Cover    Land Use	Extent
Landscape Composition		
Landscape Pattern & Structure		Pattern
<b>BIOTIC CONDITION</b>	<b>EXTENT &amp; STATUS OF ECOSYSTEMS</b>	<b>COMMUNITIES</b>
Ecosystems & Communities –Community Extent                      –Community Dynamics –Community Composition            –Physical Structure –Trophic Structure	Total Species Diversity Native Species Diversity	Biological Communities
Species & Populations –Population Size                                  –Population Dynamics –Genetic Diversity                              –Habitat Suitability –Population Structure		Plants & Animals
Organism Condition –Physiological Status –Symptoms of Disease & Trauma –Signs of Disease		
<b>ECOLOGICAL PROCESS</b>	<b>ECOLOGICAL FUNCTIONING (PERFORMANCE)</b>	
	Land Use	
Energy Flow –Primary Production –Net Ecosystem Production –Growth Efficiency	Productivity, Including: –Carbon Storage –Net Primary Production –Production Capacity	Ecological Productivity
	Lake Trophic Status	
	Stream Dissolved oxygen	<b>CHEMICAL &amp; PHYSICAL CHARACTERISTICS</b>
Material Flow –Organic Carbon Cycling –N & P Cycling –Other Nutrient Cycling	Soil Organic Matter Nutrient-Use Efficiency Nutrient Balance	Nutrients, Carbon, Oxygen
	<b>ECOLOGICAL CAPITAL: ABIOTIC RAW MATERIALS</b>	
	Nutrient Runoff to Coastal Waters	
<b>CHEMICAL &amp; PHYSICAL CHARACTERISTICS</b>		
Nutrient Concentrations –Nitrogen –Phosphorous –Other Nutrients		
Other Chemical Parameters –pH    –Organic Matter –Dissolved Oxygen                          –Other –Salinity	Stream Oxygen  Soil Organic Matter	
Trace Inorganic & Organic Chemicals –Metals –Other Trace Elements –Organic Compounds		Chemical Contamination
Physical Parameters		Physical
<b>HYDROLOGY &amp; GEOMORPHOLOGY</b>		
Surface & Groundwater Flows –Pattern of Surface Flows                      –Hydro dynamics –Pattern of Groundwater Flows                –Water Storage –Spatial & Temporal Salinity Patterns		
Dynamic Structural Characteristics –Channel/Shoreline Morphology & Complexity –Distribution & Extent of Connected Floodplain –Aquatic Physical Habitat Complexity		
Sediment & Material Transport –Sediment Supply/Movement –Particle Size Distribution Patterns –Other Material Flux		
<b>NATURAL DISTURBANCE REGIMES</b>		
Frequency		
Intensity		
Extent		
Duration		
		<b>GOODS &amp; SERVICES</b>
		Food, Fiber, & Water
		Recreation & Other Services

Each conceptual framework identifies generic attributes and/or indicators that should be included in an assessment of ecological condition. Although developed independently, the three example frameworks show considerable overlap in the set of attributes designed to capture ecosystem structure and functioning in a few, representative indicators.

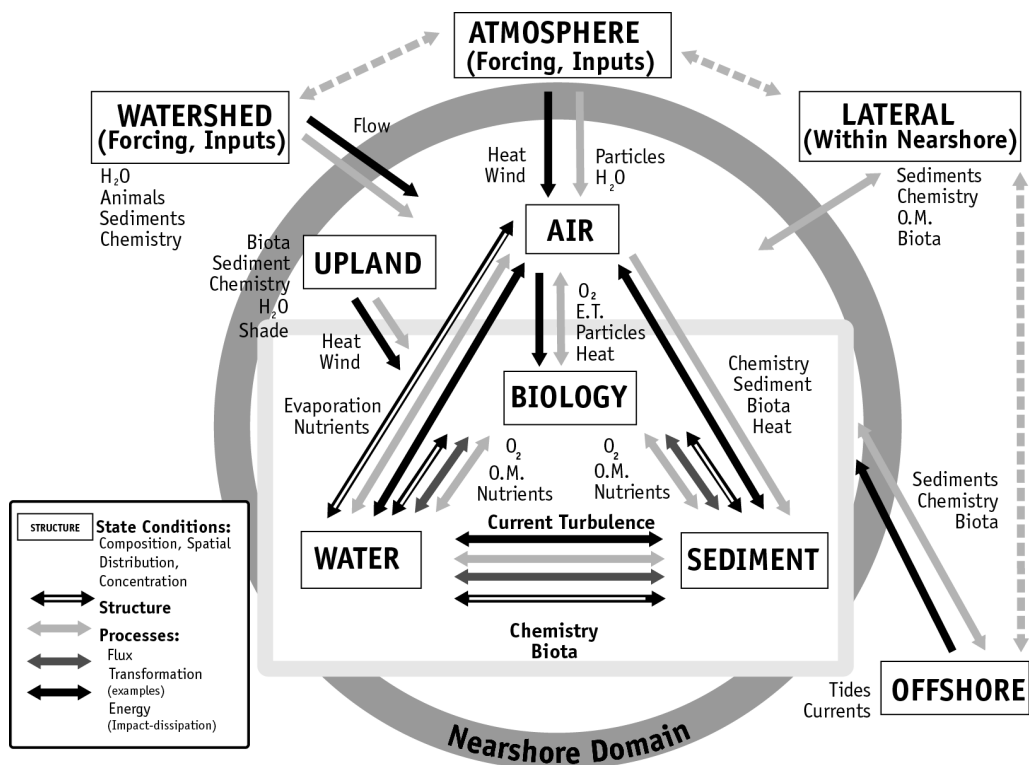
II. B. 2. Use of Conceptual Models

For well-studied systems like Puget Sound, generic conceptual frameworks, such as those described above, can and should be supplemented by ecosystem-specific models. Conceptual models are often diagrams with boxes showing important components and arrows showing important processes within a system of interest, but they need not be complex; Figure 1 shows a simple model for Yellowstone National Park, and Figure 2 illustrates a different form of model for Puget Sound. In both, key components (e.g., Aquatic Biota, Sediments) are linked to other components via energy flow or other processes, and the models attempt to include all major components. As noted by the developers of Figure 2, “Developing a consensus regarding the components and linkages in the conceptual models is the first step in the process of reaching agreement on specific hydrological, ecological, and biological measures of restoration success” (Simenstad et al., 2006). PSP Developers of the indicators appear to have thought about stressors and response variables but not to have started with this kind of broad, system-wide over-view.



**Figure 1. An example of a simple, general conceptual model for Yellowstone National Park.**

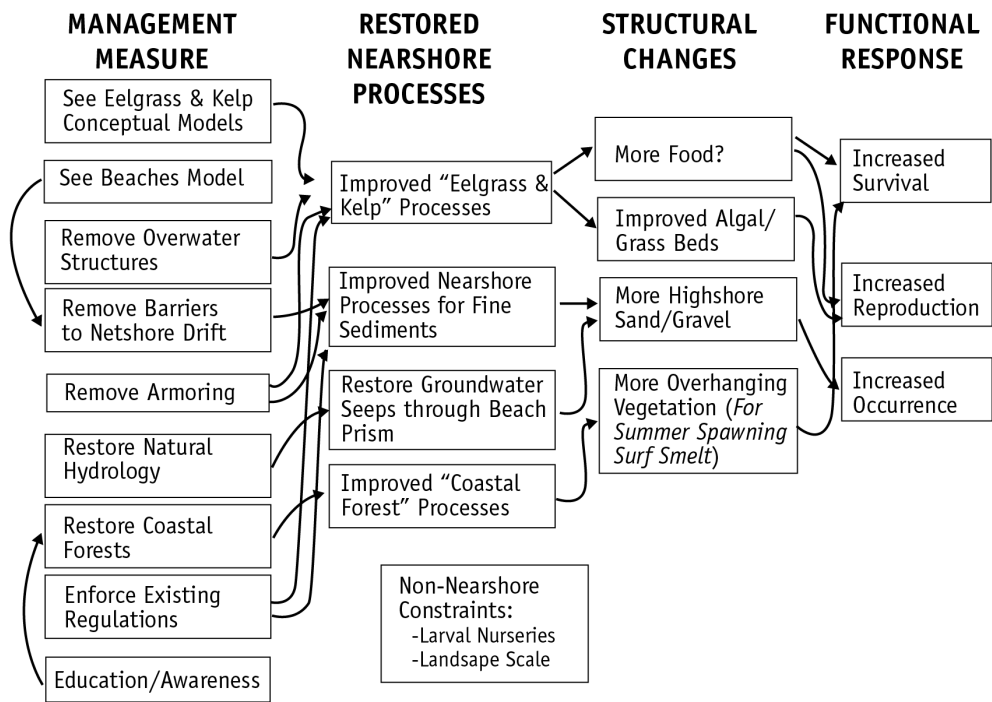
Arrows indicate that a given component affects another, e.g., herbivores affect vegetation by browsing, and vegetation affects herbivores by providing suitable habitat and food resources. (Source: D. Patten, personal communication)



**Figure 2. A general conceptual model for the diverse ecosystem components affecting the nearshore zone of Puget Sound.**

Boxes outside the Nearshore Domain (the black circle) affect components of the nearshore ecosystem via fluxes of matter (such as sediment and chemicals in water) and transfer of energy (such as heat and water flow). Within the Nearshore Domain, air, water, biology, and sediment all interact in complex ways as indicated by the different types of arrows. {Source: Simenstad et al., 2006}

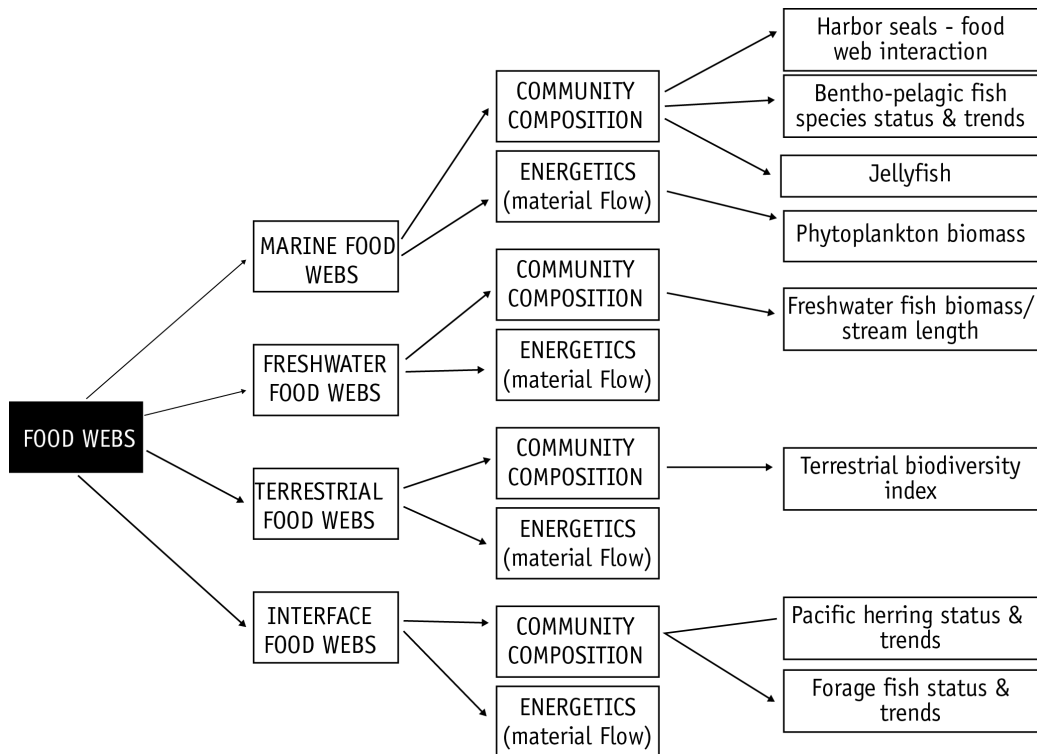
Using a generic conceptual framework (as in Table 1) ensures coverage of essential ecosystem attributes. Creation of a model specific to Puget Sound that includes these attributes provides a way to choose the most informative indicator from a particular category in a scientifically robust manner. The attributes illustrated may be processes (freshwater flow), outcomes (nutrient concentration), or measures of biotic condition (population of an important species, local biodiversity). Using expert knowledge is critical both in creating a complete list of attributes and, in the final step, identifying indicators that represent each attribute. Creating a hierarchy of models facilitates indicator selection, as shown by identifying the roles of different predators in the Yellowstone model, or factors that affect water in the Puget Sound model. A detailed sub-model is given in Figure 3, showing factors likely to affect populations of forage fish (of which herring, a Dashboard indicator, is a subset).



**Figure 3. A conceptual model of factors that could affect the restoration of forage fish in Puget Sound.**

Management measures in the left column indicate the diverse actions that could be taken to restore forage fish; these lead (via cause-effect arrows) to restored processes in the second column, which in turn result in structural changes in nearshore environments in the third column, and thus predicted functional responses of the forage fish. {Source: modified from Penttila, 2007}

Such simple models can be used to help identify stressors on components and response variables that might serve as indicators. In contrast, the arrows in the indicator-development graphics for the goals in the Puget Sound Science Update (e.g., Figure 4) do not correspond to flows of energy or cause-effect relationships. For example, “Pacific herring status and trends” is shown as a potential indicator, but the graphic does not aid PSP staff in either thinking about how herring are connected to the rest of the ecosystem (e.g., the variety of stressors acting on them) or whether there are attributes other than “community composition” for which herring might be an indicator.



**Figure 4. The organizational framework for the PSP goal of "Food Webs."**

Arrows in this diagram indicate subdivisions of categories or components into progressively more detailed categories, rather than energy flow or cause-effect relationships. {Source: Puget Sound Science Update, April 2011}

## II. C. Developing Indicators for Selected Attributes (Steps 1 Through 5)

### II. C. 1. Characteristics of Good Indicators

Once the set of attributes has been created using a conceptual framework and appropriate conceptual models (Step 1), indicators must be found for each attribute (Step 2) and associated metrics developed (Step 3). When more than one acceptable indicator is available for an attribute, Steps 4 and 5 ensure that the highest quality indicator is chosen.

Many sources of information can assist in identification of acceptable indicators (e.g., Niemeijer & de Groot, 2008) and associated metrics. The National Research Council (2000) developed a useful list of criteria for assessing the quality of indicators (Step 4). It includes the following criteria that we consider appropriate as threshold tests for an acceptable indicator: General importance (with reference to the natural system);



conceptual basis; reliability; temporal and spatial scales; statistical properties; data requirements; data quality; and robustness. Additional criteria listed in the NRC study, which might be considered to winnow the set (Step 5), include: skills required; costs, benefits, and cost-effectiveness; and international compatibility. The following discussion highlights some of these important characteristics.

In general, scientific information has been most effective in influencing public policy when it has been perceived by relevant stakeholders to be credible, salient, and legitimate. Credibility refers to the scientific adequacy of technical information and its assessment. Salience refers to the relevance of an assessment to the needs of decision makers. Data have legitimacy if they are judged to be fair, unbiased, and respectful of values and beliefs of diverse stakeholders.

Indicators are inevitably based on uncertain and imperfect understanding. Therefore, careful selection of what to measure—and of the conceptual and empirical models to use—together with recognition of the limits of the models, are vital to indicator development, interpretation, and use. To be credible, an indicator should be based on a well-understood and generally accepted conceptual model of the systems to which it is applied. The conceptual model provides the rationale for the indicator, suggests how it should be computed, and enables users to understand its features and implications of changes in its status and trends.

Indicators need to detect and report on changes at appropriate spatial and temporal scales without being overwhelmed by natural environmental variability. They need to yield reliable and useful numbers in the face of the inevitable external perturbations. They should be able to accommodate technological changes so that meaningful status and trends can be identified despite changes in measurement technologies.

To fulfill these conditions, an indicator must be judged to be reliable. Evidence for reliability is successful previous use, but all existing indicators need to be analyzed retrospectively to determine whether their continued use is warranted. A newly proposed indicator inevitably lacks a historical record of reliability, but if it is based on well-established theory, and if a retrospective analysis has indicated that it would have provided useful information had it been applied in the past, its reliability is provisionally established.

Most environmental indicators are designed to assess the status of processes and products (goods and services) that people currently value. Users value indicators that provide them with data that can inform their day-to-day decisions. This is why most environmental indicators report on specific components of the environment rather than more comprehensive pictures of environmental processes.

### **II. C. 1. a. Determining Temporal and Spatial Scales**

Key decisions about the use of indicators involve consideration of the temporal and spatial scales over which each indicator will be useful. Most environmental indicators depend on data gathered by means of long-term monitoring. Major challenges include deciding which rates of change to measure and determining which of the changes are “normal”—that is, within the range of natural variability—and which are not. Often, rate changes can be determined only after long periods of time because some ecosystem characteristics (e.g., soil properties, evolutionary changes in species) change very slowly; others change moderately slowly (vegetation succession, species ranges), but some change rapidly in response to natural (fire, storms) or anthropogenic (acid rain, wetland drainage, sea level rise) disturbances. The expected rates of change in the traits monitored by an indicator should determine the frequency with which measurements need to be made and how often it is necessary or desirable to report changes. People may not continue to pay attention to an indicator if the standard report is “no change” although “no change” over time may be the preferred response. Moreover, valuable human and financial resources are wasted when data are gathered, archived, and reported more frequently than is useful.

### **II. C. 2. Key Information for Describing Indicators**

Once a set of indicators is developed, it is important to clearly describe the rationale behind the selection and nature of the indicators and the metrics needed to quantify each one. The description acts both as a communication device and also as a check on the integrity of the selection process. The Committee found that PSP inadequately describes many of its indicators.

It is obvious that there is no single right format or list of key information for presenting characteristics of an indicator. However, how an indicator is to be used can guide what needs to be said about it.

Based upon our analysis of past approaches, the Committee suggests the following general format for presenting indicators. The order of these characteristics proceeds stepwise from description of the indicator, including its scientific justification, through how it is measured, to description of its scale.

- Introductory statement: How the indicator fits within or is applied to an attribute from the conceptual framework.
- Descriptive statement: What is the indicator?
- What does the indicator indicate? For example, does it show existing conditions, or changes over time? Does it relate to ecosystem processes, such

as inputs, environmental stressors, environmental responses, or does it focus on outputs?

- How is it measured? What basic methods are used to gather data? Do adequate methods exist?
- If the methods exist, how well can the indicator be quantified?
- How much is already known about the indicator?
- What is the scale in time and space on which the indicator reports? It is important to understand the potential value of the indicator over time at different spatial scales (e.g., local to regional).

Two other indicator characteristics may be included, depending upon the purpose of the indicator set (e.g., conditions, management). These are:

1. Explain how well the indicator is (or could be) understood by the “public” and other “users.” To be useful, an indicator needs to be understood. Is an educational program needed?
2. Explain how the indicator can be used to guide management actions.

The Committee used the above list to evaluate the descriptions of indicators in the Dashboard Briefsheets (e.g., eelgrass and shellfish). We found that the Dashboard descriptions are based more on policy, management, and target setting than on presentation of indicator characteristics, although some characteristics in the Briefsheets do relate to scale and use of conceptual models.

## **II. C. 3. Guidelines for the Use of Indicators**

An excellent set of indicators is of little value unless supporting institutions are also developed and used. Those institutions should be designed to facilitate archival, interpretation, and communication of the information gathered. These usage-steps support a learning process in which indicators assist in showing how the system changes or responds over time.

### **II. C. 3. a. Education**

Public perception of how ecosystems provide goods and services, and of the value of many goods and services, lags behind scientific understanding. For example, the vital roles of microorganisms on land and in the oceans are unappreciated. Few people understand the connections between application of fertilizers on farmlands and ocean dead zones. Therefore, an education program needs to be a part of any attempt to develop and use most ecological indicators. Educational programs need to recognize that attempts to achieve one desired outcome can undermine attempts to achieve others. If

education programs are perceived to reflect political agendas, achieving salience may come at the expense of legitimacy.

