Biennial Science Work Plan for 2014-2016:

AN ASSESSMENT OF PRIORITY SCIENCE FOR RESTORING AND PROTECTING PUGET SOUND, WITH RESEARCH PRIORITY RECOMMENDATIONS FOR THE NEXT BIENNIUM

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Executive Summary

Every two years, statute requires the Puget Sound Partnership to produce a *Biennial Science Work Plan* (BSWP). Its primary purposes are to I) assess how well ongoing research addresses decision-critical uncertainties relating to the recovery of Puget Sound; II) identify additional science needs for recovery; III) make recommendations for priority science actions in the coming biennium; and IV) suggest how science can better support recovery. This document is the third BSWP to be produced in the series, covering the 2014-2016 biennium. The four parts are summarized as follows:

Part I. Assessment of ongoing and recently completed research.

To assess how well research addresses decision-critical uncertainties for recovery, an inventory was compiled of ongoing and recently completed research projects relating to the recovery of Puget Sound. Complete or partial information was collected for a total of 181 projects, including title, a brief description, start and end dates, total budget, and funding source. Of 181 projects in the inventory, 51% were funded by EPA, and 46% by other sources (4 were not funded). Mean budget size for projects funded by EPA was $338,826, and $228,797 for projects funded by other sources. Total expenditure on science was estimated to be in excess of $50 million, spread unevenly over a period of 7 years (2009-2016), or about $7 million per year. For projects featured in the inventory, mean start date was June of 2011, and mean end date is December of 2014, an interval of 42 months. It is intended that the inventory be used to summarize and synthesize knowledge, integrate strategies and actions, identify potential collaborators and groups of scientists working on related themes, and identify potential funding sources.

Where possible, each project was subjectively assigned to the most relevant of 48 Priority Science Actions (PSAs) that were defined as decision-critical for recovery in the previous (2011-13) BSWP. All but two of the 181 projects could be assigned to one of the 48 Priority Science Actions. At face value, this suggests that ongoing recovery science is well aligned with critical research needs. However, this outcome is not surprising, not least because 48 is a relatively large number of priorities, and many of them are broadly inclusive. Taken together, they encompass the wide scope of scientific needs appropriate to an ecosystem as large and complex as Puget Sound. Ongoing recovery science does broadly address Puget Sound recovery priorities as they are stated in the 2011-13 BSWP.

The maximum number of projects assigned to a PSA was fifteen. Five PSAs were assigned no projects and / or no funding. However, assessment of how well projects met needs defined by PSAs, and of unmet needs, was precluded. This was largely because, for most PSAs, goals were not sufficiently specified, nor were criteria that would indicate whether goals had been met. An attempt was made to identify candidates to be dropped from the list of 48 PSAs on grounds that their goals have been attained. However, no PSAs qualified for elimination. This was not for lack of scientific progress, but, again, largely because PSAs were not specific enough to support a decision. A consequence is that, as currently written, the list of PSAs can grow, but cannot shrink.

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While only 45% of projects in the inventory have been completed, the imagined impact of at least 181 research projects focusing on such a diverse array of recovery priorities engenders hope that recovery gains will be forthcoming. However, it also generates expectation, justified or not, that we will have a clearer vision of how recovery should proceed, and a better understanding of why recovery progress has been slower than expected. The fact that we currently have neither amplifies the need for advances in discovery that arise from research to be more directly and efficiently applied to the recovery of Puget Sound.

Part II: Description of recommended studies

A total of 265 scientists and recovery practitioners were invited to recommend research priorities relating to Puget Sound recovery. Only 18 (6.8%) responded, with a total of 87 recommendations. To these were added recommendations from three reports: the Blue Ribbon Panel's 2012 report on Ocean Acidification (19 research priorities), an expert panel on forage fish (7 research priorities), and a workshop intended to list candidate priorities for research in social sciences (8 candidates). The total number of recommended studies was 121, the largest proportion focusing on marine and nearshore issues.

Research recommended by expert, consensus-building processes like the forage fish workshop and the OA panel are automatic candidates for priority status. However, selection of candidates for research priority status from individual recommendations, and from the list of social science candidates, requires an equivalent consensus-building process that currently is not available.

Part III: Research priorities for the next biennium

Candidates for research priorities in the next biennium include:

- The five PSAs that were not assigned projects and / or funds in Part I;
- A subset of 11 recommendations from 19 in the report by the Blue Ribbon Panel on Ocean Acidification;
- 7 recommendations from a report on forage fish;
- 8 candidate recommendations from a report on research priorities for social sciences.

In principle, all of the original 48 PSAs remain on the list of research priorities for the next biennium because none could be eliminated on the grounds that their objectives had been met. A means of getting beyond this problem is suggested in Part IV.

Part IV: Recommendations for improvement

According to the latest *State of the Sound* report (2013) we are half way to the statutory 2020 'deadline' for recovery, but most status and trends indicators ('Vital Signs') have not advanced much, if at all, towards their targets, and some, such as orcas, have lost ground. Puget Sound recovery practitioners are not alone in expending great effort and still finding recovery elusive. A recent meeting of lead scientists representing Puget Sound and six other large coastal ecosystems in the US revealed that all were struggling with this challenge.

Additional lessons from the workshop were that progress toward specified goals tended to be greater in recovery strategies that focus on fewer targets, and are more explicitly model-based. Regarding the first, progress in Puget Sound may be imperceptible because capacity

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and resources are spread too thinly over too many targets and across too large an area for recovery gains to be detectable. Even if this is true, in complex systems like Puget Sound, narrowing the scope of the recovery strategy to a feasible yet functional number of targets turns out to be one of the greatest challenges of all. This is because the number of potential targets is large, many of them interact with each other, and much of the information required to rank targets by potential to yield greatest recovery gains is lacking. The second (utility of models) is partly a consequence of the first. It is evident from this assessment that models are reasonably prevalent among ongoing and recently completed *research* projects in Puget Sound, yielding critical insights into ecosystem processes. But this is less true of recovery strategies. Too often it is left implicit how results from research (especially models) will influence and be applied to recovery.

These and other reasons that might account for little observable progress towards recovery are all are symptoms of a more inclusive explanation: that Adaptive Management (AM) is difficult to apply at the ecosystem level. No process guarantees achievement of recovery goals, but AM is the approach that, more than any other, improves the likelihood that progress can be made towards recovery under uncertainty. Practitioners at the workshop agreed that applying AM to large and complex ecosystems is challenging, but nonetheless re-affirmed unanimously that AM should remain the default approach to recovery, for three main reasons: there are too many unknowns for any alternative approach to be viable; to chart a cost-effective course towards recovery; and to demonstrate net benefits of actions in order to justify continued funding for recovery (or, if actions do not deliver desired effects, at least to understand *why*). Discussion about relative expenditure on monitoring and AM among ecosystems revealed an average of about 15% of the total spent on recovery. This was an amount limited more by what funding agencies were prepared to commit than by what is needed to address critical uncertainties.

In Puget Sound, Adaptive Management was nominally adopted as the default approach, but AM has been applied in a patchy and incomplete manner, partly because of insufficient resources. The Science Panel endorses application of Adaptive Management, and recommends that it be supported accordingly. Initial emphasis should be on completion of 'implementation strategies' for each target. These are conceptual models that describe the mechanistic theories, causal pathways, and actions by which recovery targets will be met, and are a key step in the programmatic cycle of Adaptive Management. It is further recommended that implementation strategies be designed by a separate 'recovery group' for each target. Finally, once implementation strategies have been defined and documented, funds should be awarded largely to projects – be they for research or implementation of recovery-related actions – that explicitly describe how topics featured in and justified by implementation strategies will be addressed. The next BSWP should summarize progress in the design and use of implementation strategies, including the identification of recovery research priorities, and descriptions of criteria by which attainment of research objectives will be assessed.

Finally, a summary of needs relating to recovery science that were expressed in this document is given in the table below.

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	A list of needs relating to recovery science that were expressed in this BSWP.
1	For a process to be developed by which the inventory of recovery research projects can be continuously updated (as opposed to recreating it anew every biennium) using a dedicated online database. Once operational, funding agencies should require grantees to enter project data into the database as funds are awarded.
2	For the BSWP to be published as far in advance of other work plans (including LO plans and Action Agenda Updates) as necessary to allow research recommendations to be acted upon, and funding provisions made (>6 months).
3	For results and findings of completed research projects to be synthesized and their implications for recovery assessed.
4	For effectiveness of recovery actions to be assessed, where appropriate, through effectiveness monitoring.
5	For *cost effectiveness* to guide planning and implementation of recovery priorities and actions.
6	For research recommendations and 'candidate' research priorities listed in Part III to be selected and confirmed as actual research priorities.
7	For Priority Science Actions and their goals to be made sufficiently specific to permit assessments of progress.
8	For the scope of Puget Sound's recovery strategy (e.g. number of recovery targets) to be reduced, and / or funding to be increased, such that resources are sufficient to allow Adaptive Management to be operational for every target.
9	For 'implementation strategies' to be defined and documented for every target by a separate 'recovery group'.
10	For RFPs relating to recovery science to require proposers to describe how their projects will address PSAs (and elements of implementation strategies), and how results will be applied to recovery.
11	Where appropriate, for scientists conducting recovery research to be actively involved in the process of transforming their research results to actions.

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Online Resources

- 2014-16 Biennial Science Work Plan: Appendices C-F [http://www.eopugetsound.org/sites/default/files/features/resources/2014-16_BSWP_Appendices_C-F_Apr_2_2014.xlsx]

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Introduction

The Puget Sound Ecosystem is the geographic region defined by the contiguous watersheds of 14 major rivers that drain into the marine waters of Puget Sound (about 35,500 km^2). It forms the southern half of the Salish Sea Ecosystem, a trans-national region that includes watersheds draining into the Strait of Georgia in Canada. Approximately 4.3 million people live around Puget Sound, most in the Seattle metropolitan area and city of Tacoma, the remainder in scores of smaller cities, towns, and rural communities scattered across parts of 12 counties. More than 150 years of expanding settlement, agriculture, industry, and development have taken their toll on the natural resources, ecosystem services, and abundance of species like salmon that have long supported people in the region (Lombard 2006, Ruckelshaus and McClure 2007).

