Priority Science for Restoring and Protecting Puget Sound:

A Biennial Science Work Plan for 2011-2013

Puget Sound Partnership

Science Panel

December 9, 2011

Executive Summary

The purpose of *Priority Science for Restoring and Protecting Puget Sound: A Biennial Science Work Plan for 2011-2013* is to provide strategic focus on the science needed to recover and protect Puget Sound. This strategic focus can help direct the allocation of the limited resources available for science to the issues and studies where they are most needed. The document is a key companion to the *Action Agenda Update*, which describes the long-term strategies and coordinated near-term actions to be implemented by state and federal agencies, tribes, cities and counties, other local jurisdictions, nongovernmental organizations, and the general public to recover and protect Puget Sound and the ecosystem services it provides.

The Puget Sound Partnership Science Panel (Science Panel) chose these actions based on a review of the questions that current research and monitoring are addressing, a review of recommendations from scientific reports and publications on the science needs for a program of ecosystem recovery in Puget Sound, and recommendations from a broad base of scientists, practitioners, stakeholders, and decision makers. Analyzing this information relative to a conceptual model of ecosystem recovery for Puget Sound illustrated where gaps in scientific attention and knowledge are likely present.

Identifying gaps in knowledge does not immediately make them priorities for funding and investigation. To decide which gaps are priorities, the Science Panel asked two sets of questions. The first set focused on scientific questions: How much do we know? What is the level of scientific uncertainty? The second set focused on policy-science questions: What are the decision-critical questions and information needed for ecosystem restoration and protection? Where is the lack of scientific information hindering progress in restoration and recovery?

To determine what decision-critical issues are important, the Science Panel used: (1) the perspectives collected from stakeholders and conservation practitioners who participated in multiple stakeholder meetings on developing the *Action Agenda Update*; (2) the lists of priorities for the *Action Agenda Update* provided by Action Area groups, who hold the perspectives of local implementing organizations, governments, and tribes about what is important in local areas and watersheds; and (3) feedback on proposed science priorities from decision makers on the Ecosystem Coordination Board, who represent a broad range of interests and values.

The Science Panel identified the following 48 science actions as high priority. The science actions are grouped according to the strategy sections of the *Action Agenda Update*.

Upland and Terrestrial Ecosystems

- Develop analytical tools to identify options for where to protect, where to restore, and where to develop while maintaining desired ecosystem goods and services.
- Use social science to guide development of adaptive management structures that can effectively link restoration science to management decision making.

Floodplains

- Estimate the value of floodplains in terms of the ecosystem services they provide.
- Develop key ecological indicators and implement monitoring to assess status of floodplains.
- Improve understanding of the effects of vegetation on dikes and other flood control structures.

Mitigation

- Develop ecological indicators, assess baseline conditions, and implement monitoring to measure ecosystem function relative to no net loss.
- Conduct social science studies to describe the key institutional challenges to attaining no net loss and improvements from restoration.

Freshwater Ecosystems

- Develop robust ecological indicators and implement comprehensive monitoring for stream flows.
- Validate stream flow targets in terms of their effects on abundance, productivity, distribution, and life history diversity of salmon.

Upland and Terrestrial Species and Food Webs

- Develop analytical tools to evaluate whether strategies to address factors limiting the productivity of salmon are being implemented in the most effective combinations, at the right times, and with appropriate amounts of effort to lead to recovery.
- Identify the causes of apparent decline in marine survival of salmon as they leave their natal rivers and exit Puget Sound.
- Assess risks imposed by terrestrial and freshwater invasive species.

Marine and Nearshore Ecosystems

- Develop analytical tools to identify priority areas for protection, restoration, and stewardship.
- Develop adaptive management structures that link restoration science to management decision making.
- Identify key stressors on eelgrass.

Marine and Nearshore Species and Food Webs

- Develop analytical tools and information to understand the tradeoffs in managing food webs of marine species and the multiple stressors affecting those food webs.

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- Implement biological and social studies to understand the conservation and sociological roles of marine protected areas for habitat and species protection, ecosystem restoration, and sustaining usual and accustomed tribal fishing areas.
- Identify stressors on forage fish populations.
- Implement studies to understand the causes of declines in marine bird abundance.
- Conduct studies to identify sources of nutrients that enter Puget Sound from both groundwater and external marine waters to develop strategies for maintaining water quality for Puget Sound food webs.
- Assess risks imposed by marine invasive species.

Toxics

- Implement studies to ensure that Washington State's water quality standards and sediment management standards are protective for allowing human and wildlife consumption of fish and other seafood.
- Describe the availability, feasibility, and safety of alternatives to products and processes that use and release toxic chemicals of concern into the Puget Sound ecosystem.
- Develop integrated monitoring and assessment of toxic chemical sources, exposure, and effects.
- Synthesize information on emerging contaminants of concern.

Runoff from the Environment

- Develop monitoring and assessment of benthic invertebrates in small streams to evaluate stormwater management and other efforts to protect and restore streams.
- Evaluate the effectiveness of low impact development (LID) projects and stormwater best management practices and programs.
- Evaluate land uses and associated pollutants that would require treatment beyond sediment removal.
- Evaluate projected environmental benefits of structural stormwater retrofits given varying levels of effort to guide the extent of structural retrofits needed to help meet 2020 ecosystem recovery targets.
- Evaluate individual and combined effects of commonly used pesticides on salmonids, other fish, and their foods.

Wastewater

- Evaluate nitrogen reduction in public domain on-site system treatment technologies.

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- Implement studies of human-related contributions of nitrogen to dissolved oxygen impairments in sensitive Puget Sound marine waters.

Shellfish

- Establish and sustain pollution identification and correction (PIC) programs to identify and fix nonpoint pollution problems.
- Research and implement monitoring to understand the specific environmental conditions that produce toxic harmful algal blooms (HABs) and pathogen events.

Oil Spills

- Conduct rigorous risk analyses on higher risk industry sectors to ensure there are appropriate levels of investment in reducing the risk of oil spills.
- Inventory and describe baseline conditions for key species at risk that can be used in assessments of natural resource damages from oil spills.

Cumulative Water Pollution

- Expand monitoring of freshwater and marine water areas to assess human exposures to pollution during water-contact recreation.

Emerging Issues – Ocean Acidification

- Design and implement monitoring for ocean acidification variables across Puget Sound to understand the status, diversity, and range of conditions.
- Develop and implement studies to assess the risk and vulnerability of Puget Sound species to ocean acidification.
- Develop adaptation strategies given the assessed vulnerability to ocean acidification.

Scientific Tools for Informing Policy

- Conduct institutional analyses of the overall governance and management structures in which Puget Sound recovery strategies operate.
- Conduct integrated risk assessments of the impacts of different pressures on the Puget Sound ecosystem.
- Develop a systematic, transparent, and ecologically-based prioritization tool for near-term actions in the Action Agenda that will support evolutionary learning and adaptation.

Coordinated Ecosystem Monitoring

- Implement and sustain a comprehensive, coordinated monitoring program to understand the status of Puget Sound and the effectiveness of recovery actions.

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Human Dimensions in Ecosystem Recovery

- Develop assessments of ecosystem services to help decision makers make informed decisions about restoration and protection.
- Develop socioeconomic indicators to help measure and report on the human dimensions in ecosystem recovery.
- Conduct a baseline literature review of social science research and a survey of data to identify gaps and resources that can be readily available and used by ecosystem recovery planners and practitioners.
- Evaluate the most effective combinations of regulatory, incentive, and educational programs for different demographics in Puget Sound.

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Introduction

Puget Sound is a complex ecosystem. Ecologically it is the southern part of the Salish Sea, which includes the marine waters of the Washington State's Puget Sound and San Juan Islands, the Strait of Juan de Fuca, and British Columbia's Gulf Islands and the Strait of Georgia. The Puget Sound encompasses 35,500 km^2 of fertile lowlands, uplands, islands, and scenic mountains; thousands of rivers and streams; a large, complex fjord-like estuary covering 2,330 km^2 with 4,000 km of shoreline; and many species of plants and animals. It is also home to approximately four million people – with a million or more expected to arrive in the next 20 years – who enjoy the natural resources and ecosystem services of Puget Sound. These resources are managed under a complex arrangement of local, regional, state, and national laws, governments, and economies. Like many other parts of the United States, Puget Sound is experiencing rapid ecological, demographic, and social change affecting land use, climate, nutrient cycles, and the abundance and distribution of its species that will change the ecosystem services it can provide (Brown et al. 2005, Lombard 2006, Ruckelshaus and McClure 2007, Office of Financial Management 2007, Climate Impacts Group 2009, Gaydos and Brown 2011).

The Washington State Legislature created the Puget Sound Partnership (Partnership) in 2007 to coordinate and lead efforts to restore the health of Puget Sound. It recognized the vital roles to be played by science in this effort. The Legislature noted, however, that although many of the state's universities, agencies, and tribes had studied Puget Sound for many decades, no process existed for prioritizing research and monitoring that could provide the information needed to coordinate restoration and protection in a systematic manner.[1]

This problem is not unique to Puget Sound. Policy makers and scientists are increasingly concerned about how to direct research and incorporate the scientific findings to solve real world conservation problems (Robinson 2006, Fleishman et al. 2011, and Rudd 2011). Several recent national efforts to identify and prioritize science questions (e.g., Sutherland et al. 2006, Fleishman et al. 2011, and Rudd et al. 2011) have attracted policy and media attention. A key characteristic of these efforts is the recognition that developing these priorities requires the active participation of policy makers as well as scientists (Bozeman and Sarewitz 2005, Rudd 2011). This has led to increased policy and academic attention on the methods for identifying and analyzing impacts of natural, physical, and social sciences on policy (Albæk 1995, Beyer 1997, Amara et al. 2004, Sutherland et al. 2011).

This report, *Priority Science for Restoring and Protecting Puget Sound: A Biennial Science Work Plan for 2011-2013*, identifies priority science and monitoring questions needed to coordinate and implement effective recovery and protection strategies for Puget Sound. The Puget Sound Partnership Science Panel (Science Panel) – an independent body created with the Partnership by the Legislature – chose to develop this report using a broad-based participatory approach that considered both the articulation of policy issues and scientific uncertainty. The report builds on the foundation provided by the *2009-2011 Puget Sound Biennial Science Work Plan* (Partnership 2008) and the *Strategic Science Plan* (Partnership 2010).