Public trust in the people and institutions that produce indicators underlies legitimacy. Legitimacy is also enhanced 1) by educating the public about methods, motivations, rules, procedures, and accountability, and 2) if data archiving, analysis, and reporting are institutionally separated from decision making. Data and indicators based on them that are generated by organizations without regulatory or enforcement responsibilities, such as the U.S. National Weather Service, are generally trusted. Nevertheless, no matter how legitimate the data are perceived to be, saliency requires some political or management input if the information is to be useful to politicians and managers.

### **II. C. 3. b. Data Quality and Instrument Calibration**

To ensure the technical accuracy and legitimacy of environmental indicators, procedures are needed to monitor input data, to standardize measurements, to cross-calibrate instruments—especially when measurement technology changes—and to document collection and analytical methods so that people not associated with the original data collection can reproduce them. It may be difficult to convince policy makers of the importance of data quality assurance and management, but failure to maintain appropriate standards may jeopardize the utility of the indicator.

The eventual set of indicators selected for Puget Sound should provide useful information over multiple spatial and temporal scales. Instruments that measure spatial and temporal variation must be calibrated carefully to ensure that changes in the measurements are caused by changes in the ecosystem, not in the instruments themselves. In addition, some data sets will last longer than the lifetime of any one measuring instrument. In those cases, it is vital that successive instruments be calibrated during a period of overlap. Potential degradations of instrument performance should also be monitored, assessed, and corrected if necessary.

### **II. C. 3. c. Archiving and Data Access**

Legitimacy of environmental indicators requires that data gathered are archived and available to a wide range of potential users if the indicator is to be accepted and used to guide policy. Attention needs to be paid to who has quality control over input data. Who coordinates and manages the archives? How does the system respond to queries from varied potential users? How is the data storage system integrated with systems maintained by other political entities? The rapid improvement of technology—remote sensing, computer hardware and software—is removing many impediments to the assimilation and use of large datasets. Nevertheless, their existence increases the importance

of the care, maintenance, and accessibility of data archives, (see National Research Council, 2000, for a thorough discussion of these issues).

Thus, before the indicators for Puget Sound are adopted and fully implemented, substantial thought and effort should be given to data quality control, data archiving, and data access. The integrity of long-term information is essential, because individual measurements acquire most of their value when they are compared with the same measurements from similar ecosystems or from the same ecosystem over time.

Archival issues that need attention include the following (National Research Council, 2000):

How and by whom will quality control over input data be ensured?

Who are the potential users of the data, and how can their needs be met?

How can the data be used to improve the models on which the indicator is based?

How will the archival system accommodate technological changes in both data collection and archiving methods?

Who will coordinate and manage the archives?

How can the archival system respond to user queries that may require new analyses and interpretations of existing data?

How will the data storage system be integrated with other archival systems of federal, state, and local governments?

### **II. C. 3. d. Expectations for an Indicator System**

The value of indicators derives from the premise that better understanding of the system being monitored leads to policies and management interventions that foster desirable changes and decrease the likelihood of undesirable changes. Yet, our understanding of the functioning of Puget Sound will continue to be incomplete. For example, we do not know how many species live in the region, and we know little about most of the species of whose presence we are aware. Our estimates of the value, economic and non-economic, of the goods and services derived directly and indirectly from Puget Sound are, and will remain, rough. With good investment of financial and human resources, some current unknowns will become better understood, but no amount of research will completely eliminate uncertainty. Therefore, the allocation of resources to obtaining the data needed to populate the set of indicators finally selected for monitoring the status

and trends in Puget Sound should be evaluated over time in terms of the amount of uncertainty removed per unit of effort. This is essentially a form of adaptive management: an iterative process of decision making with a goal of reducing uncertainty over time. Adaptive management can be either passive or active. Passive adaptive management is basically learning from doing, that is, monitoring ongoing interventions to assess outcomes (i.e., passively). In active adaptive management, learning is a central goal—that is, pilot interventions are initiated with the objective of filling gaps in critical information before major management actions are launched (Holling, 1978; Walters, 1986). The latter may often be applicable to Puget Sound management, owing to lack of critical information about the ecosystem. In both forms, new knowledge is used to update the models and to improve management strategies, and perhaps to alter the indicators or metrics in use.

Appropriately used, the chosen indicator set will be of value to a wide range of interested parties, but the PSP should not expect it to generate certainty or to be the source of all the information society will need to achieve the goal of maintaining a dynamic ecosystem that provides a full array of goods and services in perpetuity to the region's inhabitants. Moreover, although the basic indicator set will provide vital information about some major processes and products, it will provide limited information on the causes of those changes, and the data will be of limited use in assessing the effectiveness of specific management interventions. The Puget Sound Partnership plans to develop additional indicators that deal directly with assessing the efficacy of management interventions. These indicators can potentially provide important supplements to the set of indicators we have evaluated in this report. Nonetheless, understanding the dynamic properties of the Puget Sound ecosystem and developing effective means to monitor changes in it will always be works-in-progress.



### III. EVALUATION OF PSP ECOLOGICAL CONDITION INDICATORS

To determine the characteristics of the Dashboard Indicators and present them in an organized description (see Sections III. C and III. D), the Committee sought a section in the documents produced by the Puget Sound Partnership that presented an orderly list of indicator characteristics. We found none and had to glean them from sections of several documents. Our need to “shop” is evidence of the importance of having and using a comprehensive set of characteristics as we recommended above.

#### III. A. Overview of the PSP Indicator Selection Efforts

The Puget Sound Partnership employed a variety of methods as it developed and refined a set of indicators to assess the state of the Puget Sound ecosystem. According to the chronology provided to the committee by Currens (2011b), the following reports together describe the process PSP used to craft the Dashboard indicator set.

To develop indicators in the context of a larger ecosystem management strategy, the PSP adopted the Integrated Ecosystem Assessment Approach (Levin et al., 2008).

O'Neill et al. (2008) assembled and reviewed more than 100 documents and databases to generate a list of already-identified indicators meeting certain quality-control criteria that could be used to populate an indicator set.

The PSP's Puget Sound Action Agenda (2008a) presented a list of 79 ecosystem indicators, based on O'Neill et al. (2008), with input from the PSP Science Panel.

To provide a more robust method for integrating science into policy decisions for the Sound, and to supplement the Ecosystem Assessment Approach, the PSP adopted the Open Standards for the Practice of Conservation 2.0 (Conservation Measures Partnership, n.d.).

In the 2009-2011 “Biennial Science Work Plan,” the Science Panel adopted the Ecosystem Assessment Approach, reviewed the results of O'Neill et al. (2008), and recommended that additional indicators be developed to fill remaining gaps.

In November 2009, the PSP technical memorandum “Identification of Ecosystem Components and Their Indicators and Targets” (Neuman et al., 2009) provided a set of 160 indicators, including those relevant to human health and well-being.



The “2009 State of the Sound Report” (Puget Sound Partnership, 2010) used the above technical memorandum as a guide to report on indicators, as required by legislative deadlines.

In July 2010, the Leadership Council adopted a preliminary set of Dashboard System Indicators developed by the Indicators Action Team. Indicator selection was guided by prepublication drafts of the Puget Sound Science Update (Levin et al., 2011) and is described in “Development of the Dashboard of Ecosystem Indicators for Puget Sound” (Puget Sound Partnership Indicators Action Team, 2010-2011).

Chapter 1A of the Puget Sound Science Update (Levin et al., 2011) combined all of the previous lists of proposed indicators, proposed a framework for developing a set of indicators, proposed selection criteria for individual indicators, and screened the entire list of indicators according to these criteria. Levin et al. (2011) did not recommend a set of indicators.

Due perhaps to the challenging timeframes imposed by legislative mandates, many of these efforts overlapped in time and took slightly different directions, resulting in a disjointed progression toward the ultimate choice of indicators. Nonetheless, significant progress was achieved in a relatively short time. In this section, we review portions of the above list that have been (or should be) particularly relevant to the process by which the ultimate set of indicators will be selected.

Consistent with guidance from the Leadership Council (Levin et al., 2011) the complete system of indicators envisioned by PSP includes two sets: the top-tier Dashboard indicators and a larger set of indicators to track the condition of the ecosystem. The Committee supports the creation of a hierarchical, multitier system of indicators that uses a small indicator set to communicate with the public and a larger set to understand ecosystem conditions in more detail. It is important that both sets encompass the key structural and functional elements of the ecosystem—not simply the popular or iconic elements—and that the smaller set is derived from and consistent with the larger set.

Although substantial groundwork has been laid for the selection of the larger set of ecological condition indicators, these indicators have not yet been chosen. In the following section, the Committee reviews the work accomplished to date and the system by which the larger set of indicators presumably will be developed. We then review the initial set of Dashboard indicators and the system by which that set was selected. Finally, we review the individual Dashboard ecological condition indicators.

### **III. B. Review of the Larger Set of Ecosystem Indicators**

The initial context for development of the indicator set was provided by the Ecosystem Assessment Approach described by Levin et al. (2008) and later adopted by the Science Panel (Puget Sound Partnership, 2008b). In this approach, models of Drivers-Pressures-States-Impacts-Responses (DPSIR) are created to relate management actions to aspects of the ecosystem that people care about. At this point in time, the PSP focused on indicators of the “state” (condition) of the ecosystem (Martha Kongsgaard, pers. comm.), which the Committee defines as indicators that reflect the structural, compositional, and functional elements of the system, and that collectively provide a window into the condition of the system as a whole. The Committee supports this approach.

O’Neill et al. (2008) developed a logical platform for subsequent work. They identified the following tasks required for the first phase of indicator development: develop criteria and a framework to be used for selecting environmental indicators; create conceptual models that define key structural and functional properties of the Puget Sound ecosystem components; identify, compile, and summarize former, current, and proposed indicators for the Puget Sound ecosystem; and select and evaluate the most suitable environmental indicators based on criteria/framework and conceptual models.

To get the process started, O’Neill et al. (2008) created an initial list of criteria that should be met by individual indicators, and they adopted two complementary frameworks for assessing the set of indicators. The first, the DPSIR system, provides a method to categorize indicators and select those that are state indicators. The second, derived from the U.S. Environmental Protection Agency (2002), provides a method to organize and analyze the resulting suite of state indicators. Using a nested hierarchy of Essential Ecological Attributes, the U.S. Environmental Agency (2002) provides a framework for identifying which of the structural, compositional, and functional elements of the ecosystem are covered by the list of available indicators, and which essential elements are not represented (see Table 1).

The second task, creating conceptual models of the key ecological attributes, was beyond the scope of O’Neill et al. (2008), but was recommended as a next step. That approach, using the DPSIR system to link ecosystem components with the management framework, is reasonable. In the Committee’s view, however, conceptual models also should be developed for the functioning of the ecosystem, based on an understanding of the essential attributes and not constrained by the particular goals of the PSP (see Section II. B above). To the authors’ credit, O’Neill et al. (2008) included this recommendation.

The third task, compiling currently available indicators, resulted in a list of more than 650 indicators. The fourth task, weeding this list according to the quality-control criteria for individual indicators, resulted in a list of 124 ecosystem indicators ranked either “good” (suitable for current use) or “potential” (suitable with additional work). These indicators were categorized according to the goals of the PSP: species and food webs, habitats, water quality, and water quantity. Finally, this suite of available indicators was analyzed with reference to EPA’s essential ecological attribute hierarchy. The analysis showed, for example, that the available indicators provide substantial coverage of species, particularly higher-trophic-level species, but under-represent species at lower trophic levels and many functional groups. Community-level indicators are few, landscape indicators cover some habitats but not others, and indicators of important basic ecological processes (energy and material flows) are lacking. This analysis provided a preliminary roadmap for considering other indicators that should be developed and included in the final indicator set. In the Committee’s view, this was an excellent start.

In its 2008 Puget Sound Action Agenda, the Puget Sound Partnership adopted the indicator list provided by O’Neill et al. (2008) but did not address the major gaps in attributes that were noted in that report. In the Action Agenda, the indicators were grouped according to the four ecosystem-related goals set out by the legislation and the subsidiary “desired outcomes” (similar to objectives) that had been developed with technical and public input (Martha Kongsgaard, pers. comm.). This provided a management context for the indicators and allowed members of the public to relate indicators to outcomes per the Integrated Environmental Assessment Approach. Nonetheless, because O’Neill et al.’s analysis of the set was not referenced in the Action Agenda, the opportunity to inform the public of the ecological context of the various indicators was missed. More importantly, no attempt was made to rebalance the portfolio by suggesting that the gaps pointed out earlier should be filled. As a result, the indicator list remained incomplete; the importance of including all ecologically significant attributes was lost.

The next step in the evolution of the indicator set was influenced by the PSP’s decision to adopt the Open Standards for the Practice of Conservation 2.0, which was developed, and is now used, by a broad coalition of organizations involved in conserving and restoring small and large ecosystems. In that framework, the initial step in a project includes identifying the results to be achieved, conservation “targets,” the “key ecological attributes” of each target, and any indicators for each attribute. Conservation “targets” are defined as the “specific species, ecosystems/habitats, or ecological processes that are chosen to represent ... the full suite of biodiversity in the project area;” key ecological attributes are those relevant to determining the condition of the target (Conservation Measures Partnership, n.d., p. 9). This method is applied to situations in

which biodiversity conservation is paramount; it seems well suited to development of management (as opposed to state) indicators. There appears no intrinsic reason, however, why the method cannot also produce a set of targets, key attributes, and indicators that represent the structural, compositional, and functional elements of an ecosystem. In November 2009, Neuman et al. summarized the work to date to develop a framework for the indicator set, describing two approaches for defining the indicator categories that should be included. The first derived from the legislative goal statements (Table 1 in Neuman et al., 2009), while the second derived from the “targets” (renamed “focal components”) developed using the Open Standards for the Practice of Conservation methodology (Table 2 in Neuman et al., 2009).

In the Committee’s view, both approaches were flawed. The indicator categories in Neuman’s Table 1 do not explicitly cover the range of attributes necessary to describe an ecosystem. Selected species and habitat types dominate the indicator categories in Table 2, suggesting that the focal components were not developed with reference to a conceptual model of the structure and functioning of the ecosystem. Further, the proposed indicators for each of the key attributes of the focal components (Appendix B in Neuman et al., 2009) treat the various habitats inconsistently, making it difficult to integrate them into a coherent picture of structural and functional elements. After presenting the two systems and summarizing the earlier O’Neill et al. (2008) analysis, Neuman et al. (2009) provide recommendations for refining the indicator framework in the upcoming Puget Sound Science Update.

The “2009 State of the Sound Report” (Puget Sound Partnership, 2010) reported on selected indicators, organized according to the legislative goals and following the categories presented in Neuman et al. (2009) (Table 2).

**Table 2. Framework for indicator selection in the “2009 State of the Sound Report” (Puget Sound Partnership, 2010).**

<b>Species Food Webs (Goal)</b>
<ul style="list-style-type: none"> <li>■ Species and Communities of Greatest Conservation Concern (Indicator Category) <ul style="list-style-type: none"> <li>▫ Imperiled Native Species and Species Groups (Indicator)</li> </ul> </li> <li>■ Flagship Species <ul style="list-style-type: none"> <li>▫ Orca</li> <li>▫ Pacific herring</li> <li>▫ Listed salmon</li> </ul> </li> <li>■ Food Webs</li> </ul>
<b>Habitat</b>
<ul style="list-style-type: none"> <li>■ Extent of Ecological Systems <ul style="list-style-type: none"> <li>▫ Conversion of Upland Habitats</li> <li>▫ Marine Shoreform Change and Shoreline Alterations</li> <li>▫ Eelgrass Area</li> </ul> </li> <li>■ Condition of Ecological Systems</li> </ul>
<b>Water Quality</b>
<ul style="list-style-type: none"> <li>■ Chemical Contamination in Marine Environments <ul style="list-style-type: none"> <li>▫ Contaminants in Benthic Environments</li> <li>▫ Contaminants in Pelagic Environments</li> </ul> </li> <li>■ Water Quality in Fresh and Marine Waters <ul style="list-style-type: none"> <li>▫ Fresh Water Quality Index</li> </ul> </li> </ul>

The selection of these indicators presumably was based on availability of data, but how additional winnowing took place was not explained in the document. The report noted, however, that some indicator categories do not have indicators with available data. It also provided a useful description about why each of the indicator categories is relevant to the condition of Puget Sound.

The most recent effort to guide the selection of an indicator set is in Chapter 1A of the Puget Sound Science Update (Levin et al., 2011), which again focuses on ecosystem state indicators. The authors present a framework for identifying key ecosystem attributes—organized according to the PSP goals—list potential indicators of these attributes, develop a list of criteria for assessing individual indicators, and review the candidate list of individual indicators.

Although several frameworks for choosing indicators had previously been developed under the PSP umbrella, none was formally adopted. Levin et al. (2011) delve into considerable detail to present a new framework that attempts to combine the goal-derived system reproduced in Table 2, the procedures and terminology outlined in the Open Standards, and other frameworks (including EPA, 2002, and Heinz Center, 2008). In Levin et al.'s resulting framework, the ecosystem goals are the "Tier 1" categories. "Tier 2" names the focal components, which repeat the goal but assign it to marine, freshwater, terrestrial, or interface areas (e.g., marine species, marine food webs, freshwater species, freshwater food webs). "Tier 3" describes each of the goals in Tier 1 by two or three "key attributes" (see Table 3 in Levin et al., 2011), which in turn are defined by "relevant measures," which we label "Tier 3a." The indicators apply to the key attributes and are labeled "Tier 4" in Levin et al. (2011).

**Table 3. Framework for indicator selection in the Puget Sound Science Update (Levin et al., 2011).**

Goal	Key Attributes (Tier3)	Relevant Measures (Tier 3a)
Species		Number of individuals or total biomass; population dynamics
	Population Condition	Age structure; population structure; phenotypic diversity; genetic diversity; organism condition
Food Webs	Community Composition	Species diversity; trophic diversity; functional redundancy; response diversity
	Energy and Material Flow	Primary production; nutrient flow/cycling
Habitats	Habitat Area & Pattern/Structure	Area or extent; number of habitat types; number of patches of each habitat; fractal dimension; connectivity
	Habitat Condition	Abiotic & biotic properties of a habitat; dynamic structural characteristics; water & benthic condition
Water Quality	Hydrodynamics	Water movement; vertical mixing; stratification; hydraulic residence time; replacement time
	Physical/Chemical Parameters (Sediments & Water Column)	Nutrients; pH; dissolved oxygen/redox potential; salinity; temperature
	Trace Inorganic & Organic Chemicals (Sediments & Water Column)	Toxic contaminants; metals; other trace elements & organic compounds
Water Quantity	Surface Water	Flow magnitude & variability; flood regime; stormwater
	Groundwater Levels & Flow	Groundwater accretion to surface waters; within groundwater flow rates & direction; net recharge or withdrawals; depth to groundwater
	Consumptive Water Use & Supply	Water storage

In this framework, Levin et al. (2011) began with the legislative goals of the PSP (Tier 1); subdivided these geographically (Tier 2, not shown); listed “key attributes” associated with each goal, based on the structure and functioning of ecosystems (Tier 3); and further ensured representative coverage of attributes by listing them as “relevant measures” (which we label Tier 3a). This conceptual framework—when it includes Tier 3a—provides a reasonable initial basis for indicator selection.