Efforts to clean up the Sound and where possible restore its ecological health and functionality have gained momentum over the last two decades. The current program was initiated by the Washington State Legislature in 2007, which created the Puget Sound Partnership (PSP) to coordinate recovery. Stipulating that recovery should be based on and informed by science, the legislation specified an organizational structure for PSP that includes a panel of scientists (Science Panel or SP) to advise the governing Leadership Council (LC) and the Ecosystem Coordination Board (ECB) on issues relating to science. Members of the SP represent a wide range of disciplines relating to the status, natural dynamics, pressures on, and recovery of the Puget Sound ecosystem.

The principal role of the Science Panel is to define, facilitate, and oversee scientific support for the recovery strategy, helping to ensure that the recovery process is based on and informed by science. This includes, for example, providing scientific analyses for prioritization and setting of recovery goals. To help guide and propagate scientific support for recovery, statute requires the Science Panel to produce, every two years, a *Biennial Science Work Plan* (BSWP; Appendix A). Its primary purposes are to I) assesses how well ongoing research addresses decision-critical uncertainties relating to the recovery of Puget Sound; II) identify additional science needs for recovery; III) make recommendations for priority science actions in the coming biennium; and IV) make recommendations for improving the collective scientific effort contributing to Puget Sound recovery. This document is the third BSWP to be produced in the series, covering the 2014-2016 biennium.

Focus and Structure of the 2011-13 BSWP

The previous edition was entitled *Priority Science for Restoring and Protecting Puget Sound: A Biennial Science Work Plan for 2011-2013* (herein referred to as the 2011-13 BSWP). Its principal goal was to identify, in the ongoing program for Puget Sound recovery, where progress was hindered by a lack of scientific understanding or information, and, by implication, where research would yield the greatest gains.

Restoring and protecting an ecosystem as large and complex as Puget Sound demands a strategic program of proportional size and complexity. At the outset, there is no readily available shortlist of targets and actions that would most efficiently lead to recovery. Similarly, there is no straightforward way to objectively identify and prioritize research. The greatest asset for recovery may be the large community of scientists, resource managers, environmental

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practitioners, policy makers and other stakeholders who live and work in the region on recovery-related issues. Collectively, they possess the information about the ecosystem needed to guide its restoration: its history, the diverse pressures and mechanisms that have led to its decline, the actions likely to reduce those pressures and promote recovery, and where the critical uncertainties lie. It was by drawing on this collective awareness that the master plan for Puget Sound recovery and management, known as the *Action Agenda,* was developed. Currently in its 4th revision, the *Action Agenda Update 2014-16* describes the strategies, sub-strategies, and specific near-term actions that are intended to restore and protect key components and attributes of the Puget Sound ecosystem, and the services they provide.

A consensus approach was also used to develop a list of research priorities for Puget Sound recovery that was published in the 2011-13 BSWP. Initially, a list of gaps in scientific knowledge about the ecosystem was drawn up, based on input from three sources: a review of the questions that current research and monitoring were 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 were likely present. Importantly, not all identified gaps in knowledge became research priorities. Those that qualified did so by satisfying two further criteria: that scientific uncertainty was not only high, but also 'decision-critical', that is, it hindered progress in restoration and recovery.

Ultimately, 48 conceptual topics were nominated as recovery research priorities (called Priority Science Actions or PSAs; Table 1). These were organized into the same structure as the Action Agenda Update under four principal strategy areas: 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, and D. 'Other', including emerging issues like Climate Change and Ocean Acidification, and Human Dimensions.

The list of PSAs was intended to be used by federal, state, and non-governmental funding agencies to focus research and environmental monitoring on science within their areas of responsibility (e.g., clean water, endangered species, land conservation, transportation, etc.) that would be of greatest relevance to recovery.

Focus and Structure of the 2014-16 BSWP

When planning the 2014-16 BSWP in mid-2013, the PSP Science Panel determined that the statutory requirements should be met by describing how well ongoing research addressed the 48 Priority Science Actions listed in the 2011-13 BSWP. Accordingly, in the preparation of this document, an inventory of recently completed and ongoing research projects was compiled and, where possible, each was subjectively assigned to the most relevant of the 48 PSAs listed in the previous BSWP, as a first step towards evaluating the relevance of ongoing research to recovery. Presentation of Priority Science Actions in the 2011-13 BSWP was deliberately structured to correspond with the layout of strategies and sub-strategies in the *Action Agenda Update.* The same organizational framework was retained in this edition.

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Table 1. Priority Science Actions (PSAs) from the 2011-13 Biennial Science Work Plan

Action Agenda Focus Area	Action Agenda Strategy	PSA No.	Priority Science Action
PROTECT AND RESTORE TERRESTRIAL AND FRESHWATER ECOSYSTEMS			
Habitats	A1 A2 A3	1	Develop analytical tools to identify options for where to protect, where to restore, and where to develop while maintaining desired ecological goods and services.
		2	Use social science to guide development of adaptive management structures that can effectively linkrestoration science to management decision making.
		3	Develop ecological indicators; assess baseline conditions; and implement monitoring to measureecosystem function relative to no net loss.
		4	Conduct social science studies to describe the key institutional challenges to attaining no net loss andimprovements from restoration.
Floodplains	A5	5	Estimate the value of floodplains in terms of the ecosystems services they provide.
		6	Develop key ecological indicators and implement monitoring to assess status of floodplains.
		7	Improve understanding of the effects of vegetation on dikes and other flood control structures.
Species and Foodwebs	A6	8	Develop analytical tools to evaluate whether strategies to address factors limiting the productivity ofsalmon are being implemented in the most effective combinations, at the right times, and with appropriate amounts of effort to lead to recovery.
		9	Identify the causes of apparent decline in marine survival of salmon as they leave their natal rivers and exit Puget Sound.
	B5	10	Assess risks imposed by terrestrial and freshwater invasive species.
Freshwater	A7	11	Develop robust ecological indicators and implement comprehensive monitoring for stream flows.
		12	Evaluate and improve stream flow targets in terms of their effects on abundance, productivity, distribution, and life history diversity of salmon.
PROTECT AND RESTORE MARINE AND NEARSHORE ECOSYSTEMS			
Habitats	B2 B3	13	Develop analytical tools to identify priority areas for protection, restoration, and stewardship.
		14	Develop adaptive management structures that link restoration science to management decision making
		15	Identify the key stressors on eelgrass.
Species and Foodwebs	B5	16	Develop analytical tools and information to understand the tradeoffs in managing foodwebs of marinespecies and the multiple stressors affecting those foodwebs.
		17	Implement biological and sociological studies to understand the conservation and sociological roles ofmarine protected areas for habitat and species protection, ecosystem restoration, and sustaining usualand accustomed tribal fishing areas.
		18	Implement studies to identify stressors on forage fish.
		19	Implement studies to understand the causes of declines in marine bird abundance.
		20	Conduct studies to identify sources of nutrients that enter Puget Sound that can be used to develop strategies for maintaining water quality for Puget Sound foodwebs.
		21	Assess risks imposed by marine invasive species.
REDUCE AND CONTROL SOURCES OF POLLUTION TO PUGET SOUND			
Contaminants	C1	22	Implement studies on persistent, bioaccumulative chemicals to understand transport, trophic transfer, and associated ecological and human health risk and to ensure that Washington State's water quality standards and sediment management standards are protective of both fish and wildlife and allowhuman and wildlife consumption.
		23	Describe the availability, feasibility, and safety of alternatives to products and processes that use andrelease toxic chemicals of concern into the Puget Sound ecosystem.
		24	Develop integrated monitoring and assessment of toxic chemical sources, exposure, and effects.
		25	Synthesize information on emerging contaminants of concern.
Runoff from the Environment	C2	26	Develop monitoring and assessment of benthic invertebrates in small streams to evaluate stormwater management and other efforts to protect and restore streams.
		27	Evaluate the effectiveness of low impact development (LID) projects and stormwater management best management practices and programs.
		28	Evaluate land uses and associated pollutants that would require treatment beyond sediment removal.
		29	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.
		30	Evaluate individual and combined effects of commonly used pesticides on salmonids, other fish, and their foods
Wastewater	C5 C6	31	Evaluate nitrogen reduction in public domain on-site system treatment technologies.
		32	Implement studies of human-related contributions of nitrogen to dissolved oxygen impairments insensitive Puget Sound marine waters.
Shellfish	C7	33	Establish and sustain pollution identification and correction (PIC) programs to identify and fix nonpoint pollution problems.
		34	Research and implement monitoring to understand the specific environmental conditions that produce toxic harmful algal blooms (HABs) and pathogen events.
Oil Spills	C8	35	Evaluate existing oil spill risk assessments and complete additional risk analyses of higher risk industrysectors to ensure there are appropriate levels of investment in reducing risk.
		36	Evaluate information on baseline conditions for key species at risk from oil spills and improve these asnecessary so that baselines exist that can be used in assessments of natural resource damages.
Cumulative Water Pollution	C9	37	Expand monitoring of freshwater and marine water areas to assess human exposures to pollution during water contact recreation.
OTHER			
Emerging Issues G Ocean Acidification		38	Design and implement monitoring for ocean acidification variables across the Puget Sound tounderstand the status, diversity and range of conditions.
		39	Develop and implement studies to assess the risk and vulnerability of Puget Sound species to oceanacidification.
		40	Develop adaptation strategies given assessed vulnerability to ocean acidification.
Scientific Tools for Informing Policy	D1	41	Conduct institutional analyses of the overall governance and management structures in which PugetSound recovery strategies operate.
		42	Conduct integrated risk assessments of the impacts of different pressures on the Puget Soundecosystem.
		43	Develop a systematic, transparent, and ecologically based prioritization tool for near-term actions inthe Action Agenda that will support evolutionary learning and adaptation.
Coordinated Ecosystem Monitoring	D3	44	Implement and sustain a comprehensive, coordinated monitoring program to understand the status ofthe Puget Sound and the effectiveness of recovery actions.
Human Dimensions in Ecosystems	D7	45	Develop assessments of ecosystem services to help decision makers make informed decisions aboutrestoration and protection.
		46	Develop socioeconomic indicators to help measure and report on the human dimensions in ecosystem recovery.
		47	Conduct a baseline literature review of social science research and a survey of data to identify resources and gaps that can be readily available and used by ecosystem recovery planners and practitioners.
		48	Evaluate the most effective combinations of regulatory, incentive, and educational programs for different demographics in Puget Sound.

