Puget Sound Partnership Strategic Science Plan

At its June 17, 2010, meeting the Leadership Council voted to adopt this version of the Strategic Science Plan as an official document of the Puget Sound Partnership

PugetSoundPartnership
our sound, our community, our chance

Cover image: Geographic boundary of the Salish Sea including the Puget Sound, Straits of San Juan de Fuca and Georgia, the Olympic, Cascade, and Coast mountain ranges, major river basins, and developed and undeveloped lowlands and coastal areas. Image from ESRI Satellite http://www.geographynetwork.com

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EXECUTIVE SUMMARY

This *Strategic Science Plan* for Puget Sound provides the overall framework for development and coordination of specific science activities necessary to support Puget Sound ecosystem protection and restoration under the Puget Sound Partnership's *Action Agenda*. This document recognizes that ecosystem recovery will require increased scientific capacity, both human and technological, a transparent and structured decision-making process with open two-way communication between science and policy, and an accountability system that enables adaptive management through time.

This *Strategic Science Plan* is intended to be a high-level, living document that can be revised by the Science Panel as needed while specific implementation of science work will be guided by the *Biennial Science Work* Plan, which lays out the initiatives and activities in the context of the two-year state budget cycle. Primary audiences of this document include the Science Panel, Partnership staff, Partnership leadership boards, Puget Sound region science program managers, Puget Sound science community, and the public. In addition to this document the Science Panel with support from Partnership staff is ultimately responsible for the *Biennial Science Work Plan, Puget Sound Science Update*, and reporting on monitoring and assessment findings in the *State of the Sound*, as well as providing scientific advice for the Puget Sound Partnership's ecosystem recovery efforts. These efforts will require a number of additional scientific products, including technical reports, conference proceedings, technical guidance documents, requests for proposals, and reports on the implementation of science program activities.

Our collective knowledge of Puget Sound comes from decades of investigations and observations conducted for diverse reasons by a wide variety of dedicated people and organizations. However, much of the existing knowledge about the Puget Sound ecosystem is limited to the natural sciences, comes from studies with limited scope, which has often resulted in a somewhat fragmented and non-uniform understanding of the Puget Sound within the broader Georgia Basin - Puget Sound (Salish Sea) ecosystem.

In this *Strategic Science Plan*, we recognize there is need to synthesize existing and ongoing scientific work, to identify the information needs of policy makers, and to foster the development of new science capacity with an emphasis on integration across disciplines and political boundaries. For science to support protection and restoration we must continue to build our knowledge of ecosystem processes, structures, functions, and services as well as human dimensions, across multiple spatial and temporal scales. We must better understand the human dimensions of restoration and protection efforts that consider human health, economic well-being, and social norms and values. The latter provides foundational knowledge to determine effectiveness of restoration and conservation.

The Science Panel has endorsed an adaptive management approach that will provide a credible means by which scientists can inform policymakers and policymakers can be accountable to the public for recovery results. The adaptive management process allows ecosystem recovery to move forward in the face of uncertainty by ensur-

ing that actions are evaluated against goals and where necessary altered to optimize outcomes. The Partnership has adopted a performance management system that fully supports adaptive management: the *Open Standards for the Practice of Conservation* (The Conservation Measures Partnership, 2007). As a framework for adaptive management, *Open Standards* provides a common means of understanding and supporting the critical role of science, and a means to identify where in the project management cycle science is relevant and needed.

In conclusion, the Science Panel recommends a strategic science program that includes the following elements:

- A clear understanding by the Partnership about critical roles for science within an adaptive management framework and the *Open Standards* performance management system;
- A means to support ongoing two-way engagement between natural and social science and policy participants to continually identify and prioritize information needs as the work proceeds;
- Development of specific science capacities to assure that the program's science capabilities are responsive to identified needs including monitoring, modeling, data management, and research;
- Synthesis and communication of relevant scientific information to the right people at the right times to support protection and restoration outcomes;
- Periodic peer review of science activities at both the project and programmatic levels, with responsive modifications to the science program as needed; and
- Education and outreach to build public awareness of the value and roles of science, to foster consensus around what we know (thereby supporting public policy decisions), and to support learning about science and about Puget Sound.

1. INTRODUCTION

In 2007, the State Legislature enacted Engrossed Substitute House Bill 5372 with the stated goal of restoring the health of Puget Sound by 2020 and authorizing the Puget Sound Partnership with the responsibility. The Legislature established this goal in response to growing concerns about the health of Puget Sound basin and their belief that Puget Sound is a national treasure and a critical part of the economic and cultural fabric of Pacific Northwest.

Adoption of this *Strategic Science Plan* by the Puget Sound Partnership demonstrates a commitment to science-based recovery of Puget Sound. The Partnership's vision is that science will provide the foundation for ecosystem recovery efforts by developing and communicating a scientific understanding of the ecosystem to inform protection and restoration decisions and support a continual assessment of the effects of management actions.

This *Strategic Science Plan* provides the overall framework for development and coordination of specific science activities necessary to support Puget Sound ecosystem protection and restoration. Ecosystem recovery will require increased scientific capacity, both human and technological, a transparent and structured decision-making process with open two-way communication between science and policy, and an accountability system that enables adaptive management through time.

1.1 Ecosystem Decline and the Need for Action

Puget Sound, like many coastal ecosystems worldwide, is showing many symptoms of decline (see Ruckelshaus and McClure, 2007 for a full discussion). Trends noted for coastal systems both globally and locally include increasing numbers of imperiled species, disrupted food webs, degraded and/or loss of habitat for many species, and increasing levels of toxic contaminants (Heinz Center, 2008, U.S. Commission on Ocean Policy, 2004).

Healthy ecosystems are resilient, self sustaining systems that support human societies by providing goods and services in the form of energy, food, building materials, water purification, flood and erosion control, as well as spiritual enrichment, recreation, and aesthetic experiences (MA 2005). Natural and human induced stresses decrease the capacity of coastal ecosystem such as Puget Sound to provide highly valued goods and services.

Government agencies including the Puget Sound Partnership are responding to declines in the health of coastal ecosystems by promoting an ecosystem-scale approach to protection and restoration. This approach recognizes the shortcomings of managing ecosystem components individually (Pew Oceans Commission, 2003; U.S. Commission on Ocean Policy, 2004; Leslie and McLeod, 2007), often because responsibility for these components is dispersed widely among multiple state and local governments (Lombard, 2006). Ecosystem-based management integrates management activities across land, water, air, energy, and living resources in a manner that promotes conservation and sustainable use of resources in an equitable way (United Nations Environment Program/Convention on Biological Diversity, 2000).

An ecosystem-scale approach also requires consideration of Puget Sound within the context of the broader Salish Sea ecosystem that straddles southern British Columbia in Canada and the northwest portion of Washington State in the United States (Figure 1). The Salish Sea ecosystem encompasses the marine waters and watersheds of the Strait of Juan de Fuca, Strait of Georgia, and Puget Sound. To successfully protect and restore the Puget Sound, protection and restoration within all of the Salish Sea must also be considered.

Figure 1: The Salish Sea Ecosystem includes the land and waters of the Puget Sound and Georgia Basin
(Image courtesy of Stefan Freelan, 2009)

For protection and restoration strategies to work, the fragmented approach to managing resources across diverse geographies and governmental jurisdictions must give way to collaborative problem identification, ranking, and solving. Because the scientific knowledge needed to support this collaboration is itself fragmented, efforts must be made to knit together specific, diverse components of the human community – state and federal agencies, local governments, tribes, non-governmental organizations, businesses, and concerned citizens – to leverage their collective abilities and expertise.

For science to support protection and restoration, we must continue to build our knowledge of ecosystem processes, structures, and functions, as well as human dimensions, across multiple spatial and temporal scales. We must better understand the human dimensions of ecosystem recovery efforts that consider human health, economic well-being, and social norms and values. The latter provides foundational knowledge to determine effectiveness of restoration and conservation. We must develop models to support adaptive management (Williams et al., 2007) and design monitoring programs that support accountability (National Research Council, 1990).

The need for action is urgent, as human population growth, climate change, and other forces are fundamentally altering Puget Sound. Conditions in Puget Sound will no longer fluctuate within a definable envelope of historical variability (Milly et al., 2008); rather the entire ecosystem will likely be transformed through new states at a rate comparable to our maximal rate of scientific learning (Healy, 2007). In a setting of moving baselines, the traditional view of restoration—that is restoration to a set of historically defined conditions—may no longer be valid.

1.2 Washington State's Response: the Puget Sound Partnership

The Puget Sound Partnership is Washington State's response to Puget Sound's decline. The Partnership consists of a Leadership Council, Executive Director, Ecosystem Coordination Board, and a Science Panel working collaboratively to restore and protect the Puget Sound in a coordinated and coherent manner (Figure 2). The Executive Director employs scientific staff including a Science Program Director and Monitoring Program Manager. The Science Program Director provides oversight to assure implementation of this *Strategic Science Plan* using technical working groups and implementation teams composed of collaborators and partners from federal and state agencies, academia, tribes, local jurisdictions, nongovernmental organizations (NGOs), and other stakeholder groups.

The Partnership is founded on four fundamental beliefs: The first is that Puget Sound is a national treasure and essential to Washington State. The second is that the Puget Sound ecosystem is in serious decline and likely will worsen through time. The third recognizes that while some past activities to protect and restore the Puget Sound ecosystem have been done and offer a large body of knowledge to determine the problems in Puget Sound, these have often been underfunded, fragmented, uncoordinated, and mostly ineffective at the ecosystem scale. The fourth belief—and impetus for creating the Partnership—is that the Puget Sound ecosystem is worth protecting and restoring. In this context, the Partnership's work is intended to complement and coordinate ongoing state, federal, tribal, local, nonprofit, and volunteer efforts to protect and restore the Puget Sound ecosystem.

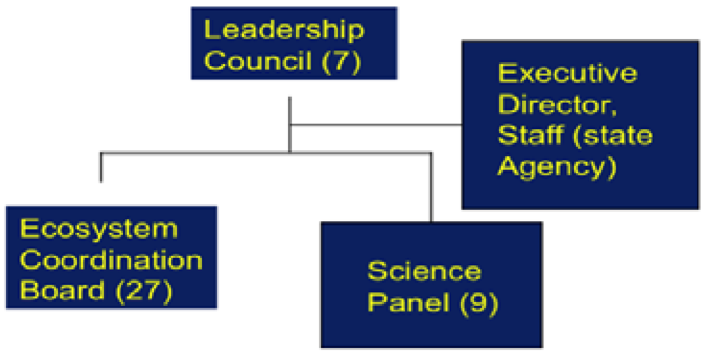

Figure 2: Puget Sound Partnership organization
(numbers indicate initial number of group members, 2007 to 2009)

Previous efforts to coordinate protection and restoration efforts for Puget Sound focused primarily on marine and nearshore areas and have failed to consider human health and quality of life issues. The Partnership's focus is more comprehensive, encompassing the upland areas of the entire watershed as well as the human dimensions of ecosystem recovery. Recovery goals are to be achieved through the development and implementation of the Partnership's strategic, science-based *Action Agenda*. The first version of the *Action Agenda*, released December 1, 2008, and updated in May 2009, is the Partnership's current roadmap to restoring the health of Puget Sound. It identifies and ranks a broad suite of activities that support the five Partnership priorities: 1) protect intact ecosystem processes, structures, and functions; 2) restore ecosystem processes, structures, and functions; 3) prevent water pollution at its source, 4) work together as a coordinated system, and 5) build an implementation, monitoring, and accountability system.

Common purpose to achieve *Action Agenda* ecosystem recovery goals is being established through a collaboratively developed vision of desired future conditions that integrates ecological, socioeconomic, and institutional perspectives (Groom et al. 2006). The process has already resulted in a broadly vetted, albeit incomplete, scientific analyses of our current understanding of the Puget Sound ecosystem (Ruckelshaus and McClure 2007), and a series of "Topic Forum" papers developed through a broad, collaborative, and public *Action Agenda* development process.

The Puget Sound Science Panel has a central role in fulfilling the Partnership's commitment to science-based protection and recovery of Puget Sound. The Panel was created to 1) assist the Partnership in developing an ecosystem level strategic science program that addresses monitoring, modeling, data management, and identifies science gaps and recommends research priorities; 2) identify indicators to measure the health of Puget Sound; 3) develop and provide oversight of a competitive peer-reviewed process for soliciting, strategically prioritizing, and funding research and modeling projects; 4) provide input to the Executive Director of the Partnership in developing the *Action Agenda* and revisions to it; 5) offer an ecosystem-wide perspective on the science work being conducted across the Puget Sound ecosystem; and 6) collaborate with other scientific groups and consult other scientists to work toward an integrated research agenda and Puget Sound science work plan. Overall, the Panel is responsible for ensuring that science is an integral and sustained part of evolving Partnership activities.

Puget Sound Partnership Goals

1. The Washington State Legislature created the Partnership (RCW 90.71.300) to restore and protect Puget Sound by striving to meet the following goals by 2020:
2. A healthy human population supported by a healthy Puget Sound that is not threatened by changes in the ecosystem
3. A quality of human life that is sustained by a functioning Puget Sound ecosystem
4. Healthy and sustaining populations of native species in Puget Sound, including a robust food web
5. A healthy Puget Sound where freshwater, estuary, near shore, marine, and upland habitats are protected, restored, and sustained
6. An ecosystem that is supported by ground water levels as well as river and stream flow levels sufficient to sustain people, fish, and wildlife, and the natural functions of the environment
7. Fresh and marine waters and sediments of a sufficient quality so that the waters in the region are safe for drinking, swimming, shellfish harvest and consumption, and other human uses and enjoyment, and are not harmful to the native marine mammals, fish, birds, and shellfish of the region.

1.3 Strategic Science Plan Purpose

The purpose of this *Strategic Science Plan*, authored by the Science Panel, is to provide the overall framework for development and coordination of the science activities needed to support protection and restoration of Puget Sound under the *Action Agenda*. Success of this plan will depend on a constructive relationship between science and policy to define, refine, and invigorate recovery actions of Puget Sound in light of new knowledge. Science activity and products should interface at multiple social scales; informing policy makers, providing best practices for managers, enlisting organizational support (e.g., private sector and NGOs), building communities of action, and engaging individuals.

This *Strategic Science Plan* is intended to be a high-level, living document that can be revised by the Science Panel as needed. Specific implementation of science work will be guided by the *Biennial Science Work Plan*, which lays out the initiatives and activities in the context of the two-year state budget cycle. It is the *Biennial*

Science Work Plan that will be the Science Panel's input on strategic prioritization for work and projects to be funded by the Partnership in a given biennium.