The meat of the framework is in the organization of Tier 3 (Table 3). It is at this level that the framework attempts to capture the full range of ecological structure and functioning. According to Levin et al. (2011) “although they differ in detail, the Key Attributes adopted here encompass all those identified by EPA (2002), Heinz Center (2008), and the PSP.” In the Committee’s view, when the “relevant measures” are included (Tier 3), the list does a reasonable job of identifying attributes that represent an ecosystem (with some exceptions, such as sediment dynamics, discussed below). However, not including certain elements of Tier 3a (e.g., primary production, species diversity) impairs the framework’s ability to encompass important attributes of Puget Sound. The authors provide an extensive and useful discussion of each of the key attributes and “relevant measures.” Together with Table 3, including the Tier 3a relevant measures, they provide a reasonable conceptual framework (our Step 1, p. 84) for constructing a set of indicators for Puget Sound.

Levin et al. (2011) then proceed to Steps 2 and 4, listing the available indicators for each of the key attributes and providing a scheme by which to evaluate their quality. To compile the list of indicators, they combined the lists of O'Neill et al. (2008), PSP Action Agenda (Puget Sound Partnership, 2008a), Neuman et al. (2009), PSP's "Ecosystem Status and Trends" (Puget Sound Partnership, 2009), and a literature-based list of potential water quantity indicators. The composite of more than 250 potential indicators was then organized according to the key attributes defined in Tier 3 of the proposed framework, but they did not sort the indicators into the properties described by the relevant measures (Tier 3a). The authors pointed out the paucity or absence of indicators for certain Tier 3 attributes (such as energy and material flow), and recommended that these gaps be filled. ***The Committee recommends that when the definitive list of condition indicators is developed, this useful exercise should be extended to the key measures (Tier 3a), so that the full range of important ecological attributes is included and matched with an appropriate indicator.*** As part of their analysis, Levin et al. (2011) also generated a list of criteria by which to judge the quality and utility of individual indicators (pp. 42-44) and graded the indicators accordingly. The appropriateness of that grading system is discussed in the next section.

These myriad and sometimes disjunct efforts, culminating in the framework presented by Levin et al. (2011), provide a solid foundation for the selection of a set of condition indicators for Puget Sound. In the Committee's experience, it is not unusual to have stops and starts and a few blind alleys during the development of indicator systems.

***To build successfully on this foundation, however, the Committee recommends that PSP follow the steps outlined above (see Section II); use a slightly refined version of Tiers 3 (key attributes) and 3a (relevant measures) of Levin et al. (2011) as part of the conceptual framework; supplement this framework with appropriate conceptual models; adjust the quality criteria used to evaluate individual indicators and associated metrics; and identify gaps that should be filled. The final step in the process—reassessing the indicator set for its coverage of important ecological attributes—is essential.***

### III. C. Review of the Set of Dashboard Ecological Indicators

The purpose of the Dashboard of Ecosystem Indicators for Puget Sound is to provide a small set of "ecologically important and socially resonant" indicators that reflect conditions in and track progress towards restoring the "health" of Puget Sound. Although the ultimate Dashboard will include management indicators, the initial set is focused on condition.

Section II. A of this report describes a stepwise procedure for identifying the key attributes (characteristics) of the system to be tracked and appropriate indicators of those



attributes. The Committee used the frameworks developed by the National Research Council, The H. John Heinz Center, and the Science Advisory Board of the U.S. Environmental Protection Agency, as well as the set of key attributes common to all of them in its analysis of the process the PSP used to develop the set of ecosystem indicators for Puget Sound.

The conceptual framework used by the PSP to develop the Dashboard was derived from that of Levin et al. (2011) shown in Table 3, above. Unfortunately, however, the flaws of the larger set became magnified. Specifically, the authors of the Dashboard adopted the 4-tier logic of Levin et al.'s framework as discussed in Section III. B (e.g., Figure 4), but used only the Tier 3 list of attributes to guide indicator selection, seemingly without reference to the "relevant measures" (Tier 3a) necessary to ensure adequate coverage. As a result, some attributes are missing (e.g., sediment dynamics), some key attributes have several indicators, and others have none. We discuss some of the missing components at the end of this section and provide guidelines for developing corresponding indicators later in this report.

We now turn to the subsequent steps in the process of developing indicators and evaluate the process the PSP used to identify potential indicators for each attribute (Step 2), to select metrics for each indicator (Step 3), to evaluate each indicator and its measures (Step 4), and to winnow the array of potential indicators to arrive at the final set (Step 5).

The PSP identified potential indicators for each attribute, using the methods and results of O'Neill et al. (2008), Neuman et al. (2009), and Levin et al. (2011). To review: PSP started with the list of more than 650 existing indicators, then shortened the list by ranking indicators into two categories—"good" (suitable for current use) or "potential" (suitable for additional work). They categorized the indicators using the legislatively mandated goals—species and food webs, habitats, water quality, and water quantity—as well as the attributes assigned to each goal in Tier 3 (see Table 3). The goals relate to characteristics of the Puget Sound ecosystem but, because their selection was not based on a sound conceptual model of the system, they do not generate an adequate set of attributes.

To choose the final indicators (Tier 4), the PSP appears to have skipped over Steps 2 and 3. Instead, the authors employed a ranking system that consisted of series of criteria—Primary Considerations (six categories), Data Considerations (eight categories), and Other Considerations (five categories)—combined with a weighting system described in the Puget Sound Science Update (Levin et al., 2011). Each criterion was given a score ranging from 0 to 1.

The Committee reviewed this process using the information available, but the written documents contain little information about the rationale behind either the selection of criteria or assignment of rankings.

Lists of criteria for indicators are about as abundant as indicators, so choosing criteria for a particular task inevitably has a subjective element. However, the Committee judges some of the criteria used by the PSP to be inappropriate. First, based on the stated goals of the indicator list, the primary criteria all should have related to the state or condition of the Sound. Instead, two of the “primary considerations” relate directly to management concerns (No. 2, “relevant to management concerns,” and No. 4, “responds predictably and is sufficiently sensitive to changes in a specific management action or pressure”). These two criteria together are in fact weighted 3 times as highly (1.5 vs. 0.5) as the criterion the Committee judges to be of highest importance, “theoretically sound” (having a strong conceptual basis). A good indicator may often also be relevant to management activities, but including these criteria and weighting them highly puts far too much emphasis on management relevance and is inconsistent with the stated purposes of the indicators.

Second, given that literature used by the PSP explains why the existence of data on a potential indicator should not be a primary criterion (e.g., Heinz Center 2002, 2008), the emphasis on “data considerations” was highly inappropriate. In fact, the total potential score given to data considerations summed to 5.25, versus a total of 3.25 for the “primary” considerations. Ironically, one of the data considerations is a valuable property of an indicator (“high signal to noise ratio”) but was given a weighting score of 0. A high signal-to-noise ratio is essential if an indicator is to detect real changes in the environment against a noisy background.

Third, the highest-weighted of the “Other considerations”—“Understood by the public and policymakers”—is inappropriate for initial screening. The Committee recognizes the importance of having some indicators that serve a communication role, i.e., easily understood metrics or iconic species (such as orcas) that the public can relate to. However, weighting this criterion heavily means that indicators that are conceptually more important but harder to understand are unlikely to be chosen.

Finally, it appears that all three types of criteria (primary, data, and other) were actually used simultaneously and summed together in the process of filtering the list of potential indicators. If “primary” criteria were really the most important, only those criteria should have been used as a filter in the first step.

The process used to assign weights was not explained in documents available to the Committee, so we cannot comment on it. However, in addition to noting that subjective judgments inevitably were made, it is clear that the different criteria are not independent. Therefore, giving them separate weights and adding up scores means that some criteria are double-counted. Other criteria, for no clear reason, were not counted at all (e.g., the zero scores given to some of the data considerations). Some of the zero scores were necessary. “Complements existing indicators” (a primary consideration) cannot be evaluated until after a potential initial list is formed. Overall, the process of choosing and scoring criteria—which appeared to be central in selecting the current list of indicators—is opaque, weightings of some criteria are inappropriate, and the legitimacy of summing the scores to rank indicators is questionable.

Thus, although the PSP states that scientific criteria were primary for selecting indicators, the scoring system the authors used violated that premise. An unfortunate result was that only indicators for which data were already available survived the first cut. Potentially valuable indicators were dropped from the list simply because they lacked existing data. The Committee judges that using availability of data as the primary criterion for initial screening of potential indicators is highly inappropriate. Only in the final stages (Step 5), when choices need to be made among indicators capable of representing an attribute, should data availability be used as a major criterion. The Committee urges the PSP to reassess the pool of indicators from which the final list was selected, using only appropriate Primary Considerations as the basis for the initial screening.

The Dashboard authors also mapped the available indicators according to two additional criteria: sensitivity (whether they are leading or lagging) and specificity (whether they are diagnostic of changes in specific ecosystem attributes). The authors judged that the set of Dashboard indicators should include indicators from each of the resulting four categories (lagging and diagnostic; leading and diagnostic; lagging and broadly informative; and leading and broadly informative). For two reasons, the Committee judges this procedure to be highly questionable. First, as we emphasized above in Section I. A, indicators should not be designed to be “diagnosticators.” Second, the four categories do not correspond to any key ecosystem attributes, so using them as a basis for selecting indicators lacks scientific justification.

The resulting list of Dashboard indicators proposed by the Indicators Action Team was mapped onto the 4-Tier framework (Figures A44a, A54b, A6; Puget Sound Partnership, 2011b) and onto the sensitivity/specificity grid (Figure A11).

**Table 4. Current Dashboard ecological indicators listed by goals, key attributes, and more recently published descriptive categories.**

Goal	Key Attributes	Dashboard Indicators
Species	Population Size	Orca, Chinook salmon, birds
	Population Condition	
Food Webs	Community Composition	Jellyfish (replaced by herring)
	Energy and Material Flow	Marine water quality index
Habitats	Habitat Area & Pattern/Structure	Eelgrass, land cover/land use
	Habitat Condition	Shoreline armored
Water Quality	Hydrodynamics	
	Physical/Chemical Parameters (Sediments & Water Column)	Water quality index
	Trace Inorganic & Organic Chemicals (Sediments & Water Column)	Water quality index, toxics in English sole, sediment triad
Water Quantity	Surface Water	Violations of in-stream flow requirements (later omitted)
	Groundwater Levels & Flow	Percentage of monitored stream flows below critical levels
	Consumptive Water Use & Supply	

Adapted from PSP Indicators Action Team (2010-2011), including Appendix A Figures A44a, A6, and A54b.

This list of indicators was modified only slightly in response to external review, including review by the Leadership Council.<sup>1</sup> The current list of recommended Dashboard indicators (with operational definitions) for the natural dimension is shown in Table 4 along with the goals (Tier 1) and key attributes (Tier 3) for which they were selected, and with indicator categories used in subsequent publications.

Table 5 organizes the same indicators more simply but includes most of the information from Table 4. It omits only the goal “Food Webs” that none of the Dashboard indicators directly addresses. It assigns each indicator to its most relevant key attribute, in conformity with the conceptual framework of the Puget Sound ecosystem discussed above.

<sup>1</sup> The jellyfish indicator was changed to Pacific herring; number of in-stream flow violations was removed.

**Table 5. Dashboard indicators initially recommended by the Indicator Science Team listed by goals and key attributes.**

Goal	Key Attributes	Dashboard Indicators
Water Quality	Physical, Chemical, and Biological Parameters of Water Column and Sediments	1. Marine water quality 2. Freshwater quality 3. Toxics in fishes 4. Toxics in sediment
Water Quantity	Percentage of Monitored Stream Flows Below Critical Levels	5. Groundwater levels and flow
Species	Abundance (Population Size)	6. Orcas 7. Salmon 8. Pacific herring 9. Birds
Habitats	Habitat Area, Pattern/Structure	10. Eelgrass 11. Shoreline armored 12. Land cover/land use

Adapted from Puget Sound Partnership (2011b) Figures A44a, A6, and A54b but reordered to fit the framework used by the Committee.

In summary, developing a framework that is grounded in an understanding of the Puget Sound system (Step 1) is necessary to ensure that the indicator set adequately represents the ecosystem. The PSP did not use this step. Step 2 ensures that all key attributes are represented by indicators. Simply choosing indicators for which data are immediately available, or indicators that are popular, guarantees that key attributes will lack indicators. PSP also missed the conceptual importance of this step, skipping instead to a procedure to choose among already-existing indicators. Following Steps 1-6 outlined in Section II. A could have avoided these shortcomings. An unfortunate outcome of using a combination of flawed processes is that some important attributes are missing, some of the Dashboard indicators do not match the attributes they are supposed to represent (compare Tables 4 and 5), and the set of Dashboard indicators as a whole is skewed toward some attributes at the expense of others (compare columns 2 and 3 of Table 5). In addition, insufficient attention was given to evaluating the specific metrics to be used for each indicator. (We describe examples of the latter problem in the evaluations of the individual Dashboard indicators below.)

These flaws, however, do not require PSP to “start over.” Much valuable groundwork has been laid, and most of the Dashboard indicators are appropriate after some tinkering and refinement. The Committee’s recommendations can be used to move forward with a process of shoring up the existing set of Dashboard indicators. PSP has developed

Dashboard 1.0. We provide a pathway to “Dashboard 2.0.” To illustrate this process, we describe four specific examples of key attributes that lack indicators. We discuss each of these in more detail in Section V.

First, the conceptual model of Levin et al. (2011) (see, e.g., Table 3) omits the role of sediment dynamics. Sediments are one of three broad components defining the Puget Sound ecosystem in Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) models (Figure 2), and sediment delivery and transport are among the most critically impaired processes in the nearshore environment of the Sound (Fresh et al., 2011). Yet the only Dashboard indicator that relates, and only indirectly, to issues of sediment dynamics is “shoreline armoring.” Second, although the attribute “habitat area” is identified, the indicator chosen to represent habitat area in the marine system—extent of eelgrass—is only one habitat type among many important habitat types for which extent information will be valuable. An index or composite indicator of extent would be far more useful than tracking extent of a single habitat.

Third, although “community composition” is correctly identified as a key attribute, the selection of a single species, Pacific herring, fails to represent the attribute. A measure of biodiversity would be a valuable addition. Diversity is a difficult indicator to develop, but there is a strong theoretical basis for its importance as a metric of ecosystem functioning. The “toxics in sediments” indicator may include a diversity component in the future (see Section III. D), but this is unclear.

Fourth, the attribute “energy and material flow” is inadequately represented by the proposed marine water quality index. Although the index provides valuable information, a better indicator for this attribute would be primary productivity. Primary productivity appears as a key attribute in all of the ecological schemes in Table 1, and is also a key component of ecosystem processes that benefit humans.

### **III. D. Review of Individual Dashboard Ecological Indicators**

#### **III. D. 1. Documentation**

The PSP Indicators Action Team (IAT) proposed its ecosystem indicators in the document “Development of the Dashboard of Ecosystem Indicators for Puget Sound,” August 9, 2010. The Committee received this as well as a version modified on July 1, 2011, and a subsequent revision of its Appendix A, titled “Description of Dashboard Indicators,” on July 13, 2011. The IAT sought to develop between 12 and 20 environmental indicators by July 2010. It selected 20; 12 of these, labeled “natural dimensions” in the Development document, are the ecological indicators reviewed in this section. The

same 12 remain in the July 13, 2011, revision, with some minor revisions and expanded information. Hereafter we cite these documents collectively as the Dashboard (Puget Sound Partnership Indicators Action Team, 2010-2011). Citation of Dashboard Appendix A (Puget Sound Partnership Indicators Action Team, 2010-2011) refers to the July 13, 2011, modification, unless otherwise stated. The Appendix B of the Dashboard document of August 9, 2010, addresses the criteria IAT used to evaluate and then select individual indicators. The July 13, 2011, Dashboard omitted Appendix B. The Puget Sound Science Update of April 12, 2011, reviews methods and criteria for selecting a set of indicators but does not specify spatial and temporal patterns of monitoring that would meet the stated goals. However, the Dashboard Appendix A does so for most of the 12 ecological indicators selected. This report thus relies primarily on the information provided in Dashboard Appendix A.

Some of the ecological indicators are simple, with single metrics; others are more complex, combining several metrics to generate single indices, some in incompletely explained ways. The PSSU partitioned some of these into a number of individual indicators. For example, one indicator in the original Dashboard, "Marine Water Quality Index," was defined as "an index of key marine water quality metrics compared to expected conditions. It uses a modular approach to generate a eutrophication index, which is combined with natural conditions to yield the overall composite index. It provides a score 0-100, while also displaying status and trends for each component." No further explanation of the index is given. However, "Marine Water Quality" becomes a "focal component" of a "goal," and "EPA Marine Water Quality Index" becomes one of its four indicators in the PSSU, where the list is also stated to be incomplete. The PSSU subsequently refers to relevant indices in use or planned by State agencies but does not precisely describe the marine and freshwater quality indices to be employed.

In addition, the PSP documents available to the Committee failed to clearly specify the attributes that each Dashboard ecological indicator was intended to indicate. Table 1 of the Development document lists the 12 selected ecological indicators (Puget Sound Partnership Indicators Action Team, 2010-2011), but it does not include attributes. Attributes are linked to their indicators in graphical representations under "Portfolio A" in Dashboard Appendix A (Figures A44a, A6, and A54b). The Committee converted these to a more convenient tabular form, shown in Table 5. This table replicates PSP's terms in documents made available to the Committee from July 2011 to September 2011, as closely as possible.

Unfortunately, the terms applied to key attributes and to the 12 selected ecological indicators differ, sometimes widely, among the various PSP documents supplied to the



Committee. PSP has evidently devoted considerable effort to update the terminology it applies to attributes and indicators. In addition, congruence of the 12 indicators with the attributes they represent varies considerably. The reviews of individual indicators that follow in this section address this problem, but only as it applies to documents received by the Committee between July 2011 and September 2011.

Additional confusion exists. For example, in early November 2011, PSP produced a new document, titled “Puget Sound Vital Signs: A Dashboard of Indicators on Puget Sound’s Health and Vitality” (Puget Sound Partnership, 2011a), which had its 14 ecological indicators arranged in three groups — “Environment,” “Animals,” and “Water” — rather than those of Table 4. Specific targets for 2020 accompany the two additional indicators, “Estuaries” and “Flood Plains,” but neither has explicit metrics nor are they stated to map to PSP key attributes.

The incomplete metrics and indices, inconsistent terminology, and changing indicators provided to the Committee reflect the continuing (albeit nonlinear) evolution of the Dashboard. The Committee has not explored in detail the vicissitudes described in the preceding paragraphs. Its review, based on a snapshot in time (September 2011), focuses on the substantive aspects of the indicators. ***The Committee offers recommendations intended to aid further development of the Dashboard and efficient employment of the Dashboard to help PSP meet its 2020 goals.***

The Committee has rearranged the order of presentation of the original 12 ecological indicators so as to group together those that pertain primarily to the same PSP goal or key attribute (Table 5). Because the titles of most of the indicators differ between the Dashboard and its Appendix A, the former are used as sub-headings of the sections below; the latter are placed in parentheses in the brief paragraphs that introduce each group.

### III. D. 2. Water Quality Indicators

We first review the four indicators best characterized as fitting the PSP goal “Water Quality” (Tables 4 and 5). These are: “Marine Water Quality” (Marine water quality index), “Freshwater Quality” (Water quality index), “Toxics in Fish” (Toxics in English sole), and “Toxics in Sediments” (Sediment triad).

#### Marine Water Quality

The Dashboard maps the indicator “Marine Water Quality” to three key attributes: “Energy and material flow;” “Physical/chemical components;” and “Toxics” (Figures A44a and A54b). As defined in the Dashboard, marine water quality is an appropriate indicator of the latter two attributes, but it does not pertain to energy or material flow.