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Approach and Methods

This section of the 2014-16 BSWP describes how the two principal features of the BSWP – an inventory of ongoing research and an inventory of research recommendations – were compiled.

Inventory of projects

An inventory of ongoing and recently completed research was compiled by seeking basic information about projects that qualified by the following criteria: (a) the project was related to the recovery of Puget Sound, (b) it was entirely or largely scientific (as opposed to, say, implementing a recovery action), and (c) it was either ongoing or had ended after 2010. For each project the following information was sought: the project title, a brief project description, the name of the principal investigator or project contact, their phone number and email address, the name of the implementing institution, the project start and end dates, funding amount, funding source, and web addresses for available reports or publications.

The information was gathered in four ways. First, members of the Science Panel and PSP staff added projects they were familiar with. Second, one or more individuals involved in recovery research were contacted at each of the 34 institutions listed in Appendix B, and asked to provide project information. In some cases, one individual assembled information about all qualifying recovery research projects based at their institution. In others, multiple individuals from an institution were independently contacted about their own projects. Third, the required information was gathered from websites of those institutions (especially the state and federal agencies). And fourth, lead authors of 103 scientific papers and reports that were related to Puget Sound recovery, and published since 2011, were invited to provide information about ongoing or recently completed projects in which they were involved.

Where possible, each project was subjectively classified under the most thematically pertinent Priority Science Action, and these in turn were nested within a sub-strategy of the four principal strategic areas of the Action Agenda (as in Table 1).

Inventory of recommendations for recovery research

An inventory of recommendations for science needed to inform Puget Sound recovery in the coming (2014-16) biennium was compiled primarily by using the same approach as was employed in the 2011-13 BSWP – scientists engaged in recovery research and recovery practitioners were asked to make recommendations about critical research needs. While no one can have a full or fully objective response, combined responses from a broad spectrum of those with an informed opinion should capture the priorities. Accordingly, a list of 265 names and email addresses was compiled from two sources: a) the primary authors of 150 scientific papers and reports relating to Puget Sound recovery that had been published since 2011 (Appendix F), and b) nominations from Science Panel members and others in the recovery community.

Respondents were invited to make as many recommendations as they liked, but were asked to base their selection on the same considerations that were applied to the selection of Priority

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Science Actions in the 2011-13 BSWP, namely:

- How much is known about a topic, and how much more do we need to know (what is the level of scientific uncertainty?).
- Where is a lack of scientific information hindering progress in recovery?
- What are the decision critical questions and information needed for ecosystem restoration and protection?

Respondents were asked to make a declarative statement defining the topic, briefly summarize its rationale and justify its inclusion. They were also invited to indicate which items should remain on or be removed from the 2011-13 BSWP list of Priority Science Actions, and to provide rationale.

Part I: Assessment of ongoing and recently completed research

This section describes ongoing and recently concluded research relating to the recovery of the Puget Sound ecosystem.

Complete or partial information was collected on a total of 181 research projects that were ongoing in the latter half of 2013, or had ended more recently than 2010. An inventory of these projects is presented in two formats: tabular, as Appendix C of this document, and online as a downloadable Excel file [http://www.eopugetsound.org/sites/default/files/features/resources/2014-16_BSWP_Appendices_C-F_Apr_2_2014.xlsx]. In all formats, projects are numbered P1-181. Appendix C1 features all project information except their descriptions, which are listed in Appendix C2 (separation of project descriptions was necessary for clarity of presentation in this document; separation was of course not necessary in the downloadable version).

Timing and budgets of projects

Of the 181 projects in the inventory, 93 (or 51%) were funded by EPA, 84 (46%) by other sources, and 4 were not funded. On average, projects featured in the inventory started in June of 2011, and are due to end in December of 2014, an interval of 42 months (Figure 1; long term monitoring projects were excluded from these estimates).

The average budget for projects funded by EPA was $338,826 (n=90, sd=$243,981; Figure 2). For projects funded by other sources, the average budget was $228,797 (n=30, sd=$147,689; the $5 million budget for project no. 29 was excluded from this

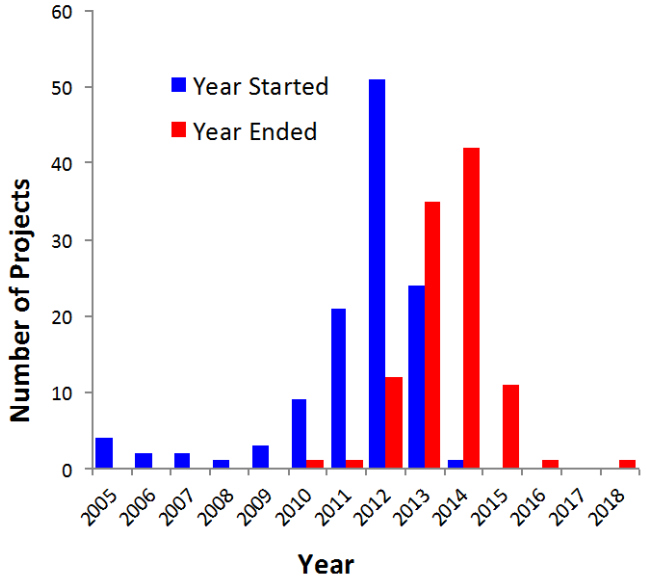

Figure 1. Distributions of the years that projects in the inventory started (n=118) and ended (n=104).

estimate). These means were used to estimate budgets of projects in the inventory that lacked budget data, so that total expenditure on recovery research could also be estimated. Only 3 (3.2%) of the projects funded by EPA lacked budget data, so the corrected total expenditure by EPA on science ($31,510,818) is close to the uncorrected total. This was not true of the corrected total for non-EPA expenditure ($23,761,359) because most (63%) of the non-EPA funded projects lacked budget data. Combining these figures gives an estimate of total expenditure on recovery research in Puget Sound over the survey period: $55,272,177. Uncertainty about budgets of non-EPA funded projects may bias this figure, but given that the inventory is not exhaustive, the conclusion that total expenditure on recovery science during the survey period exceeded $50 million seems conservative.

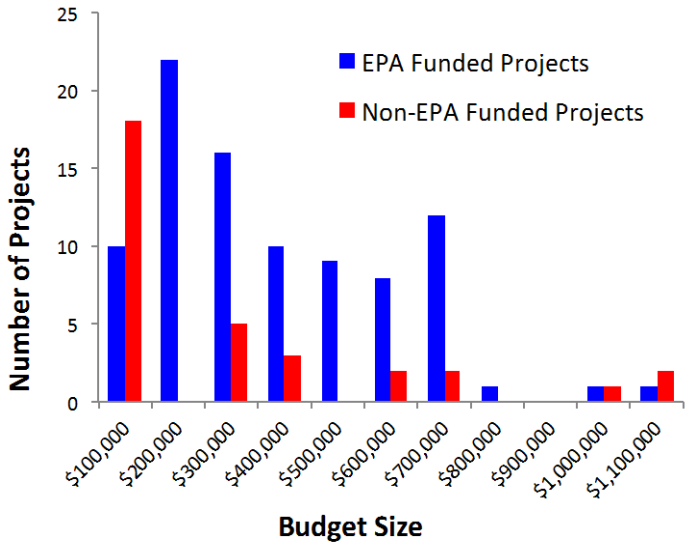

Figure 2. Distributions of budget sizes among EPA funded and non-EPA funded projects. The lowest category includes projects with budgets <= $!00,000. The highest category includes projects with budgets >$1 million.

Classification of projects among PSAs

All projects in the inventory could be assigned to one of the four principal strategic areas of the *Action Agenda*. Given the combined scope of the strategic areas, it would be surprising if this was not the case. Similarly, all but two of the 181 projects could be assigned to one of the 48 Priority Science Actions (the exceptions are project numbers 180 and 181). At face value, this suggests that ongoing recovery science is exceptionally well aligned with critical research needs. However, this outcome is also not surprising, for three reasons. First, 48 is a relatively large number of priorities, and many of them are broadly inclusive. Taken together, they encompass a wide scope of scientific needs. Second, assignment was not based on stringent criteria, but rather on whether or not a project fit the broad sense of a PSA. Third, the community of scientists and practitioners who were asked less than 3 years ago to suggest research priorities would have (and should have) nominated subjects they were familiar with, and in many cases, are still studying. Consequently, we should expect the probability of *not* being able to assign a project to a PSA to be small.