The primary audiences and uses of this document are as follows:

Audience:	**Use the Strategic Science Plan as a reference document to:**
Science Panel (SP)	• Guide the development of *Biennial Science Work Plan*s • Provide SP perspective on long-term actionable items (activities and structures) that need to be undertaken as part of the Partnership's Strategic Science Program • Record the context, approach, and elements of the Partnership's Strategic Science Program
Partnership staff (including Science Program Director)	• Organize science-policy interface discussions – at SP meetings, with science-policy advisory groups, and otherwise – to ramp up a Strategic Science Program • Understand SP priorities in Science Program development and provide resources for activities and structures • Evaluate 2010 and later *Biennial Science Work Plan* proposals
Partnership leadership boards	• Engage with SP in science-policy discussions of what's needed – long-term and more immediately – from a Strategic Science Program • Evaluate *Biennial Science Work Plan* proposals • Understand the context, approach, and elements of the Partnership's Strategic Science Program
Puget Sound regional science program managers and resource agencies	• Understand and articulate how their program addresses needs of the Partnership's Strategic Science Program • Propose adjustments to their programs to undertake activities and build or contribute to structures that are part of the Partnership's Strategic Science Program
Puget Sound science community	• Understand the Partnership's science needs • Understand the context, approach, and elements of the Partnership's Strategic Science Program
Public	• Understand the context, approach, and elements of the Partnership's Strategic Science Program, and what it is intended to deliver to the public for their investment

1.4 Science Products of the Puget Sound Partnership

Washington State statute mandates the production of a Puget Sound *Science Update*, *State of the Sound* report, and *Biennial Science Work Plan* (see text box). The *Science Update* and *State of the Sound* provide synthesis and communication of scientific findings and understanding about the Puget Sound ecosystem and strategies for ecosystem-based recovery. In the *Biennial Science Work Plan*, the Partnership describes a two-year program of scientific investigations and science program capacity development to identify priority elements of the *Strategic Science Plan* for implementation. It is anticipated that these priorities will be addressed through RFPs for science activities e.g., as discussed in section 4.3. The scientific understanding of Puget Sound, and thus one basis for prioritization, is contained in the *Science Update*.

In addition to these products, providing scientific advice for the Puget Sound Partnership's ecosystem recovery efforts will require a number of additional scientific products, including technical reports, conference proceedings, technical guidance documents, requests for proposals, and reports on the implementation of science program activities.

Principal Science Products of the Puget Sound Partnership

Washington State statute requires several types of science products to be developed by the Partnership on an on-going basis:

Puget Sound *Science Update* – produced by the Science Panel (with staff assistance provided by the Partnership's Executive Director) by April 2010, and subsequently updated as necessary to reflect new scientific understandings. The Puget Sound *Science Update* shall: (a) describe the current scientific understanding of various physical attributes of Puget Sound; (b) serve as the scientific basis for the selection of environmental indicators measuring the health of Puget Sound; and (c) serve as the scientific basis for the status and trends of those environmental indicators. [RCW 90.71.290(3)]

State of the Sound – produced by the Partnership's Leadership Council by November 1 of odd-numbered years, to include: "comments by the [Science Panel] on progress in implementing the [*Action Agenda*], as well as findings arising from the assessment and monitoring program." (This report also includes a number of other materials, not delivered by the Partnership's science program, to report on implementation and funding of ecosystem recovery activities.) [RCW 90.71.370(3)]

Biennial Science Work Plan – developed by the Science Panel (with staff assistance provided by the Executive Director) and approved by the Leadership Council every biennium to "include, at a minimum: (a) identification of recommendations from scientific and technical reports relating to Puget Sound; (b) a description of the Puget Sound science-related activities being conducted by various entities in the region, including studies, models, monitoring, research, and other appropriate activities; (c) a description of whether the ongoing work addresses the recommendations and, if not, identification of necessary actions to fill gaps; (d) identification of specific biennial science work actions to be done over the course of the work plan, and how these actions address science needs in Puget Sound; and (e) recommendations for improvements to the ongoing science work in Puget Sound." [RCW 90.71.290(5)]

2. PUGET SOUND: UNIQUE ECOSYSTEM, UNIQUE COMMUNITY

Puget Sound protection and restoration efforts must be tailored to the unique characteristics and trends of this ecosystem. The summary provided below presents a brief overview of key attributes, noting the most important implications of these attributes for ecosystem protection and restoration of Puget Sound.

2.1 Marine and Nearshore

Puget Sound is the second largest estuary in the United States, with over 3,000 kilometers of shoreline (Shipman, 2008). Carved by retreating glaciers at the end of the last ice age 11,000-15,000 years ago (Kruckeberg, 1991), the fjord-like geomorphology of Puget Sound is somewhat unique in the United States (Figure 3). Most estuaries in this country are coastal plain or drowned river estuaries, lacking significant restrictions to the coastal ocean and lacking the great depths and strong tidal currents well known in Puget Sound. The average depth of Puget Sound is 62 meters with a maximum depth of 280 meters (Thomson, 1994).

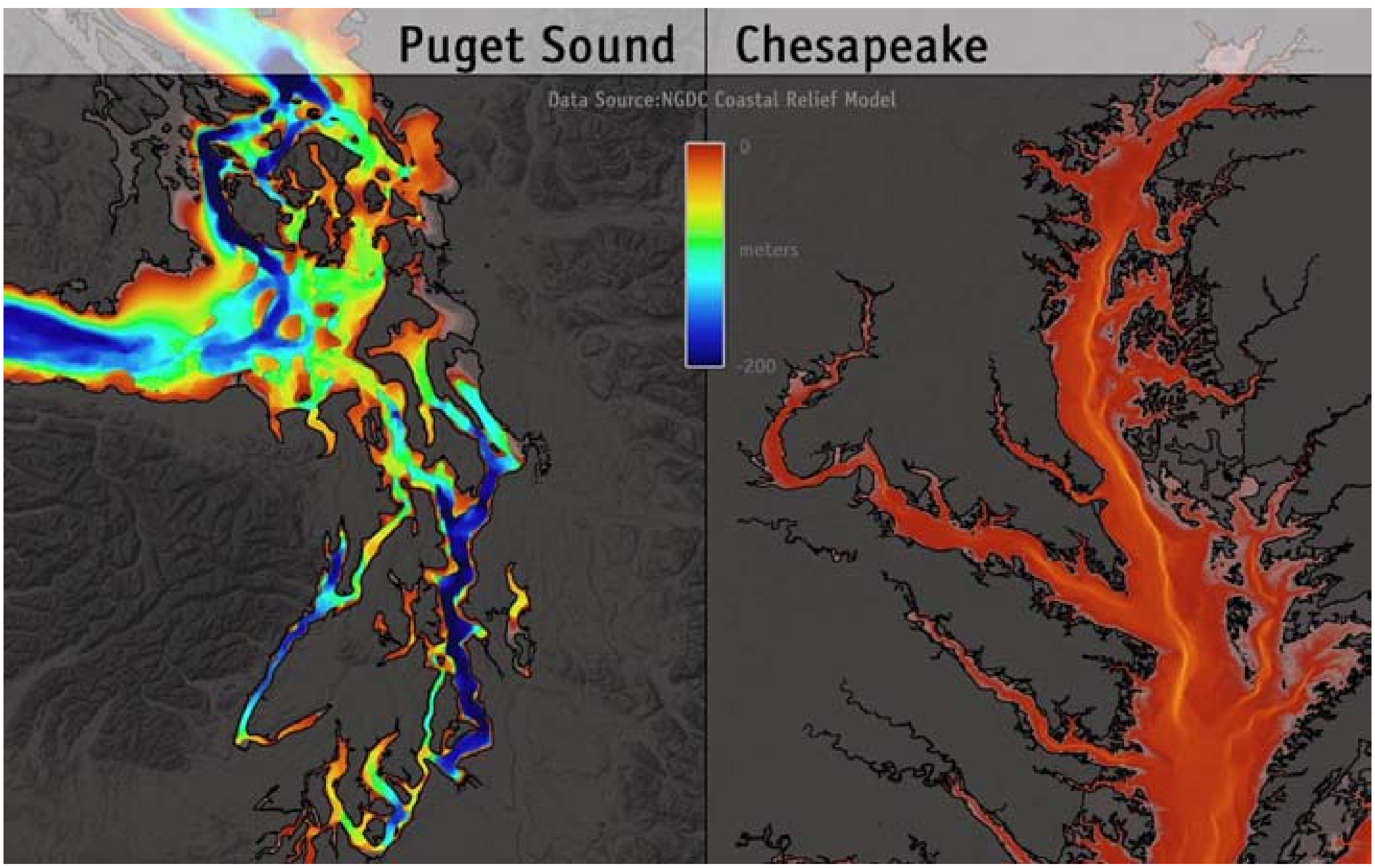

Figure 3: Comparative bathymetry for Puget Sound and Chesapeake Bay. Nearhshore euphotic zone depths, where seagrasses and submerged aquatic vegetation can typically grow would be less than 10-20 m (orange to red shading). Data source: National Geographic Data Center; Image courtesy UW Center for Environmental Visualization

Strong tidal exchanges drive much of the mixing and currents in Puget Sound while the net circulation of marine waters is a density-driven exchange between salt water from the Pacific Ocean that underlie and mix with fresh water runoff from the surrounding watershed (Cannon et al., 1990; Thomson, 1994). Less dense than seawater, the fresh water forms a surface layer that moves towards the ocean while the ocean water sinks deeper and moves toward the land. Puget Sound estuarine waters thus reflect input from, and the variation in, water from both oceanic and watershed sources. Additionally, Puget Sound is quite diverse within itself, e.g., strong gradients in salinity and circulation are evident from the Strait to South Sound; this has influenced the biota within and human impacts to the Sound.

Ridges or sills on the bottom of the Sound influence and disrupt the movement of the seawater. Near sills, the tidal pumping of water in and out of the Sound increases mixing of fresh and salt water and some of the out-flowing water returns (see Ruckelshaus and McClure, 2007). An implication of this mixing and return flow is that materials input to or suspended within Puget Sound waters can persist for a long time. Thus, planktonic (free-drifting) organisms in Puget Sound tend to have a long residence time before being exported out, which contributes to the high productivity of the Sound. However, this condition also promotes retention of contaminants, which can complicate cleanup efforts.

Characteristics of the incoming Pacific Ocean water such as temperature, salinity, oxygen, and nutrients vary on a seasonal and interannual basis. The largest variation is from the seasonal wind shifts between upwelling and downwelling conditions. Upwelled waters, typically observed in summer, are cold and salty, with lower oxygen and higher nutrient content (Hickey and Banas, 2003). This condition can be confused with, but also can compound effects of, human-related eutrophication. Upwelled waters are also CO2-rich, with implications for low pH and impacts from ocean acidification (Feely et al., 2008). Conditions in Puget Sound waters are strongly tied to climate on many scales, including seasonal, interannual, and long-term climate change.

The marine nearshore, at the nexus of the aquatic and terrestrial environments, provides habitat for many species, some for their entire life cycle and others for critical life stages. Many of these species are economically important (e.g., geoduck and other clam species, Pacific oyster, Dungeness crab) or ecologically important (e.g., sea grasses, kelp, forage fish). Nearshore habitats are created and maintained by processes involving transfers of sediment, nutrients, water, and other constituents. These attributes make the nearshore zone extremely important in maintaining ecosystem function in Puget Sound (Simenstad et al., 2006). It is also the location where much human development has occurred.

The glacial and tectonic processes that formed the Puget Sound basin resulted in a steep-sided estuary with a relatively narrow fringe of shallow, nearshore habitat. In contrast, most estuaries in the United States are shallow and support anchored vegetation over a much greater portion of the estuarine seabed (Figure 3). An implication of the morphology is that because nearshore habitat is relatively limited in spatial extent in this narrow, steep-sided estuary, removing or degrading a portion of the nearshore habitat in Puget Sound has a disproportionate impact on ecosystem sustainability compared to a shallow, flat estuary.

2.2 Watershed and Landscape

Fundamentally part of the Puget Sound ecosystem, the watershed, including its terrestrial landscape, of the Puget Sound Basin is geologically, physiographically, and biologically diverse. A variety of geological forces including plate tectonics, volcanism, and glaciation have dramatically shaped the physical conditions that help define the ecosystem. Soils of the region are derived from a complex mix of glacial and volcanic (lahar) deposits at lower elevations and in many of the major river valleys and volcanic and marine rocks at higher elevations. Puget Sound is part of the larger Puget Sound/Georgia Basin known as the Salish Sea (Figure 1). The U.S. watershed is much smaller than the Canadian watershed, which includes the Fraser River. This fact is generally important, to recognize that the scope of the ecosystem is beyond just Puget Sound, and specifically important, because of the large contribution of fresh water to the northern Puget Sound basin from the Fraser River drainage.

The climate of the Puget Sound region is the result of large–scale weather patterns superimposed upon the complex topography of the region, which ranges in elevation from sea level to over 4000 meters. In general, the Puget Sound has a temperate maritime climate from a persistent onshore flow of moisture laden air during the fall and winter months. Precipitation that falls over approximately 35,500 square kilometers of watershed area (Ruckelshaus and McClure, 2007) supplies over ten thousand rivers and streams. Characteristics of sub-watersheds, which make up the Puget Sound basin, can vary dramatically. This sharp topographic relief creates highly variable local-scale climate, and in combination with diverse soils types, results in a wide variety of environmental conditions across relatively small areas. This range of conditions supports high levels of biodiversity and other important biological phenomena.

The terrestrial landscape is dominated by some of the most productive coniferous forest communities in the world, where many of the conifer species reach their maximum growth potential for height and diameter (Franklin and Dyrness, 1988). Douglas-fir forest communities dominate the lowlands of Puget Sound by virtue of their tolerance to well drained, glacially-derived soils, while hemlock and true fir (genus Abies) communities dominate wetter areas in the foothills and more mountainous regions (Franklin and Dyrness, 1988). Interspersed among the forests, particularly at lower elevations, are other notable ecosystem such as prairie, madrone forest, oak woodland, and wetland and bog communities. While acknowledging the fact that many taxonomic groups have not been well-studied, the Center for Biological Diversity (2005) recognized about 7000 aquatic and terrestrial species that occur in the Puget basin including 4248 animals, 1504 plants, 851 fungi and 392 algae and ranks the Puget Sound basin as a “hot spot” for biodiversity nationally. The World Wildlife Fund includes the Puget Sound (along with the rest of the Northeast Pacific Coast) as one of 200 priority ecoregions for protecting biodiversity worldwide (Ricketts et al., 1999).

The Puget Sound also supports other globally outstanding biological phenomena. Lombard (2006) suggests that the Puget Sound is unique by virtue of both high salmon species richness and high natural salmon productivity, which is comparable to some of the most productive salmon areas along the Pacific Coast.