The Dashboard does not specify the criteria used to select the individual indicators bundled as marine water quality, other than that the data source they are taken from is the DOE Long-term Marine Monitoring Program. Appendix A states the overall indicator to be a “Marine Water Quality composite index....an aggregation of monthly measurements of conventional pollutants collected at ambient monitoring stations (n=27) in Puget Sound and coastal bays.” The scores report “shifting baseline conditions [1999-2008] and trends in estuarine water quality” on a scale of -50 to +50, with positive values indicating improving water quality relative to baseline. “Conventional pollutants” are not identified, but as defined by the Clean Water Act and EPA, the five conventional pollutants are biological oxygen demand (BOD), total suspended solids (TSS), fecal coliform bacteria (FCB), oil and grease, and pH.

DOE began monitoring marine waters in Puget Sound in 1967 and has done so continuously (Newton et al., 2002). Although DOE defines the term indicator as a state or level of what PSP calls an indicator, i.e., its metric, the DOE indicators have intrinsic merit as well as a long history of data at 39 stations throughout Puget Sound and other Washington State waters. The 27 stations cited above are also stated to be those in 17 regions that cover the entire extent of Puget Sound (Appendix A, col. 8; map col. 25).

The individual marine water quality indicators overlap but do not coincide with the “conventional pollutants” as stated above. Rather they are stratification (i.e., vertical profile of sea water density), fecal coliform bacteria (FCB), and concentrations of several compounds that are critical metabolic requirements of the primary producer organisms—dissolved oxygen (DO), dissolved inorganic nitrogen (DIN), and ammonium (NH<sub>4</sub>). The DOE monitoring program covers the most important processes affecting water quality in Puget Sound. It differs from the “dashboard indicator operational definitions” of Appendix A in that it focuses on these basic indicators rather than measuring only conventional pollutants.

***We recommend that PSP adopt the DOE indicators in its marine water quality monitoring program. They were perhaps omitted unintentionally from the Dashboard indicator operational definitions, because the Comments column refers to analyses that depend on measurements of nutrients and dissolved oxygen in the marine water quality indicator.***

An alternative option for constructing a pollutant-focused water quality index is to assess whether the listed chemicals fall outside acceptable concentration ranges (see, for example, Heinz Center, 2002, p. 49). This allows inclusion of additional parameters as data become available, and such an index could be used to track the U.S. EPA’s entire list of priority pollutants as well as any additional chemicals for which recognized

benchmarks exist. ***Regardless of the method used to construct the marine water quality index, we recommend that PSP consider incorporating additional constituents in the Dashboard index and/or the larger indicator set in the future.***

A water-quality index that relies solely on measurements of conventional pollutants is not capable of providing data relevant to either primary productivity or eutrophication. The five DOE indicators recommended for incorporation could be analyzed to provide primary productivity data, but satellite observations now allow direct remote determination of primary productivity. ***We suggest that PSP, perhaps in consultation with the Ocean Climate Laboratory of NOAA, incorporate primary productivity in its marine water quality indicators, or add primary productivity as a separate indicator of ecological processes, specifically “energy and material flow” (see Section V).***

The other indicators listed above and the proposed monthly frequency of data collection and annual frequency of reporting are appropriate and provide a coherent way to monitor status and trends in Puget Sound water quality. Data for 1999-present (columns N-AF) provide baselines for trend analysis and analyses related to sea temperature change due to the Pacific Decadal Oscillation. They show a decline, with negative Water Conservation and Quality Improvement (WQCI) values from 2002 to 2006 and slightly positive values from 2007 to 2008. They thus appear to respond appropriately and sensitively to changes in their attributes.

Although geographic coverage is thorough, Dashboard Appendix A reports that the present depth limit of monitoring is 50 m and states that “it should be expanded to the bottom” (column 9). However, no reason is given for this, and its benefit might not repay the additional cost, because most of Puget Sound water is well mixed and most photosynthesis occurs in the upper, well-illuminated portions (Strickland, 1983; Moore et al., 2008).

PSP should consider eliminating measurements from “coastal bays” (Dashboard indicator operational definitions, l. 4) that are appropriate to DOE but lie outside the Puget Sound basin and its watersheds.

The Dashboard does not directly address the importance of marine water quality to human well-being. However, important influences flow from harvest of high-quality food via both commercial and personal-use fisheries for finfish and shellfish; the resulting competition with marine predators such as orcas for salmon; deposition into the Sound of egested and excreted human wastes and deposition of chemicals introduced by humans into the Puget Sound watersheds; development and other human activities that accelerate soil runoff into the Sound; boating, swimming and other recreational uses of

the Sound and its beaches and shorelines; and illnesses due to harmful algal blooms, FCB, and other sea water contaminants. Although not explicitly addressed in the section on marine water quality, some components of its indicator (e.g., total suspended solids), as well as other, related indicators (e.g., toxics in fishes, toxics in sediments, and land use/land cover), provide information about features of the Sound that directly influence human well-being.

### **Freshwater Quality**

In the Dashboard, the key “Freshwater Quality” attribute is appropriately listed under “Physical/Chemical Components” (Tables 4, 5). Like the “Marine Water Quality” indicator, the freshwater indicator “consists of water quality index (WQI) scores...an aggregation of monthly measurements of conventional pollutants reported on a scale of 1 to 100. A higher number indicates better quality. The primary indicator is trends in major rivers.”

In contrast to the marine counterpart, the earlier Dashboard document specified the indicator’s components, listing bacteria, pH, temperature, dissolved oxygen, nutrients, and sediment. As data sources, Appendix A cites DOE’s River and Stream Ambient Monitoring Program, as well as King, Pierce and Thurston County sources.

Geographic extent is not explicitly stated, but data are available for the entire Puget Sound Basin. Data are collected annually by “river year” (October-September) at 14 stations in the 12 major river drainages of the Puget Sound basin.

Values from 1995 to 2010 show a general but slight trend from mainly in the 60s to mainly in the 70’s (Appendix A). A target of average annual WQI score of  $\geq 80$  by 2020 has been established. The indicator measurements thus appear sufficiently responsive to changes in the attributes.

PSP’s use of the criteria listed in Dashboard Appendix A under “dashboard indicator operational definitions” as quoted above would limit its indicators to the five conventional pollutants. This list is too short to adequately evaluate freshwater quality. The Committee considers the DOE indicators listed on the DOE website ([www.ecy.wa.gov/programs/eap/fw\\_riv/rv\\_main.html](http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html)), cited under “data sources,” to be more appropriate. They include additional components pertinent to freshwater quality that are commonly monitored in other areas, and nutrients and other compounds essential to both producer and consumer organisms in freshwater: ammonia, nitrate + nitrite, total nitrogen, total phosphorus, conductivity, suspended solids, fecal coliform bacteria, oxygen, temperature, flow, and pH. DOE sampling involves more than 80 streams and rivers in the state. Its Environmental Assessment Program (EAP) suggests that at least half are in the Puget Sound region.

In addition to omitting some basic physical and chemical characteristics of freshwater, the quality indicator lacks two other important appropriate criteria. First, by concentrating only on streams and rivers, it omits the role of lakes in the Puget Sound Basin. DOE samples lakes (Washington State Department of Ecology, n.d.), so this could be easily remedied. Second, as in the case of marine water quality indicators, primary productivity is not included. ***The Committee recommends that PSP consider including eutrophication, a special case of primary productivity, because it can be of widespread environmental and economic importance, as documented in the famous case of eutrophication of Lake Washington from phosphate addition during the 20th century, that led to the creation of Metro (Edmondson, 1991). The Committee thus recommends that the PSP monitor an expanded array of indicators of compounds that affect freshwater quality, including lakes as well as streams in the Puget Sound region, and add an indicator of primary organic productivity that is also amenable to tracking eutrophication.***

As does the proposed “Marine water quality index,” the freshwater index omits the long list of potentially problematic chemical contaminants (such as U.S. EPA’s priority pollutants and other chemicals of emerging concern) commonly found in freshwaters. The PSP should consider adding these to its index as data become available.

***With the inclusion of the additional recommendations described here, the DOE WCQI constitutes an appropriate provisional indicator of freshwater quality status and trends in freshwater bodies throughout the Puget Sound Basin.***

### **Toxics in Fish**

In Dashboard Appendix A (Figure A54b), the indicator “Toxics in English sole” is mapped to the key attribute “Marine Toxics” under the PSP goal of “Water Quality” (Table 4). According to the Dashboard document, this indicator measures tissue residues and exposure to other (undefined?) contaminants in two species, herring and English sole. The two species were appropriately selected to represent one benthic carnivore and one pelagic planktivore. The spatial extent is Sound-wide. The indicator has three components: “1) Long term time trends in Persistent Bioaccumulative Toxics (PBT’s) in English sole and herring, 2) long term time trends in English sole health (liver disease indicator), as effectiveness monitoring for urban embayment restoration, and 3) long term trends in exposure of Puget Sound fish to PAHs [polycyclic aromatic hydrocarbons] (bile FACs data).” The criterion for inclusion is evidently availability of data in the WDFW Puget Sound Assessment and Monitoring Program (PSAMP) Toxics in Fish Database. Tissue residues are appropriate because they estimate exposure of the fishes to contaminants; the liver disease component attempts to represent both exposure and effects.

Salmon species, although appropriate due to their important role in commercial and recreational fishing, are excluded owing to WDFW budget reduction, although coho salmon have been monitored for 30 years beginning in the 1970s. The prior monitoring program showed substantial decreases in polychlorinated biphenyls (PCB) in English sole (by 75% 1975-1997) and coho salmon (90% 1975-2003) (West and Redman, 2011).

The thoughtful document by West and Redman (2011) indicates that the selection criteria for the indicator accurately reflect the relevant scientific literature. The proposed indicator and methodology provide a fairly efficient way to monitor status and trends in the health of Puget Sound fishes. The range of contaminants monitored is quite limited, however. West and Redman (2011) recognize this, and express caution and concern that the fiscal necessity of selecting few toxic compounds for monitoring may preclude collection of data on other pollutants that may be as important ecologically. The Dashboard description of the indicator specifies only PAH's. However, West and Redman (2011, p. 2) emphasize that other PBTs such as polybrominated diphenyl ether flame retardants (PBDEs) are "central to the development of the Toxics in Fish indicator and its ecosystem recovery targets and will be presented at the 2011 Salish Sea Ecosystems Conference." WDFW has monitored PDBEs for a shorter period, finding a decreasing trend in herring and English sole (West and Redman, 2011). These authors also note the demonstrated effects of hormonally active substances (AKA endocrine disruptors), likely from wastewater, on Puget Sound populations of English sole, but do not propose including this as a component of the indicator. The Committee recognizes the fiscal limits on contaminant monitoring, but we emphasize again that ecologically important contaminants should not be excluded from the ultimate index because of a current lack of data.

The number of species to be analyzed for the toxics in fish indicator is very small ( $N=2$ ), but the two species represent different ecosystem components, both with respect to habitat occupied and position in the marine food web. West and Redman (2011) also note the relevance of the toxics in fish indicator to other PSP ecological indicators, particularly orcas. Members of the southern resident orca population have some of the highest PCB concentrations in marine mammals worldwide, exceeding the threshold for PCB-related health effects for a number of years, although the trend is toward decreasing levels.

Toxics in fish data are collected and reported semi-annually. Dashboard Appendix A reports the spatial scales as "soundwide systematic coverage," from the 1990s for English sole and "index sites" (not further explained) "for all years (English sole) and 1999-present (Herring)." Insufficient information is given to permit assessment of adequacy of spatial monitoring scales.

Whether the indicators if implemented will show the collective impacts of management over relevant time scales cannot be determined from the available information. Monitoring additional species, such as coho salmon, for which earlier data exist, would improve coverage.

West and Redman (2011) presented three alternative levels of both PBTs and PAHs as target options in some detail, but did not propose a single choice. Dashboard Appendix A identifies the second of these, “Toxics in fish are below contaminant- and species-specific deleterious thresholds” as the target of choice. This target is described in detail in “Puget Sound Ecosystem Recovery Targets” (Puget Sound Partnership, 2011b).

The toxics in fish indicators are both ecologically important and socially relevant. West and Redman (2011) note that because humans produce all of the contaminants monitored, the concentration of those contaminants in Puget Sound likely will increase along with human population size.

### **Toxics in Sediments**

We include this indicator in our water-quality group because many important contaminants concentrate in sediments and because sediments are a key component of marine, estuarine, and freshwater habitats. PSP maps this indicator appropriately to the key attribute “Marine Toxics” under its “Water Quality” goal. The indicator is the DOE’s “Sediment Quality Triad Index (SQTI),” indicated as “Triad” in Appendix Figure A54b and as “Sediment Triad” in Table 4. It is a composite of three components: 1) “concentrations of toxic contaminants” (sediment chemistry index or SCI); 2) “degree of toxic effects to ‘biological organisms’ (sediment toxicity index or STI);” and 3) “community structure of sediment-dwelling organisms” (sediment benthos index or SBI). Each of the components of the triad provides a separate but not necessarily independent measure of sediment quality, the vitality of the benthic community, and the quality of marine habitats. Community structure may depend importantly on the first two, or it may be mainly independent of them because many other environmental and intrinsic factors, e.g., biological interactions such as predation and competition, also affect benthic community structure and dynamics.

The U.S. Environmental Protection Agency and the National Oceanic and Atmospheric Administration have used the triad approach for some time (see, e.g., [http://ccma.nos.noaa.gov/stressors/pollution/nsandt/sed\\_triad.aspx](http://ccma.nos.noaa.gov/stressors/pollution/nsandt/sed_triad.aspx)). As part of its National Status and Trends Program, NOAA partnered with DOE to analyze Puget Sound sediments using this approach (see, e.g., <http://www.ecy.wa.gov/pubs/0203033.pdf>). Syntheses of the triad results are presented in these documents, but are not explicitly referenced in the PSP documents provided to the Committees.

Although it is not mentioned in the Dashboard documents, the state of California has adopted the triad approach for its sediment quality objectives for enclosed bays and estuaries. The supporting documentation provides useful conceptual models and implementation recommendations for applying the weight-of-evidence approach in a regulatory context (California State Water Resources Control Board, n.d.).

The spatial scale of this indicator is meaningful for decision making in the entire region; sampling sites are located in the Strait of Georgia, San Juan Islands, and eastern Strait of Juan de Fuca as well as throughout Puget Sound itself. Data are available since 1997. The data source is the DOE Puget Sound Assessment and Monitoring Program (PSAMP). It supports and “provides a framework for” objectives of the PSP Action Agenda. Dashboard Appendix A does not specify any of the toxic contaminants sampled, but the PSAMP website (Puget Sound Assessment and Monitoring Program, n.d.) indicates some, including total metal, butyl tins, PAHs, PCB, and pesticides. Long et al. (2004) provide a summary of data collection that indicates the appropriateness of the criteria and limited results on specific concentrations of contaminants in sediments and in a few benthic animals (Dungeness crab, English sole and rockfish; see also Section III. D. 2. Water Quality Indicators: Toxins in Fish, above).

In addition, Margaret Dutch of DOE kindly provided two additional documents to the Committee. One of these (Dutch et al., 2011) compares SCI scores for three sites and eight regions within Puget Sound at an approximately decadal interval (~1998-2009). Two sites rated “minimum exposure” to toxic chemicals in both years; the third (Elliott Bay) rated “low exposure” in both years. The document gives no further information about the other two components (STI and SBI) of the SQTI indicator, but does provide values for the three stations and most sites for the same periods. All were rated “unimpacted” or “lightly impacted,” but because individual STI and SBI data are not given, the overall SQTI data cannot be determined or evaluated.

The other document (Dutch et al., 2012) defines all three components of the SQTI, but states the SBI to be in process of development with a “current/interim method of classifying the benthos” to be used first. It is not defined precisely, but is stated to include five indices of overall abundance, diversity, and dominance of benthic invertebrates, and four indices of abundance of specific major groups (annelids, arthropods, mollusks, echinoderms, and miscellaneous taxa). Dutch et al. (2012) also describe calculation of the SCIs from mean values of Washington State Sediment Quality Standards (mSQS) measurements.

The methods appear to provide useful monitoring of status and trends in the relevant condition of component 1 (Sediment Chemistry Index) in the Puget Sound ecosystem, at



appropriate temporal and spatial scales. Results reported indicate that more than 90% of Puget Sound sediments sampled since 1997 have minimal exposure to toxic contaminants. The methods of component 2, tested mainly by bioassay (tests of amphipod survival, sea urchin fertilization, and microbial bioluminescence) and activity of the gene for cytochrome p-450—an enzyme that degrades toxins—is similarly appropriate. The nascent status of component 3, benthic community structure (abundance, diversity, and species composition), makes it more difficult to interpret, but the information provided suggests that a strong program is being developed.

The Committee notes that SQTI is a much more complex indicator than others in the Dashboard. SBI includes component data that require considerable specialized research efforts over an extended period to accomplish monitoring and reporting at the appropriately proposed spatial scale and annual frequency of data collection. And, as suggested above, SBI likely relates to SCI and STI in complex and non-linear ways.

Dashboard Appendix A presents explicit targets for 2020: “All Puget Sound regions and bays achieve the following: Chemistry measures reflect ‘minimum exposure’ ” (i.e., mean Sediment Quality Standard mSQS) “is  $<0.1$  and the SCI is  $>93.3$ ), Sediment Quality Triad Index (SQTI) scores reflect ‘unimpacted’ conditions (i.e., SQTI values  $>83$ ), and no measurements exceed the Sediment Quality Standards chemical criteria set in the Washington State sediment management standards.” Although Dashboard Appendix A did not describe calculation of the index, the Committee has now received documentation that adequately justifies the appropriateness of the SQTI calculation (Dutch et al., 2012).

One of the 12 Dashboard ecological indicators is best characterized as fitting the PSP goal “Water Quantity” (Tables 4, 5). This is “Analysis of Water Availability” (percentage of monitored stream flows below critical levels).

### **Stream Flows Below Critical Levels**

This indicator maps to the key attribute “Groundwater” under the PSP goal “Water Quantity” (Tables 4, 5; Appendix A, Figure 45b) although it is also pertinent to the key attribute “Surface Water.” It is termed “Stream Flows Below Critical Levels” in the Dashboard development document (Table 1), and “% of monitored stream flows below critical levels” in Appendix A, Figure 45b.

Appendix A states its metric as “the percent of 13 long-term flow gauges for rivers and streams in Puget Sound whose trends in an annual 30-day average summer [June-October] low flows were either increasing (weak or strong), no trend, or decreasing (weak or strong).” This measure is appropriate to informing ecological patterns because stable or improving low flows have “been linked to salmon habitat needs” (Appendix A). The indicator description also includes a statement of extent: The 13 streams, all of which



are named, cover about two-thirds of the total Puget Sound watershed area. The spatial scale is thus appropriate to decision making in the region and should reflect impacts of management decisions relevant to salmon runs. In addition, the list of rivers includes the Elwha, which although not in the Puget Sound watershed, is currently experiencing removal of two dams and is targeted for monitoring low flow thereafter. A chart (Appendix A, col. M) and table (col. N) present trends by river over the period 1975-2009.

The data source is U.S. Geological Survey (USGS) flow-monitoring stations with long-term records. The specific metric is “lowest 30-day average flow June-October.” It was selected because of its demonstrated link to salmon habitat needs. The overall target for 2020 is all streams with stable or increasing flow, increasing flows in highly regulated rivers (Nisqually, Cedar, Skokomish, Skagit, Green), and stable flows in presently stable unregulated rivers (Nooksack and Puyallup, as well as Dungeness).

The selection criterion is appropriate and relevant, and continued implementation would provide some valuable information about status and trends in stream flow and levels throughout the Puget Sound basin. Although the ecological importance of low flows is clear, this is not the only available surface- or groundwater quantity parameter. As the Dashboard and PSP’s larger indicator set evolves, we suggest that PSP consider additional parameters (such as changes in high flows, changes in flow variability).