[1] Revised Code of Washington 90.71.110 et seq. (see Appendix A)

Approach

Priority Science for Restoring and Protecting Puget Sound is divided into two main sections. The first section is an analysis of gaps in scientific understanding relative to the goals of the Partnership. This includes a review of the questions that current research and monitoring are addressing, a review of recommendations from scientific reports and publications on the science needs for a program of ecosystem recovery in Puget Sound, and a survey of what scientists, practitioners, and decision makers believe are the scientific needs that will help in recovery of Puget Sound. Analyzing this information relative to a conceptual model of ecosystem recovery for Puget Sound (Figure 1) illustrated where gaps in scientific attention and knowledge are likely present.

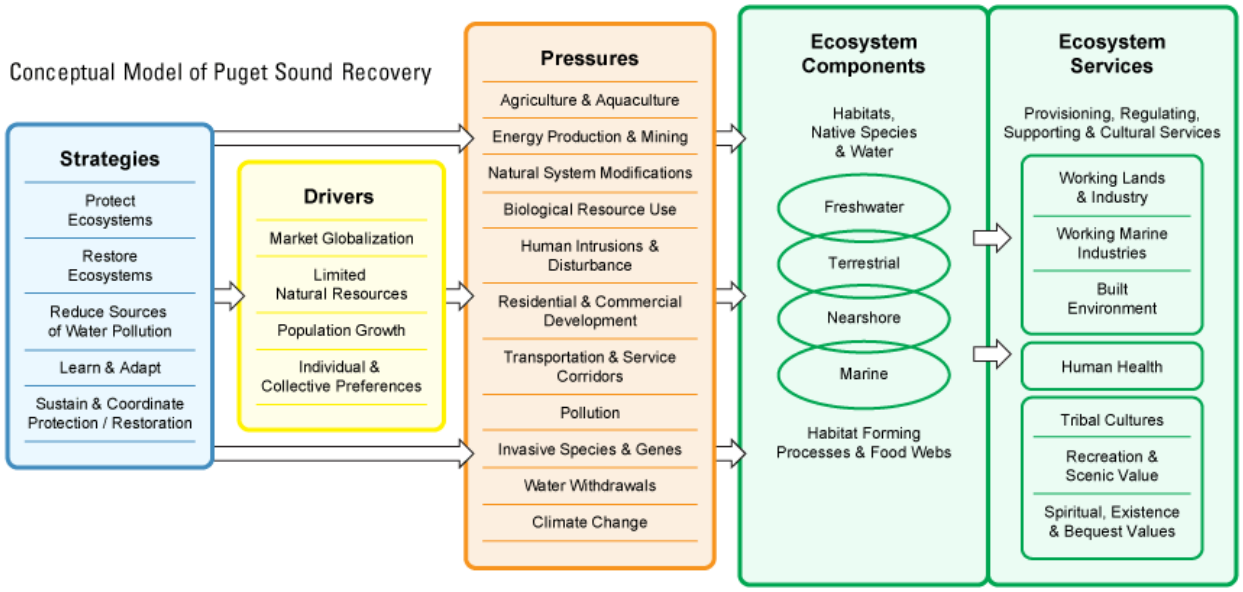

Figure 1. General Conceptual Model of Puget Sound Recovery. Ecosystem components are the major ecological characteristics used to organize information about the ecosystem (Levin et al. 2010) and the ecosystem services it provides (MEA 2003, Gomez-Baggethun et al. 2009). Pressures are human activities that impact the ecosystem leading to a change in state (EEA 1999, Carr et al. 2007). Drivers are fundamental social processes that create pressures (Lackey 2009). Strategies are suites of institutional social and economic efforts to respond to changes in the ecosystem and its services (Carr et al. 2007).

The second section of the document recommends the priority areas, questions, investigations, and capacities most needed to advance recovery and protection of Puget Sound now. Not all gaps in knowledge are priorities for funding and investigation. To determine what gaps are priorities, the Science Panel used two criteria:

- How much do we know? What is the level of scientific uncertainty?
- What are the decision critical questions and information? Where is lack of scientific information hindering progress?

Evaluation of decision-critical issues requires the perspectives of decision makers and practitioners. To understand these perspectives, the Science Panel relied on information

collected during multiple stakeholder meetings on the *Action Agenda Update*; the priorities of the Action Areas groups, who provide the perspectives of local organization and governments; and feedback from decision makers on the Ecosystem Coordination Board, who represent a broad range of interests and values.

The science priorities highlighted here intentionally do not address all the domains where science and policy interact. For the purposes of this document, the Science Panel recognized four domains of policy-oriented science (Figure 2). These domains reflect the demands on science as classified by two axes: the degree of development of scientific knowledge and the level of articulation of policy issues (Hisschemöller and Hoppe 1995, Shaxson 2009, Rudd 2011). The primary focus of *Priority Science for Restoring and Protecting Puget Sound* is on two of these domains:

- Areas where both scientific knowledge and articulation of policy issues are poorly developed (upper left quadrant of Figure 2), and
- Areas where scientific knowledge is poorly developed but consensus exists on the policy issues (upper right quadrant of Figure 2).

Areas where both scientific knowledge and articulation of policy issues are poorly developed often occur with emerging issues. Ocean acidification in Puget Sound (Feely et al. 2010, Pfister et al. 2011) is an example of such an emerging issue. Science on emerging issues can provide findings that raise new policy issues or reorient policy attention, for example. As scientific information accumulates, synthesizing results or incorporating them in analysis to evaluate risks can help policy makers understand ecological and social outcomes, which helps frame policy issues. Likewise, in areas where consensus exists on policy issues but not on how to resolve those issues, and where scientific information is lacking, focused strategic investigations and analyses can provide information to help craft solutions to policy issues. Social science investigations and tools can also help define the nature of the policy issues more explicitly. Developing the analytical tools to identify priority habitats (Brooks et al. 2006) is an example of this kind of science-policy interaction.

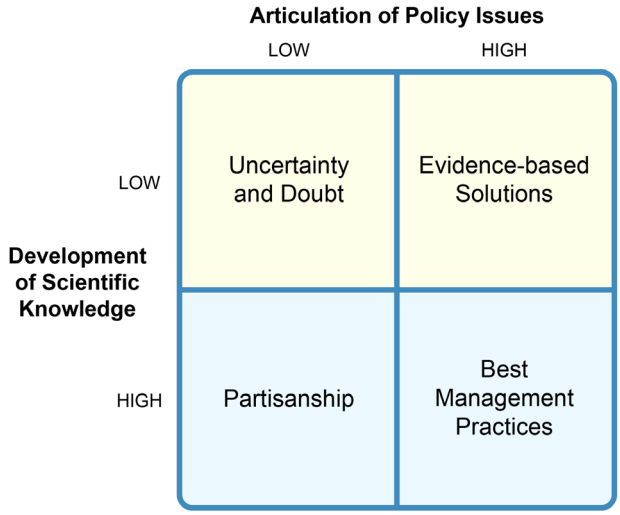

Figure 2. Demands on Policy-Oriented Science (modified from Rudd 2011)

In contrast, areas where scientific knowledge is well developed and policy issues are well understood, or where scientific knowledge is well developed but articulation of policy issues is ambiguous, are not the primary focus of this document. In the former case, the focus of science is on improving best management practices for activities in and around Puget Sound. This is part of the ongoing work and responsibilities of many state and federal agencies. This work is important and needs to continue, but it is not the focus of this report. Similarly, where scientific knowledge is well developed but articulation of policy issues is ambiguous, science is commonly used selectively to support partisan positions. Additional research or monitoring is unlikely to provide clarity to policy issues in this case. In this domain, other scientific functions, such as independent peer review, are more appropriate tools to advance science-policy interactions.

Uses of this Document

Priority Science for Restoring and Protecting Puget Sound meets a number of needs. These include the requirement for the Partnership to produce a biennial science work plan (Appendix A) and the desire to allocate limited economic resources strategically on the science that is most needed. The work plan is a key companion to the *Action Agenda Update*, which describes the long-term strategies and coordinated near-term actions to be implemented by state and federal agencies, tribes, cities and counties, other local jurisdictions, nongovernmental organizations, and the general public to recover and protect the ecosystem and the services it provides. Because of this, this work plan provides a list of priorities that federal, state, and non-governmental funding sources can use to direct research and monitoring toward science within their areas of responsibility (e.g., clean water, endangered species, land conservation, transportation, etc.) that also contribute to a larger, strategic effort. Importantly, this work plan is nested within the Partnership's overall science program, which is described in the *Strategic Science Plan* (Partnership 2010), the framework for development and coordination of science activities necessary to restore the health of Puget Sound by 2020.

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Analysis of Needs

This section is organized into two parts. The first compares completed or ongoing scientific studies with the recommended research and monitoring topics for Puget Sound recovery. The second summarizes recommendations generated from the scientific and conservation practitioner communities.

The scientific and conservation practitioner communities were invited to participate in two ways. First, interdisciplinary teams of scientists, practitioners, policy analysts, and stakeholders that formed to develop strategies for the *Action Agenda Update* were asked to provide recommendations. Second, scientists from academia, state, federal, local agencies, tribes, and environmental organizations and other stakeholders responded to an open request for recommendations on priorities given the criteria used by the Science Panel.

The following sections are organized by the four key Action Agenda strategy areas, which are:

A. Protect and Restore Terrestrial and Freshwater Ecosystems.

B. Protect and Restore Marine and Marine Nearshore Ecosystems.

C. Reduce and Control the Sources of Pollution to Puget Sound.

D. Sustain, Coordinate, and Adapt Puget Sound Recovery Efforts

Comparison of Recently Completed Research and Recommendations

Two inventories provide the basis for identifying needs for science and monitoring for Puget Sound. The first is an inventory developed specifically for this analysis of approximately 200 recently completed or ongoing scientific studies (Appendix B). The second is a list of over 100 recommended scientific studies in Puget Sound from literature published between mid-2008 and late 2011 (Appendix C). Both inventories are based on web searches and queries of federal and state agencies, local jurisdictions, tribal and non-profit organizations, and local universities. The inventory of recommendations started with review of recent Puget Sound Partnership peer-reviewed publications, especially the *Puget Sound Science Update* (Partnership 2011a) and the scientific literature cited therein and the *2009-2011 Biennial Science Work Plan* (Partnership 2008). It also extends to workshop summary reports, such as technical reviews of ecosystem indicators and targets and social science strategies (Social Science Advisory Committee 2011, Partnership Science Panel 2011), planning reports, and other gray literature referenced by the Partnership. Science Panel members reviewed the inventories and provided further additions.