2.3 Human Health and Well-Being

The human population of Puget Sound reflects significant ethnic and racial diversity, including a rich Native American heritage with numerous tribes currently living throughout the region. People from around the world are drawn to the area because of the relatively high quality of life. The lands and water of Puget Sound provide a wide-ranging array of ecosystem goods and services including commercial fisheries and timber production, abundant and clean fresh water, and a variety of outdoor recreation activities.

The Puget Sound region serves as the major North American gateway for trade with Pacific Rim countries. It shares an international border with Canada. The ports of Seattle and Tacoma together handle the second highest number of container ships in the nation (PSAT, 2007). The diversified economy creates relative economic stability. The area has one of the largest shellfish producing regions in the U.S. and at the same time is the world center for software development and information technology. It hosts eight universities and numerous other colleges. The Puget Sound basin includes five of the top 10 fastest growing counties in the state of Washington (OFM, 2009).

More than 100 cities, 12 counties, 12 conservation districts, 12 local health jurisdictions, 28 local port districts, 3 regional governmental bodies, 22 tribes, 14 state agencies, and 9 federal agencies are active in Puget Sound protection and restoration. In addition, there are hundreds of special purpose districts for water, sewer, groundwater protection, drainage and irrigation. Each of the governmental bodies has its own set of responsibilities, and each plays a role in ecosystem management and recovery. Each jurisdiction also has a unique constituency and ability to raise money and make or implement policy. This dispersion of power is consistent with and reinforces Washington's long tradition of limiting the power of state government and deferring important decisions to local authorities (Lombard, 2006).

Historical Context

The Puget Sound ecosystem has already encountered significant change in its natural and social environments (Kruckeberg, 1991; Chasan, 1981). For generations, the Coast Salish peoples (Lushootseed) lived along the shores of the Salish Sea establishing villages on the shores and rivers where they developed a rich culture based on the bountiful resources in the region. Captain George Vancouver's explorations of the Pacific Northwest in 1792 were followed by fur traders and trappers, ship builders, loggers, and railroads. By the 1880s most of the old growth timber along the shorelines of Puget Sound had been logged off and settlers to the region were busy converting much of the Puget Sound lowlands into agricultural areas with navigable rivers, building transportation corridors, and harvesting fish and shellfish from the region (Montgomery, 2003). With the 20th century came industrialization, urban development, and rapid population growth. The human population of the central Puget Sound area had reached 1.5 million in 1960 and over 3.5 million in 2006 (PSRC, 2008).

2.4 Forces of Change

Two major drivers of change will have a pronounced influence on the future of the Puget Sound ecosystem. First, the population of people in living in the Puget Sound region will likely increase substantially by 2020 and beyond, adding some two million residents within the next 20 years (Ruckelshaus and McClure, 2007). Restoring and conserving Puget Sound resources will become more complicated and difficult through time because of the increasing intensity of human impacts. People will continue to build homes along the shore and in the lowlands, and communities will need to build roads and other infrastructure to support a growing population. Many functions, structure, and processes of the ecosystem will be under increased stress, particularly in Puget Sound lowlands where most of the new residents will live and work.

Second, climate change will affect Puget Sound in ways that are both predictable and unpredictable (Watson et al., 1998), with implications for the way we think about protection and restoration (Ruckelshaus and McClure, 2007). Natural climate variation, like El Niño-Southern Oscillation, Pacific Decadal Oscillation, droughts, and interannual variation in seasonal upwelling/down-welling cycles has documented effects on Puget Sound watersheds (CIG, 2007) and marine waters of (Moore et al., 2008; Newton et al., 2003). With climate change, many affects such as sea level rise, changes in the timing and magnitude of streams flows, and variation in oceanic conditions occur (Mote et al., 2005), propagating other related changes throughout the Puget Sound ecosystem. Human infrastructure, habitats, and biological communities will be influenced by these changes, with both positive and negative effects on current species and the chances for colonization by new species, including pathogens and parasites.

Managers must account for the effects of climate variability and change on natural resources and human communities, and adapt their management practices accordingly. Conditions and processes of concern affected by a changing climate include: Water temperature and levels, precipitation patterns, freshwater supply, saltwater intrusion, atmospheric extremes, occurrence of hypoxia and harmful algal blooms, ocean acidification, and changes in human disease risk.

3. SCIENCE FOR ECOSYSTEM RECOVERY

3.1 Past and Current Science

Our collective knowledge of Puget Sound comes from decades of investigations and observations conducted for diverse reasons by a wide variety of dedicated people and organizations. Indeed, the very ideas driving the formation of the Puget Sound Partnership came from this earlier work documenting the systematic decline in the condition of the Sound (Gelfenbaum et al., 2006; Ruckelshaus and McClure, 2007). However, much of the existing knowledge about the Puget Sound ecosystem comes from natural science studies with limited scope; this science has often resulted in a somewhat fragmented and non-uniform understanding of the Puget Sound ecosystem as a whole. Inter-collaboration with Canada is largely lacking, though scientific assessments in a 1994 British Columbia/Washington Symposium on the Marine Environment (Wilson et al. (Ed), 1994) and a British Columbia/Washington Marine Science Panel report (Copping et al., 1994) fueled some transboundary science-policy interactions through the mid-2000s, including development of Transboundary Ecosystem Indicators.

In addition, the social science component of ecosystem recovery has not been purposefully researched and or included in past Puget Sound management and recovery efforts. It is clear that social science must be part of science activities with an emphasis on discussing social and economic factors involved, expressing the balances in attributes of human well being, and addressing current limitations to land and resource ownership and governance.

In this Strategic Science Plan, we recognize there is need to synthesize existing and ongoing natural scientific work, to explicitly address lacking social science research, to identify the information needs of policy makers, and to foster the development of new science capacity with an emphasis on integration across disciplines.

3.2 The Constraint of Uncertainty

What will be the result of a given ecosystem management action? Often nobody knows. In spite of the rich history of scientific endeavor mentioned above, our understanding of ecosystem-scale effects of management, protection, and restoration is incomplete. In some cases, we have sufficient scientific information to advance recommendations for meeting recovery goals. In other cases, the information is known in the scientific community, but not well linked or appropriately analyzed to inform policy makers. Other issues have simply not been well studied. Some policy decisions can proceed despite relatively high scientific uncertainty, while others may require additional scientific understanding before decisions can be made. Where success is constrained by uncertainty, a robust, strategic science program for Puget Sound will help reduce uncertainty and enhance the Partnership's ability to succeed.

3.3 Adaptive Management to Reduce Uncertainty

"…coastal scientists must be prepared to contribute effectively to adaptive management as a means of dealing with uncertainty. There must be sufficient cross-training of scientists and managers to allow the communication of relevant knowledge and predictions effectively."

—National Research Council (1994)

Adaptive management is a cycle of exploration, action, evaluation, and adjustment that links science and policy. Murray and Marmorek (2004, with modification) describe the following elements of adaptive management, once ecosystem recovery objectives have been identified and agreed upon:

- explore alternative actions to achieve recovery objectives;
- predict outcomes explicitly (for example with process-based models);
- implement one or more of these actions, recognized as somewhat experimental and therefore designed with evaluation in mind;
- measure outcomes objectively with monitoring;
- adjust the actions after comparing the measured outcomes to the predicted outcomes

The *Action Agenda* recognizes adaptive management as a key aspect of performance management, noting that Puget Sound currently "lacks an adaptive management program that works all the way from monitoring to evaluation to altering management approaches or strategies." Adaptive management will provide a credible means by which scientists can inform policymakers and policymakers can delineate a process for accountability to the public for recovery results. The adaptive management process allows ecosystem recovery to move forward in the face of uncertainty by ensuring that actions are evaluated against goals and altered to optimize outcomes. Williams et al. (2007) make clear the scientific basis for adaptive management by describing it as "a comparison of hypothesis-based predictions against evidence."

Although many natural resource professionals believe they are already practicing adaptive management (Williams et al., 2007), implementing this approach as a guiding framework for Puget Sound recovery will challenge the status quo. It is therefore vitally important that participants understand what adaptive management is and is not (Van Cleve et al., 2004) and provide a thoughtful treatment of social science for both the process and outcomes of Puget Sound recovery. This understanding must cut across all Partnership groups, in support of the scientific and policy rigor necessary for success. For example, stakeholders must openly confront unresolved uncertainties, change-resistant institutions must alter practices in fundamental ways, and policy makers may be faced with choosing between objective scientific findings and the desires of particular interest groups. Adaptive management also requires a capacity investment beyond that of traditional natural resource management programs that includes conceptual frameworks and social science applications, such as acknowledged by Deitz et al. (2003), and investment in modeling, as a central organizing tool.

The Partnership has adopted a performance management system that fully supports adaptive management: the *Open Standards for the Practice of Conservation* (The Conservation Measures Partnership, 2007). As a framework for adaptive management, the *Open Standards* process provides a common means of understanding and supporting the critical role of science, and a means to identify where in the project management cycle science is relevant and needed. This framework also helps define recommendations for structured science/policy collaboration that clarify roles in implementing the *Open Standards* cycle.

4. SCIENCE IMPLEMENTATION: SIX KEY NEEDS

Based on legislative guidance to the Puget Sound Partnership, the Science Panel believes that a strategic science program should include the following elements:

1. A clear understanding by the Partnership about critical roles for science within an adaptive management framework and the *Open Standards* performance management system;
2. A means to support ongoing two-way engagement between science and policy participants to continually identify and prioritize information needs as the work proceeds;
3. Development of specific science capacities to assure that the program's science capabilities are responsive to identified needs;
4. Synthesis and communication of relevant scientific information to the right people at the right times to support ecosystem recovery outcomes;
5. Periodic peer review of science activities at both the project and programmatic levels, with responsive modifications to the science program as needed; and
6. Education and outreach to build public awareness of the value and roles of science, to foster consensus around what we know (thereby supporting public policy decisions) and to support learning about science and about Puget Sound.

Each of these elements is discussed below.

4.1 Science and Performance Management

4.1.1 Open Standards for the Practice of Conservation

The Partnership has adopted the *Open Standards* for the Practice of Conservation (Conservation Measures Partnership, 2007) as its tool to guide Puget Sound recovery. The *Open Standards for the Practice of Conservation* (*Open Standards*) were developed by a consortium of conservation organizations in an attempt to develop and promote common standards for the process of conservation and measuring conservation impact. The *Open Standards* present an idealized adaptive management process and a conceptual framework for good program design, implementation, monitoring, and evaluation and have become the common and accepted practice within the community of conservation practitioners, including The Nature Conservancy (Conservation Measures Partnership, 2007).

In adopting the *Open Standards* the Partnership has made a strong commitment to accountability for the protection and restoration of Puget Sound. The *Action Agenda* lays out a scope and vision for Puget Sound recovery, as well as the actions needed to achieve that recovery. The *Open Standards* process includes the following steps:

- Identify components of the ecosystem that are the focus of proposed recovery actions
- Develop conceptual models, termed "results chains," to link strategies to their intended effects on the focal components, accounting for known threats within the ecosystem
- Identify indicators that appropriately measure effects of actions on focal components or other elements of the result chains
- Design and implement the strategies arising from the conceptual models
- Design and implement a formal monitoring program incorporating the indicators
- Analyze, summarize and link monitoring and research findings back to action planning and implementation as an adaptive management loop

From a science perspective, the *Open Standards* process provides a general model for adaptive management, in which science has specific roles in designing, measuring, and enhancing the results of ecosystem recovery. By using this process, science activities are transparent; their relevance to management actions and policy is more formally defined and clearer to participants than they would be otherwise. In overall effect, both the actions of restoration or protection and the activities of science become less opportunistic, and more focused, mutually reinforcing, and effective. Rykiel et al. (2002) has summarized some of the principal science roles, as they feed into an adaptive management cycle like *Open Standards* (Figure 4). Conceptual models such as this offer the starting point and need to be developed for Puget Sound, as the Partnership's program evolves.

The *Open Standards* process produces results chains, which are essentially conceptual models that summarize how the scientific community's current understanding of certain elements of the ecosystem, including threats, drivers, and ecological cause-and-effect relationships relate to program manager and stakeholders interest in the ecosystem and recovery efforts. Another important use of such conceptual models is to document uncertainty by defining testable assumptions (National Ecological Assessment Team, 2006).

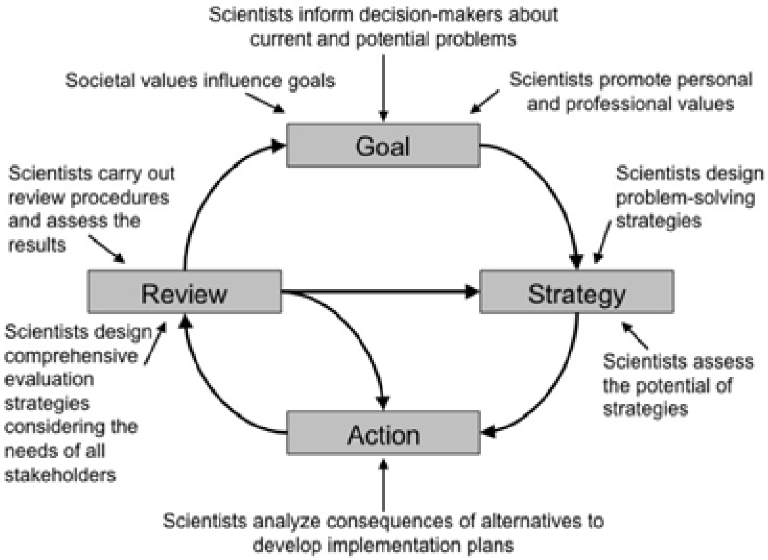

Figure 4: Role of science in the decision making process. Redrawn from Rykiel et al. (2002).

4.1.2 Integrated Ecosystem Assessment

The Science Panel has adopted Integrated Ecosystem Assessment (IEA) as a central organizing tool; it offers a means to model and test linkages among ecosystem threats, management activities, and environmental and social/economic goals (Levin et al., 2009). The Partnership has adopted the framework of IEA as the outline for its Puget Sound *Science Update*. The Science Panel endorses full development of the various elements of IEA for Puget Sound, as only some of these exist now. IEA is complementary to the *Open Standards* approach, because while IEA can help the Partnership to evaluate an understanding of science linkages, needs, etc., those results will inform the science-policy integration within the *Open Standards* forum and provide scientific context to identify preferred policy recommendations for recovery actions. Elements of the IEA discussed below include: (1) refining ecosystem goals and objectives, (2) conducting risk analyses, (3) developing and evaluating policy strategies, and (4) monitoring ecosystem status and effectiveness of actions.

1. Refine ecosystem goals and objectives: Refinement of ecosystem goals and objectives involves developing quantitative metrics, or the best set of ecosystem status indicators, including indicators of ecological and human dimensions that are currently available. Thresholds associated with certain levels of ecosystem function need to be identified and discussed with decision makers for possible use as targets and benchmarks against which restoration and protection activities are judged.