As with freshwater quality, a reliably adequate quantity of freshwater is also a basic requirement for human well-being, both for direct use by people and indirectly for agriculture, aquaculture (e.g., fish hatcheries), dissipation of heat, freshwater fisheries, and recreational uses.

### **III. D. 3. Marine and Terrestrial Species Indicators**

The next group (Table 5) includes four indicators that represent attributes of the biological resources or biological capital of Puget Sound. In Puget Sound Partnership (2011a), this group is aptly named “Animals” (Table 4). These indicators all focus on particular species or more inclusive taxonomic groups of animals. The first three—orcas, salmon (Chinook salmon), and Pacific herring—all are predators but occupy different levels in the food chain. Southern resident orcas prey primarily on Chinook salmon, and the salmon prey on herring. Herring in turn prey primarily on smaller zooplankton such as copepods. In Appendix A, the first two indicators map to the key attribute “Abundance” under the PSP goal “Species,” while herring, which replaced jellyfish after issue of the Dashboard development document, maps to the key attribute “Marine Community Composition” under the PSP goal “Food Web.” The fourth indicator, birds, is a broader and more diffuse group primarily of upland rather than marine birds. It is mapped to the key attribute “Terrestrial Abundance” under the PSP goal “Species.”

## Orcas

This Dashboard indicator is appropriately mapped to the key attribute “Abundance of Marine Species” (Appendix A, Figure A44a) (Tables 4, 5). It is defined as “Southern Resident killer whale population trends” and is stated to be Sound-wide (Appendix A). Data sources are listed only as “Multiple (NOAA Fisheries and Center for Whale Research).” Frequency of data collection and reporting are indicated as annual, appropriate for a large, long-lived mammal, but no information relevant to criteria for indicator selection, impacts of management decisions, or appropriateness of spatial scales is given. Size of the Puget Sound southern resident population, on the Endangered Species List since 2005, has increased somewhat, from 74-80 in the 1980s to 89 in 2010. PSP has established targets of 95 orcas by 2020, an annual increase of 1%, and 168 by 2038, an annual increase of 2.3% from 2010 to 2038.

No criteria or basis for these targets were given in the Dashboard or PSSU, but on September 29, 2011, the Committee received access from PSP to a draft technical memorandum (Redman) issued May 23, 2011, that discusses the range of threats to viability of the southern resident orca population from pollutants, disturbance, oil spills, disease, and limited prey availability. This document asserts, “Orcas are an iconic species whose reliable presence in Puget Sound waters supports an ecosystem-focused tourist industry in and near the San Juan Islands. The condition of orca populations provides an indication of the health of marine food webs and a measure of the cultural services provided by the marine portion of the Puget Sound ecosystem” (p. 1). The tourism industry cited is top-predator-focused, not ecosystem-focused. The document gives no evidence that orca population condition is an indicator of marine food web health.

Redman (2011) does provide bases for targets; they derive from the “NMFS Recovery Plan for Southern Resident Killer Whales”. Population attributes monitored are age and social structure (number of pods, age and reproductive status distribution of pod members). They allow quantification of indicator values at stated time intervals, permitting reporting of trends in orca population size and structure.

The targeted 2.3% population increase rate per year may be unrealistic. Adding 20 individuals (25%) in the next decade (2011-2020) would yield a population 10% larger than at any time in the last half-century. In addition, concurrently increasing salmon, especially Chinook populations on which orcas directly depend, and maintaining adequate herring populations for salmon prey, may not be feasible. Attempting to expand populations of all three indicator species may generate internal conflict, because each can increase only at the expense of the others.

As Redman (2011) notes, the major positive impact of the southern resident orca population to human well-being is via the tourism and recreation industry outside Puget Sound, i.e., in and around the San Juan Islands. None of the PSP documents available to the Committee addressed the impact due to competition with humans for salmon, especially Chinook, the favored prey of this orca population, or the impact on human well-being of requirements of the Recovery Plan under the Endangered Species Act (ESA).

### **Salmon**

As with orcas, the Chinook salmon Dashboard indicator maps to the key attribute “Marine Species Abundance” (Figure A44a; Tables 4, 5). This indicator refers to the number of wild Chinook salmon returning to spawning streams, considered “a good non-specific indicator of the status of freshwater/nearshore ecosystem and the status of an important ESA-listed species” (Appendix A of August 9, 2010). The indicator includes “population estimates of annual run, spawning escapement plus catch (not hatchery salmon)” and “encompasses the entire Puget Sound Chinook Evolutionary Significant Unit” (Appendix A). Data sources include a NOAA status review: (<http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/upload/trtpopesu.pdf>).

Puget Sound Chinook salmon has been listed as threatened since 1999, and WDFW developed a comprehensive management plan in 2004 (Washington Department of Fish and Wildlife). This document contains management threshold targets for rebuilding different Chinook salmon runs in Puget Sound. More recently, the Draft Monitoring and Adaptive Management Approach (MAMA) for the Puget Sound Chinook Salmon Recovery Plan of March 2007 (Shared Strategy for Puget Sound, 2007) identified updated targets for Puget Sound ecosystem goals, providing individual watershed targets, short- and long-term numerical goals, and specific strategies for reaching them. Appendix A notes targets of 261,300 for “Puget Sound Chinook” and an additional 42,200 for “Skagit Chinook.” Monitoring five of the six populations of the latter provides important historical context, as data are available back to 1952. Data for all 22 “Puget Sound” populations that make up the Puget Sound Chinook salmon evolutionarily significant unit are available only since 1985. Between then and 2009, Puget Sound Chinook salmon abundance declined from ~200,000 fish to <100,000, and Skagit Chinook salmon declined from >100,000 to <50,000. Appropriate indicators and monitoring for status and trends of wild Puget Sound Chinook salmon appear to be in place.

Appendix A also mentions the desirability of adding two other salmon, Hood Canal summer chum and Puget Sound steelhead, to the monitoring effort. This would enhance use of existing and ongoing data to track local and system-wide changes, and to evaluate additional impacts of management decisions.

The largest of the five salmon species native to Puget Sound, Chinook or king salmon is an iconic symbol of the region to many people, enhancing its importance to human well-being. Although it is listed as a threatened species under the Endangered Species Act, harvest of fish spawned in streams that enter Puget Sound continues to occur, primarily treaty-protected fishing in Canadian waters and by members of Indian Tribes (Lombard, 2006).

### **Pacific Herring**

Although PSP maps this indicator to the key attribute “Community Composition” (Figure A44a; Table 4), the Dashboard defines it as “Pacific herring spawning biomass abundance—status and trends.” We therefore consider it more appropriate to the “Marine Species Abundance” key attribute (Table 5). The meaning of the term “biomass abundance” is obscure. The indicator focuses on abundance of the species and has little to do with community composition. Although herring is an important component of the Puget Sound pelagic community, and two other indicator species (Chinook salmon and orcas) depend directly or indirectly on herring, the proposed indicators do not directly address the dynamics of this food chain or of community composition.

The selection criterion appears to be availability of data on standing stocks from annual acoustic-trawl surveys by WDFW between the early 1970s and 2010. All known Puget Sound stocks were surveyed from 1996 to 2010. During this period, total spawning biomass throughout Puget Sound decreased from >20,000 tons to <10,000 tons. However, these surveys have been terminated for lack of funding. They have been replaced by surveys of spawn deposition. Dashboard Appendix A states that herring stocks throughout Puget Sound are monitored, and it provides a map. Population age structure, and recruitment and mortality rates, can be calculated from acoustic-trawl surveys, but whether spawn surveys—an indicator of an indicator—can reliably provide any such data is not seriously addressed.

However, a technical memorandum on setting targets, dated “not later than March 23, 2011,” i.e., antedating Dashboard, was not provided to the Committee until September 29, 2011. Fortunately this document (Stick and Palsson, 2011) avoids the misleading term “biomass abundance” and changes the indicator title to “Pacific herring spawning biomass.” Stick and Palsson note that “biomass is based primarily on spawn deposition surveys of Puget Sound herring stocks” conducted annually by WDFW. However, they do not specify the algorithm for determining biomass from spawn mass, or any test of its adequacy. They cite evidence that the species biomass indicator “may not reflect the abundance of juvenile herring and their interactions.”

Stick and Palsson (2011) assert that since WDFW began to census herring stocks, all three of the genetically identifiable populations or evolutionary significant units in Puget Sound have plummeted, and age distribution has shifted to younger and smaller fish with concomitant reduction in reproductive capacity. The causes have not been identified. Stick and Palsson (2011) cite evidence that adult herring are important prey of numerous fishes (including salmon), and birds are particularly important predators of juvenile herring in Puget Sound. They also note important ecological effects of herring on other PSP indicators, including use of eelgrass as spawning substrate and conveyance of toxic compounds from lower to higher trophic levels, especially to other fishes. A herring indicator is thus advantageous in detecting functional relationships among different PSP ecological indicators, and it adds coherence to the group of ecological indicators.

PSP has established a 2020 target of increased spawning biomass for each evolutionarily significant unit, totaling about 22,000 tons. Although the Dashboard gives no criterion or basis for the target, Stick and Palsson (2011) thoroughly review the PSP target-setting mechanism, using the existing WDFW Forage Fish Management Plan (Bargmann, 1998) as the basis for further evaluation and modification. The WDFW target is a healthy population, defined as a 2-year mean spawning biomass within 10% of the long-term mean population biomass. WDFW sets the maximum harvest by the commercial bait fishery at 10% of spawning biomass in central and south Puget Sound and protects spawning habitats from development activities during spawning seasons.

Stick and Palsson (2011) describe three alternative target-setting processes, based on: 1) historical baseline of spawner biomass estimates; 2) 25% of the unfished biomass of each of the three genetic stock units; and 3) "alternative thresholds for fishery or ecosystem needs." All three approaches appear to be under consideration as PSP's choice at the present time; all are based on analyses of the same spawning biomass data. This is likely the best available metric of herring population status in Puget Sound. If it had more time and unlimited financial resources, or had it reached this stage of decision-making several years ago, we would have recommended that PSP continue its evaluation of the relative merits of different metrics. However, in view of its need to enhance herring stocks in the next few years, we recommend that PSP shift its focus. The reasons for continuing comparative evaluation of rather similar target values, selecting one of these alternatives, and rejecting the others do not seem strong enough to merit the additional costs. ***We recommend rather that all three be adopted as guidelines rather than hard targets, and that PSP concentrate on acquisition, management, and reporting of monitoring data, and implementing actions that will move toward accomplishing any of these targets.***

Nevertheless, the absence of a more direct source of population data than spawning biomass suggests that the current indicators do not provide a sufficiently accurate way to monitor status and trends of herring in Puget Sound. This presents a serious problem because herring is an abundant primary consumer in the pelagic ecosystem that is important to both lower and higher levels in the food chain. Moreover, the goals of increased orca population size, and the need to provide more Chinook salmon to feed them, likely will require higher productivity of herring.

The PSP substituted herring for the prior taxon of this indicator, jellyfish, without explanation. Also pelagic predators on zooplankton, jellyfish represent a much broader and more diverse taxon than herring. With shorter life spans and with many species occurring seasonally in Puget Sound (Mills, 1981), jellyfish might well have afforded more sensitive indicators of states and problems in the planktonic biota of Puget Sound.

Important aspects of herring to human well-being include tribal and non-tribal commercial fishing of herring roe, and commercial and recreational use of mainly juvenile herring as bait by fishers.

## **Birds**

This indicator, also defined as “Terrestrial Bird Species,” is mapped to the attribute “Terrestrial Abundance” (Dashboard Appendix A: Figure A44a; Table 4; “Abundance” in Table 5).

As described in the Dashboard, this indicator is poorly characterized and developed. Appendix A introduces four possible component indicators and allows for combinations of them, but does not indicate selection criteria. These are: 1) marbled murrelet population trend; 2) breeding seabird population trends; 3) over-wintering seabird population trends; and 4) terrestrial bird population trends. In contrast, Pearson (2011a, p. 1) asserts, “This indicator consists of trends associated with two different monitoring programs: 1) Marbled murrelet population trends derived from at-sea counts, and 2) Breeding Bird Survey trends for species associated with urbanizing landscapes, forest interiors (sensitive to forest fragmentation), riparian habitats, and potentially species associated with specific habitat structures such as snags.”

Marbled murrelet is a threatened species under both the ESA and Washington State law. Its populations have declined by >7%/year over the past decade (Pearson, 2011b). Its status is monitored under the Northwest Forest Plan, which estimated approximately 8,900 individuals in Zone 1 (Strait of Juan de Fuca + Puget Sound) in 2001, and approximately 4,400 in 2010 (Pearson, 2011a). However, it is not clear how many marbled murrelets occur in the Puget Sound basin, because they require old growth and mature trees for nest sites, and most Zone 1 birds occur along the Strait of Juan de Fuca. The

most precise available avian indicator thus applies to a species that feeds at sea, nests in forests, and is of very limited ecological importance in Puget Sound. It thus lacks sufficient ecological importance to serve as a Puget Sound indicator. The recovery plan for marbled murrelet under the ESA (U.S. Fish and Wildlife Service, 1997) sets a target of a stable population at or near the 1997 level, probably exceeding 10,000 individuals in Zone 1, and reduced threats from gill-net fisheries and oil spills (Pearson, 2011a).

The breeding bird survey cited by Pearson (2011a) is intended to use breeding bird population trends as indicators of bird habitat conditions, but it is in preparation under contract between EPA and the USGS Patuxent Wildlife Research Center. No other, existing sources of bird census data are cited.

Data and funding sources vary, but U.S. Fish and Wildlife Service (USFWS) funding for the first three possible avian indicators is likely to end after 2011, while (4) depends on census(es) currently being planned. Criteria include established census methods and published trends; these exist for (1) and (2), and are being analyzed for (3). Information necessary to address the other questions posed is lacking. According to Dashboard Appendix A (Column L), PSP plans to establish targets in October 2011.

***Because terrestrial bird populations relate only very weakly to Puget Sound, and the importance of marbled murrelet in Puget Sound is not adequately justified, the Committee recommends that this indicator be considered to be of low priority or eliminated, but that PSP continue to develop an indicator involving bird species that are more importantly associated with the Puget Sound ecosystem.***

### **III. D. 4. Habitat Area, Pattern, and Condition**

The last group includes three indicators of the key attributes “Habitat Area & Pattern/Structure,” and “Habitat Condition” under the PSP goal “Habitats.” This category was changed to “Environment” in Puget Sound Partnership (2011a) (Table 4). The indicators are “Eelgrass,” “Shoreline Armoring,” and “Land Cover/Land Use.” Areal extent is an important aspect of all three. We evaluate them individually in this section and then discuss them synthetically in Section V. Together the three PSP indicators in this group address a small proportion of the marine habitats present in Puget Sound. However, the preceding groups partially cover some of these, e.g., “Marine Water Quality” and “Sediments” in the first group (Section III. D. 2).

#### **Eelgrass**

The “Eelgrass” indicator is mapped to the “Habitat Area & Pattern/Structure” key attribute (Dashboard Appendix Figure A6; Table 4). Its development benefited from considerable recent study of eelgrass extent in Puget Sound by the Washington Department



of Natural Resources (WDNR) (Dowty et al., 2010). Eelgrass beds in Puget Sound are dominated by only one or two species but they are appropriate habitat key attributes because they are a characteristic marine habitat that diverse marine organisms depend upon. The indicator currently incorporates two aspects: 1) area of eelgrass beds in the entire greater Puget Sound (in acres); and 2) prevalence of sites showing declines, i.e., the proportion of sites with declines in area between annual measurements, out of all those with significant change in either direction. Development of the prevalence metric (2) is ongoing. The data source is the WDNR Nearshore Habitat Program.

The criteria for selecting the indicator are those of the WDNR report: “We recommend soundwide eelgrass abundance as the indicator to track progress toward a desired ultimate outcome related to eelgrass. The associated metric is total areal extent. This indicator and metric are a nationally recognized measure of submerged aquatic vegetation abundance” (Dowty et al., 2010, p. 2). The criteria appear to have been appropriately applied, and the indicator itself is simple, direct, and appropriate. As Dowty et al. (2010) state, eelgrass area is a commonly used measure of ecosystem health. Eelgrass is an easily observed and measured component of low intertidal and shallow subtidal marine habitats of Puget Sound, but it is not an indicator of the comprehensive array of in-shore habitat types. These also include, e.g., sand and mud flats, clam beds, man-made rocky shores and jetties, kelp beds and other attached benthic algae, etc. ***The Committee supports provisional inclusion of the eelgrass indicator, but we recommend that an index incorporating additional habitat types be developed (see Section V).***

Both parts of the indicator broadly cover the relevant ecological domains and processes in Puget Sound. The prevalence metric (2) but not the area metric (1) will permit meaningful monitoring at smaller spatial scales throughout the Sound region. However, major geographic gaps exist between some monitoring sites.

This ecological indicator has already been measured sufficiently to assess its adequacy. DNR began monitoring eelgrass in 2000. However, PSP provided the Committee with somewhat conflicting information on the current status of eelgrass area. Dowty et al. (2010) state that there is some evidence for decline of eelgrass area during DNR monitoring (2000- ), but its “magnitude is relatively minor in comparison to current abundance and distribution of eelgrass.” Specifically, the number of sites with declines exceeded the number with increases. However, most differences were not statistically significant. The report also states that there are no reliable estimates of historical or potential eelgrass areas for the greater Puget Sound. In contrast, the brief unpublished report provided subsequently to the Committee by the same authors (Dowty et al., 2011) states, “The available information suggests that there have been significant eelgrass losses relative [to] historical conditions and losses are continuing today.”



Dowty et al. (2010) also acknowledge difficulty in establishing baselines, because of the lack of both historical and ecological data adequate to support an assessment of ecosystem goods and services from eelgrass beds. Nevertheless, the authors recommend a target of either stable or increasing area, and they state as reasons that “Research has demonstrated the significance of seagrass to ecosystem processes that provide a vital link connecting upland and other marine habitats...Eelgrass is considered an important natural resource in Puget Sound. Some of the services eelgrass provides [are] shoreline stabilization (erosion control, sediment trapping); oxygen production; nutrient and carbon sequestration and export; maintenance of biodiversity; forage, shelter, and nursery areas for estuarine organisms; scientific research; and tourism. In addition, a number of projects have demonstrated the ecological importance of eelgrass for Pacific herring (Phillips, 1984), migratory salmon (Simenstad et al., 1988; Simenstad, 1994), and coastal birds and waterfowl (Dowty et al., 2010, p. 57). They also discuss the alternative target of an unspecified increase in eelgrass area.

Dashboard Appendix A recommends a more specific target of 20% increase in area by 2020. No reason is given for this target. The Appendix A description states, “eelgrass is an indicator of environmental condition and an important habitat for many species.” The ecosystem services of eelgrass cited above are accurate, and eelgrass is a keystone species whose loss causes the extirpation of animals dependent on it (Mills, Soulé, and Doak, 1993). However, eelgrass also alters its habitat so as to exclude other species, and some of these such as clams and oysters have positive economic, cultural and recreational importance in Puget Sound.

### **Shoreline Armoring**

This indicator is also termed “% shoreline armored” in Dashboard Appendix A, Figure A6, where it is mapped to the attribute “Habitat Interface Condition” (between marine and terrestrial) (Figure A6; Table 4). We map it more simply to “Habitats” (Table 5). It is defined as the length of new shoreline armoring added per year. Although not explicit, the value appears to be the total length (in miles) added, rather than net change. Although the column assigned to Data Source(s) in Appendix A was left blank, the Operational Definition suggests that the criteria used to select the indicator are appropriate, because additional marine shoreline armoring must be done under a WDFW permit for Hydraulic Project Approval, and its database was used to determine lengths. Geographic extent of coverage is not addressed explicitly, but data are presumably available for the required Sound-wide calculation from WDFW: “Percent of the PS shoreline armored will be calculated using the PSNERP database for Tier 2 stressors as pre 2005 baseline” (Dashboard Appendix A). As a part of the PSP Action Program, WDFW can provide funding to assist removal of existing shoreline armoring through the Puget Sound Marine and

Nearshore Protection and Restoration Grant Program (Washington Department of Fish and Wildlife, n.d.). The WDFW Hydraulic Project Approval database indicates that shoreline armoring has increased by 10,000-26,000 feet annually between 2005 and 2010 (Carman et al., 2011, Figure 1).