Neither inventory is comprehensive. In particular, scientific studies being conducted at local or watershed scales or by smaller organizations may be underrepresented. It is important to identify these in future updates because they may provide key findings to the broader recovery effort. The Puget Sound Partnership Science Program is exploring tools to develop more comprehensive inventories of research, monitoring, and modeling and to describe existing functional networks of scientists working on Puget Sound issues. Taken together, however, the

analyses of these two existing inventories are likely to illustrate the major gaps in science needs.

Figure 3 provides a visual comparison and summary of the recently completed or ongoing studies and the recommended studies used for this analysis. In general, human dimensions – human health, wellbeing, and ecosystem services – are the least represented of the areas of study. In contrast, marine and nearshore ecological domains are a major focus of recommended studies and recently completed or ongoing studies. Several striking differences occur, however, between recently completed or ongoing studies and recommendations. Recently completed or ongoing studies have a broader scope and focus and address more attributes of the freshwater, terrestrial, and nearshore domains than the scope of the recommendations for those domains. Recommendations focus on only a subset of those attributes. In contrast, recently completed or ongoing studies that focus on the human dimensions domain have a narrow scope and focus almost exclusively on human health issues related to the environment, whereas the scope of recommendations call for study of a broader suite of ways that humans benefit from the environment.

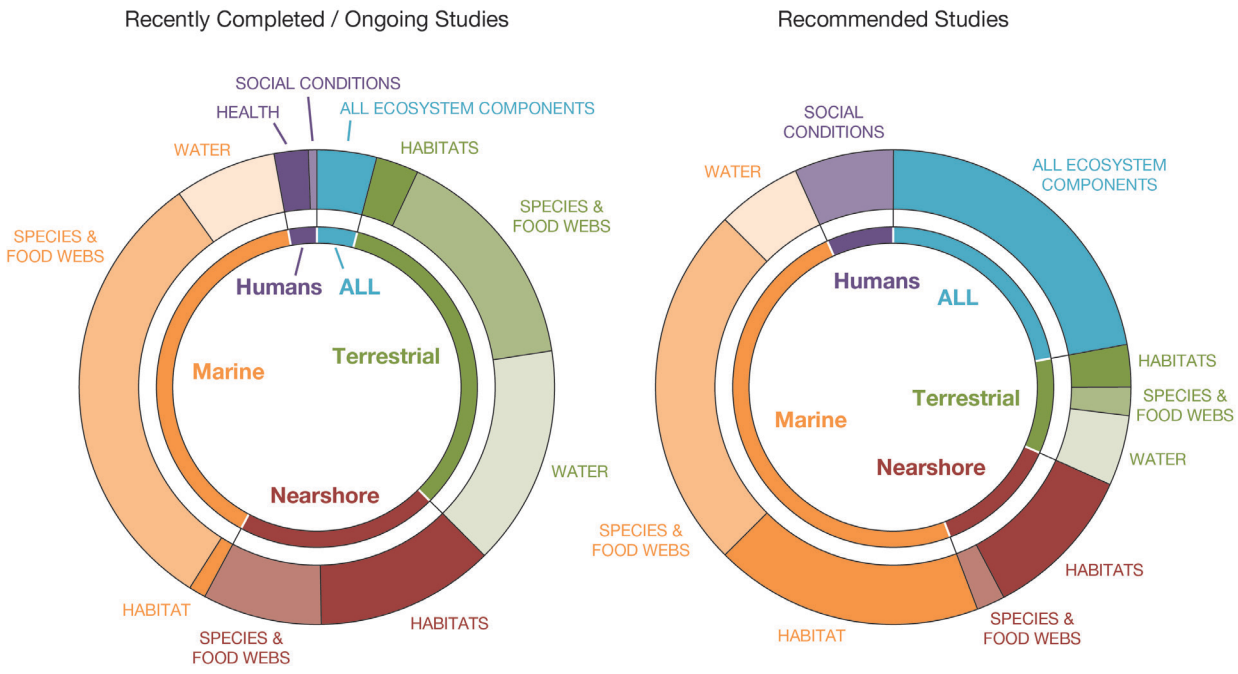

Figure 3. Proportion of recently completed or ongoing studies (left) and recommended studies (right) focused on ecosystem components of Puget Sound. Ecosystem components are four major ecological domains (terrestrial, freshwater, nearshore, and marine) and humans represented by the inner ring. The proportion of studies or recommendations within the ecosystem components are classified by the primary goals of the Puget Sound recovery (habitat, species and food webs, water, and human health, well-being, and social conditions (as designated Figure 1, Levin et al. 2010).

Comparing the focus of recently completed or ongoing studies with the Puget Sound Partnership's assessment of pressures on the ecosystem is also revealing (Figure 4). Most studies are focused on non-point and point source pollution, biological resource use (e.g., studies related to the use and management of salmon, shellfish, and forests), and climate change. This is generally consistent with the assessment of pressures for those areas. Climate change and fishing and harvesting are assessed as posing "very high" or "high" impacts on the ecosystem, whereas impacts of pollution ranged from "high" to "low" depending on the source of the pollution (Partnership 2009). Gaps are also obvious, however. For example, although invasive species has a "high" impact rating, almost no studies are focused on this pressure.

Table 1. Number of recently completed or ongoing studies and recommended studies focused on ecosystem pressures on Puget Sound. Taxonomy of pressures follows the IUCN classification (International Union for Conservation of Nature 2001) as modified by Salafsky et al. (2008). Ratings are from Partnership (2009).

Rating	Pressures	Recently Completed / Ongoing Studies	Recommended Studies
Very High	Climate Change	19	12
	Residential, Commercial, Port & Shipyard Development	5	6
High	Dams, Culverts, Levees & Tidegates	5	1
	Invasive Species – Freshwater	1	
	Runoff from the Built Environment	13	12
	Transportation and Service Corridors	1	
	Marine Shoreline Infrastructure	4	3
	Biological Resource Use	33	19
Medium	Air Pollution & Atmospheric Deposition	1	
	Invasive Species – Marine	3	
	Oil & Hazardous Material Spills	1	
	Industrial & Domestic Municipal Wastewater (On Site Sewage)	4	
	Recreational Activities	1	
	Water Withdrawals & Diversions	8	4
Low	Agriculture & Livestock Grazing	7	1
	Aquaculture	2	1
	Derelict Fishing Gear	1	
	Industrial & Domestic Municipal Wastewater (Point Source)	14	
	Industrial & Domestic Municipal Wastewater (Wastewater Treatment Discharge)	5	
	None Addressed (e.g., monitoring, fundamental science Other Issues (Monitoring, basic research, etc.)	46	45

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Terrestrial and Freshwater Ecosystems

Habitats and Species

The two inventories contain many more recently completed studies (27) than recommendations (5) for research in terrestrial and freshwater habitats. Only a limited number of upland habitat studies contributed to the inventories. Recently completed studies focus on multiple topics related to salmonids (e.g., effects of climate change, benefits from stream restoration, and effects of hatchery management, etc.), presence of toxins and pesticides in freshwater fish, protection of biodiversity in urban areas, and other native species (e.g., Olympic mudminnow, pocket gopher). Recommendations in the *Puget Sound Science Update* (Partnership 2011a) propose analyses of altered hydrology and soil conditions due to impervious surface impacts, compaction, and reduced absorption. Comparison of the inventories suggests studies of impervious surface on hydrology and soil conditions are a current research gap.

Water Quality and Quantity

Similar to habitats and species, there are many more recently completed studies (26) than recommendations (3) for research specific to water quantity and quality. Recently completed studies focus on water quality of streams and lakes, sediment contamination, groundwater contamination, sediment transport and stream channel development, and freshwater flows. Key recommendations include assessing freshwater flows using improved stream gauge data and work to institutionalize agricultural best management practices in target watersheds to improve water quality. In addition, analyses suggest that studies to establish groundwater requirements to support regional stormwater management strategies are a need.

Marine and Nearshore Ecosystems

Habitats

The inventories contain 40 recently completed/ongoing studies and 29 recommended studies specific to marine and nearshore ecosystems. Study recommendations for habitats focus on coordinating and measuring the benefit of a network of marine protected areas (MPAs), understanding the effects of shoreline armoring, understanding changes in abundance and distribution of eelgrass, using adaptive management for nearshore restoration, and measuring the benefits of restoration. Analyses of the inventories suggest that research is occurring in these areas, as well as derelict fishing gear impacts, sediment quality and transport along shorelines, and effect of dams (e.g., Elwha) on beach morphology. Recommended work is needed to improve marine protected area (MPA) management and effectiveness, analyze and monitor the effects of shoreline armoring, and conduct nearshore restoration in an adaptive management framework. Specifically, adaptive management recommendations suggest that the restoration should be measured in ways that are compatible with land use planning models, that emphasize ecological function, and that provide feedback to decision making during future restoration planning and implementation (Partnership 2008).

Species and Food Webs

For marine and nearshore species and food webs, the inventories contain many recently completed/ongoing studies (50) as well as recommendations (31). Most recommendations were in the *Puget Sound Science Update* (Partnership 2011), the *21st Century Salmon and Steelhead Initiative* (WDFW 2008), and the *2009-2011 Biennial Science Work Plan* (Partnership 2008). Recommendations focus on salmon recovery but also include other fish, such as forage fish and mid-water species of fish. Research gaps include a long-term assessment of both major forage fish species and bentho-pelagic fish in Puget Sound, food web structure and processes, and more detailed analysis of trends in marine bird abundance. Recommendations indicate a need to identify stressors within the food web, their effects on forage fish, and food web influences on the population dynamics of valued species in Puget Sound. For salmon recovery, recommendations generally relate to improved coordination across the region to effectively and efficiently implement goals for salmon recovery, monitor juvenile fish to determine effectiveness of recovery actions, and continued work on improving the management of recreational and commercial fisheries.