2. Conduct risk analyses: Risk analyses are conducted to improve the understanding of ecosystem status and to estimate how major threats, drivers and stressors affect the ecosystem. Developing qualitative and quantitative models that relate the most important threats, drivers and stressors to outputs of ecosystem goods and

services helps to identify the most imperiled parts of the system, and the likely causes of depressed status. IEA risk analysis – linking threats, drivers, pressures, states, impacts, responses (aka DPSIR; EEA, 2000) – provides a science basis for Partnership-adopted results chains that depict common understandings of how threats and contributing factors collectively affect current ecosystem states and which threats, drivers or pressures have the largest impact on focal components of the ecosystem. Risk assessment and model development requires mining existing data to improve understanding of historical conditions and stressors and to predict future trajectories. Model development also reveals important scientific knowledge gaps that, with policy input, can become the basis of exploratory and directed research activities (for example, defining cause-effect relationships). Exploratory studies help identify and explain threats, conditions and impacts not routinely evaluated, and can help ensure that the Partnership can respond to newly emerging issues.

3. Develop and evaluate policy strategies: Development and evaluation of policy strategies for meeting ecosystem goals and objectives is facilitated by qualitative and quantitative models that simulate the effects of management strategies and become the tools for predicting how policy decisions affect future ecosystem states (scenarios planning) based on a common set of assumptions. These scenarios can also address or highlight the most important set of scientific and socioeconomic uncertainties and effectively convey to policymakers what we know and do not know (Baker et al., 2004, Peterson et al., 2002).

4. Monitor ecosystem status and effectiveness of actions: Monitoring ecosystem status and management effectiveness is required to close the loop on adaptive management. Synthesis of monitoring information is a key component of the assessment stage of adaptive management. In addition, information from monitoring will support updates and refinements of risk analyses and may also support re-evaluation of indicators, thresholds, and benchmarks.

Integrated Ecosystem Assessment, if fully developed, can provide scientific support for Partnership performance management:

(1) Viability Analysis: What set of ecosystem components and attributes represent and encompass the Partnership's interests in a recovered Puget Sound ecosystem? What is the current status of Puget Sound? What is a viable Puget Sound? The IEA can highlight the indicators that most reflect changes in the functions of ecosystems and provide quantitative tools to forecast future conditions of the ecosystem, including human health and well-being. The IEA indicators process can also identify thresholds related to levels of ecosystem function. The IEA risk assessment summarizes current ecosystem conditions.

(2) What are the biggest threats to the Puget Sound ecosystem? The IEA risk assessment identifies quantitative relationships among the most important set of drivers and stressors, as well as the most at-risk ecosystem components (goods and services);

(3) What actions must we take to move from where we are today toward a healthy Puget Sound? Where should we start? The management strategy evaluation step provides estimates of the individual and cumulative effects of different strategies on ecosystem indicators. This evaluation can simulate different implementation scenarios to provide information to support decisions about optimal packages and sequences of actions.

4.2 Science/Policy Engagement

A viable linkage between science and policy depends upon effective, interactive communication among the individuals engaged in science and policy. *Open Standards* and the related adaptive management activities of the Partnership provide a beneficial framework within which to work, but the framework must be used in forums in which people can engage. To foster this engagement, groups that include participation from the Partnership across policy, management, and science are needed.

The development of such cross-Partnership work groups will help address science and policy issues by serving as a sounding board for initiatives, identifying key policy issues that need scientific and technical support, and facilitating open discussions on science and policy issues. This work will support better coordination among the Leadership Council, Ecosystem Coordination Board, and the Science Panel. Cross-Partnership work groups will be established to address:

1. Performance management framework
2. Threats to ecosystem health
3. Implementation strategies
4. Social and outreach strategies
5. Finance and funding strategies

The Science Panel envisions that these groups will enhance the discussions between scientists and decision makers to clarify key areas of uncertainty, define critical scientific and technical information needs, and focus efforts to achieve effective science-based decision support. To foster this engagement, working groups that include participation from policy, management, and science participants are needed.

The Science Panel recommends that communications issued by the Partnership be reviewed for technical accuracy, consistency, and disseminated throughout the organization and participating groups. While there may be differences of opinions and interpretations of the meaning of data and information from the ecosystem, the Panel strongly agrees that the underlying data and facts should be freely available, subject to scientific review, and that open and frank discussions will lead to workable solutions and testable hypothesis.

As these groups move forward, the Science Panel recommends engagement on issues that include science roles such as those identified in Figure 4. The cross-Partnership work groups will provide the charge and direction to and set priorities for Partnership activities that will be implemented by technical working groups and teams involving participating stakeholders and partners. For example, the "Implementation Strategies" group should explicitly move integrated human and ecological systems research into action.

These groups will bring scientists together with those responsible for implementing actions to assure integration of science appropriate to particular ecosystem restoration and protection actions. These groups should consider how best to interact with Canadian efforts for the Georgia Basin.

Through the actions of the cross-Partnership work groups, activities assigned in statute to the Science Panel—and generally, all science activities—will be coordinated throughout the Partnership via direct engagement and interaction. Specifically, the cross-Partnership work groups will:

- Collaborate on ways in which the Panel can assist in updating the *Action Agenda* [per RCW 90.71.280(1)(a)] and in developing biennial implementation strategies [per RCW 90.71.280(1)(d)].
- Assure that the identification and refinement of environmental indicators and benchmarks meets ecosystem recovery needs [consistent with July 2008 assignment in RCW 90.71.280(3)].
- Assure that *Biennial Science Work Plan*s are developed in full collaboration with, and are supportive of the overall strategic direction of the Partnership (e.g. the revisions of the *Action Agenda*, the activities of agencies consistent with implementation, and the needs for monitoring and its connection to policy refinement).

Within the larger Puget Sound/Salish Sea community, the Partnership also recognizes the value and importance of informal or ad hoc interactions with other entities engaged in protection and restoration of Puget Sound. This includes groups within Puget Sound as well as in Canada, including:

- Nearshore Science Team, advising the Puget Sound Nearshore Ecosystem Restoration Project and Estuary and Salmon Restoration Program;
- Regional Implementation Technical Team, advising the salmon recovery council;
- Puget Sound Human Dimensions Forum;

- Topical technical groups, such as the Toxics Loading Study Steering Committee advising the development of a regional toxics control strategy, and many others;
- Sub-regional technical committees, such as has been established by the Hood Canal Coordinating Council to support the evaluation and selection of corrective actions to address low dissolved oxygen problems in Hood Canal, and many others;
- Tribal, university, federal, state, and local scientific programs engaged in science planning and actions;
- Data and information dissemination groups, such as the Information Exchange Network, Northwest Association of Networked Ocean Observing Systems, and several others; and
- Transboundary scientific, technical, and management groups, such as the Transboundary Ecosystem Indicators group.

4.3 Science Capacity Building

A fundamentally sound science program for ecosystem recovery will need to achieve the ability to (1) analyze and synthesize existing information; (2) develop and apply innovative tools to understand structure and function and to predict and document change; (3) foster exploration and discovery; and (4) effectively communicate and integrate science; and (5) continually review the quality, depth, and breadth of our understanding in open, transparent, and constructive ways. The capacity to attain these scientific abilities relies on four cornerstone capabilities, below, which collectively are necessary to fulfill the expectations for science outlined in this plan. These are:

- **Monitoring:** critical to understand status and trends, for accountability and assessing effectiveness of ecosystem management, and to support ongoing insights within the adaptive management cycle
- **Modeling:** an essential element of the IEA and the *Open Standards* process for evaluation of ecosystem strategies, as well as to identify mechanistic processes, high priority uncertainties, and knowledge gaps;
- **Data Management:** required for effective access, use and archiving of data from a monitoring program and also to allow integration of data from diverse efforts of partners engaged in activities
- **Research:** the only means to understand cause and effect in a complex system, required to verify models, understand how the ecosystem works, and respond to emerging issues.

Puget Sound must sustain and enhance its scientific capacity in all four of these capabilities. These capabilities should be built across institutional sectors (e.g., federal, tribal, state, local, private, academic), as appropriate, to increase function for the goal of Puget Sound assessment and recovery.

The matrix below shows how these four capabilities directly address the requisite needs for scientific ability in the service of ecosystem recovery for Puget Sound. A critical aspect of this plan is the integration across research, monitoring, and modeling activities to summarize knowledge, propose hypotheses, and provide forecasting capabilities needed for effective natural resource management (Harris, 2002) within the Puget

Sound/Salish Sea ecosystem. This will require decision-based assessments, coordinated monitoring coupled with multidisciplinary models deployed at a variety of domains, scales, and applications (Roberts and Pelletier, 2008), integration of human and ecological trends, effective and flexible data management, and timely research conducted to verify model assumptions, measure key model parameters and rates, and inform the decision making process (Parker et al., 2002).

Our need for increased science capacity extends from the natural sciences to the social sciences. We also urgently need tools that better integrate human and ecological trends. Simply adding people to ecological models as stressors is not sufficient. Studying coupled human-natural systems requires us to recognize the effects of humans on the environment (how human stressors influence ecosystem processes) and effects of environmental change and management responses on human behavior, as well as human health and well-being.

The Puget Sound Partnership has laid the foundation for the defining its science needs by establishing their six goals for Puget Sound ecosystem recovery (section 1.2). Attaining the science to achieve these goals, the underpinning of this document, will require both the **application of existing knowledge** and **aggressive exploration of key unknowns** relevant to specific ecosystem protection, restoration and recovery actions. The Appendix to this document provides specific examples of both types of these science needs for each of the six Partnership's goals. All of these science needs, however, will be served by enhanced capacity in monitoring, modeling, data management and research, which is discussed in this section in terms of approaches, needs, and recommendations for enhancing these four capabilities.

Science capacity in monitoring, modeling, data management and research already exists to various degrees in diverse Puget Sound organizations, but not at the scale, nor with the degree of integration needed to meet Partnership goals. Without the development of new natural and social science capacity, the scientific abilities identified in this plan cannot be fully achieved. In addition, strong coordination and cross-communication is necessary to assure that these science capabilities work in a mutually supportive, integrated fashion.

Science Capacity Necessary to Support the Partnership's *Action Agenda*

		Monitoring	Modeling	Data Management	Research
Analysis & Synthesis	Organizing questions	Provides context for assessment questions, delivers data on indicators Frame and scope for assessment questions and indicators	Explores questions via scenario testing Scope of strategic interests in modeling capabilities	Unites available data to address question Scope of interests in scientific data and information	Leads to new questions General frame for specific research questions
	Intellectual & technical capacity	Staff, governing committees & work groups develop coordinated designs and implementation plans Funding for "focused, sustained, high-quality observations"	Staff, peer networks and/or work groups coordinate efforts Competitive award of funding for top priority investigations	Information managers to interact with work groups & peer networks Funding for hardware & software	Staff and advisory committees identify top priority research topics & integrate among projects Competitive award of funding for top priority investigations
	Integration & synthesis	Coordinated synthesis of findings in program reports & PS *Science Update*	Coordinated synthesis of findings in PS *Science Update*; integration with monitoring and research programs	Web-based data locators and portals for accessing and compiling data from multiple sources	Coordinated synthesis of findings in PS *Science Update* and institutional analyses
Innovative Tools		Implements new observational and analytical technologies to improve quality or efficiency of observations and synthesis Utilizes citizen networks and other cost-effective approaches	Develops regional capabilities to simulate ecosystem behavior and to simulate and support decisions related to human drivers and management responses e.g., IEA, futures analysis	Develops and adopts new technologies to improve flows, timeliness, stability, etc.	Develops new observational and analytical technologies; promotes adoption of new technologies in PS region research
Exploration & Discovery		Discoveries published & shared in peer networks Program adapts in response to discoveries from across science program	Discoveries published & shared in peer networks Models are adapted in response to discoveries across science program	System facilitates data discovery and comparative analyses	Program invests in exploratory, anticipatory investigations, fellowship program for new ideas Discoveries drive adaptation of recovery efforts

	Monitoring	Modeling	Data Management	Research
Effective Communication and Peer Review	Program findings are translated to effectively inform and educate communities and leaders regionally, transboundary, and nationally through products (*State of the Sound*, PS *Science Update*, PS-GB conference) and via PSP web. Information used for Science-Policy advisory groups, outreach and education	Models are used as tools for decision support tools and visualization; findings are communicated in PS *Science Update*, PSGB conference, etc. Information used for Science-Policy advisory groups, outreach and education	Data, analyzed & synthesized information, and visualizations available via web Information used for Science-Policy advisory groups, outreach and education	Findings are communicated in PS *Science Update*, PSGB conferences, workshops, guidance, etc. Information used for Science-Policy advisory groups, outreach and education

4.3.1 Monitoring

"…Environmental managers need to consider the risks and uncertainties inherent in most actions. Risk-free decision making is not possible. When well developed, applied, and used, environment monitoring can help quantify the magnitude of uncertainty, thereby reducing but not eliminating uncertainty in decision making."

—National Research Council (1990)

Monitoring allows quantification of ecosystem status across spatial and temporal scales and is indispensible for achieving the goals of the Partnership. Although it requires long-term stable funding to achieve, without monitoring, there can be no performance accountability, and the opportunities to make improvements in ecosystem recovery are constrained. Because of its critical importance, the Partnership will develop and implement a coordinated regional monitoring program to inform the adaptive management process and support decisions about future ecosystem recovery and information needs. The monitoring program will inform policy choices, balance needs among ecosystem components, address issues of geospatial scale, facilitate coordination among existing monitoring and assessment efforts, and incorporate high standards for experimental design, statistical power, and support for indicator tracking.

The Partnership must assure that monitoring design and implementation account for the various ecosystem components, consistent with conceptual modeling and strategy development within the Partnership's performance management system. An effective monitoring strategy must include coordination with Canada. Restoration and protection strategies based on IEA modeling within the *Open Standards* process require particular data, and these data must be spatially coordinated to support accountability and Sound-wide modeling goals. Monitoring must be designed with different uses in mind, such as status and trends, and effectiveness of restoration or protection actions.

The Partnership must assure that monitoring is closely coordinated with research so that monitoring strategies use the best technologies available for accurate assessments. The research community will help identify where changes need to be made to monitoring, as models are validated and improved with collected data.

The Science Panel will address monitoring through collaboration in the cross-Partnership work groups and provide overall criteria and direction for monitoring development, working with Partnership's Monitoring Program Manager and staff. This will permit scientific input into priority setting for limited available funds. It is envisioned that implementation of the monitoring capability will involve a steering committee and topic-specific work groups.