PSP adopted a target of miles removed > miles added from 2011 to 2020, but did not indicate criteria for target selection. Carman et al. (2011) rank this target the best among four alternatives; the three others simply track miles of armoring. Despite their document's title, these authors also failed to indicate criteria for target selection.

Shoreline armoring is a significant modifier of natural habitat in Puget Sound. Carman et al. (2011) suggest that extent of armoring may be a useful indicator of human development projects on shorelines. Many people probably apply for armoring permits from WDFW because they perceive armoring as a way to receive an environmental service that improves their own well-being. However, as Carman et al. (2011) note, broader impacts of armoring such as land-beach disconnection, increased erosion due to less dissipation of wave and tidal energy, and interruption of long-shore sediment flow, generally impose costs on the human population at large.

***The Committee recommends broadening the indicator to include measurement of the fraction of total shoreline armored, as implied by the title “% shoreline armored,” as well as total length of shoreline armored.*** Employing both absolute and relative measures would more coherently monitor status and trends in linear shoreline armoring in Puget Sound. Otherwise, its use in tracking local and system-wide changes and in showing impacts of related management decisions would generate unacceptable levels of uncertainty. According to Appendix A, PSP is currently developing improved methods for data retrieval that would enable tracking of individual projects.

### **Land Use/Land Cover**

Dashboard Appendix A vaguely defined this indicator as “Land use and land cover monitoring and detecting landscape feature changes to assist state, county and city governments in planning for growth in the Puget Basin.” Appendix A maps it to the attribute “Terrestrial Habitat Pattern/Structure” (Figure A6) (Table 4). The selection criterion was availability of land use data in the form of satellite-derived estimates of areas and proportions of different major different land cover types in the Puget Sound Basin. The data source is the NOAA Coastal Change Analysis Program (CCAP), collected from Landsat records at 5-year intervals beginning in 1992 and analyzed by the USGS Western Geographic Science Center to report areas and proportions of land surface as forest, agriculture, urban, and impervious surface (NASA, n.d.). In 2006, these proportions were respectively about 53%, 26%, 12%, and 9%, and the four categories composed 80% of

the region's land surface. Freshwater bodies and wetlands composed most of the rest (Dashboard Appendix A, Figure 1). The dataset covers the entire Puget Sound Basin.

CCAP provides finer-scale data, e.g., "Developed High Intensity, Developed Low Intensity, Developed Open Space, Cultivated Crops, Pasture/Hay, Grassland/Herbaceous, Deciduous Forest, Evergreen Forest," but use of these by PSP is not indicated (Dashboard Appendix A). The selection criterion for this indicator is appropriate. The indicator provides a straightforward estimate of status and trends in land use/land cover over the entire Puget Sound Basin. It should both monitor and show collective impacts of management decisions at the broad temporal scales and cover types employed. The indicator calculates the rate of increase in urban areas over time and the concomitant decreases, primarily in forest and agricultural area. The 1992-2005 data indicate an approximately 25% increase in urban area and 7% decrease in forest area (Dashboard Appendix A, Figure 1).

The August 2010 version of Dashboard Appendix A—but not the July 2011 version—noted further uses of the indicator, including threats to obligate species associated with land cover types, and habitat changes relevant to delisting criteria for endangered or threatened species.

Dashboard Appendix A did not identify targets for this indicator, but rather stated, "Target to be considered in October 2011." However, the subsequent technical memorandum (Lee et al., 2011) altered and expanded the nature of the indicator to include both an ecosystem condition indicator and three pressure-reduction indicators. This document defines the Land Cover Dashboard indicator as "Area of Non-Federal Forested Land-Cover Converted to Development."

In Lee et al. (2011), policy statements that are labeled subtopics accompany the three Land Development Pressure Reduction Indicators:

**Subtopic 1:** "Avoid development of ecologically important areas." Its indicator is "Change from vegetated to developed land cover on undeveloped ecologically important lands under high pressure from development." Its desired objective is "Land conversion due to development is directed away from the most ecologically valuable lands."

**Subtopic 2:** "Direct growth into urban growth areas and protect rural lands." Its indicator is "Proportion of basin wide population growth occurring within UGAs." Its desired objective is "Population growth within the Puget Sound Basin is directed into Urban Growth Areas."

**Subtopic 3:** “Encourage compact growth patterns.” Its indicators are: 3a. Rate of change in population growth relative to the rate of change of impervious surface. Its desired objective is “Undeveloped land is not converted to developed land in order to accommodate population growth.” 3b: “Annual rate of population change within UGAs relative to the annual rate of UGA expansion.” Its desired objective is “Population density within UGAs is increasing at a higher rate basin wide.”

The Committee considers the shift from indicators that merely monitor change in proportion of major land uses over time to those closely linked to advocated policies stated as subtopics and objectives, as recommended by Lee et al. (2011), to be problematic. The latter include some terms that are undefined but appear to involve value judgments, e.g., “high pressure from development,” and “ecologically valuable lands.” The objective of Indicator 3b includes a comparative statement, “Population density within UGAs is increasing at a higher rate basin-wide.” Higher than what is not stated, but the statement presumably refers to higher than the rate of change of the UGA footprint.

***The Committee recommends that “Land Use/Land Cover” indicator(s) be characterized more independently of the subtopics and objectives, as is the case with the other Dashboard ecological indicators. The indicator(s) should represent the extent of key habitat types as a proportion of the whole, as we have recommended in Section V for the marine ecosystem.***

Lee et al. (2011) propose broad ranges of targets and a detailed discussion for each of the proposed indicators that should provide adequate criteria for final selection, but these evidently have not yet been selected. ***The Committee recommends that this be accomplished expeditiously. Human well-being is more directly and intimately associated with land use/land cover than with several other ecological indicators, and in extremely complex ways.***

### III. D. 5. Synthesis of Dashboard Ecological Indicators

The Committee has evaluated the processes PSP used to develop a system of indicators and assessed how well the indicators, both individually and as a set, can track the condition of Puget Sound.

The criteria PSP used to select the ecological indicators, found in the PSSU (Levin et al., 2011, p. 43ff), were pragmatic rather than based on a conceptual model of the Puget Sound ecosystem. Although some of the criteria were appropriate to PSP’s goals, the Committee identified several discrepancies between indicators and their assigned key attributes. As a result of this lack of congruence, the set of Dashboard indicators

is less informative about the key attributes than one would assume looking at Table 4. Moreover, analysis of the groupings of the selected Dashboard ecological indicators (cf. Table 4) reveals bias and imbalance. For example, four of the 12 are individual marine animal species (3) or a higher taxon (1). Only two, eelgrass and shoreline armoring, pertain to marine habitat attributes, although indicators in the “Water Quality” group map to attributes that apply to broader marine pelagic and benthic environments. A set of Dashboard indicators more balanced in its representation of the system’s functioning and structural elements (i.e., more tightly tied to a conceptual model) would more likely provide a good tool for tracking the condition of the Sound and the outcomes of the combined management efforts.

The adequacy of the documentation for the individual indicators varies considerably. Even for well-described indicators, only brief summaries are provided about what, where, and when the metrics have been, are being, or will be monitored. It is thus not possible for the Committee to thoroughly evaluate the potential performance of the Dashboard indicators and their component metrics and hence to determine their adequacy to judge progress toward meeting goals and objectives.

The Dashboard explicitly addresses targets associated with some indicators. In general, the criteria for selecting targets were not supplied, so it was not possible for the Committee to evaluate whether these targets are appropriate. On September 29, 2011, PSP provided new technical memoranda relevant to some Dashboard indicators. We incorporated as much pertinent information as possible in the limited time that remained. In sum, the Committee’s view is that the PSP’s development of the Dashboard provides a reasonable start for monitoring status and trends in the condition of the Puget Sound ecosystem, at appropriate frequencies and geographic scale. Many of the indicators have been developed and tested in the past by state and federal agencies. This permits PSP’s program to incorporate indicators that have been proven informative and adequate, while avoiding overlap and duplication. At least some of the indicators are also sufficiently sensitive to reflect impacts of management decisions over appropriate time scales (years to decades). Exceptions to these generalities as well as other shortcomings are mentioned in the preceding reviews of individual indicators. The Committee also concludes, however, that most Dashboard indicators require refinement as detailed in this section. Also, the Dashboard would benefit greatly from the additions we describe below in Section V.

## IV: REVIEW OF THE DEVELOPMENT OF SOCIAL INDICATORS BY THE PUGET SOUND PARTNERSHIP

### IV. A. Introduction

The Puget Sound Partnership has invested considerable time and effort to develop social indicators to complement the set of Puget Sound ecological indicators. These efforts include background papers (Cassin, Knauer & Wellman, 2008; Schneidler & Plummer, 2009) and a major chapter in the 2011 Puget Sound Science Update (Plummer & Schneidler, 2011). The PSP Indicators Action Team recommended the inclusion of a number of social indicators of human health and well-being in the draft Dashboard report.

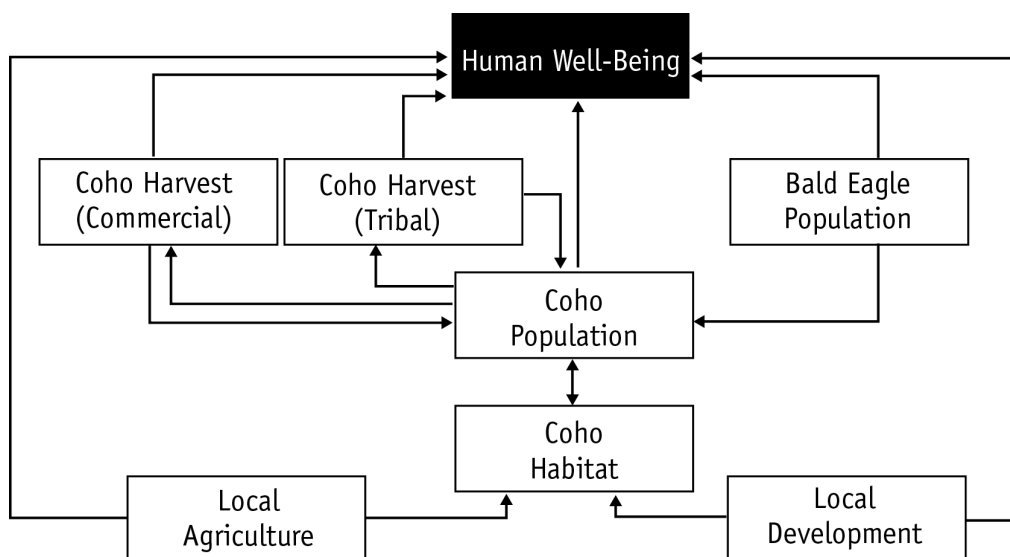
The legislation that established the Puget Sound Partnership placed a high priority for understanding how the vitality of the Puget Sound ecosystem affects human well-being and how human actions affect the Sound. Indeed, human actions are the most important cause of changes to the natural habitats that constitute the Puget Sound ecosystem. For most people who live in the Pacific Northwest, Puget Sound is a major economic, social, and cultural resource. The Sound is also a national and international treasure that attracts visitors who draw inspiration from its beauty, flora, and fauna.

In spite of these priorities and investments, the PSP has made only limited progress in the development of meaningful and reliable social indicators. The problem arises, in large part, because of the complexity of relationships between human communities and the natural environment. A broad literature on population-environment relationships exists, but no dominant social science paradigm integrates the field. The PSP reports contain many insightful observations that intelligently discuss the prospects and problems of developing appropriate indicators. Overall, however, the reports do not present a consistent and cumulative framework with which to assess how human actions affect the Puget Sound ecosystem and how human communities will be affected by restoration and maintenance of a more vibrant Puget Sound ecosystem.

The Committee first discusses the need to develop a clear conceptual framework of the relationships between human communities and the Puget Sound ecosystem. Then we review the proposed social indicators recommended by the Indicators Action Team. Although it is beyond our purview to recommend specific indicators, we suggest directions that the PSP should consider as it develops them. ***In particular, we recommend that the PSP adopt a conceptual framework that clearly separates the “pressures” caused by human actions from the determinants of human well-being that come from the Puget Sound. We also recommend that indicators of human well-being be tied very clearly to measurable attributes of Puget Sound.***

## IV. B. Conceptual Frameworks

The classic conundrum of social science models of the population-environment relationship is the problem of endogeneity—the actions of humans on the environment are conditioned by the outcomes of prior human-environment interactions. This principle is illustrated with Figure 5, which shows a Driver Pressure State Impact Response (DPSIR) model of Puget Sound. Human communities are the “drivers” that exert “pressures” on the environment. These pressures change the state of the environment in both favorable and unfavorable ways. The altered environment, in turn, influences human well-being. Figure 5 shows the negative effects of human actions on the environment, which reduce human well-being, and through the feedback loop lead to changes in human behavior (Plummer & Schneider, 2011, Figure 9, p. 177). In this illustration, humans have lowered the numbers of coho salmon in Puget Sound through agriculture and development. Fewer salmon result in lower harvests of salmon and fewer numbers of other valued species, such as bald eagles. In a rational model of sustainable development, once humans have understood the interdependency between the quality of the Puget Sound ecosystem and human well-being (the size of the harvest of fish for human consumption and opportunities to view bald eagles), humans would modify their behavior.



**Figure 5. Connections between biophysical & human-based components**

An example of the connections between biophysical and human-based components of the Puget Sound ecosystem, and between those components and human well-being. Identifying these connections can facilitate the identification and evaluation of biophysical and human well-being indicators.

(Figure adapted from Figure 9 from Plummer and Schneider, 2011, p. 177)



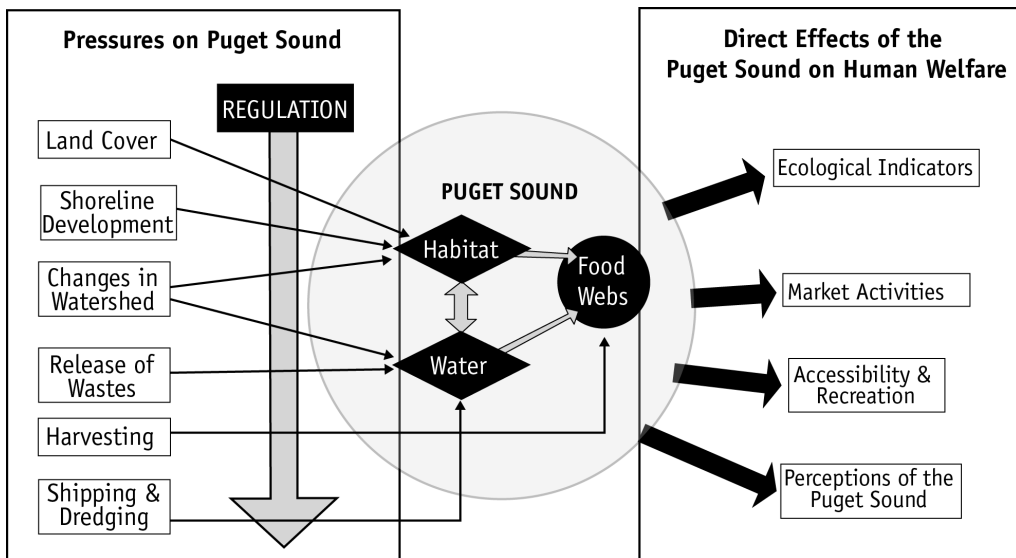
In Figure 5, human well-being is both the driver that creates pressures on the ecosystem and the beneficiary (or diminished beneficiary) of ecosystem resources. People put pressure on the Sound via their efforts to increase other components of well-being through their numbers, consumption levels, and varied behaviors. If the millions of people in the Puget Sound region could be represented by one individual—or one collective mind—then the assumptions that underpin the DPSIR model might be a realistic representation of interactions between humans and the environment.

Human communities, however, are not simply the sum of atomistic individuals, but rather are complex entities that are shaped by conflicting interests of groups, organizations, and institutions. Their collective actions are influenced by population size and other demographic characteristics, market forces, politics, technology, and values. Some actors and organizations have more resources, power, and influence than others. Although it is possible to describe the salient features of populations and social organization, and to measure some of the attributes that create environmental pressures, no simple model can map societal characteristics on environmental pressures. For example, significant pressures on the over-harvesting of local fish populations could be driven by demands (and the profitability of trade) from distant markets.

These complexities prevent us from precisely identifying the human drivers (demographic, social, and economic characteristics of local populations) that exert pressures on the Puget Sound ecosystem. However, we can identify and measure the specific human actions—“pressures”—that adversely affect the environment. The Committee’s provisional conceptual framework, represented in Figure 6, suggests a tentative list of human-made pressures on the Puget Sound ecosystem: Land Cover, Shoreline Development, Changes in the Watershed, Release of Wastes, Harvesting, and Shipping and Dredging. Two of these pressures—Land Cover and Shoreline Development (Armoring)—are indicators of condition and are components of the Dashboard Ecological Indicators.

The conceptual framework in Figure 6 lacks the feedback loops that characterize all population-environment relationships. These loops result from the actions of individuals, but more importantly from the actions of governments and regulatory authorities. Such regulatory actions are represented in the conceptual model by a line between the human pressures and Puget Sound. The regulatory actions are considered to be exogenous in this preliminary conceptual framework.





**Figure 6. Preliminary conceptual framework for indicators of human well-being**

The right side of Figure 6 includes several direct consequences of the condition of Puget Sound on human well-being. These interconnections should form the basis for indicators of human well-being. The concept of human well-being is very broad and multidimensional—a point well recognized by Plummer and Schneider (2011, p. 157-158)—among which is human happiness. Puget Sound certainly contributes to human happiness, but because the Sound is only one of many things that influence it, happiness is not a good candidate for an indicator.

***We strongly recommend that the PSP focus on attributes of human well-being that are unambiguously due to the state and functioning of the Puget Sound ecosystem.***

Four broad attributes of Puget Sound that clearly have important and measurable impacts on human well-being warrant special attention: Ecological Indicators of a Thriving Puget Sound; Market Activities; Accessibility and Recreation; and Subjective Perceptions of Puget Sound. We offer the following guidelines for their development:

- 1. Ecological Indicators of a Thriving Puget Sound.** The ecological indicators reviewed in the previous section include some that have direct effects on the health and well-being of people in the Puget Sound region.
  - **Marine Water Quality** directly affects the health of human populations through the consumption of finfish and shellfish, as well as recreation—swimming, boating, and the enjoyment of the beaches and shorelines. Marine water quality also indirectly affects human well-being by maintaining populations of fish, birds, and mammals.
  - **Freshwater Quality** is a sine qua non of human well-being in the Puget Sound Basin. All human residents require a reliable source of freshwater both for direct use by people and indirectly for agriculture, aquaculture

(e.g., fish hatcheries), dissipation of heat, freshwater fisheries, and recreational uses. In addition, freshwater quality is critical to anadromous fishes (all local salmon species) that reproduce only in rivers and are in turn important for tribal and recreational use fisheries.

- **Eelgrass** has an indirect effect on human well-being through its positive effects on populations of marine animals, e.g., the early life history stages of salmon and Dungeness crab.
- **Marine and Terrestrial Species** Indicators include populations of salmon, birds, and mammals, which in turn support tourism and recreational viewing.