Pollution

The inventories contain a moderate number of recently completed/ongoing studies (13) and recommended studies (6) specific to pollution. More inventory work could help determine additional studies and how well current work answers critical questions. Recently completed/ongoing studies focus mostly on water quality topics such as nutrients, pathogens, and toxins; dissolved oxygen trends in Hood Canal (Newton et al. 2011), South Sound (Kolosseus and Roberts 2009), and the greater Puget Sound Region (Department of Ecology 2011a); harmful algal blooms; and the ecological coupling between the watershed and the estuarine and marine waters of the Puget Sound/Salish Sea. Recommendations are generally more specific to stormwater pressures and were from *Control of Toxic Chemicals in Puget Sound, Phase 2: Pollutant Loading Estimates for Surface Runoff and Roadways* (EnviroVision et al. 2008) and the *2009-2011 Biennial Science Work Plan* (Partnership 2008). Analyses of the inventories suggest that research needs are to analyze the effects of stormwater on receiving waters, habitat, biota, or human health in a watershed; study the relationship between pollution source control efforts and specific land uses; and support further understanding of the effectiveness of stormwater management techniques at the watershed scale.

Climate Change

Several studies and recommendations in the inventories identify climate change as one of the key pressures on ecosystem components. Recently completed/ongoing studies (14) and recommended studies (12) focus on specific questions about climate change that are applicable to some or all ecosystem components. These include focused climate modeling, impacts to humans, and impacts to natural resources. Recommended study topics are to focus on collaboration, communication, and partnership of research communities to foster understanding of climate change consequences. Work yet to be done in this area includes

downscaled climate projections, vulnerability assessment of local communities and infrastructure, and development of adaptation strategies.

Human Dimensions

The inventory contains few recently completed/ongoing studies (4) related directly to humans. These were specific to human health and focus on the risks of heat events and air pollution associated with climate change, recent trends in fecal coliform pollution in shellfish, and recent trends in paralytic shellfish toxins. Recommendations for research in human dimensions (5) show increasing awareness of the importance and breadth of human dimensions as part of the science agenda (Partnership 2011). Suggested studies include additional focus on environmental contributions to human health, the use of social sciences for ecosystem management; developing a human dimensions actions framework; and developing a Social Sciences Strategic Plan targeted toward ecosystem recovery in Puget Sound. The *2009-2011 Biennial Science Work Plan* (Partnership 2008) recommends specific social science research to advance our understanding of how people and the environment interact. Recommendations include developing socioeconomic indicators to measure the impact of ecosystem change or restoration on human uses of ecosystem services, estimating monetary values for some ecosystem indicators using relevant economic models, socioeconomic factors and empirical studies of human uses of the ecosystem, and human response to climate changes.

Sustaining, Coordinating, and Using Science to Adapt Actions

A variety of primary sources recommend actions for sustaining, coordinating, and using science needed for adaptive management of recovery and protection actions in Puget Sound. The *Puget Sound Science Update* (Partnership Science Panel 2010, Partnership 2011), *Strategic Science Plan* (Partnership 2010), and *2009-2011 Biennial Science Work Plan* (Partnership 2008) include and summarize these. These recommendations target two fundamental issues: (1) identifying priority research and monitoring and (2) developing and sustaining the technical and institutional capacity to generate, analyze, and communicate scientific information for decision-making. This section focuses on the second issue. The following key topics emerge from recommendations on this issue:

- Sustaining and improving monitoring
- Developing an integrated set of decision support tools
- Managing and communicating data
- Supporting science education and outreach

Recommendations for monitoring occur universally in the source documents addressing adaptive management. These include sustaining ongoing programs that currently provide data on the status and trends of ecosystems. Key areas include improving status and trend monitoring through better coordination and implementing effectiveness monitoring to test whether conservation actions are having the intended results. Other recommendations are to improve decision support tools including developing ecosystem and human well-being

indicators; conducting risk assessments of the pressures on the ecosystem; using viability analyses to help decision makers identify recovery targets; and developing and using quantitative and qualitative tools for evaluating how policy decisions affect future ecosystem states and the benefits to humans.

Recommendations for management and communication of data focus on developing flexible data exchange capabilities to make indicator data and other assessment information available and accessible to broad communities of users. Recommendations for science education and outreach suggest enlisting conservation scientists to work with educational institutions in training younger scientists and practitioners, developing a network of scientists to provide advice and support to decision makers, and encouraging internships and fellowship programs.

In terms of ongoing research to sustain, coordinate, and use science to adapt actions, monitoring is occurring throughout Puget Sound via a wide variety of programs. In 2010, a matrix of current agency monitoring programs was developed for the Natural Resources Reform Workgroup (see Appendix D). The Workgroup was formed in response to the Governor's 2009 initiative (EO 09-07) to better coordinate efforts of state natural resource agencies. The matrix highlights ongoing agency monitoring programs (rather than one-time studies, individual research projects, etc.) and is not an exhaustive inventory of all monitoring. For example, the inventory of recently completed and ongoing research completed for this report (see Appendix B) documented several monitoring studies not listed in the Workgroup matrix of programs, including focus on environmental stressors in lakes, pesticides in freshwater streams, eelgrass trends in areas of the San Juan Archipelago, Chinook salmon life history traits in the Nisqually River estuary, and shallow groundwater flows in the Skagit River delta. In February 2011, the Partnership Leadership Council endorsed a Puget Sound Coordinated Ecosystem Monitoring and Assessment Program to coordinate and improve ecosystem monitoring.

In 2010, the Partnership established a Dashboard of Ecosystem Indicators (Indicators Action Team 2010) and 16 recovery targets related to these indicators to judge progress of recovery. The Partnership completed a qualitative assessment of threats (Partnership 2009) but based on the *Puget Sound Science Update* (Partnership 2011) the Science Panel recommended that the scientific basis of this be improved to inform decisions about where and when to focus on different risks to the ecosystem. Inventories indicate that qualitative and quantitative tools to evaluate policy options and future scenarios exist or are being developed, but these are often specific to an issue or topic and are not adequately integrated to address ecosystem outcomes.

Recommendations from the Scientific, Practitioner, and Stakeholder Communities

This section summarizes science recommendations offered by the scientific and conservation practitioner communities. Scientific and conservation practitioners provided their recommendations through two different processes. First, a variety of technical teams convened during development of the *Action Agenda Update* identified science needs that were later reviewed by the Science Panel. Topic-specific interdisciplinary teams and working groups of scientists, practitioners, policy analysts, and stakeholders convened by the Partnership to

develop strategies and near-term actions for stormwater, runoff from the built environment, shoreline alteration, land development, and floodplain management were asked to assess and describe areas of scientific uncertainty and decision-critical needs. Other science teams, such as the Recovery Implementation Technical Team and Nearshore Ecosystem Recovery Team, provided a list of science needs associated with salmon recovery and nearshore ecosystems, respectively. Finally, organizations implementing recovery and protection actions at the scale of local geographies and watersheds, such as Action Area caucuses, submitted recommendations to the *Action Agenda Update* that included science needs. Summaries of these recommendations are provided in Appendix E.

Second, the Partnership contacted approximately 200 scientists from academia, state, federal, local agencies, tribes, environmental organizations, and other stakeholders to request recommendations on scientific needs. Respondents were asked to identify key areas of scientific uncertainty and areas where the lack of social, natural, or physical scientific work is impeding our ability to recover Puget Sound. Approximately 45 scientists and other stakeholders responded to the request, providing over 150 responses (Table 2). Their responses are provided in Appendix F.

Table 2. Number of recommendations from the scientific community summarized by ecosystem components or pressures corresponding to key strategies of the *Action Agenda Update*.

Ecosystem Component or Pressure		# of Responses
Upland, Terrestrial & Freshwater	Habitats	12
	Species & Food Webs	7
	Mitigation	4
Marine & Nearshore	Habitats	10
	Species & Food Webs	36
	Mitigation	8
Pollution	Toxics	15
	Runoff from the Environment	10
	Wastewater	3
	Shellfish	1
	Oil Spills	0
	Other	1
Climate Change		7
Human Dimensions		8
Sustaining, Coordinating, & Using Science to Adapt Actions	Building Capacity	4
	Foundational Questions	9
	Scientific Tools for Informing Policy	5
	Integrated, Sustained Monitoring	9
	Education, Training & Outreach	3
Total		**152**

Upland, Terrestrial and Freshwater Ecosystems

Key scientific questions pertinent to upland and terrestrial habitats center on freshwater stream flows, biodiversity protection, corridors and connectivity, and soil absorption as it

relates to groundwater recharge. Recommendations for stream flows include improving the scientific basis for determining water budgets needed to set low stream flow standards in critical watersheds identified in the salmon recovery plans (Shared Strategy 2007), understanding how land use patterns influence peak events across a watershed, assessing pressures that specifically affect stream flow, and linking these to ecologically more robust indicators of stream flow than the current indicator chosen by the Partnership. Other habitat recommendations focus on reducing uncertainties about the effectiveness and response of habitat restoration in estuaries and testing the assumptions about regulatory standards, such as the effectiveness of the critical area ordinances for site-scale protection of habitats and priority species, and attaining no net loss in mitigation projects.

Recommendations for species and food webs identify key needs for research and monitoring on specific factors that might be limiting recovery of salmon in fresh water (e.g., predation, harvest, hatcheries, loss of habitat), along with better analyses of how these are related and interact. Other species and food web recommendations include questions about basic distribution, habitat requirements, and abundance of native freshwater species, such as non-game fish and freshwater mussels. Suggestions also identify the effectiveness of stormwater management, as measured by the response of instream biota at different geographical and biological scales, as a science need.

Marine and Nearshore Ecosystems

Approximately one-third of the recommendations are directed toward marine and nearshore ecosystems. Attention on habitat focuses on the historical abundance of eelgrass and kelp, understanding how the modification of shorelines and sediment affects nearshore biota, and research on the outcomes and effectiveness of restoration. Several suggestions focus on monitoring large-scale restoration (such as the Elwha River) while others are specific to restoration strategies such as beach nourishment.