Judging from the total number of projects assigned to each PSA, research resources were not allocated evenly (Figure 3 and Appendix D). Some were well attended with up to 15 projects, while others were entirely neglected (at least in this sample – recall that the project inventory was not comprehensive). Given that the 48 PSAs differed in their degree of specificity, however, our 'null' expectation was not that each should have the same number of projects (equal to the mean of around 4 projects per PSA, derived by dividing 181, the total number of projects, by 48, the total number of PSAs). Rather, the null expectation was that the more 'generally' defined PSAs should have more projects assigned to them, and the more 'specific' PSAs fewer, than the

mean. Subjective comparison of PSAs with the most projects and the least projects suggests that this expectation was supported. PSAs with the most projects (>9) and largest total allocation of funds (>$3,000,000), and those having 1 or 0 projects and <$300,000 are listed in Table 2 (all PSAs and assigned projects are listed in Appendix D). The latter tend to be not only more specific, but also to define goals that have more components and conditions than the former (their descriptions also tend to be longer). In the conditional probability sense, we should expect fewer projects to comply with their provisions, and this partly explains the pattern that was observed. Thus, if recovery science priorities were represented by a dartboard made with 48 sectors (PSAs) *of unequal width*, at which 181 darts (projects) where thrown, the distribution of darts in each sector would resemble the distribution of projects among PSAs in Figure 3.

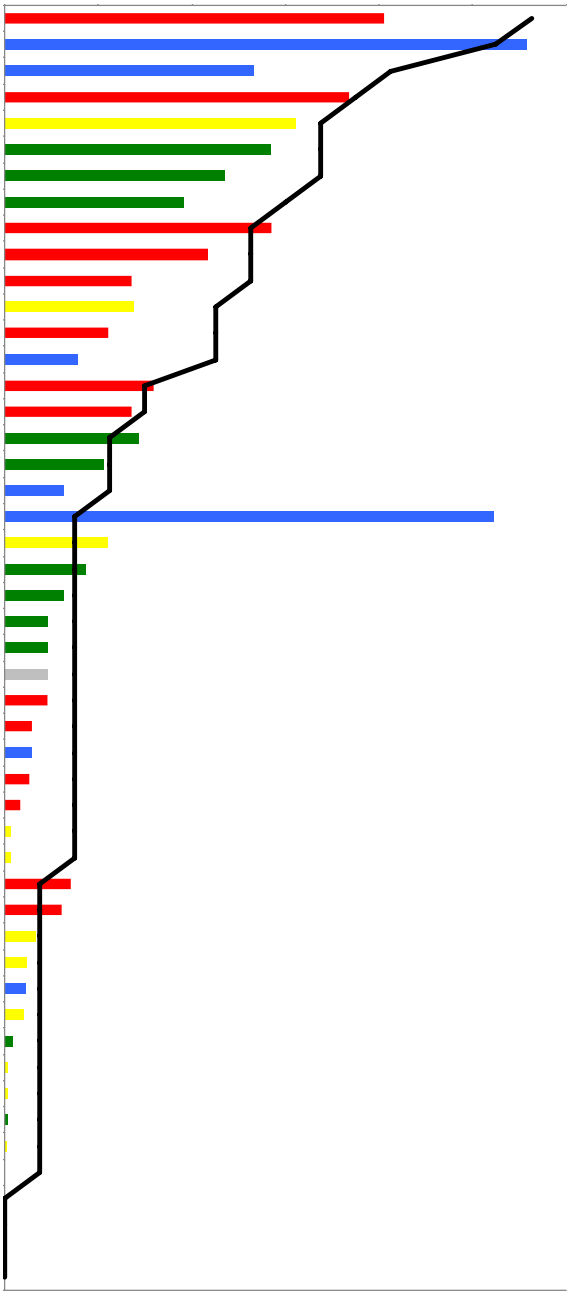

Figure 3. Comparison of the total number of projects (black line), and the sum of their budgets (columns), for each of the 48 PSAs. PSAs were sorted by number of projects, then by total expenditure. They are color-coded by Action Agenda strategy: Terrestrial and Freshwater (green), Marine and Nearshore (blue), Pollutants and Toxics (red), and Other (yellow).

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Table 2. PSAs with the most projects (>9) and total budgets (>$3,000,000), and those with the least projects (1 or 0) and budgets (<$3,000,000).

PSA No.	Priority Science Action title (from 2011-13 BSWP)	Total budgeted ($, corrected)	No. of Projects
	PSAs with the >9 projects and >$3,000,000		
24	Develop integrated monitoring and assessment of toxic chemical sources, exposure, and effects.	$4,051,104	15
14	Develop adaptive management structures that link [marine and nearshore] restoration science to management decision making.	$5,583,470	14
13	Develop analytical tools to identify priority areas for [marine and nearshore] protection, restoration, and stewardship.	$2,663,003	11
27	Evaluate the effectiveness of low impact development (LID) projects and stormwater management best management practices and programs.	$3,674,044	10
44	Implement and sustain a comprehensive, coordinated monitoring program to understand the status of the Puget Sound and the effectiveness of recovery actions.	$3,107,542	9
	PSAs with 1 or 0 projects, and <$300,000		
43	Develop a systematic, transparent, and ecologically-based prioritization tool for near-term actions in the Action Agenda that will support evolutionary learning and adaptation.[3]	$242,116	1
19	Implement studies to understand the causes of declines in marine bird abundance.	$228,797	1
42	Conduct integrated risk assessments of the impacts of different pressures on the Puget Sound ecosystem.	$200,000	1
7	Improve understanding of the effects of vegetation on dikes and other flood control structures.	$89,499	1
40	Develop adaptation strategies given assessed vulnerability to ocean acidification.	$40,000	1
48	Evaluate the most effective combinations of regulatory, incentive, and educational programs for different demographics in Puget Sound.	$37,500	1
8	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.	$30,408	1
38	Design and implement monitoring for ocean acidification variables across the Puget Sound to understand the status, diversity and range of conditions.	$20,000	1
16	Develop analytical tools and information to understand the tradeoffs in managing foodwebs of marine species and the multiple stressors affecting those foodwebs.	$0	1
17	Implement 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.	$0	0
20	Conduct studies to identify sources of nutrients that enter Puget Sound that can be used to develop strategies for maintaining water quality for Puget Sound foodwebs.	$0	0
30	Evaluate individual and combined effects of commonly used pesticides on salmonids, other fish, and their foods.	$0	0
35	Evaluate existing oil spill risk assessments and complete additional risk analyses of higher risk industry sectors to ensure there are appropriate levels of investment in reducing risk.	$0	0

Budget data in Figure 3, Table 2, and Appendix D estimate absolute and relative funding applied to each PSA. Total project funds were distributed among PSAs in a way that closely mirrored the distribution of projects (with one obvious exception). This pattern was also expected, not least because the two were not entirely independent (mean budgets were applied to projects for which budget data were lacking; see Approaches and Methods). The obvious exception is PSA 9, which relates to causes of mortality in out-migrating salmon. Of two projects assigned to PSA 9, project no. 29 will examine causes of salmon and steelhead mortality in the Salish Sea over the next 20 years, for which funding for the first five years ($5 million) has been secured.

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Ranking PSAs by project number and total budget (Figure 3) provides only a crude measure of relative recovery effort expended on each PSA. It reveals nothing about whether support for a given PSA is *sufficient*. But it does suggest candidates for future support, starting with those PSAs in the long tail of the distribution with one or zero projects and <$300,000, particularly those that have received no funds at all (Table 2). These are further discussed in Part III.

Assessment of how ongoing science addresses stated needs

Ideally, further scrutiny would reveal how well projects meet the needs defined by PSAs, and expose unmet needs. However, such scrutiny was precluded by several factors. First, while most of the 181 projects in the inventory addressed one or more of the general topics captured by PSAs, few were specifically designed to address a given PSA (most projects were conceived before the list of PSAs was published; P29 was an exception). Assignment of projects to PSAs was possible, therefore, but only in hindsight, and only subjectively (different observers, even the same observer on different occasions, would assign projects in different ways). Second, for most PSAs, goals were not specified, nor were criteria that would indicate whether goals had been met. Extending the dartboard analogy, if the distance from the bulls-eye to a dart in the board relates to how well a project met a stated need, there is no ring around the center by which to determine that the bulls-eye was hit. Third, even if criteria had been provided, more than half (55%) of the projects in the inventory are ongoing and thus have no documented results or conclusions (Appendix D). Even if all projects were completed and documented, evaluating their 'success' without such criteria would require expert level familiarity with the subject, details, relevance, import, and limitations of all projects in the inventory.

Candidates for removal from the list of PSAs

The inventory of projects was scrutinized to identify candidates to be dropped from the list of 48 PSAs on grounds that their goals have been attained. Criteria used to select candidates were basic: a) the PSA description had to be specific enough to permit a decision; b) the PSA had to have at least one project assigned to it; and c) PIs and PSP staff had to confirm that goals had been attained. No PSAs qualified by these criteria (only 4 passed the first two criteria). This was not because of a lack of scientific progress, but rather because most PSAs are not specific enough to support a decision.

The Science Panel's 7 'orphan' PSAs

When the original list of PSAs was finalized in 2011, the Science Panel undertook to promote implementation of seven that were considered otherwise unlikely to gain support (Table 3). This section reports the status of these PSAs.

All were awarded projects and funding, but in widely varying amounts. Of a total of 15 projects, only five are completed. Five of the seven PSAs were addressed by projects designed specifically to meet the stated need (PSAs 41, 42, 43, 45, and 46). For example, the ongoing 'Pressures Assessment' (Project 159) directly addresses the need stated in PSA 42 to conduct integrated risk assessments of the principal pressures on Puget Sound. Results are expected to objectively inform and facilitate selection of recovery targets and actions. Depending on outcomes, further

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assessment may be warranted, for example, of interactions among pressures, and of the spatial and temporal co-incidence of stressors and ecosystem endpoints. Projects 173-175 directly address the need to assess ecosystem services (PSA 45). Development of human wellbeing indicators (PSA 46) is in advanced state of completion at the watershed scale for Hood Canal, and has begun in the Puyallup and Whatcom watersheds (results expected in June 2014). Plans for proceeding with 1-2 workshops to select basin-wide human wellbeing indicators for the vital signs are expected by September 2014, with completion by December 2014.