**2. Market Activities.** The resources of Puget Sound make a substantial contribution to local employment. The ports of Seattle, Tacoma, Bellingham, and Bremerton, and many others generate considerable income and employment for workers at the ports as well as in the processing of raw materials and goods that flow through them. A considerable service economy is also generated by the domestic and international trade that flows through Puget Sound ports. Tourism, another economic engine of the Puget Sound region, is generated in large part by the spending of domestic and international tourists who are drawn to the natural beauty and recreational opportunities of Puget Sound. The commercial harvest of finfish and shellfish also is a very important contributor to the region's economy.

These economic activities are distinct from one another, but they share a common metric through valuation generated by the market economy. The Puget Sound seafood harvest does not completely enter the market economy, but there are simple methods for estimating the total economic product from fishing and the harvest of other natural resources. ***The contribution of Puget Sound to the local economy is mentioned occasionally in PSP reports, but we recommend that the topic be given a more central and unified focus in the development of the Dashboard indicators.*** Policy makers and citizens need to be better informed of the economic value of the Puget Sound to jobs and incomes.

**3. Accessibility and Recreation.** Residents and visitors to the region use Puget Sound waters, shoreline, and beaches for a variety of recreational activities, including swimming, boating, and observing wildlife and nature. Because many of these activities do not enter into the market economy, they represent a major challenge for measurement and social accounting.

Recreational opportunities are not equally available to all. The most fundamental obstacle is limited access. Much of the Puget Sound shoreline is owned privately,

but this need not be a major problem if there are sufficient points of public access. Accessibility is an especially important issue in areas with large populations, but it is also important in remote areas.

An indicator of recreational participation would help decision makers recognize the impressive non-economic value of Puget Sound. Among the potential metrics are the number of permits issued for fishing and boating; and measures assessed via general population surveys, targeted surveys of specific populations (students in schools), or surveys of participants at recreational sites.

- 4. Subjective Perceptions of Puget Sound.** Several PSP reports noted that the aesthetic, cultural, and spiritual values of the Puget Sound are difficult to measure. However, there are several direct and indirect approaches, some of which are discussed in the PSP reports on social indicators that could be employed to appraise subjective perceptions of the value of the Puget Sound ecosystem.

## **IV. C. Dashboard Social Indicators**

In the draft report, “Development of the Dashboard of Ecosystem Indicators for the Puget Sound,” the PSP Indicators Action Team recommended two indicators of human health:

1. Swimming beaches
2. Shellfish beds restored

Neither the rationale for these indicators nor the details of data or measurement were discussed in the Dashboard report. Apparently these indicators are to be operationalized as follows:

The swimming beach measure is the percent of marine swimming beaches meeting water-quality standards.

The shellfish indicator is measured by the net increase in the approved (not closed for pollution) acreage of harvestable shellfish.

Without additional information, it is impossible for the Committee to evaluate the adequacy of these indicators relative to other potential measures. At a minimum, there should be some discussion of the relationship between indicators of marine water quality, and the levels of pollution of beaches and shellfish beds, because it certainly influences the numbers of people who swim and consume shellfish.

The PSP Indicators Action Team identified six focal components of “Human Well-Being” for consideration:

1. Regional makeup (including demographics, economic, water use, and transportation trends);
2. Social capital (e.g., environmental stewardship, citizen scientists);
3. Impact of recovery strategies on marine and land based natural resource industries, (unintended consequences of Action Agenda implementation);
4. Ecosystem services that provide benefits to people;
5. Behavioral changes of public as awareness increases;
6. Existence value of the ecosystem (including aesthetics and willingness to pay to ensure continued survival of individual species or general health of the ecosystem).

But it recommended only four indicators for “Human Well-Being:”

1. Regional Makeup—Puget Sound Regional Council Trends Index;
2. Impact of recovery strategies: Commercial Fisheries Harvest (tribal and nontribal);
3. Ecosystem services that provide benefits to people: Participation in recreational fish, shellfish and hunting harvest (number of permits issued);
4. Behavioral changes of public as awareness increases: Personal vehicle miles traveled.

The draft Dashboard report notes: “This list of strategic outcomes has appeared repeatedly throughout the Partnership’s work on human well-being indicators” (p. 7). Actually, only minimal overlap exists between the Dashboard indicators and the 14 social indicators in the 2008 Cassin et al. report (p. 20) and the 2009 Schneider and Plummer report (pp. 32-35). Appendix C of the draft Dashboard report provides additional background on the selection of “Human Well-Being” Indicators, but the overall rationale and details of measurement are not described.

1. The first proposed indicator, the “Regional Makeup—Puget Sound Regional Council Trends Index,” appears to represent the first focal component of human well-being: “Regional makeup (including demographics, economic, water use, and transportation trends.”

Appendix C of the Dashboard report notes (p. 40) that the Puget Sound Regional Council Trends Index:

- Reflects what is guiding the region’s economic development and sustainable growth goals; and
- It exists and data is [sic] being collected and reported monthly—Rick Olsen.

Although no further explanation is provided, the Committee assumes that this indicator is intended to represent demographic and economic drivers that exert pressures on the Puget Sound ecosystem. The IPAT model posits that I (impact) is the product of Population, Affluence, and Technology (York, Rosa, and Dietz, 2003). But this approach would require a number of unrealistic assumptions for local areas with long distance trade and technological change.

2. Social capital (e.g., environmental stewardship, citizen scientists). The notes in Appendix C of the Dashboard report that “social capital might be measured as (the) number of individual membership(s) in environmental organizations, citizen science groups, philanthropic foundations, and professional employment” (p. 42). However, no specific indicator was recommended by the Indicators Action Team.

One version of the concept of social capital, popularized by political scientist Robert Putnam (2001), is intended to capture the strength of community cohesion represented by the percentage of adults who participate in local organizations and community events. To indicate the level of willingness to support government or voluntary programs for Puget Sound conservation, it might be interesting to assess the level of civic engagement in the Puget Sound region. But this measure may be far removed from the population-environmental relationship and the direct effects of Puget Sound on human well-being. Although not directly stated in the Dashboard report or other PSP documents, the PSP may assume that social capital is a resource that could be mobilized to create popular support, or the political will to support conservation or mobilization programs. If so, it would be advisable to directly measure the desired outcome—popular support for Puget Sound—rather than an uncertain predictor of it.

3. Impact of recovery strategies on marine and land based natural resource industries, (unintended consequences of Action Agenda implementation). The IAT recommended that Commercial Fisheries Harvest (tribal and nontribal) be the social indicator of this attribute. Appendix C of the Dashboard report notes that the

annual harvest (pounds) of non-tribal commercial fisheries is reported annually by the Pacific Marine Fisheries Commission. There is no mention of the source of data from tribal fisheries. Because there are surely variations in harvest due to other reasons beyond the PSP Action Agenda, the labeling of this indicator as “Impact of Recovery Strategies...” seems too narrow.

Harvest of fish from Puget Sound is only one component of the broader economic impact of Puget Sound on employment and income of residents in the region. Harvests of seafood and other natural resources, ports and trade, and tourism all contribute to the economy of the Puget Sound region. ***Therefore, the Committee recommends that the PSP develop an indicator that incorporates all of these elements. That indicator should be constructed so that it can be disaggregated to report on specific sectors and localities.***

4. Ecosystem Services that provide benefits to people. This attribute, recommended as the social indicator of Participation in Recreational Fish, Shellfish, and Hunting, is to be measured by the number of recreational fishing permits sold annually.

Despite the misleading label, this is an important social attribute, but the proposed indicator is too narrow. The term “ecosystem services” is unlikely to be understood by most social scientists or by the general public. The general meaning of “services” refers to the non-goods sector of the economy—commerce, government, entertainment and recreation, personal services, social services (health, education, etc.), and business services (accounting, real estate, etc.). Ecosystem Services, as proposed by the IAT, represents the non-economic value of the Puget Sound. The Committee’s proposed conceptual framework suggests that more specific social attributes—Economic Resources (as measured by the market economy), Accessibility and Recreational Participation, and Subjective Perceptions of Puget Sound—of Puget Sound would be more useful. Regardless of the label, the number of people spending their leisure time in, on, or near the waters represents a potentially important indicator of the value of Puget Sound.

Recreational activities depend on the vitality and accessibility of the Sound. A polluted Puget Sound without salmon, orcas, and bald eagles would draw few boaters, swimmers, and visitors to its beaches or shorelines. Similarly, unless public access to the Sound is widespread and affordable, few residents or visitors could participate in recreational activities, and public support for investment in conservation would probably be low.

The number of people applying for fishing permits may be highly correlated with other Puget Sound recreational activities, but this assumption should be empirically tested. Recreational activities vary widely with age and gender, and other demographic, social and economic characteristics. Changes over time in fishing permits may be a function of changing population composition and economic conditions as well as by the condition of the Sound. A broad survey of recreational patterns might allow for the development of indicators that broadly reflect how recreational activities are directly affected by the state of the Sound.

5. Behavioral changes as awareness increases: Personal vehicle miles traveled. The notes in Appendix C of the draft Dashboard report provide little justification or interpretation of this attribute and social indicator. It appears to be part of the Puget Sound Regional Council Trends Index. Apparently, the IAT may be anticipating that increasing public awareness of environmental issues, perhaps as a result of a public education campaign, will reduce driving. Automobile emissions do affect the Puget Sound ecosystem, but they are likely to work indirectly through one of the other pressures identified in Figure 6.

More importantly, the assumption that the primary emphasis of Puget Sound conservation and restoration efforts should be to change individual behaviors is highly questionable. Automobile driving is primarily determined by the locations of work places and residences as well as disposable income and the price of gasoline. Any changes in average per capita mileage inspired by conservation efforts will be dwarfed by these larger macroeconomic forces.

6. Existence value of the ecosystem (including aesthetics and willingness to pay to ensure continued survival of individual species or general health of the ecosystem). The IAT does not recommend a specific social indicator for this attribute.

In addition to economic resources and recreational participation, there is a widespread belief that many, if not most, Puget Sound residents “feel better” if the ecosystem thrives and is protected from pollution and over-harvesting. Although data collection on this topic will be challenging, the Committee strongly encourages the PSP to test alternative methods of measuring public sentiments toward Puget Sound, including the willingness to pay higher taxes (or make private contributions) to ensure that Puget Sound is maintained for future generations.

## V. MISSING ATTRIBUTES AND INDICATORS

The Committee described a framework (Section II) for identifying a complete set of indicators that encompass the key processes of the Puget Sound ecosystem. Guided by that framework, our analysis of the Dashboard Indicators identified four important attributes that lack an adequate indicator. The following discussion identifies four of these missing indicators, explains why they are needed, and provides guidance to the Science Panel of the PSP for their design and implementation. Detailed information on the rationale for three of the indicators, the state of the science that supports them, and guidance on devising them also are found in the 2000 NRC report.

### V. A. Extent

Many of the important environmental changes caused by humans—replacing native biological communities with agricultural and plantation systems, damming rivers, diking tidelands, building cities, and creating transportation corridors—result from land use. Changes in use of land (and marine benthic habitats) alter the ability of ecosystems to provide the goods and services on which human society depends. The extent of different marine and terrestrial cover or habitat types is an important attribute of an ecosystem. An indicator set that adequately characterizes the “condition of Puget Sound” needs to include indicators that represent the extent of each habitat type and other measures of marine landscape pattern and structure. This information is required to compute many of the indicators the Puget Sound Partnership has proposed. In addition, information on extent of different types of cover is essential if resource managers and restoration practitioners are to understand and evaluate tradeoffs. For example, if improvement of water quality leads to an increase in acres of eelgrass, what will be lost? Might this include oyster beds, also of value to humans, or would only low-productivity bare sand habitat be lost? Which other types should be sacrificed and from where?

An extent indicator would measure the proportion of the landscape and seascape covered by each member of a set of cover (use) types that add up to the total area of the focal region. The marine habitats of Puget Sound are unusually well represented in regional habitat classification systems (e.g., Dethier, 1992; Berry et al., 2007) and the entire shoreline plus shallow subtidal zone has been mapped (Nearshore Habitat Program, 2001). The historic database assembled by PSNERP (Simenstad et al., 2011) has coarse-grain maps of landscape conditions in the 1880s. It provides a valuable baseline for monitoring long-term changes in extent of marine habitat types. The PSP could build on these efforts, e.g., subdividing or combining categories in ways relevant to their goals. The categories must be comprehensive if the system is to serve as a basis for computing other indicators. New technology, such as marine LIDAR mapping, may enable the PSP to devise extent indicators and track changes in them rapidly and inexpensively.



## V. B. Productivity

The primary productivity of an ecosystem is measured by the amount of light energy captured by chlorophyll and associated molecules (photosynthesis), and its conversion to chemical energy in the form of compounds containing reduced carbon. In Puget Sound itself, and in major freshwater lakes in its watershed, the conversion rate of inorganic to new organic matter by photosynthesis is a basic determinant of entire ecosystem functioning. Changes in productivity usually affect the ability of an ecosystem to provide goods and services, but the relationships between productivity and different ecosystem services are neither simple nor easy to evaluate. Decreases in primary productivity are often of concern, but increases may result in eutrophication of freshwaters and create marine dead zones. Moreover, alterations of ecosystem productivity to increase a particular ecosystem service (wood production, food) often reduce the ability of an ecosystem to provide other services (biodiversity preservation, recreation). In its discussion of the Dashboard indicators, the PSP recognizes the importance of primary productivity but proposes no indicator for it.

The models of ecosystem energetics and carbon economy that justify total chlorophyll as an indicator of ecosystem productivity are mature and well developed (VEMAP, 1995). Models that demonstrated that net primary production (NPP) could be predicted from information on precipitation and temperature were first developed in the 1960s and 1970s. Satellite images are being used to calculate the Normalized Difference Vegetation Index (NDVI), a measure of chlorophyll per unit area. Plant physiologists have developed mechanistic models of NPP (Collatz et al., 1992). Until recently technological tools could measure only aboveground carbon, but aerial and remote sensing methods being developed today will enable us to estimate the amount of carbon stored in the soil as well (Asner, 2009). Thus, technological advances allow ecosystem productivity to be monitored at a modest cost. A useful estimate of ecosystem productivity in the Puget Sound basin can be obtained by summing the measured chlorophyll in each of the land and sea habitat types. Thus, computing an indicator of ecosystem productivity requires a well-developed extent indicator. Requisite monitoring data are very likely available from the NOAA Ocean Climate Laboratory.

## V. C. Biodiversity

The capacity of ecosystems to provide goods and services depends, among other things, on the many species that drive and maintain vital ecosystem processes. That is, the ecological capital of the system—the number of species found in it—strongly affects the functioning of the system and its responses to environmental variability. The causal relationships between biodiversity and ecosystem processes, particularly productivity,

are incompletely understood (Millennium Ecosystem Assessment, 2005; Willig, 2011; Adler et al., 2011), but the overall importance of biodiversity for maintaining vital ecosystem processes is not in doubt (Hooper et al., 2012; Kareiva et al., 2011). The Dashboard has several indicators for individual species (eelgrass, orca, salmon, herring), but it lacks one that reports on the overall biodiversity of the Puget Sound region. Moreover, the species of current greatest interest and concern to people, the ones that PSP has assigned Dashboard indicators, are not primary drivers of ecosystem processes, nor are they likely to be the species of greatest interest to people in the future. The Puget Sound Partnership needs to initiate a process to develop and use indicators of biodiversity to supplement the indicators that focus on individual species.

Most useful biodiversity indicators have the form of observed/expected (O/E). That is, a current measure of biodiversity in a particular cover type is compared with what might be expected in that type. Determining how to measure both the numerator and denominator of such an indicator is difficult. Problems with numerator estimation arise because we have identified and named only a small fraction of the species living on Earth today. Many groups of marine organisms are yet to be explored thoroughly. For this reason, implementation of a biodiversity indicator can begin with only a few groups of organisms or a few habitats, but it can and should be expanded over time as knowledge of other groups improves.

For several reasons, estimating the denominator is especially difficult. We do not have baseline biodiversity data for any marine habitat for any pre-European period or even 100 years ago. Surveys from a variety of Puget Sound sites do exist from the 1960s to 1980s (reviewed in Dethier 1990). For many habitat types, however, the only option may be to identify and use reference sites as operational baselines.

Once an appropriate baseline has been chosen, the next task is to determine what biological diversity should be expected in each of the cover types selected for the extent indicator. Ideally, we would have a measure of the expected densities of all species found in each cover type, but such information is impossible to obtain for most groups of organisms even with massive investment of human and financial resources. In addition, because species abundances fluctuate widely over time, all estimates of expected abundance have high variability. The difficulty is compounded in estuaries such as Puget Sound because strong environmental gradients (e.g., in temperature and salinity) are usually accompanied by strong gradients in biodiversity (Villnas & Norkko, 2011). Fortunately, much information can be gained from unweighted lists of the species present (National Research Council, 2000).

Finally, a sampling and monitoring program needs to be established. Decisions need to be made concerning how often and at what times during the year the biodiversity of each cover type should be measured and for what groups of organisms enough information is available to allow them to be included in the aggregate biodiversity measure.

The NRC report (2000, pp. 75-82) contains a detailed discussion of the empirical species/area relationships that underlie and inform the design of biodiversity indicators. It also provides practical advice about how to establish values for the denominator of the indicator, how to integrate it with the extent indicator, and how to add new taxonomic groups as new information becomes available. The development of an indicator of biodiversity for Puget Sound is an effort that will unfold over time, but, given the importance of biodiversity for the functioning of the Puget Sound ecosystem, this task should be initiated in the very near future. The WSAS is prepared to be of service to the PSP in that effort.

## **V. D. Sediment Delivery and Transport**

***The Committee recommends that PSP develop an indicator of the critical processes of sediment delivery and transport, which are among the most critically impaired processes in the nearshore environment of the Sound*** (Simenstad et al., 2011; Shipman, 2010; Fresh et al., 2011). Table 1 illustrates that soil or sediment characteristics and dynamics are key components in the three national systems that categorize ecosystem attributes. In terrestrial ecosystems, soil organic matter is a good measure of productive capacity (National Research Council, 2000). Similarly, sediment characteristics in the marine realm are key physical parameters (along with energy, salinity, and a few other variables) that define benthic habitats and limit the organisms found there (Dethier, 1992). In conceptual models of Puget Sound, sediments are one of three broad components (along with water and biology) defining the marine ecosystem (Figure 2).

As for other process indicators, quantifying sediment dynamics is difficult, but it is possible to measure relative rates of erosion and accumulation of sediment in the near-shore. This is complex in Puget Sound because the irregular shoreline shape leads to the division of the coast into “hundreds of discrete littoral cells, each with its own sources and sinks of sediment” (Shipman, 2010). Sediment dynamics have been studied extensively in other parts of the U.S. where “sand rights” are a recognized legal issue for beachfront property owners. Conservationists in Europe similarly have devoted considerable effort to understanding “beach sedimentary status,” and have developed indicators such as beach width (Sanchez-Arcilla et al., 2011). Bluff erosion rates, width of “dry beach” (low elevation backshore), median grain sizes, beach profiles, and similar parameters could be monitored at representative or randomly selected littoral cells to create indicators of sediment dynamics (e.g., Osborne et al., 2010; Nordstrom et al., 2010).

Armoring of a large proportion of the eroding bluffs in Puget Sound has cut off the major source of sediment that creates Puget Sound's beaches. Beaches are essential habitats for harvested mollusks and for reproduction of forage fish. Those species are vital components of the Puget Sound food web that support other important species such as salmon and orcas. Yet the only Dashboard indicator that relates to sediment dynamics is "shoreline armoring," and then only very indirectly, i.e., an increase in armoring probably leads to a decrease in sediment supply.