Scientists note that the lack of long-term system monitoring has resulted in a poor understanding of food web interactions and how transboundary processes (e.g., migrations, oceanographic fluxes, runoff, human activities, etc.) influence the internal dynamics of the marine ecosystem. Recommendations include developing better species and food web indicators, understanding distribution and habitat use of forage fishes, and assessing genetic connectivity among populations of marine biota in Puget Sound with other parts of the Salish Sea and the Washington coast. Recommendations for individual species are focused on the decline of marine birds (western grebe, marbled murrelet), native oyster restoration, variability of Dungeness crab production by year, and rockfish conservation and recovery strategies.

Pollution

The majority of scientific recommendations pertaining to pollution are directly related to toxins. Scientists and practitioners indicated there are basic uncertainties about the source of some toxic chemicals, the threshold for adverse effects on biota and humans, and the effects of these toxins on marine species at the population and community level. Scientists recommend an assessment of the relative impacts of various toxins along with targeted science on their

specific sources, transport, and fate. Others suggest priorities for pollution that focus on runoff from the built environment. These include monitoring of bacteria and harmful algal blooms (and biotoxins) on nearshore beaches and work to understand the community structure and dynamics of phytoplankton in marine waters. Recommendations focus on the source, transport, and fate of nitrogen from upland areas and the effects of changes in dissolved oxygen concentrations on species. Scientists identify emerging contaminants (e.g., endocrine disruptors, pharmaceuticals and personal care products, Bisphenol A, etc.) in wastewater as an important priority and recommend developing analytical methods and monitoring to understand their potential to cause adverse effects on both biota and humans.

Climate Change

The submissions by science and practitioner communities highlight several key uncertainties about future impacts from climate change. They suggest a variety of indicators and monitoring studies to collect data about the degree of ongoing change. These include monitoring stream and lake temperatures, the structure of benthic communities, salinity, and pH. Scientists also raise broader questions, such as: how will ocean acidification affect the food web; how will invasive species respond to a changing climate and what impacts will those changes have on ecosystem health; and in what ways will genetic variability limit or allow populations of native species to adapt?

Human Dimensions

Natural and social scientists identify significant gaps in our understanding of human dimensions in ecosystem recovery. Key recommendations include synthesizing the existing social science literature and data, and assessing the assumptions and techniques that can be used to engage the public and change behavior. Scientists and practitioners also recommend analyses of the economic and social impacts of biological resource uses. Ideas include assessing the economic values of the ecosystem and monitoring these over time. These are considered part of an overall empirical valuation of how restoration and protection activities, such as those implemented by Action Agenda strategies, affect ecosystem services.

Sustaining, Coordinating, and Using Science to Adapt Actions

This broad category includes submissions pertinent to building capacity for a coordinated ecosystem restoration program, answering foundational science questions, developing tools for informing policy, and education and outreach. The scientific and conservation practitioner community notes that the current systems of governance and management should be analyzed to determine where programs and actions are most efficient and effective. Related to this is building capacity for better coordination between science disciplines, institutions, non-governmental organizations, and the tribes.

Scientists also identify basic research questions about the Puget Sound ecosystem that were not specifically targeted in one of the categories discussed above. One group of questions focuses on developing quantitative links between when, where, and how land-based human activities (e.g., urban development, agriculture, industrial development, or logging) influence

ecosystem function in marine ecosystems. Another group is interested in understanding the natural variability of ecosystem components, such as salmonid distributions and uses of specific nearshore habitats, the role of natural sources of nitrogen on dissolved oxygen levels, and climate variability.

Developing tools to coordinate and prioritize science is also important. Recommendations consider coordinated ecosystem monitoring focused on indicators of ecosystem recovery targets to be a high priority. Other aspects of recommended monitoring include sustaining existing monitoring programs, developing and coordinating effectiveness monitoring of restoration projects, and monitoring to test the effectiveness of critical areas ordinances and other regulatory programs executed by state resource agencies. Other scientific tools that scientists recommend for informing policy included seafloor mapping, spatial analysis of stressors, and mathematical models to prioritize recovery efforts.

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Priority Science for 2011-2013

This section describes priority areas for research, monitoring, and modeling that are most needed to advance recovery and protection of Puget Sound in the next few years based on the approach and analyses described above. This section is organized by the *Action Agenda Update* strategies that give rise to these priorities. The *Action Agenda Update* provides addition detail on the relationship of these strategies to ecosystem recovery targets.

Upland, Terrestrial, and Freshwater Ecosystems

Upland and Terrestrial Habitats

Strategy A1. Focus land development away from ecologically important and sensitive areas.
Strategy A2. Permanently protect the intact areas of the Puget Sound ecosystem that still function well.
Strategy A3. Protect and steward ecologically sensitive rural and resource lands.

- Analytical tools to describe options for where to protect, where to restore, and where to develop are a key priority for managing how human dominated landscapes across a range of pressure intensities can best contribute to maintaining desired ecosystem goods and services. Globally, conservation efforts have used a variety of approaches that emphasize different characteristics of ecosystem function and biodiversity, usually on a spectrum of irreplaceability and vulnerability (Brooks et al. 2006). These have different strengths and weaknesses, including the inherent biases associated with the kind of data that were availability and failure to incorporate broader ecosystem services and other factors into the assessments (Kareiva and Marvier 2003). In Puget Sound, the Department of Ecology and Department of Fish and Wildlife are developing tools that attempt to identify the most important areas to protect, restore, and develop using characteristics of water flow (surface storage, recharge, and discharge), water quality (sediment, nutrients, pathogens, and metals), and landscape assessments of terrestrial, freshwater, and marine fish and wildlife habitat (http://www.ecy.wa.gov/puget_sound/characterization) (Stanley et al. 2011). Not all of these have been completed. Additionally, no decision support tools exist to resolve ambiguities and conflicts or identify synergies among the different watershed characterization tools and other analyses for identifying priority habitats, such as the *Puget Sound Chinook Salmon Recovery Plan* (Shared Strategy 2007). Key priorities for this work are to:
    - Complete the watershed assessment tools that have been started.
    - Develop decision support tools to assist in resolving ambiguities or conflicts and to identify synergies among the different watershed characterization tools.
    - Improve the assessment tools by incorporating additional characteristics of the ecosystem and ecosystem services that are not in the initial tools.
    - Validate key assumptions in the models.

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- Incorporate social science research to guide development of adaptive management structures that link restoration science to management decision-making.

Floodplains

Strategy A5. Protect and restore floodplain function.

- Estimating the value of floodplains in terms of all the ecosystem services they provide is a key scientific priority. Floodplains are vital for storing floodwaters, recharging aquifers, filtering water, retaining sediment and nutrients, and supplying crucial habitat components needed fish and wildlife (Beechie 1994, Spence et al. 1996, Benda et al. 2001, Ziemer and Lisle 2001, Collins et al. 2002). Much of the built environment also occurs in floodplains and is subject to damage from floods, slides, and other natural disasters. Floodplains are often constrained by levees and dikes to reduce these damages and enhance the built environment. However, decisions based on economic analyses of the tradeoffs between these different aspects of floodplains do not usually include the full valuation of floodplains (Batker et al. 2008).
- Developing key ecological indicators and implementing monitoring to assess key ecological functions of floodplains and to track their status is a key science priority. Although land use planners and scientists have identified many of the services and functions floodplains provide, little effort has been given to establishing a functional set of indicators and metrics for Puget Sound that can measure how floodplains are performing. Smith (2005), for example, resorted to a qualitative analysis of floodplain status in Puget Sound because of the lack of consistent data, and she also noted areas where no data for floodplains were available.
- Improving the understanding of the effects of vegetation on dikes and other flood control structures is a key scientific priority for floodplains.

Mitigation

Strategy A7. Increase the success rate of mitigation projects to achieve, at a minimum, no net loss of ecosystem function on a watershed scale.

- Developing key ecological indicators, assessing baseline conditions, and implementing subsequent monitoring to measure ecosystem function is a key priority for this strategy to be effective. Where current regulations address no-net-loss, such as in the Shoreline Management Act (RCW 90.58) and Shoreline Master Programs Guidelines (WAC 173-26-186s(8)), agencies have suggested lists of potential indicators but provide little more direction for choosing a suite that represents the ecological function of the area (Department of Ecology 2010).
- Conducting social science studies to describe the key institutional challenges to attaining no net loss or overall improvement is a key priority.

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Freshwater Ecosystems

Strategy A8. Protect and conserve freshwater resources to increase and sustain water availability for instream flows.

- Developing robust ecological indicators and implementing comprehensive monitoring for stream flows is a key priority. The Partnership currently has an ecosystem target based on 30-day summer low flows as a measure of ecological function of water quantity in streams. An increasing number of analyses, however, conclude that a single indicator, such as summer low flows, is inadequate for representing the ecological functions that flow regimes provide (Poff et al. 1997, Bunn and Arthington 2002, Naiman et al. 2002, NRC 2007). In addition, the indicator is based on existing data for 13 rivers in Puget Sound, which only partially represents the region's key rivers and streams.
- Validating stream flow targets in terms of their affects on the abundance, productivity, distribution, and life-history diversity of salmon (McElhany et al. 2000) is a key priority.

Freshwater Species and Food webs

Strategy A9. Protect and recover salmon.

- A key priority for salmon recovery is to develop analytical tools to evaluate whether strategies to address factors limiting the productivity of salmon are being addressed in the most effective combinations, at the right times, and with the appropriate amount of effort to lead to recovery. Ruckelshaus et al. (2002) noted that single-factor analyses of the primary pressures on salmon populations – loss of habitat quantity and quality, hydroelectric dams, artificial production, and harvest – were inhibiting salmon recovery because they failed to capture all the pressures on salmon or the interactions among pressures. In addition, single-factor analyses tend to focus on causes (and therefore blame) rather than solutions. Ruckelshaus et al. (2002) called for integrated analysis of pressures that could inform decisions about how to prioritize and sequence recovery actions. The *Puget Sound Salmon Recovery Plan* (Shared Strategy 2007) also identified this need. Efforts to collect data on intensively monitored watersheds by state, federal, and tribal scientists (http://www.ecy.wa.gov/programs/eap/imw/index.html) are underway but analytical tools remain largely undeveloped and salmon recovery implementers are making crucial decisions without these analyses.
- Information on the causes of decline in marine survival of salmon as they leave their natal rivers and exit Puget Sound is a key priority. Growth and survival of salmon during this life-history phase are strongly correlated with overall marine survival (Duffy 2009). Evidence that survival rates of some species during the Puget Sound phase are rapidly declining (Moore et al. 2010) is a warning that the environment may be changing in unanticipated ways. This could have important effects on the success of salmon recovery.