In order to build Puget Sound's monitoring capacity, tasks the Science Panel recommends, and will participate with Partnership leadership and staff to oversee, include:

- In coordination with cross-Partnership work groups, convene a steering committee to develop assessment questions to be addressed by the monitoring and assessment program. The coordinated program will use Science Panel endorsed criteria to address the goals of monitoring, and to develop guidelines accounting for effectiveness studies, geospatial scales needed, and design of data collection. The program will also assure that monitoring is designed to address indicators adopted by the Partnership, that monitoring programs Sound-wide are developed collaboratively, and that monitoring is closely coordinated with identification of critical research questions.
- Convene topic-specific technical working groups to implement the guidance from the coordinated monitoring and assessment program steering committee. Working groups will include key scientists from agencies, universities, and tribes to create and improve selection of variables, experimental designs, methods, protocols, data handling, and quality assurance/quality control.
- Facilitate the broadest public use of and contribution to monitoring results. Through cross-Partnership work groups and other science-policy collaboration, assure that monitoring findings serve as feedback in ecosystem recovery strategies; assure that stakeholders are engaged in the process of data collection and data use, and promote the value of citizen monitoring networks.
- Recommend enhancements to monitoring by developing and evaluating different scenarios for where, when, and how to improve and/or expand monitoring of ecosystem conditions, drivers, and pressures. Recommendations can include assessments to determine baseline conditions as well as new monitoring of emerging issues.

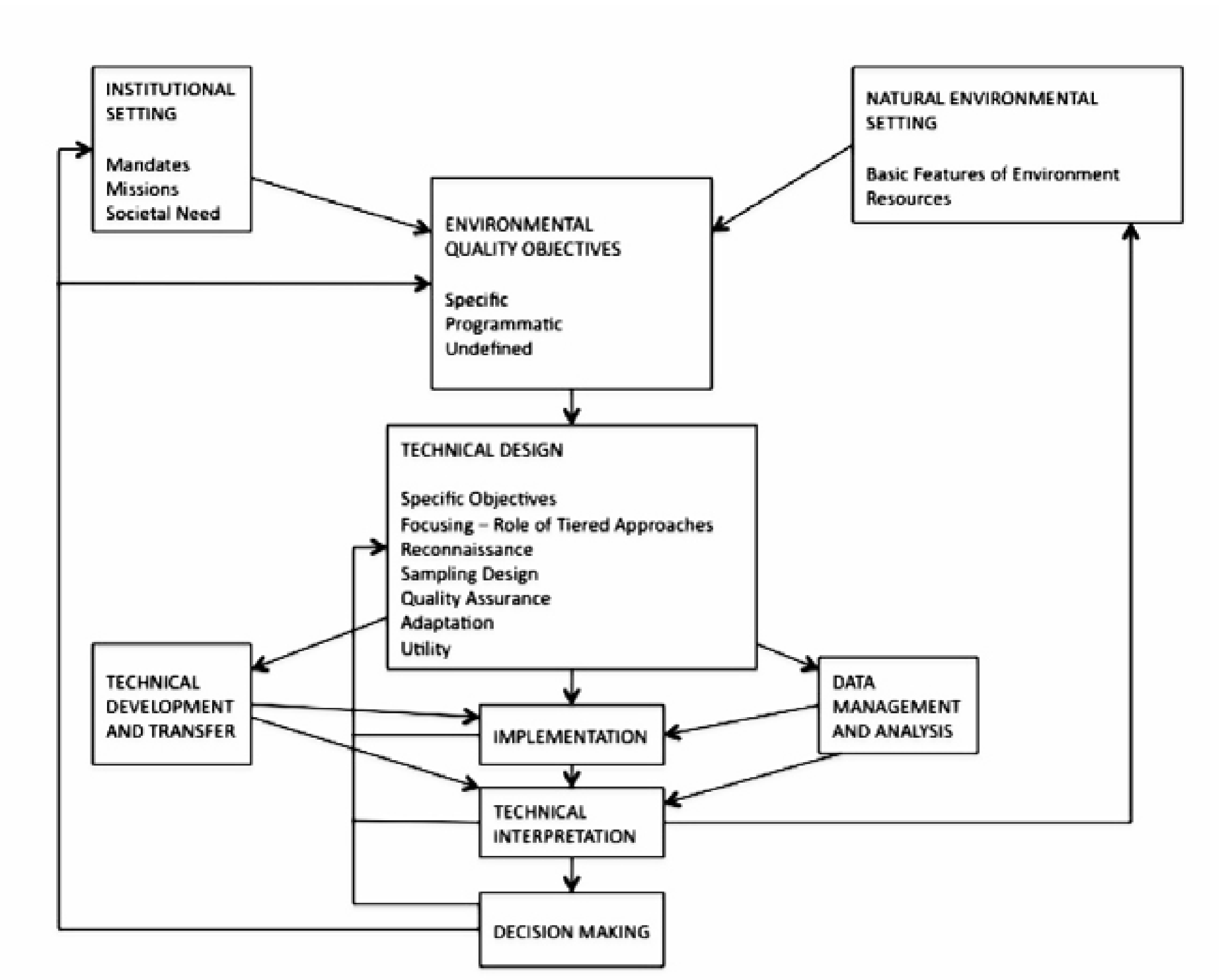

Figure 5: Conceptual design and principal components for an ecosystem monitoring system (Reprinted with permission from National Research Council (1990), courtesy of the National Academies Press, Washington, D.C.).

4.3.2 Modeling

"…models are increasingly essential for synthesizing and applying current knowledge about species and habitats. Through models, [scientists] document uncertainties as testable assumptions, creating a direct link between management and research."

—National Ecological Assessment Team (2006)

Management actions must be developed on the basis of the best scientific knowledge about ecological functions (National Research Council, 1993). Achieving *Action Agenda* performance goals under the Partnership's performance management system requires suites of models that predict how drivers/stressors (e.g., human population size, land-use, climate) impact the ecosystem. Ecological models that incorporate human dimensions then become the basis for enhancement of ecosystem services and human well-being.

Tools to describe future conditions of the Puget Sound should integrate what is known about structure, function, and process with estimates of future drivers. While the Puget Sound will continue to change, the exact trajectory it will follow is not precisely known. How effectively we might select policies that steer us toward desirable ecosystem conditions, requires ecosystem-scale prediction tools. The Partnership science program must support development and implementation of quantitative tools for future analyses, in which various scenarios can be systematically evaluated.

Models are theoretical constructs and rarely can these tools replicate reality completely, especially in their first incarnation. Without ongoing scientific research and comprehensive monitoring, inaccurate or imprecise models will remain so. Science is needed to verify assumptions that drive model processes, validate hypothesized cause-effect relationships, test predictions, and to develop conceptual models into quantitative forecasting tools. Data are needed to validate and calibrate model output as well as to provide critical boundary conditions.

The process of modeling, whether building conceptual models or running complex numerical quantitative models, is inherently collaborative. A solid conceptual model is indispensible for development of consensus. Frequently, alternative explanations exist for how the ecosystem works; modeling forces a discussion and reconciliation of assumptions about ecological processes and human drivers, and therefore how well protection or restoration actions will work. Modeling needs feed directly towards requirements for monitoring data. Modeling can fill in spatial content where no data exist. Additionally, modeling can assist in supporting decisions, e.g., by allowing approximations of future or unmeasured conditions as well as identifying key uncertainties. The use of models to quantify uncertainty leads directly to identification of critical research that is directly relevant to Partnership recovery goals.

Modeling also supports understanding and interaction with the public about how human behavior can affect tradeoffs in ecosystem goods and services. The process of using models in ecosystem analysis should include the identification of monitoring indicators, ecosystem thresholds or breakpoints, and information gaps, as well as quantifying uncertainty. In particular, new models that integrate across natural, economic, social, and political systems are required. This will catalyze significant interactions among a wide variety of technical and policy communities, which in itself will drive innovative thinking about restoration and protection.

In order to build Puget Sound's modeling capacity, tasks the Science Panel recommends, and will participate with Partnership leadership and staff to oversee, are to:

- Engage modeling directly in the Partnership's recovery strategy, starting with *Open Standards* results chain development through science-policy collaboration. With results chains serving as a general, but un-validated framework, the Science Panel will identify specific modeling needs, such as IEA modeling and the development of projects via requests for proposals (RFPs) to support development and testing of model elements that serve as critical components of *Open Standards* conceptualization and Partnership strategy development.

- Enhance ecosystem-scale modeling, by facilitating coordination and integration of the many existing groups and efforts in the region. Current modeling activities are widely diverse including climate, ecosystem, watershed restoration, salmon recovery, hydrological, landscape, and human valuation. Needed is better coordination within and among these components of ecosystem modeling and linking these groups with what the needs of the Partnership are, via RFPs. The Puget Sound Marine Environmental Modeling Consortium is one example of a peer network, which has demonstrated utility of bringing together modeling capabilities with coordination and synergies to members.
- Strengthen modeling efforts identified as high priority for the IEA, by soliciting and utilizing information and capabilities from existing ecosystem-scale modeling groups within the region. To do this will require a forum or otherwise coordinated capability.
- Address modeling needs other than those directly arising from strategy development under *Open Standards*, such as the need for future scenario modeling (identifying the goals and milestones for this work, and describing the roles and relationships of collaborators in carrying the work forward in increments). This effort will include assessment of the capacity needed for modeling biogeochemical and physical processes, social and economic systems, as well as decision support models and tools.

4.3.3 Data management

"…Data management activities are as important to the success of monitoring programs as the collection of data…Data should not be collected unless a commitment is made at the outset that support for analysis activities will be commensurate with that of data collection."

—National Research Council (1990)

The Partnership and other groups involved in the Puget Sound ecosystem are already making substantial investments in data collection to support decision-making and enable effectiveness and accountability. The Partnership must have a data management system that provides access to data from current and historic monitoring, assessments, and research studies. All these data have the potential to provide important contributions to understanding the ecological condition of the Puget Sound, especially if the data can be integrated and made available to support site-specific to regional scale analyses.

Being able to analyze complex, incomplete and often contradictory data and information is critical. Many individuals, groups, organizations, and agencies in the Puget Sound region collect data, make observations, and develop analysis tools. The Partnership should lead the integration (gathering together) and synthesis (developing coherent and consistent interpretations) of this information. This requires the capacity to address several types of organizing questions.

Data uses include everything from long-term trend analysis to real-time decision support. Therefore the data management system must be flexible; capable of accessing data from various organizations and agencies; proficient at cataloging and archiving critical data and information to document Partnership activities; and accessible to a wide-user community consisting of managers, researchers, stakeholders, and the public. Data management must also encompass the capability to analyze and synthesize (convert data to meaningful information) for particular high priority data uses.

The Partnership envisions a data architecture that provides functions for users to discover, access, and visualize data that are maintained in dispersed information management systems that are intuitive and easy to access and manipulate, similar to that being developed for the Northwest Association of Networked Ocean Observing System (Risien et al., 2009), with wide access to scientists, managers, stakeholders and the general public, not only in the US but also in Canada. The data management system utilized by the Partnership should take advantage of the existing data repositories and clearinghouses already established within the Puget Sound region and work to provide connectivity that would foster and enhance a collaborative user network capable of responding to a wide variety of information needs. The system must be designed around the data sets that are most important, since a single system to manage all Puget Sound data is not warranted.

Data management will be geared to producing Partnership science products like *State of the Sound* and the *Puget Sound Science Update* (e.g., report cards and indicators results and trends). Just like reporting and quality assurance, data management and processing should be a required component of all work funded by the Partnership.

In order to build Puget Sound's data management capacity, tasks the Science Panel recommends, and will participate with Partnership leadership and staff to oversee, are to:

- Establish a data and information management working group to coordinate data related activities, identify opportunities and obstacles for data management, and develop a data management implementation plan for the Partnership.
- Through the working group, carry out an assessment of Partnership's needs for information access and management. For example, determine the Partnership's needs for information reporting (e.g., *State of the Sound*) based on data collected for indicators. Particularly, determine what routine analyses will be required, and how findings can best be presented.
- Oversee conceptual design for the data management system. This should occur concurrently with establishing the experimental design for monitoring, so that the system directly supports the goals of monitoring and the necessary conversion of data into critically needed information for reporting.
- Assure that development of the data management system is coordinated with needs identified by the modeling, monitoring, and research working groups, and direct that data exchange capabilities exist for key information flow needs (for example the use of monitoring data needed both for indicator reporting and for model prediction testing).
- Require a capability to make indicator data and other assessment information available and accessible to a diverse user community consisting of managers, researchers, stakeholders, and the general public.

4.3.4 Research

"We must carry out the necessary fundamental research and develop appropriate technologies to detect and correct environmental problems, to manage natural resources, and to sustain the environment."

—Clinton and Gore, 1994

Monitoring and model development efforts will reveal knowledge gaps. These gaps are due to inadequate understanding of ecosystem processes or a lack of understanding of emerging issues such as climate change. To fill these gaps, the Science Program must support new research that explores relevant questions to better define links between critical ecosystem components, management actions, and human behavioral response. Research is a fundamental element in the development and testing of predictive models and supports interpretation and synthesis of monitoring data and model outputs (National Research Council, 1990). Research helps test competing hypotheses about ecosystem cause and effect relationships. Another element of research is the development of tools for emerging observational methods based on newly evolving technology.

Research is sometimes viewed as "basic" or "applied," and frequently the perception of basic research includes concern that this kind of science is irrelevant to immediate needs of managers and policy makers. The Science Panel advocates a view of research that recognizes "tactical" and "strategic" research. Tactical investigations might be closely tied to a specific problem, for example determining nutrient inputs to a portion of Puget Sound. Tactical research might be relatively short term, and highly focused. Strategic research, alternatively, might address larger questions, particularly concerning ecosystem processes; sometimes requiring multi-year data sets and tests of multiple hypotheses. Both kinds of research are necessary in a balanced program. The test of the value of research is not whether it is basic or applied, rather whether it is relevant to Puget Sound ecosystem recovery needs. Further, that research can and should be conducted regardless of institutional affiliations. Research involving scientists from different sectors often has an advantage in the breadth of perspectives the participants provide.

Examples of critical questions that research can help address include:

1. How is the Puget Sound natural system structured and how does it work? We cannot manage a complex system that we don't understand. Just as medical professionals must first understand the anatomy (how is it structured?) and physiology (how does it work?) of healthy individuals before addressing injury and disease, environmental scientists must describe linkages among ecosystem components and quantify how materials (water, biota, pollutants) and energy move through the Puget Sound ecosystem. In addition, scientists must be aware of the issue of land ownership (i.e., public vs. private) and land uses in Puget Sound and how that intersects with the science and research needs.

2. How can Puget Sound residents, who benefit from and impact the natural system in a wide variety of ways, define a healthy, functioning natural system? Research needs extend well beyond the natural sciences, to address critical social science questions. Because of the significant diversity in objectives, perceptions and values of Puget Sound regional residents and visitors, determining what defines a healthy functioning natural system will be challenging. To one person (living on a hillside overlooking the Sound with no other direct contact with it) the Sound may appear healthy just as it is. To another person (actively engaged in shellfish harvest) a healthy Sound could be one in which shellfish closures due to pollutant loadings do not occur. In order for the Partnership to proceed on an effective track, research is necessary to better understand how people use and relate to the Sound, what incentives lead to stewardship and behaviors to mitigate ecosystem impact, and what tradeoffs people are willing to make if faced with opposing perspectives of what needs to be done to restore the Puget Sound.