## VI. CONCLUSIONS AND RECOMMENDATIONS

The Washington State legislature directed the Puget Sound Partnership to develop an Action Agenda to “include near-term and long-term benchmarks designed to ensure continuous progress needed to reach the goals, objectives, and designated outcomes by 2020.” The PSP thus needed a set of indicators that could provide both the scientific justification for management interventions and a solid basis for evaluating the consequences of those interventions. When properly designed, indicators capture the complex economic, sociological, or scientific data underlying ecological processes and their societal counterparts that are too expensive to measure directly or too difficult to explain to broad audiences.

The WSAS has reviewed both (a) the procedures used by PSP to develop a system of indicators of ecosystem condition and human well-being, and (b) the current published choice of indicators that constitute the Dashboard. The Committee’s analysis is based on documents supplied to it by PSP on or before September 30, 2011. Specific recommendations are denoted by bullets.

The Overall Process Used by the Puget Sound Partnership. PSP chose initially to focus on indicators of the “state” or condition of Puget Sound. The Committee supports this decision. In addition, the system of indicators envisioned by PSP contains two sets: a top-level “Dashboard” plus a larger set of indicators to track the condition of the ecosystem. We recognize the value of a hierarchical, multilevel system of indicators with a small indicator set to communicate with the public and a larger set to understand ecosystem condition in more detail. The smaller set should be derived from and track the larger set. Both sets should represent the structural and functional elements of the ecosystem.

The Committee analyzed the documents available to it to identify procedures the PSP used to select a set of indicators and to assess the quality of individual indicators. Due in part to the challenging timeframes imposed by legislative mandates, these PSP efforts overlapped in time and were not always internally consistent. The Committee was unable to find documents that described some of the criteria that were used to evaluate indicator characteristics. Nonetheless, the PSP has made considerable progress in identifying indicators of ecological condition; it is not unusual to have stops, starts, and blind alleys during the development of indicator systems.

- ***Based on our experience and efforts of other groups, the Committee strongly recommends that the PSP use the following overall “roadmap” as it refines its choice of indicators. The indicator selection process is ongoing, so it is not too late to adopt the following steps:***

- Step 1.** Develop a conceptual framework that summarizes the major structural elements and processes of the ecosystem to identify the key attributes (characteristics) that should be tracked.
- Step 2.** For each attribute, identify potential indicator(s), explicitly describing the rationale for determining that the indicator accurately represents the attribute by using a conceptual model or an empirical association with predictive power.
- Step 3.** Develop an appropriate measure (metric) that demonstrates the response of the indicator to changes in the ecosystem.
- Step 4.** Evaluate each potential indicator and its associated measure (metric) for quality, using criteria (detailed below) such as reliability.
- Step 5.** If more than one high-quality indicator has been identified for an attribute, winnow the set of potential indicators using other factors appropriate to the application, such as cost or response time.
- Step 6.** Reassess the resulting set of indicators to ensure that they capture all of the important attributes identified in Step 1 above.

**Conceptual framework and conceptual models.** An effective set of condition indicators should comprehensively but concisely represent current understanding of the condition and key functional processes of an ecosystem, including its human components. Such an understanding can best be formed and expressed using a conceptual framework that includes the system’s component parts, the way they fit together, and their dynamical interactions. This framework can guide the selection of indicators so that every key ecosystem attribute is represented by at least one indicator. For well-studied systems like Puget Sound, the conceptual framework can and should be supplemented by conceptual models that describe the relationships among selected attributes. These conceptual models can be used to identify the most informative indicator for particular attributes in a scientifically robust manner.

- ▷ *We recommend that future refinement of the Dashboard indicator list, as well as evaluation and selection of additional indicators, be based on development and use of a comprehensive conceptual framework that describes the Puget Sound ecosystem and clearly identifies the key ecological processes that determine its dynamic properties. It is not necessary or desirable to include popular or iconic elements.*

**Sets of Indicators.** The PSP indicator-selection process initially used several approaches. The initial work by O'Neill et al. (2008) provided an appropriate foundation; using an ecosystem-based conceptual framework while also responding to the legislative goals, the authors categorized existing indicators and identified important ecological attributes for which no indicators were available. They also recommended development of conceptual models to refine the process for choosing indicators. The next iterations of the indicator set, however, focused on the legislative goals, then employed “targets” developed using the Open Standards methodology. In the Committee’s view, these latter approaches were flawed because neither explicitly covered the range of attributes necessary to fully describe an ecosystem. Levin et al. (2011) provided a draft conceptual framework (Table 3) that again attempted to incorporate ecological science into the interpretation of the legislative goals. Dashboard indicators, however, were selected with inadequate reference to an ecosystem-based conceptual framework, and without using conceptual models that the Committee can document. Instead, the focus on legislatively mandated goals resulted in the omission of important ecological attributes, such as species at lower trophic levels, community-level attributes, landscape-level attributes, and basic ecological processes (energy and material flows). In addition, some of the Dashboard indicators do not match the attributes they are supposed to represent. The Committee concludes that failure to utilize a comprehensive, ecosystem-based conceptual framework led to many of the problems with the Dashboard indicator set.

These flaws, however, do not require PSP to “start over.” Much valuable groundwork has been laid, and most of the Dashboard indicators are appropriate if they are adequately refined. ***The Committee anticipates that the ongoing evolution of both the Dashboard and the larger set of indicators will be dynamic and adaptive, and makes the following recommendations to help PSP move forward with refinement of their provisional Dashboard indicators:***

- ▷ *To help implement the recommendation regarding the use of a conceptual model (above), we recommend that the PSP reconsider and fine-tune the framework created by Levin et al. (2011) (their Table 3, reproduced in Section III. C). That framework includes “key attributes” and “relevant measures;” this combination could form the basis for a framework that*



*does a creditable job of representing an ecosystem. This conceptual framework should then be evaluated with reference to existing conceptual models of the Puget Sound ecosystem, supplemented with additional and finer-scale conceptual models as appropriate. The criteria used to evaluate individual indicators should be adjusted; gaps should be identified and filled. The Committee stresses the importance of the final step in the process—reassessing the indicator set for its complete coverage of important ecological attributes.*

- ▷ *All documents describing indicator sets should contain language that clearly describes the purpose served by each indicator, its role in the total set, and how to interpret any changes it reports; this is a vital component of communicating the rationale for the choice of individual indicators and the design of an indicator set.*

**Human Dimensions Indicators.** The development of indicators for human health and well-being has clearly lagged behind development of ecological indicators. Therefore, the PSP needs to devote considerable effort to develop indicators of human well-being that are clearly and directly related to the state of the Puget Sound ecosystem. Because they are still under development, the Committee was unable to evaluate the adequacy of the social indicators being considered for the Dashboard or to compare them to other potential measures; however, none of the indicators under consideration relates clearly to quantifiable aspects of the state of the Sound. *We have suggested a draft conceptual model that shows functional linkages among human actions, the condition of the Sound, and human well-being.*

- ▷ *We recommend that PSP use this model to help develop better indicators of human well-being.*
- ▷ *Indicators chosen to represent human well-being should include only concrete, measurable parameters that are clearly linked to resources provided by Puget Sound.*
- ▷ *The contribution of Puget Sound to the local economy is mentioned occasionally in PSP reports, but we recommend that its importance to human well-being be given a more central and unified focus in the development of Dashboard indicators.*
- ▷ *The Committee agrees that subjective elements (e.g., aesthetics, “existence value” of a thriving ecosystem) are important parts of the connection between human well-being and Puget Sound, but measuring*

***subjective perceptions with a high degree of scientific reliability is problematic.***

**Criteria for Choosing Indicators.** Overall, the Committee found the documented process of choosing and scoring criteria for selecting the Dashboard indicators difficult to understand. Criteria were binned into “primary considerations,” “data considerations,” and “other,” the latter including being readily understood by the public. Some of these criteria are inappropriate for initial screening of candidate indicators or are inappropriately weighted. For example, favoring currently popular indicators or indicators for which data are immediately available guarantees that important changes in the functioning of the system will be missed. Although the Committee was told that the PSP is focusing on indicators of the “state” of the ecosystem, the selection criteria used appear to be at odds with this approach. For example, the PSP states that scientific criteria were the primary ones for selecting indicators, but potentially valuable indicators were dropped from the list simply because no data were available to populate them. Similarly, relevance to specific management activities was heavily weighted. Finally, the weights given to the different criteria and then used to sum the scores for ranking indicators do not agree with their importance.

The Dashboard authors also judged that the Dashboard should include indicators from each of four combinations of “sensitivity” (lagging versus leading) and “specificity” (diagnostic versus broadly informative). Those four categories do not correspond to any key ecosystem attributes; using them to pick indicators lacks scientific justification. Moreover, as stated earlier, indicators generally should not be designed to be “diagnostic.” ***To rectify these problems, we recommend that:***

- ▷ ***The criterion of “theoretically sound” be given the highest weighting in choosing indicators rather than the low weighting it was assigned.***
- ▷ ***The PSP adopt an approach that focuses on condition indicators that describe the state of the ecosystem, rather than on management-driven indicators. This would eliminate the need to try to balance “sensitivity” and “specificity.”***
- ▷ ***The PSP reassess the pool of indicators from which the final list was selected, using, appropriately revised, the “primary” considerations as the basis for the initial screening.***
- ▷ ***For practical reasons, the finally selected indicators be ones that can be disaggregated to characterize geographical subunits of Puget Sound as well as the ecosystem as a whole.***

- ▷ *Most indicators need not have “communication” as their primary function. Populating the Dashboard with indicators that scored highly on “understood by the public and policymakers” undermines the scientific basis for the indicator set. An education program must be a part of the development and use of an indicator system, but it should play only a minor role in the selection of indicators.*

**Evaluating individual Indicators.** The PSSU and Dashboard currently include targets associated with some indicators; during the Committee’s deliberations, these were mostly works-in-progress and were not thoroughly reviewed. In addition, PSSU provided neither criteria for evaluating the metrics to be used for each indicator, nor criteria for evaluating the performance of the indicators over time. For these reasons, the Committee is unable to determine the adequacy of the proposed indicators to monitor progress toward meeting goals and objectives.

- ▷ *We recommend that priority be given to monitoring and reporting trends in the ecological indicators to allow “adaptive management” of the indicator set, i.e., permitting change in the set if some initially selected indicators turn out to be ineffective.*
- ▷ *The Committee evaluated the PSP’s provisional list of Dashboard indicators and placed them into four categories of recommendations, discussed below.*

## **VI. A. Refine and Use in the Initial Dashboard**

- **Marine Water Quality**, if PSP adopts the DOE measurement parameters cited by the Committee, and considers omitting “monitoring to the bottom” and coastal bays).
- **Toxics in Fish**
- **Toxics in Sediment**
- **Water Quantity Salmon**
- **Eelgrass**
- **The Orcas** indicator has poor scientific justification as a condition indicator for Puget Sound, but the Committee recognizes its important iconic status.

## **VI. B. Continue to Develop for Possible Use in the Dashboard**

- *For Freshwater Quality, we recommend expansion of the list of monitored parameters beyond “conventional pollutants.”*

- **The Shoreline Armoring** indicator is appropriate as one part of a marine habitat “extent” attribute but needs to be complemented by other habitat extent data.
- **The Land Use/Land Cover** indicator is important in recognizing tradeoffs inherent in different types of land use. *We recommend that it be modified so that the metrics are independent of policy and goal statements, and that further development of this indicator be accomplished expeditiously.*

## VI. C. Do not Use in Its Current Form

- ▷ *We recommend that PSP reconsider its decision to include herring spawning biomass as a metric of the “Pacific Herring” indicator. We suggest that PSP use either its influence or funding to encourage WDFW to return to monitoring herring standing stock, or give additional consideration to investigating jellyfish populations as a Food Web indicator.*
- ▷ *Because terrestrial bird populations relate only weakly to the condition of Puget Sound, we recommend that this indicator be eliminated from the Dashboard, although some metrics relating to terrestrial birds may be relevant as an indicator of terrestrial condition.*

## VI. D. Add Indicators of Important Attributes Overlooked/Omitted by PSP

- ▷ *We strongly recommend inclusion of indicators of key ecosystem attributes that currently have little to no representation in the indicator set. These include:*
  - **Extent** of the range of marine habitat types in Puget Sound, to parallel the terrestrial land use/land cover indicator. Data already exist to begin creating such an indicator. The data gathered for this indicator are essential for understanding the status of other indicators such as eelgrass, shoreline armoring, and biodiversity.
  - **Primary productivity**, the conversion of inorganic to organic matter by photosynthesis, is the base or sine qua non of the entire ecosystem yet was nearly completely neglected by PSP. Efficient methods exist to assess and monitor productivity, and data may already be available from the Ocean Climate Laboratory of NOAA.

- **Freshwater quality in lakes as well as streams**, and primary organic productivity in freshwater habitats.
- **Biodiversity** of selected types of organisms that populate selected habitat types.
- **Sediment delivery and transport** along beaches, as a key process that affects ecosystem condition in the nearshore of Puget Sound.

In conclusion, the Committee has identified and described significant flaws and inconsistencies in the processes the PSP used to select a set of indicators to monitor trends in the condition of the Puget Sound ecosystem and to assess the consequences of management interventions. Yet we recognize the complexity of the task that confronted the Science Panel and the Leadership Council and judge that their efforts, although at times uncoordinated and contradictory, have laid a solid foundation on which the PSP can build as it refines its procedures and outcomes. Again, we stress the importance of developing and using a conceptual model of the Puget Sound system to identify the key attributes for which indicators need to be developed. We have suggested a stepwise procedure that, if adopted, would help the PSP select, describe, and provide the rationale for the indicators that it needs to develop and refine. The Washington State Academy of Sciences looks forward to continuing to be of service to the Puget Sound Partnership as it builds upon its valuable efforts to provide a solid scientific basis for maintaining and improving the ability of the Puget Sound ecosystem to enrich the lives of the people that live near it.

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# Review Committee Biographies

## Review Committee

### **Gordon H. Orians,**

University of Washington

**Gordon H. Orians, Chair,** is Professor Emeritus of Biology, University of Washington, Seattle, Washington. He received a Ph.D. in Zoology from the University of California, Berkeley, in 1960. He then joined the Department of Zoology, University of Washington, where he remained until he retired. He was Director of the University's Institute for Environmental Studies from 1976 through 1986. He is an elected member of the National Academy of Sciences as well as the American Academy of Arts and Sciences. His most intensive research area has been behavioral ecology, focusing on habitat selection, mate selection and mating systems, selection of prey and foraging patches (foraging theory), the relationships between ecology and animal social organization, and population dynamics. He chaired the National Research Council Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments, which published its report—Ecological Indicators for The Nation—in 2000. He also served on the Design Committee of The H. John Heinz Center that guided the production of the Center's "State of the Nation's Ecosystems" reports in 2002 and 2008.

### **Megan Dethier**

University of Washington

**Megan N. Dethier** is a Research Professor in the Biology Department at the University of Washington but is in full-time residence at the Friday Harbor Laboratories. She did her undergraduate work at Carleton College in Minnesota, then Ph.D. work under Bob Paine at the University of Washington. Since about 1978 she has worked on the shoreline ecology of the Pacific Northwest. Her first love is rocky shores, but she now also works in mud, gravel, and salt marsh habitats. She designed a marine habitat classification system for Washington state, and has worked with the National Park Service and various Washington agencies designing shoreline mapping and monitoring programs. Her current research efforts are mostly focused in Puget Sound, investigating the linkage between physical features of shoreline habitats and their biota, and the effects of human impacts (such as shoreline armoring) on this linkage.

## **Charles Hirschman**

University of Washington

**Charles Hirschman** is Boeing International Professor in the Department of Sociology and the Daniel J. Evans School of Public Affairs at the University of Washington-Seattle. He received a BA from Miami University in 1965 and a Ph.D. from the University of Wisconsin in 1972. Prior to his appointment at the University of Washington in 1987, Hirschman taught at Duke and Cornell. At the University of Washington, he served as director of the Center for Studies in Demography and Ecology (1987-95) and as chair of the Department of Sociology (1995-98). His areas of specialization include demography, immigration and ethnicity, and Southeast Asia. He is past President of the Population Association of America (2005) and former chair of Section K (Social, Economic, and Political Sciences) of the American Association for the Advancement of Sciences (2004-05). He is an elected fellow of the American Academy of Arts and Sciences and the American Association for the Advancement of Sciences. He served in the National Research Council Panel on the Demographic and Economic Consequences of Immigration (1995-97), and currently serves in the National Academy of Sciences Committee on Population and on the National Institute of Child Health and Human Development Population Sciences Committee. He was a Peace Corps Volunteer in Malaysia from 1965 to 1967.

## **Alan J. Kohn**

University of Washington

**Alan J. Kohn** is Professor Emeritus of Biology at the University of Washington, where he has been a member of the faculty for 50 years. He was educated at Princeton University (A.B.) and Yale University (Ph.D.). At Washington, he taught undergraduate and graduate courses mainly in invertebrate and marine biology and ecology (1961-2007), and he supervised the Ph.D. dissertations of 21 graduate students. His research focuses on the ecology and evolution of tropical marine biodiversity. He has published more than 120 research papers, and is the author or co-author of three books and co-editor of three others. He is Honorary Life President of the American Malacological Society, and served as President of the Society for Integrative and Comparative Biology and as a member of the Council for International Exchange of Scholars. He has consulted on environmental matters for King County, Washington State Department of Natural Resources, Olympic Coast National Marine Sanctuary (NOAA), and several companies, and he has served as a program officer and panel member at the U.S. National Science Foundation, most recently for programs in Systematic Biology (2009) and Environmental Life Sciences (2010).

## **Duncan Patten**

Montana State University

**Duncan Patten** is Research Professor with the Department of Land Resources and Environmental Sciences at Montana State University, Bozeman. He is also Professor Emeritus in the School of Life Sciences at Arizona State University and past director of the ASU Center for Environmental Studies. Dr. Patten received a Ph.D. from Duke University. His research interests include arid and mountain ecosystems, especially the understanding of ecological processes of riparian, wetland, and riverine ecosystems. He was Senior Scientist of the Bureau of Reclamations Glen Canyon Environmental Studies. He is a Fellow of the American Association for the Advancement of Science and has been a member of several National Academy of Sciences/National Research Council (NAS/NRC) committees, including a Board and Commission. He was a member of the USFS Rangeland Roundtable, which selected indicators for rangeland sustainability, and he worked with the NPS Greater Yellowstone Network program on vital signs. Patten was on the Design Committee of The H. John Heinz Center that helped develop the Center's 2002 and 2008 "State of the Nation's Ecosystems" reports and also served on an Independent Science Board guiding restoration and science for the California Bay Delta Authority estuary/river/water/levee programs. He is presently on EPA's Science Advisory Board.

## **Terry F. Young**

Environmental Science Consultant

**Terry F. Young** is an independent consultant who specializes in water quality, ecological indicators, and the use of economic incentives to control pollution. In 2007, she was appointed as a member of the San Francisco Regional Water Quality Control Board and is currently the Board's Vice-Chair. From 1992 to 2002, Dr. Young was a member of the U.S. EPA's Science Advisory Board, chairing its Ecological Processes and Effects Committee and serving on the Executive Committee of the Board. In this capacity, she edited the Board's report: "A Framework for Assessing and Reporting on Ecological Condition." Dr. Young has served on committees of the National Research Council and boards of environmental organizations. She also served on the Design Committee of The H. John Heinz Center for its report on the "State of the Nation's Ecosystems." Dr. Young received her Ph.D. in Agricultural and Environmental Chemistry from the University of California at Berkeley and an undergraduate degree in Chemistry from Yale University.



WASHINGTON STATE  
**Academy of Sciences**

Washington State Academy of Sciences  
410 11th Avenue SE, Suite 205  
Olympia, WA 98501  
[programs@washacad.org](mailto:programs@washacad.org)  
<http://www.washacad.org>  
(360) 534-2336