Strategy A11. Prevent and respond to the introduction of freshwater and terrestrial invasive species.

- Assessing the risks imposed by invasive species is a key priority. The Partnership rated the impact of invasive species on the ecosystem as "high" (Partnership 2009) but more detailed taxonomic and geographic descriptions of the likelihood of impacts are lacking. The Washington Invasive Species Council currently uses a qualitative screening tool for prioritizing the most problematic species in or near Puget Sound. More precise risk assessments are needed for problematic species. Tools to do this for the Puget Sound are needed as well as the situation-specific data that many quantitative ecological risk assessment frameworks require (Andersen et al. 2004). However, relative risk can be estimated using relative risk frameworks across varying scales with existing information to better inform management actions (Colnar and Landis 2009).

Marine and Nearshore Ecosystems

Marine and Nearshore Habitats

Strategy B2. Protect and conserve relatively intact ecosystems to maintain the health of Puget Sound.
Strategy B3. Implement and maintain priority nearshore and marine ecosystem restoration projects.

- Developing the analytical tools to identify priority areas for protection and stewardship is a key need for these strategies. Valuable information is available on the status and historical changes in physical structure of marine and nearshore shorelines (Simenstad et al. 2011). This information can assist in making decisions about the potential for restoration and protection. Information and analytical tools linking these to other key considerations that are important are lacking, however, and need to be improved. Important improvements include:
    - Incorporating additional physical attributes as well as biogenic structures like eelgrass, kelp, or coastal forest condition into estimates of ecosystem services provided by shorelines
    - Assessing the impacts of barrier features on embayments
    - Increasing understanding of the effects of protection and restoration at different spatial and ecological scales ranging from local domains (e.g., marshes, beaches, drift cells) to process domains (e.g., geomorphic units and salinity regimes) to landscape domains spanning many kilometers (Simenstad et al. 2006).
    - More robustly incorporating rare forms, species, and processes in understanding landscape composition
    - Including landscapes and habitats used by target species
    - Incorporating threats to ecosystem services and potential for protection
- As state and federal agencies, local governments, tribes, and citizen groups invest in nearshore restoration; it is a high priority to develop the adaptive management structures that link restoration science to management decision-making. Nearshore areas are critical

Puget Sound environments supporting salmon, forage fish, shellfish, wetlands, tribal trust uses, and crucial hydrologic and geologic inputs. Habitat features of large river deltas are particularly important in Puget Sound restoration because more than 50 percent of intertidal areas, including marshes and mudflats, in these deltas has been lost since 1850 (Bortleson et al. 1980). Nearly 33 percent of Puget Sound shorelines have some type of shoreline modification structure. Across all tidally influenced areas of Puget Sound (shorelines, estuaries and rivers) 82 percent of vegetated wetland area has been lost since historic maps were created in the 1850s to 1890s (Nearshore Habitat Program 2000, Washington Department of Natural Resources as cited in PSAT 2007, Simenstad et al. 2011). Recent research on the role of large river deltas in supporting the ecosystem as a whole emphasizes the need for restoration of these systems. In fact, significant restoration actions are now planned or underway for several of the Sound's large deltas – for example the Skagit, Nisqually, Skokomish, and Elwha (Ellings 2008, Ellings et al. 2010, USGS 2011a, 2011b, PSNERP 2011a, 2011b). Developing a robust system of evolutionary learning from these important but diverse efforts is critical.

Strategy B6. Implement a coordinated strategy to achieve the 2020 eelgrass recovery target

- Information the about key stressors on eelgrass, the source of the stressors, and locations where they occur is a priority for developing a recovery strategy. Review of the scientific literature documents an extensive suite of ecosystem services associated with eelgrass (Mumford 2007, Dowty et al. 2010). In the Puget Sound, for example, eelgrass provides spawning habitat for Pacific herring, protection and cover for young juvenile salmon and important feeding areas for water birds (Phillips 1984, Simenstad 1994, Wilson and Atkinson 1995, Butler 1995) and other benefits. The Puget Sound Partnership adopted eelgrass as an indicator of the health of Puget Sound and set a target of increasing eelgrass area in the Puget Sound by 20 percent by 2020. Reaching this target will require a focused strategy that reduces stressors on eelgrass and allows eelgrass to expand geographically.

Species and Food Webs

Strategy B7. Protect and restore marine and nearshore species.

- Having information and analytical tools that allow decision makers to understand the tradeoffs in managing a suite of marine species and the multiple stressors affecting those species is a key science priority. The Partnership, for example, has adopted recovery targets independently for different marine species including eelgrass, herring, shellfish, Pacific salmon, orcas, and for reducing different stressors such as shoreline armoring and toxic pollution. Attaining all of these targets may be impossible given the food web dynamics of Puget Sound. Current food web models (e.g., Harvey et al. 2010) are largely static and not spatially explicit. Understanding how Puget Sound food webs change over time and space with respect to different stressors will greatly improve the ability to make informed, strategic decisions.

- Biological and sociological studies to understand the conservation and sociological roles of marine protected areas for habitat and species protection, ecosystem restoration, and sustaining usual and accustomed tribal fishing areas in the Puget Sound (Van Cleve et al. 2009) is a key science priority. Conversation groups and agencies often advocate for marine protected areas and reserves (WDFW 1998, Gaydos et al. 2005) but successful implementation requires understanding both the conservation and sociological benefits (Agardy et al. 2003).

- Identifying the stressors on specific groups of species in the Puget Sound food web and the potential magnitude of their individual and combined effects is a key science need. Several key groups of species are priorities for focus:
    - Forage fish - Pacific herring, sand lance, surf smelt, longfin smelt, eulachon and other schooling forage fishes occupy a key position in the Puget Sound food web. Ecological processes involving forage fish – both up and down the food chain – may control other important ecosystem processes and populations of valued species in the Sound directly or indirectly. The open-water food web provides ecological life-support for valued species in Puget Sound such as salmon, orcas, and water birds. Forage fish are a valued economic resource themselves. Understanding the stressors on forage fish – which could include changing species compositions of prey, competitors, or predators; loss of forage fish spawning habitat; invasive species; novel disease; ocean acidification; and the driving climate change and human population impacts (Penttila 2007) – is important in identifying where stressors occur, the magnitude of their impacts, and how they can be reduced.
    - The abundance of multiple species of Puget Sound marine birds has declined sharply over the last 20 years, in some cases as much as 95 percent (Nysewander et al. 2005, Wahl 2002, Bower 2009). The causes of these changes in abundances are not well known. Without understanding the causes, such as the possibility that changes reflect changes in geographic distribution or response to stressors in the Puget Sound or elsewhere, for example, it is difficult if not impossible to develop appropriate recovery strategies.

- Information on the sources of nutrients (nitrogen compounds) that enter Puget Sound both from groundwater and external marine sources is important for developing strategies to maintain water quality for Puget Sound food webs. Decomposition of large biomasses of phytoplankton that feed on nutrients can drive dissolved oxygen concentrations to levels that can threaten marine life in late summer and early autumn in Hood Canal and other areas with low overturning circulation (Warner et al. 2001). One source of nutrients is likely from humans and other terrestrial sources (Paulson et al. 2006, Newton et al. 2011), but the largest source of nitrogen is seawater entering the Canal. Historically, cycles of low oxygen have been occurring in Hood Canal long before the 20th century, suggesting that physical mixing from deep-water ventilation may be the most important natural process controlling oxygen levels in Hood Canal (Crecelius et al. 2007). Understanding the relative contribution

of these sources seasonally and geographically is a key need for developing strategies to address low dissolved oxygen levels.

Strategy B8. Prevent and respond to the introduction of marine invasive species.

- Assessing the threats of invasive species is a key priority. Tools to do this for the Puget Sound are needed, as is the situation-specific data that many quantitative ecological risk assessment frameworks require (Andersen et al. 2004). However, relative risk can be estimated using relative risk frameworks across varying scales with existing information to better inform management actions (Colnar and Landis 2009).

Pollution

Toxics

Strategy C1. Reduce the sources of toxic chemicals entering Puget Sound.

- Implementing studies to ensure that Washington State's water quality standards and sediment management standards are protective of human and wildlife consumption of Puget Sound fish and other seafood is a scientific priority. This requires scientific information, including identifying appropriate assessment factors and benchmarks for assessing fish and shellfish consumption rates, especially by tribal members and other subsistence fishers; contaminant levels in Puget Sound crab and prawns; environmental transport and trophic transfer and accumulation of persistent toxicants; linkages between contaminant levels in the ecosystem and population-level effects on biota (Department of Ecology 2011b; Department of Ecology and King County 2011), and other health risks for the most vulnerable populations of Puget Sound residents.
- Describing the availability, feasibility, and safety of alternatives to products and processes that use and release toxic chemicals of concern in the Puget Sound ecosystem is a scientific priority. This includes information on the non-agricultural use of copper-based pesticides in Washington and evaluation of alternatives to copper for these pest control purposes; identification and assessment of alternatives to commercial uses of phthalates; evaluation of toxic materials in roofing materials; standard practices for alternatives assessment; and development of Green Chemistry expertise and capacity in Puget Sound region institutions.
- Developing integrated monitoring and assessment of toxic chemical sources, exposure, and effects is a scientific priority. This includes status and trends monitoring of toxics in and released to Puget Sound; effectiveness of strategies and actions to reduce and prevent toxic chemicals from entering the Puget Sound environment; and annual reports that compile and synthesize information on results and effectiveness from multiple programs. Risk assessments of contaminants in the Puget Sound in the context of other stressors are needed to quantify the relative magnitude of risks and to help prioritize actions appropriately. The risk analysis would also identify important data gaps and monitoring needs for evaluating the effectiveness of corrective actions. This could include synthesis efforts such as might be developed by enhancements of the Puget Sound Toxics Box Model

(Pelletier and Mohamedali 2009), the Puget Sound food web toxics model (Stern et al. 2009, Condon 2007), and site-specific mass loading studies (King County 2011). Validating assumptions and information needs about releases of toxic chemicals assessed in the Puget Sound Toxics Loading Study (Norton et al. 2011) is also important.