These provide some of the better examples of how a stated science need can be directly addressed by research (for example, projects 159, 160, 176). For these projects it is clear how results are expected to advance recovery.

Table 3. A list of the 7 'orphan' PSAs that the Science Panel adopted to ensure they would be attended, with a summary of total funds awarded, the number of associated projects, and project numbers (see Appendix C1 and C2 for project descriptions).

PSA No.	Priority Science Action title	Total Budget (corrected)	No. of Projects	Project No. & Status (green = completed, red = ongoing)					
2	Use social science to guide development of adaptive management structures that can effectively link [freshwater and terrestrial] restoration science to management decision-making.	$872,607	2	P10	P11				
41	Conduct institutional analyses of the overall governance and management structures in which Puget Sound recovery strategies operate.	$70,613	2	P157	P158				
42	Conduct integrated risk assessments of the impacts of different pressures on the Puget Sound ecosystem.	$200,000	1	P159					
43	Develop a systematic, transparent, and ecologically-based prioritization tool for near-term actions in the Action Agenda that will support evolutionary learning and adaptation.	$242,116	1	P160					
45	Develop assessments of ecosystem services to help decision makers make informed decisions about restoration and protection.	$1,383,763	6	P170	P171	P172	P173	P174	P175
46	Develop socioeconomic indicators to help measure and report on the human dimensions in ecosystem recovery.	$70,000	2	P176	P177				
48	Evaluate the most effective combinations of regulatory, incentive, and educational programs for different demographics in Puget Sound.	$37,500	1	P179					
	TOTAL	$2,876,599	15						

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Using the Inventory of Projects

The inventory of projects was used to answer a series of questions intended to illustrate its utility:

1. *How many projects address recovery issues at the level of the entire Puget Sound ecosystem?*

   Projects in the inventory address issues at different spatial scales, from local (e.g. the Nisqually delta; P58), to watershed or county (P6), to the entire Puget Sound ecosystem. Ultimate recovery goals encompass the Puget Sound ecosystem, but it is neither necessary nor appropriate that all research projects cover the entire region. Geographic scope of research projects must often be reduced for practical reasons (among others). However, scaling up results or actions from a spatially limited project often exposes additional uncertainties. An answer to the question posed above should provide an expectation of the scope of science-informed recovery interventions and actions that are likely to be pre-adapted for application at the level of the entire ecosystem.

   Inclusive assignment criteria were used: a project was considered 'Sound-wide' if its stated scope, targets, sampling locations, and / or results respectively encompassed, were distributed over, or could be applied to the entire ecosystem. For example, one study will "identify floodplain areas in Puget Sound that have the highest potential to advance multiple benefits such as habitat and flood protection". This study qualified as 'Sound-wide' because its description implied that all candidate floodplains will be screened.

   The answer was surprisingly large: nearly half (48%) of the 181 projects qualified by these criteria (qualifying project numbers are listed in Table 4). Collectively, they evoke a rich and expansive body of knowledge with potential to inform actions that are scaled to recovery at the ecosystem level.

Table 4. Projects in the inventory that qualify by the stated descriptors.

Descriptor	Total number of projects	Project Numbers
Puget Sound-wide projects	86	P1, P2, P4, P8, P11, P13, P17, P24, P26, P29, P30, P31, P45, P47, P48, P51, P56, P57, P59, P63, P64, P69, P70, P72, P73, P74, P75, P76, P77, P80, P81, P82, P83, P84, P85, P86, P87, P88, P89, P90, P91, P92, P95, P96, P97, P98, P99, P100, P101, P103, P104, P108, P109, P111, P112, P113, P115, P119, P126, P130, P131, P133, P134, P144, P145, P147, P149, P152, P153, P156, P157, P158, P159, P160, P161, P162, P163, P165, P166, P167, P169, P173, P174, P175, P178, P181
Projects with models	30	P3, P7, P11, P34, P36, P37, P39, P40, P42, P43, P44, P48, P52, P53, P54, P55, P59, P73, P74, P84, P89, P92, P94, P97, P104, P119, P131, P146, P149, P156,
Puget Sound-wide models	14	P11, P48, P59, P73, P74, P84, P89, P92, P97, P104, P119, P131, P149, P156
Nearshore	16	P11, P14, P25, P46, P47, P51, P54, P57, P59, P62, P66, P75, P76, P95, P108, P157
Hood Canal	10	P5, P25, P66, P129, P132, P137, P138, P166, P170, P176

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2. *What proportion of projects use, are based on, and / or are intended to create models?*

   Williams et al. (2009) designed a decision support key to indicate when adaptive management is the most appropriate approach to decision-making for ecosystem restoration. Of 10 steps in the key, step 5 stipulated that adaptive management cannot proceed without predictions generated by models. The question in this part addresses the prevalence of modeling among Puget Sound research projects, with implications for the potential for adaptive management in recovery programs.

   Again, inclusive criteria were applied: any type of model (conceptual, simulation, systems, etc.) qualified a project for this category.

   The answer was 30 (or 17%; Table 4). This figure is probably conservative in that models might not have been mentioned in the descriptions of some projects that use models. Conversely, it probably over-estimates the number of models that actually support management actions or decision-making (given that the process of applying an academic model incurs several further steps). The result nonetheless suggests that the potential to advance model-based adaptive management and decision making may be higher than generally assumed.

3. *What proportion of projects use, are based on, and / or are intended to create a model that operates at the level of the entire ecosystem?*

   This question was answered simply by counting projects that featured in both parts 1 and 2 above. The result was 14, or 8% of the total (Table 4). Given that this figure does not include all Puget Sound-level models, there is great potential to integrate models or model outputs to address novel questions in the service of recovery at the ecosystem level (depending on model compatibility, available data, etc.).

In further examples, the inventory was queried (searched, sorted or filtered) to yield the tally of projects focusing on issues relating to nearshore environments, and to Hood Canal (Table 4). It is intended that the inventory be used in this way to summarize knowledge, integrate strategies and actions, identify collaborators and groups of scientists working on related themes, and find potential funding sources.

Conclusions

If, as envisaged above, PSAs were represented by 48 sectors on a dartboard, the most obvious conclusion to draw from the observed pattern of darts (projects) in the dartboard is that few missed the board entirely. Before concluding that recent and ongoing recovery science in Puget Sound does address stated recovery priorities, however, two caveats warrant repetition. The first is that most PSAs are relatively nonspecific, and the criteria used in assigning projects to PSAs were broad and subjective (the dartboard is large and could hardly be missed). Second, we should ask: *to what extent were the darts thrown first, and the dartboard designed around them?* In other words, to what extent were research priorities defined by projects? The most probable answer is: *to a limited – but inevitable – extent*. Although many of the projects featured in the inventory did not start until after PSAs were selected, their conception began before the 2011-13 BSWP was published. It is likely that some, perhaps many, projects were

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conceived by members of the recovery science community whose opinions also contributed to consensus about recovery science priorities. Some predetermination of this nature is unavoidable when the best available approach to prioritizing recovery science depends on consensus among experts working in the same ecosystem. It does not mean that research priorities were defined by ongoing projects, or that PSAs are in fact not priorities – far from it: PSAs were derived by consensus, and justified as 'decision-critical'. A key lesson to draw from this survey is that ongoing recovery science does broadly address Puget Sound recovery priorities *as they are stated in the 2011-13 BSWP*.

A second lesson is that the number and diversity of ongoing and recently completed research projects relating to recovery are large (>181), and in terms of scope, almost half of them encompass the entire ecosystem (as opposed to only a part of it). It is recommended that a process for updating the inventory of recovery research projects be developed (as opposed to recreating it anew every biennium), using a dedicated online database. Funding agencies should require grantees to enter project data into the database as they are awarded.

A third lesson, however, is that coverage of PSAs by projects was incomplete, in that some PSAs received little or no attention. These are candidates for funding in the coming biennium, as is further discussed below.

A fourth lesson is that, because PSAs generally lacked criteria by which to judge when they have been attained, it is difficult to evaluate progress, or determine when a PSA can be removed from the list. Consequences are that, as currently written, few if any PSAs are candidates for removal. Accordingly, the list of PSAs can grow, but cannot shrink. A pressing need is for Priority Science Actions and their goals to be made sufficiently specific to permit assessments of progress. This should include requirements for projects relating to goals and assessment of progress to be described in RFPs for recovery science, matched by more exacting reporting obligations for grantees to describe how their results should be applied. Wherever appropriate, scientists conducting recovery research should be actively involved in the process of transforming research results to actions.

A fifth lesson relates to total expenditure on recovery science. This may be the first time such an estimate has been attempted. A few respondents expressed surprise at a total in excess of $50 million, but in opposing ways: some were surprised by how large it is, others by how small. Additional perspective is needed to put this figure in context. The total was derived from projects spread over a number of years. If we assume that interval to be seven years between 2009 and 2016, estimated expenditure on science *per year* is about $7 million. This figure seems modest, especially when further considered in context of:

- the vast size and complexity of the ecosystem;
- the long duration of its decline (> 100 years), compared to the proximity of the recovery deadline (2020);
- the colossal amount expended over that period which contributed, directly or indirectly, to its decline, compared to the amount expended so far on its recovery;
- the fact that humans – the principal source of stresses to the ecosystem – are already numerous, and are projected to continue to increase for the foreseeable future;
- the current status of the ecosystem, compared to its targeted status;
- the huge proportion of what is currently unknown that must be learned to achieve recovery;
- the fact that recovery efforts to date have had little detectable effect on most indicators

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of ecosystem status (Puget Sound Partnership 2013).