3. How has the Puget Sound natural system evolved in response to natural and human-induced stressors? How will the Puget Sound continue to change and what will it look like in 2020? The Puget Sound ecosystem is not static, and will continue to change driven by both natural and human influences. Identifying the drivers that caused prior changes and understanding previous rates of change allow us to build credible predictive capabilities. Unless we project the most likely conditions in 2020, and beyond, it is not possible to develop effective assessment and ecosystem recovery strategies. These analyses must address not only natural sciences, but also economics, sociology, and institutional analysis and use all available information to project future conditions, including (1) possible future states where thresholds for multiple objectives are simultaneously met; (2) ecosystem services that may be provided under alternative futures; and (3) the major trade-offs in objectives or ecosystem services under potential future states.

4. What indicators of ecosystem function and human well-being best track Partnership progress towards goals? Indicators must accurately reflect the key properties of the ecosystem, and be linked through conceptual models to external stresses. For example, levels of chemical contaminants in sediments is only a useful indicator if we understand how and at what threshold level this stressor harms either valued individual species or ecosystem function, or negatively impacts human uses. In both upland and aquatic ecosystems, ecologists have made progress in developing 'lumped' indicators of ecosystem resilience and stability. Others are refining specific processes within conceptual models, providing needed linkages within this complex ecosystem. Applying these indicators and models to the Puget Sound recovery is critical to assessing progress. In short, development of 'indicators' should continue to drive the discussion of what is valued and how individual processes work together to provide ecosystem services.

5. What are the individual and cumulative effects of restoration and protection actions? The restoration and protection of the Puget Sound is inherently defined by the complex connections and interactions within and between the natural, social, economic, and political systems. Yet, to date a piecemeal approach has been taken, as illustrated by single-species recovery plans. Restoration projects are often at a local scale, and it is unclear how these impact larger spatial regions. We need to better understand how deliberate actions will influence the future conditions in the ecosystem; how effective each contemplated action will likely be on the desired outcome; and what will be the effects on the regional economy and on individual quality of life and health. Actions may be synergistic and mutually beneficial, or may work at cross purposes.

It will be impossible and undesirable for the Partnership or the Science Panel to develop a comprehensive research strategy that incorporates all regional scientific research. It is tenable that the Science Panel and Partnership can work with other groups in the region to help establish research priorities. Multiple independent scientists and organizations can then use these priorities to seek funding and conduct the work, the results of which will benefit the overall process of designing a healthy Puget Sound. In addition to helping to set regional research priorities, research capacity building tasks that the Science Panel recommends, and will participate with Partnership leadership and staff to oversee include:

- Identify and rank specific research priorities in the *Biennial Science Work Plan* for effective use of limited funding; this should happen through the science/policy collaborations discussed in this plan and build capacity across scientific community sectors.
- Develop a process for issuing Requests for Proposals (RFPs) reflecting emerging research needs, commensurate with available funding. At the direction of the Science Panel, Partnership staff will manage the processes for competing and awarding contracts.

Coordination of these tasks will be the responsibility of the Partnership's science staff, advised by the Science Panel, and will be achieved using the methods explained in section 4.2.

4.4 Synthesis and Key Products

The Partnership's science program should include the means to integrate and synthesize information to communicate a scientific understanding of the Puget Sound ecosystem to the Partnership, its stakeholders and citizens. In terms of products, this effort will focus on producing the *Puget Sound Science Update*, incorporating findings from the monitoring and assessment program in Partnership's *State of the Sound* reports, and producing other materials or convening workshops and conferences as needed. These products will then be used to identify needed policy or management actions, essential information gaps and help direct future ecosystem recovery efforts.

4.4.1 Puget Sound Science Update

The *Puget Sound Science Update* will be the state-of-the-science document supporting the work of the Partnership to restore and protect the Puget Sound ecosystem. It will be a comprehensive reporting and analysis of Puget Sound science, synthesized to support the science-based ecosystem-scale recovery of Puget Sound. The scope of the document includes scientific understanding of the lands, waters, and human social systems within the Puget Sound basin.

The content of the *Puget Sound Science Update* will be developed following the rigorous peer-review process used by the Intergovernmental Panel on Climate Change (IPCC), in which small author groups produce draft assessment reports synthesizing existing, peer-reviewed scientific information on specific topics identified by policy leaders. The *Puget Sound Science Update* will be published on-line following a wiki model, in which further refinements and expansion occur via a moderated dialog.

Applying an IPCC-type process to develop the *Puget Sound Science Update* should help engage a broad community of scientists in summarizing what is known, highlight areas of key uncertainties, and reduce opportunities for 'dueling science' underpinning challenging policy decisions the Partnership will make. The wiki publication model is designed to shorten production time, improve transparency and participation, enhance access to a broad audience, and facilitate revisions and expansions.

4.4.2 State of the Sound

The Partnership's *State of the Sound* report will be produced every two years (November 1 of odd-number years) and will present the findings of the monitoring and assessment program. This provides an opportunity to present information on the status and trends of ecosystem conditions and factors affecting ecosystem conditions using high-level indicators adopted by the Partnership. Indicators included in these reports will be selected through science-policy interaction, as discussed above, and will (partially) rely on data collection from the monitoring program, discussed in section 4.3.1.

4.4.3 Conferences and Workshops

The Partnership may also advance synthesis and communication by convening conferences or workshops to facilitate exchange of information and collaboration across science disciplines, geographies, jurisdictions, and recovery programs/projects. This might include broad conferences similar to Puget Sound-Georgia Basin Research Conferences or more focused symposia or workshops to develop syntheses on specific topics. Continued international coordination with Canada on such conferences is recommended.

4.5 Peer Review

Peer review is a fundamental tenet of good science. Independent peer review is the accepted tool for rigorous, impartial evaluation of scholarly manuscripts, research proposals, complex institutional research programs, academic faculty and federal agency science staff promotions and most other decisions affecting how science is conducted.

Restoration and protection of Puget Sound ecosystems under the oversight of the Partnership will involve extensive assessment of scientific direction and priorities, and scrutiny of background science and restoration performance; all of these aspects demand some level and type of peer review. Peer review will help to ensure that the "best available science" (Van Cleve et al., 2004) is pursued. Moreover, peer review will help to avoid potential conflicts of interest and minimize the influence of other, subjective factors, such as funding sources or undue influence of special interest groups.

For the above reasons, the integrity and effectiveness of the Partnership's scientific investigations will require that peer review be applied to science activities ranging from individual research proposals to long-term review of the entire science program.

4.5.1 Research Proposal and Product Review

Peer review of research proposals and science products is fundamental to maintaining high science quality. For proposals, difficult decisions about research funding allocation and dissemination of results can be objectively based on scientific validity, originality, and importance and relevance. For products, peer review ensures scientific credibility; this kind of peer review has a long history of effectiveness, competence, usefulness, and security. Partnership products with science underpinnings also require scientific review.

To prevent real or perceived conflict of interest, reviewers would be limited to individuals dissociated from the activity or product being reviewed. However, the expertise of reviewers should fit the proposal or product topic.

While most reviews would follow the traditional scientific peer review model (e.g., the processes used to select proposals or publish manuscripts), other reviews might follow alternative designs. For example, the Science Panel recommends use of the IPCC review model for the Puget Sound *Science Update*. The IPCC uses a small working group of authors to prepare the Assessment Reports, which are published every five years or so. Authors follow an outline provided by the IPCC and their work is then subject to several rounds of intensive peer-review before the Assessment Report is completed. Criteria for data or analyses that can be included are set in advance, and not limited to peer-reviewed journal articles (e.g., assessment data and evaluations can be included, as long as they meet peer review standards). Such a peer review process for the Puget Sound *Science Update* would elevate the quality of the document, and broaden its scope to include priority science reporting needs defined by the Partnership. This type of peer review would ensure easy access to major scientific conclusions and elevate the quality of the science by filtering it through a rigorous but very collaborative peer review process.

To support peer review, written guidance should be developed by the Partnership to assure consistency and quality of peer reviews. Existing peer review programs for various organizations could serve as a starting point for development of the guidance. Draft guidance prepared by Partnership staff should be reviewed and approved by the Science Panel.

4.5.2 Science Program Review

Designing a complex ecosystem restoration and protection program such as the Puget Sound Partnership is a difficult task with seemingly endless alternatives to integrating and balancing science, management, governance and evaluation (Van Cleve et al., 2004). Periodic review of the entirety of the Partnership's science program is critically important to assure the best possible uses for science to support ecosystem recovery.

Balanced outside advice supports pivotal strategic program decisions and helps maintain societal accountability for uses of scientific knowledge. That is, the review transparently affirms the validity of science activities—or, just as constructively, recommends improvements—in the context of the entire Puget Sound community. Such a review could also help dispel internal controversy and support more efficient and effective public policy development.

An independent review of the Partnership's progress in ecosystem recovery is authorized in Washington statute (RCW 90.71.380). Statute specifies that this review would be conducted by the Washington State Academy of Sciences (WSAS) and include, but not be limited to, a determination of the extent to which implementation is making progress toward ecosystem recovery goals and a determination of whether the ecosystem indicators and benchmarks adopted by the Partnership accurately measure and reflect progress toward ecosystem recovery goals.

The Science Panel recommends that the WSAS review occur on a periodic basis (e.g. every three or every five years) and provide a review the entirety of the Partnership's science program. The Panel envisions that reviewers would have science backgrounds, but their perspectiv e should be programmatic, to ensure that science is most effectively deployed and managed toward the goals of the Partnership. The Science Panel recommends that WSAS's review panel include individuals who have some experience in large, ecosystem-scale recovery in other regions (as might be represented by key individuals involved in the case study programs reviewed in Van Cleve et al., 2004).

4.6 Education and Outreach

The goal of restoring and protecting Puget Sound requires a community effort of citizens, governments, tribes, scientists, and business working cooperatively to rank ecosystem recovery needs, leverage resources, and develop a cohesive plan that will hold people and organizations accountable for the outcomes of actions. Technological advancement, leadership in the sciences, and effective conservation and management of coastal and marine resources are not the only vital components necessary to restoring the health of Puget Sound. Equally important is an informed and empowered society. Success of a healthy Puget Sound among this diverse group of stakeholders (including local, state and federal resource managers and policy decision makers, the general public, and those affected directly by management strategies) will require an outreach and education strategy that optimizes gathering and dissemination of information and effective communication. The Science Panel recognizes the ongoing work of PSP education and outreach staff and will work with and make recommendations as needed including empirical inquiry about the extent, effectiveness and consequences of outreach and science communication in society.

Outreach and education are defined in many different ways. In the context of this plan, **outreach** is considered to be any information, activity, or program that is designed to translate scientific knowledge, build awareness, develop relationships, or inspire individuals to pursue further learning opportunities, while **education** is considered to be any information, activity, or program that is designed to increase learning. Importantly, learning encompasses both knowledge and skills development.

A number of recent national and regional efforts, including the Partnership's *Action Agenda*, the U.S. O ceans and Human Health Act (U.S. Code Title 33, Chapter 44) and the work of the U.S. Commission on Ocean Policy (2004) have emphasized the importance of outreach and education. Meaningful stakeholder involvement improves the chances for successful ecosystem management. Meaningful involvement entails including stakeholders in every phase of the process, legitimizing all stakeholders' knowledge and beliefs, and ensuring that decision making is transparent. Though stakeholder involvement may slow down the process, it is critical to breaking down sociopolitical boundaries.

Targeted, high-quality outreach and education efforts will enable the Partnership to:

- Better fulfill its responsibilities to provide the scientific basis to meet the Partnership's stewardship role by: 1) ensuring resource managers (this needs to be inclusive of local, private, state, tribal, and federal resource managers) have the scientific information they need to conserve and manage living resources and their habitat; and 2) by helping to create a well-informed public that understands the Puget Sound ecosystem.

- Ensure a dynamic, diverse, and interdisciplinary workforce with competencies critical to advancing ecosystem research and recovery, now and in the future.

Outreach and education efforts should span several arenas, including media relations, public and internal events, publications, the internet, formal education, informal education, professional development, and research and career opportunities.

By its actions, the Science Panel shall act as an advocate for science and science training in Washington State, to encourage more degrees in science and also more exposure to scientific and analytical thought processes for those in other disciplines.

The Panel supports the establishment of Scholarship/Fellowship and Internship Programs to enhance the Partnership's science program. This investment in young scientists and engineers will pay off by providing additional resources to work on specific science and technology projects while fostering the training and experience of the next generation of scientists and technicians needed to continue enhanced understanding, recovery, and stewardship of the Puget Sound ecosystem.

The Panel supports devoting resources to foster and utilize citizen science monitoring networks to enhance the Partnership's capabilities (Litle et al., 2009). Investments in citizen science can be a win-win enterprise, both a cost-efficient approach to gaining scientific observations, samples, and data as well as a successful means of increasing public awareness and actively engaging citizenry in the understanding, recovery, and stewardship of the Puget Sound ecosystem.

In the context of science, the Science Panel recommends that the Partnership's education and outreach capacities should:

- Assure that scientific messages are well reviewed and accurate prior to release in public education and outreach.

- Interact with citizen groups and individuals to transmit messages about the science and status of the Puget Sound ecosystem. Coordinate regionally to offer advice and content to K-12 and beyond (K-gray) educational organizations, such as NAME, E3, Salish, and COSEE and various universities and educational institutions regarding the Puget Sound ecosystem and its status.

- Develop resources to foster and utilize citizen science monitoring networks to enhance the Partnership's capabilities.

- Improve science literacy of the Puget Sound region. Examples of priority activities include: working to improve Washington State science education in partnership with specific institutions; working with school districts and local non-profit organizations to provide professional development for middle and high school teachers in statistics and scientific inquiry: developing fellowships and traineeships to develop and strengthen science workforce.

5. SUMMARY

This Strategic Science Plan is designed to provide the overall framework for coordinating specific science activities needed to support the Partnership's efforts to protect and restore the Puget Sound/Salish Sea Ecosystem. The overarching themes and high-level recommendations are presented in the Executive Summary, at the start of this document.

The content of this document has greatly benefited from input from numerous reviewers who provided science-related comments on the *Action Agenda*, *Biennial Science Work Plan*, Draft Strategic Science Plan, and other supporting information developed to describe the science program for the Puget Sound Partnership. This Strategic Science Plan is intended to be a living document, which will be updated and revised as necessary.