- Synthesizing information on emerging contaminants of concern and describing their risk to the Puget Sound is a scientific priority. This includes investigations of the chemical causes of endocrine disruption in Puget Sound species; pharmaceuticals and personal care products, surfactants, and their degradation products, plasticizers, pesticides, and nanomaterials; and emerging pathogens and viruses.

Runoff from the Environment

Strategy C2. Use a comprehensive approach to manage urban stormwater runoff at the site and landscape scales.

- Developing monitoring and assessment of benthic invertebrates in small streams to evaluate stormwater management and other efforts to protect and restore streams and their functions is a priority. Priority assessments related to this issue include establishing and maintaining a comprehensive inventory of benthic indexes of biological integrity (B-IBI) in small streams; using monitoring results to identify basins for focused attention to achieve the Partnership's 2020 ecosystem target streams (basins where streams have "excellent" and "fair" B-IBI scores); and status and trend monitoring of stormwater and other sources of stressors in small streams using B-IBI and other stream quality parameters.
- Evaluating the effectiveness of low impact development (LID) projects and stormwater management best management practices and programs is a science priority. Assessment of these will guide the adaptation of stormwater management practices and programs by local and regional jurisdictions to ensure that stormwater does not impair receiving waters as measured by 2020 ecosystem recovery targets for shellfish bed restoration, swimming beaches, toxics in fish, marine sediment quality, freshwater quality, and benthic invertebrates in small streams.
- Evaluating land uses and associated pollutants that would require treatment beyond sediment removal is a science priority for ensuring that stormwater management can achieve stormwater-affected 2020 ecosystem recovery targets.
- Evaluating the projected environmental benefits of structural stormwater retrofits given varying levels effort to guide the extent of structural retrofits is a priority to help meet 2020 ecosystem recovery targets and ensure that the investments are efficient. Capital costs of retrofits will likely be $8 billion and involve $300 million per year in maintenance (Parametrix 2010). Spatially explicit assessments and considerations of how the potential benefits of habitat restoration are integrated into stormwater control technologies are important components of this.
- Studies to fill the key information gaps on the direct and indirect effects of pesticides on salmon and the food web they depend on are a science priority. Pesticides interact in

complex ways with the aquatic ecosystem, affecting primary producers, macroinvertebrates, and the growth and survival of salmon and other native species of fish, and also reflecting different patterns of use by humans. Integrating knowledge of the effects of pesticides and how they can be mitigated with habitat restoration is important to ensure that investments in salmon recovery are effective (Macneale et al. 2010, Johnson et al. 2011, Spromberg and Scholz 2011).

Wastewater

Strategy C5. Prevent, reduce and/or eliminate pollution from decentralized wastewater treatment systems.
Strategy C6. Prevent, reduce and/or eliminate pollution from centralized wastewater systems.
Strategy C8. Control and manage pollution from discharges of wastewater from boats and vessels.

- Evaluating nitrogen reduction in public domain on-site system treatment technologies is a science priority. These evaluations will help guide development and construction of decentralized wastewater treatment infrastructure that reduces the release of nitrogen (Horner 2011).
- Studies of human-related contributions of nitrogen to dissolved oxygen impairments in sensitive Puget Sound marine waters are critical to identify the need for and elements of water quality cleanup plans. This includes completing the South Sound Dissolved Oxygen Study (Kolosseus and Roberts 2009), which will clarify the need for a South Puget Sound water quality improvement plan, and completing the development of the Puget Sound Dissolved Oxygen Model (Ecology 2011a), which will help identify areas where enhanced wastewater treatment may be needed for water quality improvements.

Shellfish

Strategy C9. Abundant, healthy shellfish for ecosystem health and for commercial, subsistence, and recreational harvest consistent with ecosystem protection.

- Establishing and funding sustainable pollution identification and correction (PIC) programs to identify and fix nonpoint pollution problems is a critical contribution to shellfish bed restoration, swimming beach protection and restoration, and other aspects of water body cleanup. Key factors affecting shellfish in the Puget Sound – temperature, salinity, oxygen, pollutants, and food types – can be influenced by land use, stormwater and sewage discharges, introduction of invasive species, and other human activities in addition to natural changes and cycles (Dethier 2006). The ecology of shellfish, which depends on the characteristics of the water column, makes them good indicators of ecological changes and of potential threats to human health and wellbeing. Shellfish also provide multi-million dollar ecosystem services to the Puget Sound (Northern Economics 2009).
- Research and monitoring are needed to understand the specific environmental conditions that produce toxic HAB and pathogen events. Harmful algal blooms (HABs) may not be as concentrated as toxic chemicals in some areas of Puget Sound, but they can produce toxins that kill fish and contaminate shellfish making them unsafe to eat (Backer and McGillicuddy

2006). Detection of HABs is increasing although the causes are not well understood (Van Dolah 2000, Zingone and Enevoldsen 2000, Sellner et al. 2003). This information is an important complement to existing HAB monitoring by federal, state, and tribal partners and will improve the prediction and forecasting capability so that health managers can mitigate economic impact to the shellfish industry and risk to the public from consuming tainted seafood.

Oil Spills

Strategy C10. Effectively prevent, plan for, and respond to oil spills.

- Completing a rigorous risk analysis of industry sectors to ensure there is an appropriate level of investment in reducing the risk of oil spills is a high priority science action. Many valuable species, habitats, and ecosystem services of the Puget Sound and much of the investment in restoration and protection to protect the Puget Sound are vulnerable to oil spills. A major oil spill could cost the state's economy more than $10 billion, impact 165,000 jobs, and reverse progress in ecosystem restoration (Department of Ecology and Partnership 2010). This analysis includes identifying high-risk areas and developing strategies to mitigate risks in these areas based on models of marine traffic, assessments of incidents and near-misses, and assessments of prevention measures such as vessel inspections and improvements in oil spill prevention standards.
- Inventory and describe baseline conditions for key species at risk from oil spills that can be used in assessments of natural resource damages from oil spills. These assessments are critical for not only assessing potential natural resource damages but also understanding the value of ecosystem.

Cumulative Water Pollution

Strategy C11. Address and clean up cumulative water pollution impacts in Puget Sound.

- Expanded monitoring of freshwater and marine water areas used for contact recreation will help protect human health from exposures during water-contact recreation, increase recreational services from the Puget Sound ecosystem, and engage the public in stewardship and monitoring associated with cleaning up Puget Sound's waters (e.g., O'Brien 2006).

Emerging Issues – Ocean Acidification

In the last 250 years of industrialization, the pH of the world's oceans has changed from 8.25 to 8.14 or approximately 30 percent (Jacobson 2005). This rate may be as much as two orders of magnitude more than any changes that have occurred in the last 65 million years (Ridgwell and Schmidt 2010). Acidification is also happening in Puget Sound (Feely et al. 2010). These changes are likely to have major impacts on many marine-dwelling species (Raven et al. 2005).

- Designing and implementing monitoring for variables of ocean acidification variables in and across the Puget Sound to understand the status, diversity and range of conditions.

- Developing tools to assess the risk and vulnerability of Puget Sound species to ocean acidification is a key priority.
- Developing adaptation strategies given the assessed vulnerability is a key priority.

Sustaining, Coordinating, and Using Science to Adapt Actions

Scientific Tools for Informing Policy

Strategy D1. Provide the leadership and frameworks to strategically set priorities for actions and funding to guide the Puget Sound recovery effort.

- An institutional analysis of the overall governance and management structure in which Puget Sound recovery strategies operate is a key social science priority of this plan. Understanding governance systems and management networks can guide strategies for using governance to make better decisions, help identify institutional reasons for actions that are inconsistent with Puget Sound recovery (called for in the Partnership's enabling legislation, RCW 90.71.370), and help identify solutions that might not otherwise be obvious. This analysis could increase the capacity for institutions, non-governmental organizations, and the tribes to work better together, recognizing the need to bridge values and management approaches.
- An integrated risk assessment of the impacts of different pressures on the ecosystem is a key science priority. Lack of a comprehensive estimate of the risks to the Puget Sound and the Salish Sea basins and the valued ecosystem services they provide is a major limitation for using science to inform recovery strategies and make decisions. Where assessments exist, they are typically based on only a few endpoints and stressors and at limited spatial/temporal scales (Hart Hayes and Landis 2004, Markiewicz and Landis 2011). Assessments are a key step in integrated ecosystem assessment (Levin et al. 2008). Conservation strategies often prioritize actions that address pressures that have potentially high impacts and that are imminent. The Partnership rated pressures qualitatively at the Puget Sound geographical scale in 2009 (Partnership 2009) using *Open Standards for the Practice of Conservation* protocol (https://miradi.org/openstandards). Although useful, the assessment needs to be improved to incorporate structural elements common to most risk assessment frameworks to make it more useful. These include incorporating different geographical scales (watershed and Puget Sound), uncertainty, interaction among pressures, consistent application of criteria, and more comprehensive data. In addition to providing an assessment of pressures by how they affect different ecological indicators, risk assessments can describe the affects on tangible services that people value. Developing the structure for this kind of analysis also provides the quantitative foundation for comparing and evaluating different strategies by how much they reduce pressures.
- The *Action Agenda Update* can have over 200 near-term actions spread across the four main strategies for recovering and protecting Puget Sound. Prioritization of these near-term actions for limited available funding based on their likely effectiveness in protecting and recovering the ecosystem is scientifically and socially challenging. Developing a systematic,

transparent, and ecologically based prioritization tool that will support evolutionary learning and adaptation is a key science priority.

Monitoring

Strategy D3. Implement a transparent performance management system that tracks and reports progress in achieving ecosystem recovery targets, identifies barriers, and finds solutions to adaptively manage recovery.
Strategy D4. Implement a strategic science and regional monitoring program that improves decisions about how to restore and protect Puget Sound.