It is largely for these reasons that we are not close to being able to estimate how long recovery will take and how much it will cost. Absolute cost is of abiding concern, but systematic assessment of cost *effectiveness* rarely features in our approach to recovery. Since ecosystem recovery is an expensive process largely underwritten by public funds, costs should feature as the denominator in virtually every aspect of planning and implementation phases.

Finally, the imagined impact of at least 181 research projects focusing on such a diverse array of recovery priorities engenders hope that recovery gains will be forthcoming. However, it also generates expectation, justified or not, that we will have a clearer vision of how recovery should proceed, and a better understanding of why recovery progress has been slower than expected. The fact that we currently have neither amplifies the need for advances in discovery that arise from research to be more directly and efficiently applied to the recovery of Puget Sound.

Part II: Description of Recommended Studies

This section describes recommendations from recovery scientists and practitioners for research priorities relating to Puget Sound recovery over the next biennium.

A total of 265 scientists and recovery practitioners were invited to recommend research priorities relating to Puget Sound recovery (see Approaches and Methods, above). Only 18 (6.8%) responded, with a total of 87 recommendations. These are listed in Appendix E under the same Action Agenda strategy and sub-strategy headings that were used in Appendix C. All submitted responses were informative, but some were constructively critical. One respondent accompanied insightful recommendations with a comment that "there are very few real research priorities on that old list (some exceptions are PSAs 16, 19, and 20, all of which still apply)". Several respondents remarked that PSAs on the list varied greatly in degree of specificity, or were not sufficiently specific, while others noted redundancies (see the General Commentary column in Appendix E). Few recommended removal of PSAs, but none provided sufficient justification for removal.

To these recommendations were added 19 for research on issues relating to ocean acidification from the Blue Ribbon Panel's report on Ocean Acidification (2012), 8 from a report on social science priorities (Biedenweg and Nelson 2013), and 7 from a report on Ecosystem-based Management of Forage Fish in Puget Sound (Francis, 2013; listed in Part III below).

Comparison between 2011-13 and 2014-16 BSWPs

Proportions of recommendations within each Action Agenda sub-strategy from the 2011-13 and 2014-16 Biennial Science Work Plans are compared in Table 5. As presented, the lists are positively but not significantly correlated with each other ($r=0.41$, $df=17$, $P<0.1$). However, if recommendations within the marine and nearshore strategy relating to habitats are combined with those relating to marine and nearshore species and food webs, the proportions become highly correlated ($r=0.9$, $df=16$, $P<<0.001$). Rationale for combining the two categories is that subjective assignments of recommendations to sub-strategies may not have been consistent from one BSWP to the next, and that this may apply more to marine and nearshore projects than others. For example, eelgrass, which features frequently among marine and nearshore

projects, is both a species *and* a habitat and can be classified as either. Correspondence between the two lists is of interest because, all else being equal, a correlation would result if on both occasions responses represented a random sample from the community of recovery scientists. The correlation may simply reflect the (testable) possibility that among different disciplines within Puget Sound's recovery science community, the largest group focuses on marine and nearshore issues, and their numbers have not changed much in the last 2 years. The implication is that this method of generating recovery science priorities may better reflect the make-up of the recovery science community than priorities for research.

Table 5. Comparison of recommended science priorities within each Action Agenda Sub-strategy between the 2011-13 BSWP and 2014-16 BSWP.

Action Agenda Strategy	Action Agenda Sub-strategy	Percent of recommendations in each category	
		2011-13 BSWP	2014-16 BSWP
Upland, Terrestrial & Freshwater	Habitats	7.9	6.9
	Species & Food Webs	4.6	8.0
	Mitigation	2.6	1.1
Marine & Nearshore	Habitats	6.6	26.4
	Species & Food Webs	23.7	11.5
	Mitigation	5.3	0.0
Pollution	Toxics	9.9	4.6
	Runoff from the Environment	6.6	2.3
	Wastewater	2.0	2.3
	Shellfish	0.7	2.3
	Oil Spills	0.0	0.0
	Other	0.7	0.0
Climate Change / OA		4.6	4.6
Human Dimensions		5.3	10.3
Sustaining, Coordinating, & Using Science to Adapt Actions	Building Capacity	2.6	0.0
	Foundational Questions	5.9	0.0
	Scientific Tools for Informing Policy	3.3	4.6
	Integrated, Sustained Monitoring	5.9	14.9
	Education, Training & Outreach	2.0	0.0
	Total Number of Recommendations	152	87

Comparing Ongoing with Recommended projects in the 2014-16 BSWP

For the 2014-16 BSWP, recommendations were received for all Action Agenda sub-strategies that also featured in the inventory of projects. Climate change received the minimum number of recommendations (1), and marine and nearshore habitats received the maximum (23; Appendix E). Proportions of projects within Action Agenda sub-strategies of ongoing and recently complete research differed from those within recommended studies, especially when recommendations from reports were included (Figure 4). Within ongoing and recently completed research, most projects addressed issues relating to pollution and contaminants (red), while relatively few address 'Other' issues relating to ocean acidification, scientific tools, ecosystem monitoring and human dimensions (yellow). This pattern was reversed among recommended studies: sub-strategies for ocean acidification, ecosystem monitoring, and social sciences are expanded, whereas those for toxics and pollutants are diminished. In addition, a greater proportion of projects focused on Marine and Nearshore issues among recommended

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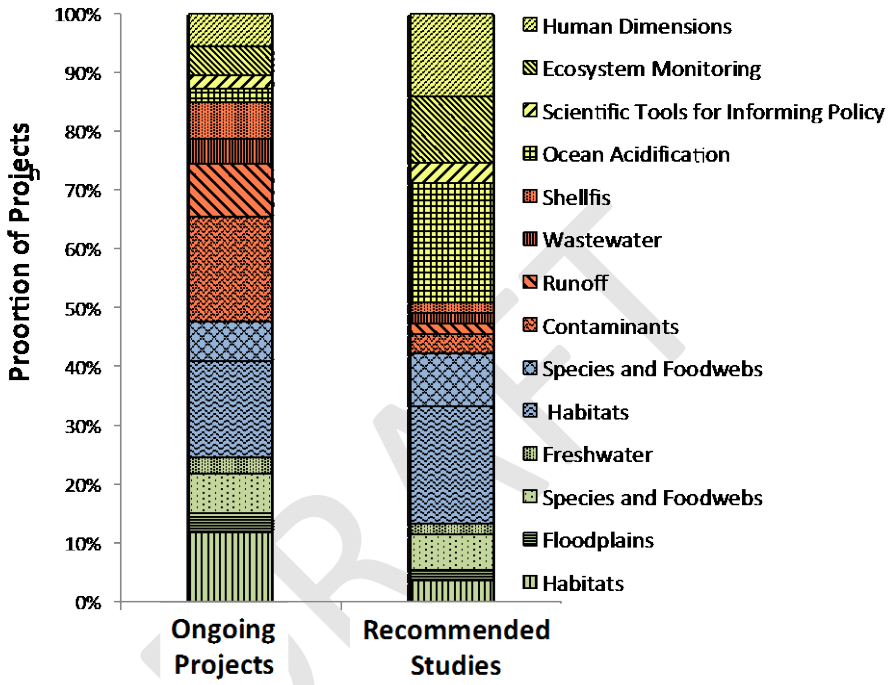
studies than among ongoing projects (Figure 4). These differences reflect changing emphases in research relating to recovery, in particular, the addition of ocean acidification as a major category, and re-emphasis on social sciences.

Figure 4. Proportion of projects assigned to sub-strategies of the Action Agenda in the inventory of ongoing and recently completed projects (left, from Appendix C) and in the inventory of recommended studies (right; from Appendix E). Action Agenda strategy areas are color coded as Terrestrial and Freshwater (green), Marine and Nearshore (blue), Pollutants and Toxics (red), and Other (yellow).



Prevalent themes among studies recommended by respondents

Recommendations for research drawn from reports (e.g. Blue Ribbon Panel on Ocean Acidification) or consensus-building processes (Social Sciences and Forage Fish workshops) qualify as candidates for research 'priority' status. However, recommendations made by individual respondents (Appendix E) require further assessment and consensus before acquiring candidate status. To facilitate that process, research themes that were recommended by more than one respondent in the inventory are described below.

1. *How are beach formation processes affected by human actions, especially armoring?*

   Beaches are dynamic features of the land-sea margin, morphed by the balance of erosion and sediment deposition processes operating at multiple scales. A total of 17 recommendations (R16-R32) from 5 respondents urged better understanding of beach formation processes, sediment budgets, and their interactions with ecological communities, such that effects of natural processes and human actions (e.g. armoring) can be distinguished.

2. *Human impacts on eelgrass*

   Two respondents made 5 recommendations (R34-R38) for research on a diversity of themes relating to eelgrass: effects of climate change, ocean acidification, and increased CO_2; effects on donor eelgrass populations of harvesting for transplantation; effects of shoreline development, nitrogen supplementation, and algal blooms on eelgrass.

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3. *Basic understanding of marine food webs*

   Three respondents made 10 recommendations (R40-R49) for research on marine food webs. These were largely intended to improve basic understanding of how food web dynamics vary spatially across the Sound, how recovery strategies targeting linked species in the food web are likely to conflict with each other, and the factors that limit forage fish populations.

4. *Relationships between human inputs of nitrogen, dissolved oxygen, and harmful algal blooms.*

   Four respondents made 4 recommendations (R56-R59) for research relating to effects of human inputs of nitrogen to Puget Sound on dissolved oxygen and harmful algal blooms, and how ocean acidification might change these relationships. Better understanding is needed about the triggers of harmful algal blooms and their threats to human health, with focus on communicating the risks associated with HABs among Tribal people.

Overall, one third of all recommendations targeted uncertainties relating to marine, nearshore, and shoreline processes.