6. ACKNOWLEDGEMENTS

The Strategic Science Plan has been authored by the 2010 Science Panel: Timothy Quinn, Chair; Joel Baker, Vice Chair; Joseph Gaydos; Robert Johnston; William Labiosa; Tom Leschine; Jan Newton; John Stark; Usha Varanasi; and Katherine Wellman, with significant contributions from former Science Panel members Guy Gelfenbaum and Frank Shipley, and from Partnership staff members Scott Redman, Mary Ruckelshaus, with editorial assistance from Margaret Clancy and administrative support from Tammy Owings.

APPENDIX: EXAMPLES OF SCIENCE NEEDED TO SUPPORT ATTAINING GOALS OF THE PARTNERSHIP

Under the recommendations described in this Puget Sound Strategic Science Plan, what kind of science will be needed to achieve the six ecosystem recovery goals identified by the Partnership? Effective uses of science to address the needs will require both the application of existing knowledge and aggressive exploration of key unknowns relevant to specific ecosystem protection, restoration and recovery actions. Explicit attention toward incorporating both of these approaches is important in order to achieve progress on the Partnership goals while gaining enhanced insights that will lead to improvements of strategies. This appendix provides some specific examples of both of these science needs for each of the Partnership's goals.

The examples are meant to be illustrative, not comprehensive. In practice, specific needs such as those identified here will be recognized through Partnership collaboration, occurring in the adaptive management/*Open Standards* context. These needs will be defined by the Science Panel in the Partnership's *Biennial Science Work Plan*.

A rigorous science-based program includes anticipatory science; we must adapt as new threats and drivers arise. There is a natural tendency to focus on known issues, but efforts could be overcome if emerging threats are not considered. For example, altered hydrology driven by climate change may overwhelm restoration of salmon habitat structure. Emerging chemical threats such as those from nanotechnology, including nanoparticles, is another example. A healthy science portfolio must reserve resources for exploratory, anticipatory investigations. More importantly, the program must be able to incorporate these new issues in the science-policy loop of adaptive management. A challenge for the Partnership is to understand when existing scientific knowledge is sufficient to frame policy, and when a lack of knowledge is limiting to effective decision-making.

Needs identified by the Partnership will frequently require the application of both social science and natural science. Understanding how people in the region value Puget Sound (and the diversity of the values they hold) is key to setting ecosystem goals and in defining 'what is healthy?' Effective restoration and protection strategies can only work within the social, economic, and political structures of the region.

A.1 Human Health: Healthy People Supported by a Healthy Puget Sound

Oceans and humans are inextricably linked: human activities on land, sea, and air affect the health of Puget Sound, and conversely, degraded water quality in Puget Sound (for example) threatens the health of humans and marine wildlife. Over the last several decades efforts to clean up Puget Sound waters led to decreased loadings of some pollutants from point sources (Puget Sound Action Team, 2007; Brandenberger et al., 2008). However our waters continue to be conduits for a diverse array of chemical and biological contaminants posing threats to sea life and to human health (Ruckelshaus and McClure 2007), including disease causing pathogens (Stewart et al. 2008), biotoxin producing harmful algal blooms (HABs) (Trainer et al., 2003), and toxic chemical contaminants (McCarthy et al., 2008). Humans are increasingly at risk of eating contaminated seafood or coming into direct contact with polluted drinking waters and recreational beaches (Stewart et al., 2008). Furthermore, some human population groups (e.g., Native Americans, Asian-Pacific Islanders) may be at increased risk of exposure through their location of residence and or dietary needs and preferences.

The relationships between Puget Sound's health and human health have already received some direct attention. Examples of current scientific knowledge that is well-established and applicable to actions in support of this goal include:

- Programs such as Puget Sound Ambient Monitoring (PSAMP) and research conducted over the last few decades show that chemical pollution, through the growing rise of on-road vehicle use, land development, and industrial and stormwater inputs, has left a toxic legacy in Puget Sound. Past and present chemical contaminants (including PCBs and PAHs and emerging contaminants such as PBDEs and pharmaceuticals) pose a serious problem for the Puget Sound food web and to humans (Puget Sound Action Team, 2007).
- Recent research on salmon and other Puget Sound sentinel species has identified novel and sometimes poorly understood interactions among multiple chemical contaminants in mixtures and between chemical and non-chemical stressors (e.g., contaminants and rising water temperatures due to climate change) (Monosson, 2005). For example, studies on mixtures of polycyclic aromatic hydrocarbons (PAHs) from oil spills and urban runoff have revealed unexpected cardiovascular toxicity in fish (Carvan et al., 2008). Other studies on fish have shown that pesticides can enhance or synergize the toxicity of other pesticides when they co-occur as mixtures (Nishitani and Chew, 1988). This continues to be a challenging issue because Puget Sound wildlife and humans are widely exposed to chemical mixtures that are constantly changing.
- Repetitive exposure to toxins in harmful algal blooms leads to a chronic disease state in a sentinel marine mammal species, and repetitive, low level exposure alters basic cellular processes in a biomedical fish model (Lefebvre et al., 2009). Pathogen (e.g., bacteria, viruses, parasites) loading into the marine environment may be increasing due to some of these same factors that contribute to increased HABs, as well as human popula-

tion growth and changes in infectious disease vectors (ASM, 2009). These pathogens may infect humans during recreational use of contaminated beaches, and consumption of tainted fish and shellfish (Steward et al., 2008). Effective collaboration among biologists, ecologists and public health officials (e.g. ORHAB, SoundToxin Program) in this area has led to improved early warning of harmful toxic events. However, we do not have a sustained and standardized program to measure the bioavailability of these chemical and biological pollutants to humans and subsequent health impacts.

- In recent years, the frequency and geographic extent of some HABs in Puget Sound have increased (Trainer et al., 2003), enhancing the risk of human encounters with HAB toxins and causing economic losses to the seafood industry (Nishitani and Chew, 1988). There have been studies (Dale et al., 2006) linking global/regional climate change to worldwide increases in the frequency of HAB outbreaks and shellfish toxins leading to more frequent beach closures. For example, innovative models have shown that the number of days that conditions are favorable for shellfish toxicity each year has nearly doubled since the late 1970s, and are due to natural patterns of large-scale climate variation (Moore et al., 2009). In the future, warmer air and water temperatures associated with the regional impacts of climate change may promote earlier and longer-lasting HABs in Puget Sound.

Examples of additional information required to meet this goal include:

- The ocean and human health connection need to be studied from the whole ecosystem context, with specific emphasis on the role of changing climate and potential direct and indirect impacts on human health. Predicting human health effects from poor water quality or beach conditions, contaminants, waterborne pathogens or HABs requires an integrated scientific approach that incorporates the disciplines of hydrology, climatology, meteorology, hydrodynamics, microbiology, biological oceanography, and ecology.
- A focus on developing and implementing early warning systems for chemical contaminants, HABs and pathogens, communicating seafood benefits and risks, and improving assessments of ecosystem change and their effect on human health is warranted. Ecosystem forecasting can provide decision-makers and the public with more accurate predictions of when human health might be at risk. Research scientists, coastal users and management decision-makers must work closely together to identify the types of forecasting, as well as the time and space scales that are required to reduce the risks to humans.
- Process-level ecological models and novel forecasting methods must also be closely linked to coastal observing systems that serve to drive and validate the models. This requires improved baseline monitoring and surveillance to establish effectiveness of new tools and effectively monitor changes in human health risk.
- There is a growing body of scientific literature (Trainer, 2002) supporting the connection between marine mammal health and human health, especially on the U.S. West Coast. Research is needed on the role of marine mammals as infectious disease vectors and the potential for transmission of microbial agents from marine animals to humans. Similarly, improving and expanding monitoring of sentinel fish species most at risk of exposure to toxic chemical contaminants (Dickhoff et al., 2007) would not only reveal a great deal about contaminants of emerging concern or the effectiveness of pollution reduction strategies, but chemical

interactions that may threaten human health in unexpected ways. Moreover, expanding the use of sophisticated biomedical tools would provide the best possible scientific information to guide the long-term conservation and recovery of the Puget Sound ecosystem.

- More information is needed on the many naturally occurring zoonotic (diseases that can be transferred to humans from animals) and human pathogens in the marine environment (Bogomolni et al., 2008). Consequently, research is needed to improve understanding as to what strains of a pathogenic bacterial species in Puget Sound waters are truly virulent, and what environmental conditions (e.g., climate, temperature, salinity, pH) promote the selection or amplification of these more virulent pathogens (Zo et al., 2008).
- The "One Health" approach contributes to the concept of "conservation medicine" (AVMA, 2008; ASM, 2009). While conserving the Puget Sound ecosystem is unquestionably vital for human health and well-being, new tools and technologies adapted from human biomedical research are proving increasingly useful in terms of accurately diagnosing the adverse effects of pollution on Puget Sound inhabitants. More work is needed to continue integration among biomedical research, ecosystem monitoring and conservation, and human health.
- Finally, climate is a primary driver of ecosystem services humans rely on, and can influence the extent by which chemical contaminants, HABs and pathogens, or changes in pH of coastal waters (i.e., ocean acidification) can exert their toxic effects (Ruckelshaus and McClure, 2007). Research is needed that improves our understanding of the influence of climate variability and change on these environmental processes and provides critical information needed by resource managers, the shellfish industry, and seafood consumers in minimizing economic losses and human health risks. In addition, adaptation and mitigation of climate-related impacts needs to be addressed in order to allow us to predict likely future changes more robustly and to reduce our effect on these changes.

A2. Human Quality of Life: Quality of Human Life Sustained by a Healthy Puget Sound

"Quality of life" refers to the human dimensions of ecosystem management, recognizing the benefits people derive from the goods and services provided by healthy ecosystems as well as the unintended consequences (or costs) of utilizing these ecosystem goods and services. In addition, quality of life recognizes the benefits that people derive from the built environment in terms of a vibrant economic and social base, rich in tradition and culture. The tradeoffs in attributes of quality of life may include traditional land uses such as agriculture and forestry that can be preformed sustainably and provide raw material, jobs, and a traditional way of life but also contribute to habitat and ecosystem process degradation. Shoreline property owners benefit from a healthy Puget Sound aesthetically as well as in terms of their property values but they also may have negative impacts on water quality, beach habitat, and public access to the shoreline.

Examples of current knowledge that is well established and applicable to actions to support this goal:

- The human population of the Puget Sound region will increase (approximately 5.3 million residents by 2025; UERL, 2008, based on Washington State OFM), increasing economic activity as people build homes, businesses, roads and other infrastructure; consume fish, shellfish, and other animals; harvest timber and other resources, and recreate in marine waters, streams, and lakes.

- The Puget Sound economy is projected to remain highly diverse at least until 2030 (UERL, 2008, based on Washington State OFM). Over the last several years the stability of the Puget Sound economy has been applauded as national economic status declines while local industry remains unencumbered. One mechanism to account for the sector contribution is capital production and number of employees employed (UERL, 2008).
- The Puget Sound ecosystem is an important foundation of our market economy, supporting a high level of human well-being and representing priceless natural capital. Despite the well-documented increase in urbanization, diverse factors such as agriculture, aquaculture, fishing, timber, and tourism contribute substantially to the region's economy and established way of life. Production from Whatcom and Skagit counties is sufficient to place Washington State first in production of red raspberries, growing 78% of national production (Canty and Wiley, 2004). Skagit county leads the nation in the production of tulip, daffodil, and iris bulbs and produces nearly 50% of the world's spinach, beet and Brussel sprout seeds, while Whatcom County is ranked 1st in the state and 12th in the nation for dairy production (Canty and Wiley, 2004). In addition, Washington State is the leading producer of farmed bivalve shellfish in the United Sates generating $77 million in sales and accounting for 86% of the West Coast production in the year 2000 and 2006 estimates of non-tribal commercial fish landings total 109.4 million pounds generating $65.1 million in ex-vessel value (TCW Economics, 2008). Based on a 2001 wildlife viewing survey by the U.S. Fish and Wildlife Service, Industrial Economics, Inc. (2006) found that approximately 208,000 U.S. residents over the age of 16 travel annually to Washington State to view killer whales and other marine mammals; in 2001, Washington's whale watching industry generated approximately $18.4 million in sales and 205 jobs in counties adjacent to the coastal habitat of orca.
- People act as agents of both positive and negative change. Examples of positive change include successful conservation initiatives within the region to protect ecologically rich areas, working resource lands, and parks, regional trails, and open spaces, organic farming, use of alternative fuels, and low impact development efforts. Examples of negative changes include highly consumptive land use alterations, inefficient use of resources, shoreline armoring, introductions of invasive species, and pollution.
- People value ecosystems goods and services provided by the Puget Sound Region as indicated in recent literature (Stinchfield et al., 2009; Earth Economics, 2008).

Examples of additional information required to meet this goal include:

- Perceptions and values - Understanding the relationship among social, economic, and cultural perceptions and values and their influence on nearshore ecosystems. Better understanding of people's relationship and reliance upon Puget Sound ecosystems will transform the way in which we approach Puget Sound recovery and management.
- Acceptance of alternative management strategies - Understanding social response or behavioral change related to alternative management or policy strategies.
- Value of ecosystem services - Understanding the linkages between Puget Sound ecosystem services and

quality of life. Understanding the myriad contributions of ecosystem services to quality of life can be used in the design of effective incentive and non-regulatory management approaches as well as the development and implementation of targeted educational, participatory, and voluntary resource management strategies. Understanding these linkages will be critical for managing trade-offs over time and will inform the identification and evaluation of management recommendations intended to achieve both human well-being and a healthy Puget Sound (e.g., Thom et al., 2005). Specific questions include:

- How do specific changes in Puget Sound health affect specific quality of life attributes (e.g., how do water quality changes such as increased turbidity, nutrient enrichment, algal blooms, toxins/pathogens, or pollutants from stormwater runoff affect economic, social, health, and/or cultural attributes of human well-being)?
- How do these quality of life attributes differ across geographic areas of the Sound, population sectors, or business/economic sectors?
- How do the ecological scales of ecosystem services in the Sound differ from (or match) the governance, management, or regulatory/ jurisdictional divisions of the Sound?
- Who uses the ecosystem services provided by the Basin? What are the ecological and social scales of ecosystem services? (i.e., at what scales are benefits provided? At what scales is management most effective?)

A.3 Species, Biodiversity & Foodwebs: Puget Sound Species and the Web of Life Thrive

Puget Sound residents place high value on the region's fish, wildlife, and other species that contribute the biodiversity of the region. Natural resources (e.g., salmon, shellfish, trees) have helped support humans for up to 15,000 years in the region, and still represent some of the most obvious expressions of a functioning ecosystem to many residents. By virtue of the Endangered Species Act (ESA) and related laws, individual species often become the focal point of protection and restoration efforts (Brown and Gaydos, 2007). This ESA listing process focuses effort on compiling existing information on the species, often leading to information (hypotheses) on how best to recover that species. The ESA listing and recovery activities also encompass critical habitat elements, supporting (or sometimes conflicting with) the needs of a variety of other species. Some of Puget Sound's most imperiled species have been relatively well studied, and restoration or protection can—and is—proceeding.