- Ecosystem recovery is complex, outcomes are difficult to predict, and surprises are inevitable (Christensen et al. 1997). If regional ecosystem recovery efforts are to be efficient and effective, they need to be designed to learn and improve (Holling 1978, Lee 1993). This does not occur without comprehensive, coordinated monitoring supported by long-term, stable funding (Busch and Trexler 2003, Lindenmayer and G. E. Likens 2010). This is a key priority for the success of Puget Sound recovery.

Human Dimensions in Ecosystem Recovery

Strategy D7. Build social and institutional infrastructure that supports stewardship behaviors and removes barriers.

- Developing assessments of ecosystem services (MEA 2003) to help decision makers make informed decisions about restoration and protection is a key social science priority. As more studies begin to assess the value of ecosystems (Austin et al. 2007, Naber et al. 2008, Batker et al. 2008), it is becoming obvious that many conservation decisions are made with incomplete information. For example, risk assessment can formally incorporate ecosystem services as endpoints, but this requires better information than current exist. The availability of this information will help decision makers advocate for funding, set priorities for protection and restoration, and make better-informed decisions about the consequences of different actions.
- Developing socioeconomic indicators to help measure and report on the human dimension component of the Partnership's conceptual model for ecosystem recovery is a key science need. This framework could be refined for unique "place based" analyses to capture the stressors and valued social, economic, and cultural components of different communities and geographies.
- Social science research, reviews, literature databases, and synthesis papers relevant to ecosystem recovery have not been institutionally as available as physical and natural science literature to inform recovery strategies. A key social science priority is to conduct a baseline literature review and survey of data to identify resources and gaps that can be readily available and can be used by ecosystem recovery planners and practitioners.
- A key science need is to evaluate the most effective combination of regulatory, incentive, and educational programs for different demographics in Puget Sound. Characterizing the

role and connections of different communities and age groups to different ecosystem services and the Puget Sound environment provides key information for engaging citizens in stewardship. Understanding where incentive programs will or will not work and the characteristics that motivate changes in behavior as they relate to tradeoffs between the natural and built environment is key strategic information. This is important for engaging public support.

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Summary

Purpose and Approach

The purpose of *Priority Science for Restoring and Protecting Puget Sound: A Biennial Science Work Plan for 2011-2013* is to provide strategic focus on the science needed to recover and protect Puget Sound. This strategic focus can help direct allocation of the limited resources available for science to the issues and studies where they are most needed. The document is a key companion to the *Action Agenda Update*, which describes the long-term strategies and coordinated near-term actions to be implemented by state and federal agencies, tribes, cities and counties, other local jurisdictions, nongovernmental organizations, and the general public to recover and protect the ecosystem and the services it provides.

The Puget Sound Partnership Science Panel chose these actions based on a review of the questions that current research and monitoring are addressing, a review of recommendations from scientific reports and publications on the science needs for a program of ecosystem recovery in Puget Sound, and recommendations from a broad base of scientists, practitioners, stakeholders, and decision makers. Analyzing this information relative to a conceptual model of ecosystem recovery for Puget Sound (Figure 1) illustrated where gaps in scientific attention and knowledge are likely to occur.

Identifying gaps in knowledge does not immediately make them priorities for funding and investigation. To decide which gaps are priorities, the Science Panel asked two sets of questions. The first set focused on scientific questions: How much do we know? Where is the level of scientific uncertainty greatest? The second set focused on policy-science questions: What are the decision-critical questions and information? Where is lack of scientific information hindering progress in restoration and recovery?

Scientists are trained in evaluating scientific uncertainty. Evaluation of decision-critical issues, however, requires dialogue with decision makers and conservation practitioners. To determine which decision-critical issues are important, the Science Panel used (1) the perspectives collected from stakeholders and conservation practitioners who participated in multiple stakeholder meetings on developing the *Action Agenda Update*; (2) the lists of priorities in local areas and watersheds from the *Action Agenda Update* provided by Action Area groups, who hold the perspectives of local implementing organizations, governments, and tribes; and (3) feedback on proposed science priorities from decision makers on the Ecosystem Coordination Board, who represent a broad range of interests and values.

Scientists and decision makers often have different expectations about how science helps in making decisions about complex natural resource issues (Lee 1993). To minimize confusion about the expectations of science in this prioritization process, the Science Panel focused explicitly on two domains where science and policy interact (Figure 2, Rudd 2011). The first domain is where both scientific knowledge and articulation of policy issues around a topic are poorly developed. This domain is often characteristic of emerging issues. Science has a key role in providing more information on these issues to help elucidate the policy questions. The

second domain is where science is used for evidence-based problem solving. Many non-scientists expect all science to fall in this domain, but this domain is characteristic of issues where scientific knowledge on a topic is relatively poorly developed but consensus exists on the policy issues.

Strengths and Weaknesses

The Science Panel used two different approaches to identify ideas and recommendations for priority science actions. Each approach has different strengths and weaknesses. The first approach was to identify recently completed or ongoing studies focused on Puget Sound and compare the goals of these studies with recommendations from the scientific literature to identify discrepancies or gaps. The enabling legislation that created the Science Panel and Puget Sound Partnership directs the Science Panel to use this approach. Because of the limitations of the gap analysis, the Science Panel added a second, civic and community-based approach for gathering information on science needs.

Review of Recent Studies

The strength of this approach is that it builds on existing work of universities, state and federal agencies, tribes, and non-governmental research groups. Several challenges exist in relying only on this approach, however. First, no comprehensive list exists of recently completed or ongoing studies. The analyses of recently completed and ongoing studies presented here came from extensive web searches and queries, but it is almost certainly incomplete and biased toward larger research groups, agencies, and universities. Building inventories of projects at different scales, by different groups, with different levels of collaboration, from different funding sources, and for different purposes is logistically and institutionally challenging (Katz et al. 2007). The Partnership is exploring tools for improving the inventory.

Second, the analysis presented here used the number of studies as the basis for identifying gaps rather than funding levels, number of reports produced, or a more detailed analysis of individual results. This provides a qualitative indication of whether current scientific efforts are well aligned to contribute to ecosystem recovery efforts. Comparing studies in detail based on content produced, relevance to ecosystem recovery, and utility of the information for making decisions is much more difficult. Depending on the issue and where the study needs to be done (e.g., in a laboratory or in open water), studies have vastly different scopes, use different techniques, have very different ultimate objectives, and require different levels of investment and resources. In addition, some issues have a trajectory of investigation that can be difficult to change because of a long history of work at universities and agencies, whereas others can adapt more easily because the issues, techniques, and questions are new. This analysis could be improved in the future by developing ways to standardize across studies.

Third, recommendations in the scientific literature do not share a common framework for how strategies and pressures affect recovery of Puget Sound. Consequently, in conducting this analysis, the Science Panel used the Puget Sound Partnership conceptual model (Figure 1) as a framework for identifying gaps and emphases.

Finally, comparison of recently completed and ongoing studies with recommendations in the scientific literature relies on information from a very small, specialized portion of society compared to the community that ultimately depends on these results. In contrast, conservation efforts are increasingly incorporating broader civic and community representation in identifying scientific questions and conservation solutions (Lee 1993, Ghimire and Pimbert 1997, Berkes et al. 2003).

Civic and Community-Based Approach

The Science Panel asked interdisciplinary teams of scientists, practitioners, policy analysts, and stakeholders that formed to develop strategies for the *Action Agenda Update* to provide recommendations. In addition, the Science Panel solicited recommendations and ideas from scientists from academia, state, federal, local agencies, and tribes; conservation practitioners from local governments and environmental organizations; and stakeholders.

To prioritize science actions, the Science Panel used a framework that identified four science-policy domains (Figure 2). A major strength of this framework is that it allowed the Science Panel to explore the different roles of science and policy in each domain and to identify domains in which science would contribute most to decision-critical issues. The framework is based on assessing how well policy issues are articulated relative to how well developed scientific knowledge is. However, the framework currently lacks clear definitions for how to apply such judgments. Consequently, consistent application of the framework depends on how well Science Panel members understood or interpreted an issue. Because of this, the priority science section may contain actions that other scientists might judge as not high priority because they believe that articulation of both the policy issues and scientific knowledge are relatively well developed. Likewise, some scientists may believe that scientific issues that deserved to be included were not. A particular weakness of the approach as it was applied for this analysis is that it required the Science Panel to judge how well articulated policy issues are. All these weaknesses can be addressed in future analyses by developing criteria that can be consistently applied and by using science-policy dialogue to assess how well articulated policy issues are.

Summary of Priority Science Actions

Priority Science for Restoring and Protecting Puget Sound contains 48 high-priority scientific actions. Twelve priority science actions are associated with upland, terrestrial, and freshwater ecological domains, which corresponds to *Action Agenda* strategy group A. The marine and nearshore ecological domain (*Action Agenda* strategy group B) has nine priority actions. Pollution issues have 16 science actions (*Action Agenda* strategy group C). The Science Panel highlighted one key emerging issue – ocean acidification – that has three science actions. Finally, nine key science actions are important for sustaining, coordinating, and adapting actions, which corresponds to *Action Agenda* strategy group D.

A striking result of the gap analysis is the small proportion of scientific studies focused on the human dimensions in ecosystem recovery. In the current list of priority science actions, almost one-third (17) address at least one aspect of the human dimension.

The priority science actions in this list are not focused exclusively on new research. Within the two science-policy domains emphasized by the Science Panel, the actions in this list represent five different kinds of information that contribute in different ways to decisions. The five kinds of information are: (1) reviews and synthesis of existing information, (2) development of analytical and decision support tools, (3) monitoring of status and trends, (4) monitoring of actions to assess their effectiveness, and (5) research to understand mechanisms and relationships. One-third (33 percent) of the science actions rely on existing information to do reviews, synthesis, and develop decision support tools. Almost one-fourth (23 percent) are focused on status and trends monitoring and effectiveness monitoring. Less than one-half (44 percent) of the science actions focus on research that is needed to understand mechanisms and relationships.

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Appendices

Appendix A: Puget Sound Partnership Science Program Legislation – RCW 90.71.290

Appendix B: Inventory of Recently Completely and Ongoing Research

Appendix C: Inventory of Recommended Research

Appendix D: Summary of State Monitoring Programs

Appendix E: Science Needs Identified During Action Agenda Update

Appendix F: Science Needs Identified by Scientific, Practitioner, and Stakeholder Communities

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