Conclusions

Possible reasons for such a low response rate to requests for recommendations include insufficient incentive to respond, given competing demands for time. A related possibility is lack of confidence in this process for prioritizing science. Another is that it is less than 3 years since scientists were polled about recovery priorities for the 2011-13 BSWP, and perceptions may not have changed enough to motivate a response.

Recommendations from individuals and reports meet the statutory requirement to identify research recommendations. However, recommendations from individuals do not automatically qualify as research priorities, and the sample size was too small draw conclusions based on consensus. No process currently exists for transforming 'raw' recommendations from Appendix E, or even the salient 'themes' described above, into candidates for research priority status. An alternative way to register research recommendations in future is sketched below in Part IV (Recommendations for Improvement).

Research recommendations that were selected by a consensus-building process and documented in reports are automatic candidates for priority status. These include:

- 19 recommendations from a report by the Blue Ribbon Panel on Ocean Acidification, especially those labeled as key early actions, or 'KEAs';
- 7 recommendations from a report on Ecosystem-based Management of Forage Fish in Puget Sound (Francis et al. 2013).
- 8 candidate recommendations from a report on research priorities for social sciences (Biedenweg and Nelson 2013);

They are further described in the next section.

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Part III: Research priorities for the next biennium

In this section research priorities for the next biennium are listed.

PSAs that may not have been funded in the 2011-13 biennium

As described in Part I, none of the 48 Priority Science Actions listed in Table 1 could be judged to have been completed and thus dropped from the list. In the strict sense, therefore, all retain priority status for the coming biennium. However, there were five that may not have been awarded funds:

- PSA 16: Develop analytical tools and information to understand the tradeoffs in managing food webs of marine species and the multiple stressors affecting those food webs.
- PSA 17: Implement 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.
- PSA 20: Conduct studies to identify sources of nutrients that enter Puget Sound that can be used to develop strategies for maintaining water quality for Puget Sound food webs.
- PSA 30: Evaluate individual and combined effects of commonly used pesticides on salmonids, other fish, and their foods.
- PSA 35: Evaluate existing oil spill risk assessments and complete additional risk analyses of higher risk industry sectors to ensure there are appropriate levels of investment in reducing risk.

In principle, these should be of high priority, but confirmation is needed that funds were not awarded, that they are indeed priorities, and that these subjects have yet to attain sufficient recognition as priorities among funding agencies. For example, PSAs 16 and 20 focus on stressors affecting marine food webs, including nutrients, issues that are echoed among recommendations from individuals in Part II, and for forage fish in this section (below). The potential of marine protected areas (PSA 17) requires attention to establish their potential for recovery, if any. And the risk of and status of preparedness for oil spills (PSA 35) requires review. These issues need attention by the Science Panel early in the coming biennium.

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Ocean Acidification research priorities

"Between 2005 and 2009, disastrous production failures at Pacific Northwest oyster hatcheries signaled a shift in ocean chemistry that has profound implications for Washington's marine environment. Billions of oyster larvae were dying at the hatcheries, which raise young oysters in seawater. Research soon revealed the cause: the arrival of low-pH seawater along the West Coast, which created conditions corrosive to shell-forming organisms like young oysters. The problem, in short, was ocean acidification" (quoted from Washington State Blue Ribbon Panel on Ocean Acidification, 2012; for a technical summary of ocean acidification in Washington, see Feely et al., 2012).

"Recognizing the risks of ocean acidification to Washington, Governor Christine Gregoire created the Washington State Blue Ribbon Panel on Ocean Acidification to chart a course for addressing the causes and consequences of acidification. The Panel, convened in February 2012, was assembled under the auspices of the Washington Shellfish Initiative, a regional partnership established to implement the National Oceanic and Atmospheric Administration's (NOAA) National Shellfish Initiative. Members included scientists; public opinion leaders; industry representatives; state, local, federal, and tribal policymakers; and conservation community representatives.

The Governor charged the Panel to:

- Review and summarize the current state of scientific knowledge of ocean acidification,
- Identify the research and monitoring needed to increase scientific understanding and improve resource management,
- Develop recommendations to respond to ocean acidification and reduce its harmful causes and effects, and
- Identify opportunities to improve coordination and partnerships and to enhance public awareness and understanding of ocean acidification and how to address it."

A recommendation of the Blue Ribbon Panel on Ocean Acidification was to create the Washington Ocean Acidification Center, which was established in July 2013 under direction from the Washington State Legislature and Governor Inslee. The Center is led by the College of the Environment at the University of Washington and includes faculty and staff from multiple departments and disciplines. It is modeled after and integrated with the UW's Climate Impacts Group, a leader in developing and delivering decision-relevant science. The Center is co-directed by Jan Newton (Applied Physics Laboratory, Oceanography) and Terrie Klinger (Marine and Environmental Affairs).

The Center is charged by the legislature to execute five priority actions:

- Ensure continued **water quality monitoring at the six existing shellfish hatcheries** and rearing areas to enable real-time management of hatcheries under changing pH conditions. The monitoring data have enabled hatchery operators to avoid drawing acidic water into the hatcheries and rearing areas.
- Establish an **expanded and sustained ocean acidification monitoring network** to measure trends in local acidification conditions and related biological responses. This monitoring will allow detection of local acidification conditions and increase our scientific understanding of local species responses.
- Establish the **ability to make short-term forecasts of corrosive conditions** for application to shellfish hatcheries, growing areas, and other areas of concern. A real-

time online tool will be developed and accessible to shellfish growers and managers to track acidification on a scale of days to weeks, giving them time to change or adjust their hatcheries' operation.

- Conduct **laboratory studies** to assess the direct causes and effects of ocean acidification, alone and in combination with other stressors, on Washington's species and ecosystems. The studies will focus on determining the biological responses of species of ecological, economic, and cultural significance, to a full suite of stressors to which they are exposed, and will help estimate the genetic potential of these species to adapt to ocean acidification.
- Investigate and develop **commercial-scale water treatment methods** or hatchery designs to protect larvae from corrosive seawater. Scientists from the UW will help shellfish growers assess the effectiveness of the adaptation measures.

The Center will achieve these goals and others by:

- Bringing a regional focus to research priorities and serving as a regional hub for research endeavors
- Training the next generation of scientists, managers, and decision-makers to face the challenges posed by ocean acidification
- Using a distributed network model of organization to join the expertise of UW scientists with that of other regional academic institutions, agencies, and organizations
- Engaging with industry representatives, state, local, federal, and tribal policy makers, and public opinion makers through specific activities and through the formation of an advisory board and a science advisory team, both of which will be used to help guide the activities of the Center.

The WOAC will participate in the implementation and / or management of actions recommended by the Blue Ribbon Panel that were summarized in Washington State Blue Ribbon Panel on Ocean Acidification report of 2012. Actions requiring or relating to science are listed in Table 6, with commentary from WOAC's director (Jan Newton) about funding, priorities, partners, and relevance to this BSWP.

Ocean Acidification is a new addition to the list of issues relating to the health and recovery of Puget Sound, with its own priorities for research that will compete with others for limited available funds. Funds for OA research may derive from a mix of Federal (NOAA & EPA, possibly USGS), State (LOs, Legislature to WOAC), tribes, foundations, and others. Newton notes that a new Vital Sign for OA is needed, based on the saturation state of aragonite in Puget Sound, as others have adopted (e.g., California Current Acidification Network, C-CAN, developed by Sea Grant, Moore Foundation, NOAA, US IOOS, scientists, growers, and other industry reps; also the Global Ocean Acidification Observing Network, GOA-ON, spearheaded by NOAA and UK OA Program through two workshops with ~100 scientists from ~30 countries). Development of the Vital Sign will be based on results of Action 7.1.1 in Table 6.

Recommended priorities for research on OA in the coming biennium are highlighted in green in Table 6.

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Table 6. Research recommendations from the Washington State Blue Ribbon Panel's report on Ocean Acidification (2012).