Examples of current knowledge applicable to actions to support this goal:

- Pacific salmon are highly valued, culturally central to tribes of the Salish Sea, and some populations are listed as threatened under the ESA. Considerable effort has been directed to understanding salmon life histories, population dynamics, habitat limiting factors, and in establishing recovery goals for populations and some elements of the habitat necessary to support populations. This understanding has been supported by relatively high levels of Federal and State funding and public visibility.
- Shellfish are a high value commercial resource, a critical component of tribal cultural life, and provide a popular recreational fishery. Because of the relatively well known human microbial and toxic risks associated

with shellfish under some environmental conditions, the state of Washington, tribes, and private industry have a well developed data gathering, indicator development, risk assessment, and public communication effort supporting management of shellfish. We know a great deal about affects of nutrients, pathogens, and toxics on shellfish and what creates human health risk, but we continue to have harvest closures due to microbial and toxic contamination, suggesting we have not fully addressed known sources of the problems.

- The Puget Sound basin supports a variety of terrestrial ecological systems (e.g. coniferous forest, prairies, oak woodlands) which in turn support a diversity of plant, fish, and wildlife species. These systems also play a vital role in maintaining water temperatures, cycling nutrients, sequestering carbon, supporting stream base flows and aquifer recharge, and contributing to healthy in-stream habitats. Converting and/or simplifying these systems for human use (agriculture, housing development and silviculture) can have serious consequences for meeting the Partnership's species and food web goal.

Some elements of the ecosystem are less completely understood. Examples of poorly known aspects of the Sound, particularly those exerting a strong influence on the larger ecosystem and its condition, which will require scientific focus are:

- Food webs - The pelagic (open-water) food web of Puget Sound provides ecological life-support for highly valued species and populations. Food web components and processes are complicated, dynamic, and difficult to study. Yet the food web provides ecological controls up and down the food chain from phytoplankton to orcas. Many food web elements (forage fish, for example) are subject to significant, but poorly recognized stressors. New science is needed to understand how changing compositions of predators, prey, competitors, invasive species, water quality, and other components interact to support (or harm) the Sound's valued populations and species. This knowledge will support development of predictive models that will support adaptive management of Puget Sound recovery.

- Climate change - Climate change will create new stressors on living things that we do not now understand. Seawater acidification is already occurring in Puget Sound, and may affect a wide range of invertebrate species dependent on structural calcium. This, in turn, will affect organisms that either eat or are eaten by these species. Pronounced seasonal changes in river flow driven by climate will influence estuarine salinity and salmon spawning, rearing, and migration habitats. Increasing water temperature may already be supporting unwanted species invasions, including fish pathogens and their reservoirs/hosts. Sea level rise will change the distribution of shoreline habitats, and decrease some critical components such as wetlands, where inland migration is prevented by human development or topography. Climate models are currently being scaled downward by various groups from global to regional. A critical need is to link regional predicted climate trends for Puget Sound with ecological outcomes such as population and species endpoints. Ecological forecasting is necessary to develop recovery of Puget Sound in a way that can adopt to coming climate-driven changes.

- How much is enough? - Conservation in terrestrial environments usually comes down to the question of: what to save, where to save it, and how much to save. Answers to these questions may be species and process specific, and largely unknown for any species let alone for communities. In addition, while species and ecological communities may well be resilient to certain levels of human activities very little work has been done on this issue.

- Land use and salmon recovery - Most salmon recovery actions focus on in-stream and in-estuary areas, with little attention paid to how upland development will affect recovery efforts. We need to better understand how development (conversion to urban or agricultural land-uses) and its interaction with physical environments affect salmon viability.

A.4 Habitat and Land Use: Puget Sound Habitat is Protected and Restored

"Habitat" is the biological and physical condition of an area that supports a particular species or species assemblage (Ruckelshaus and McClure, 2007). Habitats are created and maintained by the interaction of physical, chemical and biological processes (i.e., ecosystem processes) occurring at multiple spatial and temporal scales (Spence et al., 1996; Dale et al., 2000; Roni et al., 2002; Stanley, 2005; Simenstad et al., 2006). The science underlying this Partnership habitat goal is linked to the 'species and food web' goal, as both goals address healthy ecosystems. Since some alteration and degradation of habitat is inevitable with human habitation on the watershed, science is needed to evaluate and prioritize 'critical' habitat to insure that the Puget Sound maintains a sufficient mosaic (quantity, quality, and connectedness) of habitat types.

Current scientific knowledge about habitat and land use that is well-established and applicable to actions in support of this goal includes:

- The scientific underpinnings of habitats is sufficient in many cases to identify 'valuable' or 'critical' habitat, allowing high priority conservation and restoration areas to be mapped in terrestrial and some fresh water aquatic portions of the Puget Sound ecosystem. Estuarine wetlands, for example, are known to be ecologically important, but Puget Sound has lost the majority of this habitat type.
- Coupling observations with theory, the Puget Sound Nearshore Ecosystem Restoration Program is working to map high priority conservation and restoration areas in the marine nearshore zone. This approach will provide much of the information needed to rank the importance of nearshore restoration at a finer scale of resolution than previously.

Examples of scientific knowledge needs pertinent to this goal where additional information would be valuable for planning actions include:

- While we have a fairly good geospatial understanding of where habitats are in the Puget Basin, our knowledge of the ecological functions of these habitats is far less complete. For example, we need a much better understanding of the cumulative effects of multiple stressors on ecosystem structures, functions, processes, and services provided by the ecosystem. In the development of results chains for *Open Standards*/adaptive management, causes and effects of habitat stressors for conceptual modeling are often hypothesized but not tested. Testing cause and effect links with real data will greatly reduce the uncertainty of restoration actions based on development of results chains.
- Identification of a particular habitat, say seagrass, is far easier than determining its role in support of particular species or biodiversity generally. How impaired is a particular habitat, what is its trend, and how does its condition support ecosystem recovery goals? Definition of the habitat's quality and quantity thresholds that

are necessary to support animal and plant populations in the long term is a critical science need.

- How do the effects of climate change interact to influence habitats? Understanding the marine and terrestrial effects of climate-induced changes on sea levels, air and water temperatures, precipitation and surface water movement patterns, circulation, and water quality are needed to develop future ecosystem recovery actions.
- We lack a clear understanding of how humans influence certain habitats. We need a better understanding of the effects of land use practices on terrestrial systems, wetland systems, and the land fresh-water and land-marine water interface. For example, coho salmon have been subject to alarming levels of pre-spawn mortality in some urban fresh water habitats, for unknown reasons. Determining the cause of this mortality is a primary need to reduce this mortality and restore the suitability of these habitats for this species, and in this example that research is proceeding to yield answers. Much less is known, for example, about the effects of land use on marine food webs.

A.5 Water Quantity: Puget Sound rivers and streams flowing at levels that support people, fish and wildlife and the environment.

This goal is to maintain an ecosystem supported by groundwater, river, and stream flow levels sufficient to sustain people, fish, and wildlife, and the natural functions of the environment. Abundant freshwater is critical to human health, to both terrestrial and marine ecosystems, and to many of the fish, bird, and other species around Puget Sound that humans care deeply about. Freshwater is derived from precipitation, which averages around 40 inches a year but varies tremendously (15-140 in/yr) around the greater Puget Sound watershed, and from melting glaciers in the Olympic and Cascade mountain ranges. Despite the Puget Basin's reputation as a rainy place, many watersheds around the Sound have local areas where freshwater supplies are not adequate to meet both instream ecological needs and out-of-stream, primarily human, needs.

The primary threats to abundant water quantity around the Puget Sound basin include: consumptive use from surface and groundwater; land-use practices that increase impervious surfaces; disconnections of surface/groundwater linkages; reduced wetland storage; saltwater intrusion; and modified stream channels, including effects of flow regulation. In the future, as the human population is projected to increase, and due to unknown future changes in the timing and quantity of rainfall due to climate change, stresses on abundant freshwater for human and ecological uses will demand wiser management of this critical resource.

Unfortunately, even the most basic instream ecological needs have not been determined for several of the Water Resource Inventory Areas (WRIAs) in the Puget Sound basin. Moreover, there has been no regional evaluation of freshwater availability or needs, the availability and accessibility of groundwater resources, or how they may change in the future.

Examples of current scientific knowledge about water quantity that are well-established and applicable to actions in support of this goal include:

- Most watersheds in the Puget Sound region have been altered by urban or suburban land uses, agriculture, or forest practices and many contain facilities that store water or generate power. The hydrology of these watersheds has been altered to varying degrees (Konrad and Booth, 2005).

- Instream flow rules have been set by Washington State Department of Ecology in twelve watersheds in the Puget Sound region to facilitate water availability assessments and appropriation of additional water. The science behind instream flow rules is based on two approaches, a relatively simple and a relatively complex approach that can be tailored to the basin of concern. The relatively simple "Toe-Width Method" was developed by the Department of Fisheries (WDF), the Department of Game (WDG), and the U.S. Geological Survey (USGS) in the 1970s to determine minimum instream flows for salmon and steelhead primarily for small streams. The more complex Instream Flow Incremental Methodology / Physical Habitat Simulation (IFIM/PHABSIM) method was developed by U.S. Fish and Wildlife Service in the late 1970s (Bovee, 1982) with enhancements in the 1990s (Bovee et al., 1998). IFIM is generally considered the best available method for predicting how the quantity of available fish habitat changes in response to incremental changes in streamflow. Nearly all instream flow rules in Washington State have been based primarily on this science.

Examples of scientific knowledge needs pertinent to water quantity where additional information would be valuable for planning actions include:

- Advancements in stream flow science suggest that allocations of water to sustain native species and functioning ecosystems, commonly called "environmental flows," need to address the five components of flow: extreme low flows, monthly low flows, high-flow pulses, small floods, and large floods. Instream flow rules in Washington State typically address only extreme low flows rather than the full range of "environmental flows." A number of methods have recently been developed for determining optimal environmental flows (Tharme, 2003), although these methods will need to be tested and evaluated in Puget Sound streams and rivers prior to reliably modify existing flow rules. This testing will require monitoring and scientific studies to document applicability to Puget Sound streams and rivers and to document improvement in resource management based on new policies.
- Current stream flow modeling is generally applicable at the scale of a particular reach of stream or river, but lacks a consideration of watershed scale factors. Because protection and restoration must occur in a watershed context, including focus on groundwater, precipitation regimes, diversions, and other influences, a new generation of instream flow modeling tools is needed. Existing management tools available to help meet instream flow rules generally focus on limiting future water withdrawals through basin closures. Advancements in the ability to simulate and predict complete and detailed water-budgets for (including such processes as when and where groundwater pumping can affect streamflow) will provide water-resource managers with a much broader array of water supply and use scenarios to more effectively meet competing demands. These tools could be developed even beyond the basin scale to address regional uncertainty in meeting future freshwater needs of Puget Sound's growing human population while maintaining healthy aquatic ecosystems.
- As the climate of the Pacific Northwest changes in response to global forcing, better understanding of the impact of climate change on regional water supplies, especially the timing and magnitude of precipitation and the frequency and magnitude of flooding, will be required. Detailed monitoring, especially in higher elevations, will allow refinement of existing regional hydrological models, which in turn will provide better predictions of the impact of climate change on Puget Sound restoration and protection efforts.

A.6 Water Quality: Puget Sound Marine and Freshwater are Clean

The term "water quality" encompasses multiple issues, but is typically based on concentrations of chemical pollutants, including metals, persistent organic chemicals, pesticides, and excess nutrients, abundance of natural toxins and pathogens and characteristics of water such as temperature, pH, turbidity, dissolved oxygen, hardness, dissolved organic matter, salinity, and other dissolved and suspended constituent concentrations and effects. Water pollutants come from many different sources (point and non-point), have different entry pathways into surface and ground waters and have different dispersal and degradation rates in the environment. The various environments within the Puget Sound ecosystem process and cycle these pollutants differently.

Examples of current scientific knowledge about water quality that is well-established and applicable to actions in support of this goal include:

- Toxic loads to Puget Sound are not simply a legacy from past pollutant discharges, but continue to exist and in many cases increase due to new sources and delivery pathways. Without new management strategies and behavioral changes, continued population growth is expected to cause a concomitant increase in impervious surface and larger volumes of stormwater runoff, which will carry many pollutants into surface and marine waters. Generally, the influence of non-point runoff on receiving water quality is well enough known to proceed with actions to reduce pollutant loading from runoff.
- Due to its bathymetry and circulation patterns, Puget Sound effectively retains many pollutants entering from the surrounding watersheds, and transport through the Straits to the ocean is a relatively inefficient process. This means that chemical pollutants often accumulate in relatively high concentrations near where they enter the Sound, where they may reside for long periods of time.
- Certain toxic compounds (e.g. PCBs) bioaccumulate and/or biomagnify once they enter the food chain. Thus many of the top predator species in Puget Sound have significant body burdens.

Examples of scientific knowledge needs pertinent to water quality where additional information would be valuable for planning actions include:

- Stormwater management - A better understanding the relationships among current and future land uses, the quantity and quality of stormwater runoff, and toxics loading to Puget Sound is necessary. Developing a strong knowledge base on the effectiveness of various Low Impact Development (LID) techniques for reducing stormwater volumes and pollutants in stormwater is essential.
- Effects of chemical mixtures - Although many types of pollutants have been measured in Puget Sound, the effects of these chemical mixtures on various organisms is not well-understood. The cumulative impacts of multiple stressors on aquatic food webs, including chemicals (mixtures of pesticides and other chemical mixtures), physical changes to water (e.g. temperature changes), increases in disease, emergence of new diseases, and the establishment of invasive species are not well-known. Little is known about the effects of mixtures of single classes of compounds, such as pesticides, on organisms let alone the effects of multiple stressors such as temperature, pesticides, and persistent organic pollutants. Filling these knowledge gaps would be beneficial in targeting particular pollutants (or particular combinations), for example through regulations that

affect the original source.

- Effects of emerging chemical pollutants - A large number of chemicals used in commerce, including pharmaceuticals, flame retardants, components of personal care products, and plasticizers enter the Puget Sound. Our poor understanding of the sources, persistence, and impacts of these chemicals greatly limits our ability to evaluate the risk and consequences of these materials.
- Climate change - We need to understand how climate change may ultimately affect water quality, either via new processes such as ocean acidification, or by alterations in environmental conditions, such as temperature, wind, sunlight, or precipitation amounts and timing. Essential is to understand the implications of climate change within the unique environment of Puget Sound. For instance, ocean acidification, while a factor in the global ocean, its severity and impact to biota can be exacerbated by loading of organic material or other human-caused processes within the estuary, such as occur in Puget Sound, making its impact amplified.

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