Action No.	Action Title (Actions that WOAC was funded by State Legislature to implement are in blue)	Commentary from Jan Newton (with recommendations for the BSWP in green)
Action 4.1.3	Review data to determine if there is a causal relationship between local air emissions and local marine water acidity. If the data confirms such a relationship, take actions to reduce local air emissions that contribute to acidification.	None of this is funded directly by WA state, but NOAA PMEL is conducting this data review and assessment. Results should be available within the biennium. Dick Feely and Simone Aline contacts.
Action 6.1.1	Develop vegetation-based systems of remediation for use in upland habitats and in shellfish areas. [KEA]	This is unfunded. A pending Allen Challenge proposal by Davis et al. would address this, if funded.
Action 6.2.1	Ensure continued water quality monitoring at the six existing shellfish hatcheries and rearing areas to enable real-time management of hatcheries under changing pH conditions. [KEA]	This has been funded and WOAC is implementing via PCSGA (Pacific Coast Shellfish Growers Association). This should be part of our BSWP. Newton/Klinger contacts with PCSGA.
Action 6.2.2	Expand the deployment of instruments and chemical monitoring to post-hatchery shellfish facilities and farms.	This is unfunded, though funds to NANOOS from US IOOS (United States Integrated Ocean Observing System, NOAA) is partially funding this work.
Action 6.2.3	Investigate and develop commercial-scale water treatment methods or hatchery designs to protect larvae from corrosive seawater. [KEA]	This has been funded and WOAC is implementing via PCSGA (Pacific Coast Shellfish Growers Association). This should be part of our BSWP. Newton/Klinger contacts with PCSGA.
Action 6.2.4	Develop and incorporate acidification indicators and thresholds to guide adaptive action for species and places.	This work will be informed by 7.1.1, 6.2.1, 7.4.1 and 6.2.3 so probably next bienium.
Action 6.3.5	Investigate genetic mechanisms and selective breeding approaches for acidification tolerance in shellfish and other vulnerable marine species.	This is not funded.
Action 7.1.1	Establish an expanded and sustained ocean acidification monitoring network to measure trends in local acidification conditions and related biological responses. [KEA]	This has been funded to WOAC and we are implementing with network partners. This should be part of our BSWP. Newton/Klinger contacts.
Action 7.1.2	Develop predictive relationships for indicators of ocean acidification (pH and aragonite saturation state).	This is not funded directly by state, but NOAA PMEL is doing this data review and assessment (they have done this for coastal waters and will be looking at Puget Sound). Results should be available within the biennium. Would be helpful if this is part of BSWP. Dick Feely and Simone Alin contacts.
Action 7.1.3	Support development of new technologies for monitoring ocean acidification.	This is not funded by state but two acitivities address this that WOAC, NOAA PMEL and others are directly involved with. 1) Wendy Schmidt X-PRIZE is offered for this. WOAC and NOAA PMEL will be involved with the demonstrations at Seattle Aquarium and other venues. 2) NOAA IOOS and OAP (Ocean Acidification Program) offered an FFO for this. NANOOS (Northwest Association of Networked Ocean Observing Systems, the PNW regional component of US IOOS) is involved with 5 proposals that could be funded this FY14 or FY15. NOAA PMEL is a partner on 4 of these.
Action 7.2.1	Quantify key natural and human-influenced processes that contribute to acidification based on estimates of sources, sinks, and transfer rates for carbon and nitrogen. [KEA]	This will be investigated by Ecology with potential funding by EPA. The WOAC model (7.4.1) may also contribute capacity to assess, if additional funds are available. Should be part of BSWP. Mindy Roberts & Hedia Adlesman contacts.
Action 7.2.2	Develop new models or refine existing models to include biogeochemical processes of importance to ocean acidification.	NOAA NWFSC is making progress with this. For use in Puget Sound, to couple with physical models, likely best to do once 7.4.1 and 7.2.1 models complete, e.g., next biennium. Would be helpful if part of BSWP. Stein would be contact
Action 7.3.1	Determine the association between water and sediment chemistry and shellfish production in hatcheries and in the natural environment. [KEA]	WA DNR is working on this in field. Should be part of BSWP. Cinde Donohue is contact
Action 7.3.2	Conduct laboratory studies to assess the direct effects of ocean acidification, alone and in combination with other stressors, on local species and ecosystems. [KEA]	This has been funded to WOAC and we selected a proposal based on RFP and peer review. Experiments will be on copepods, krill, crab, oysters and geoduck by a team from UW, WWU, and NOAA NWFSC. This should be part of BSWP. Newton/Klinger contacts; Keister et al. PI
Action 7.3.3	Conduct field studies to characterize the effects of ocean acidification, alone and in combination with other stressors, on local species.	Not currently funded.
Action 7.4.1	Establish the ability to make short-term forecasts of corrosive conditions for application to shellfish hatcheries, growing areas, and other areas of concern. [KEA]	This has been funded to WOAC and we selected a proposal based on RFP and peer review. Model will address outer coast, Puget Sound and Columbia and is being done by a team from UW. This should be part of BSWP. Newton/Klinger contacts; MacCready PI
Action 7.4.2	Enhance the ability to predict the long-term future status of carbon chemistry and pH in Washington's waters and create models to project ecological responses to predicted ocean acidification conditions.	Likely best done in future biennium.
Action 7.4.3	Enhance the ability to model the response of organisms and populations to ocean acidification to improve our understanding of biological responses.	Likely best done in future biennium.
Action 9.1.2	Create an ocean acidification science coordination team to promote scientific collaboration across agencies and organiza- tions and connect ocean acidification science to adaptation and policy needs.	This is what the State Legislature funded WOAC to be. Should be in BSWP. Newton/Klinger, co-directors, are contacts.

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Ecosystem-based Management of Forage Fish in Puget Sound

In the Spring of 2013, the Puget Sound Institute convened a 9-member study panel ("the Study Panel") to assess the state of the science, and to recommend and conduct data analyses related to ecosystem-based management of forage fish in Puget Sound. Members of this panel include forage fish experts from across the West Coast from universities and state and federal (including Canadian) government agencies. In August 2013, the Study Panel met for its first workshop. A day of presentations by and discussions with other regional scientists and stakeholders, followed by 3 days of discussions internal to the Study Panel, resulted in this summary and proposed research plan.

The Study Panel agreed upon several facts with respect to Puget Sound forage fish and, specifically, Pacific herring (a Puget Sound Partnership Vital Sign):

1. Spawn deposition surveys are sufficient for estimating herring adult spawner biomass, and for describing trends in adult spawner biomass through time. However, the assumptions contained in the model that converts egg density estimates to adult biomass should be re-evaluated. The spawn deposition surveys and acoustic/trawl surveys (conducted before 2009) estimate the same abundance trends overall.
2. The major herring spawning locations are known.
3. Herring and sand lance are key prey items in the diets of several Puget Sound predators, including fish, birds and mammal.

However, several key gaps exist in our understanding of Puget Sound forage fish, preventing effective management. The Study Panel's work plan was developed to address these gaps, which include:

1. Status of/trends in abundance of forage fish species other than herring;
2. Key vulnerabilities of forage fish;
3. Abundance/biomass of forage fish needed to support key ecosystem predators;
4. Prey base/food supply for forage fish;
5. Consequences of herring age truncation;
6. Partial migration by herring out of Puget Sound.

The Study Panel recommended *analyses that are of key importance to the recovery of Pacific herring*, and achieving recovery targets established by the Puget Sound Partnership:

1. Identify key vulnerabilities of herring to determine what limits their populations.
2. Determine how much herring biomass – of what size, and where – is needed to sustain top predators.
3. Develop a life-cycle model for use in determining how the most likely stressors affect herring populations.
4. Build a management strategy evaluation to test the effects of individual, or suites of, management actions on key stressors to herring, based upon identified key vulnerabilities and using a life-cycle model.

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Several key gaps in information cannot be filled by a study panel, but rather ***require ongoing monitoring***. The Study Panel also made recommendations for monitoring actions that are necessary for ecosystem-based management of forage fish in Puget Sound. These include:

5. Collect biological samples to establish age/size composition (including of herring, to support the Vital Sign Indicator/Target).
6. Conduct ichthyoplankton surveys, to provide information about early life stages, and especially for estimating abundance of sand lance.
7. Conduct zooplankton surveys, to provide information about prey base for forage fish.

A list of research priorities for ecosystem-based management of forage fish

1. Identify key stressors to forage fish and effective management actions to protect them

Action 1.1: Build life-cycle model for forage fish (Proposed Work Plan Project 7)
Who: Ole Shelton/NOAA, Tessa Francis, UW grad student
Status: Awaiting funding for UW grad student
Completion: Spring 2014
Budget: $20,000 (3 months PSI)

Action 1.2: Identify critical stressors for forage fish, *using above life-cycle model* (Proposed Work Plan Project 7)
Who: Essington/UW, Dayv Lowry/WDFW, Shelton/NOAA, UW grad student
Status: Awaiting funding for UW grad student
Completion: Spring 2014
Budget: $75,000 (12 months PhD + 1 month PSI)

Action 1.3: Management Strategy Evaluation: Construct operating model to determine the effects of different management actions to limit key stressors, given their effects at different life stages, *using above life-cycle model and identified critical stressors* (Proposed Work Plan Project 1)
Who: Essington, UW postdoc
Status: Need funding for postdoc
Completion: 12 months
Budget: $110,000 (18 months postdoc)

2. Determine abundance of (non-herring) forage fish

Action 2.1: Estimate forage fish abundance using predator diets (Proposed Work Plan Project 8)
Who: Ole Shelton/NOAA, Megsie Siple/UW, Lowry/WDFW
Status: Not yet begun
Completion: ?adsf
Budget: $34,000 (6 months PhD)

Action 2.2: Estimate forage fish abundance using seabird behavior (Proposed Work Plan Project 10)
Who: Marc Mangel/UWT and PSI
Status: Starting January 2014
Completion: May 2014

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Budget: $20,000 (2 months Senior Scientist)

3. Determine biomass needed to support key predators (Proposed Work Plan Project 2)
   Action 3.1: Estimate predator needs in space and time
   Who: Essington, Lowry/WDFW, Doug Hay/DFO, UW Grad student
   Status: Seeking UW grad student
   Completion: Summer 2014
   Budget: $68,000 (12 months PhD + 1 month PSI)

Candidates for research priorities in the Social Sciences

Humans are both the cause of and the opportunity for addressing the majority of recovery challenges such as ocean acidification and salmon habitat loss. At the same time, the Puget Sound Partnership is tasked with restoring the Puget Sound for human quality of life. On the immediate horizon, we need to synthesize and conduct social science to better link the pressure assessment to accurate human drivers and human wellbeing outcomes, to develop appropriate and viable implementation strategies, and to monitor the effect of restoration strategies on human wellbeing or quality of life.

Candidates for social science research priorities for the 2014-2016 Biennial Science Work Plan were identified via a participatory workshop in October 2013 involving 17 social scientists from public agencies, universities and consulting firms working throughout the Puget Sound region. Information was gathered during small and large group sharing across four social domains. The following were identified as candidates for priorities, based on a qualitative highlighting of the topics participants felt were either immediate or critical to respond to Puget Sound recovery (no attempt was made to rank these candidates).

Descriptions of candidates for Social Science research priorities

1. **Explore the effects of corporate ownership on natural resources:** The impact of large corporate ownership of natural resources and related opportunities is minimally understood but is potentially a critical driver in the status of Puget Sound ecosystems and human wellbeing. This research priority includes an overview of the larger economic picture as it affects Puget Sound natural resources as well as the relevant corporate culture and practices that influence specific aspects of natural resource use. Research can also highlight opportunities for improvement and the alternatives to standard corporate processes.

2. **Conduct research on motivators of landowner behaviors**: Improve understanding of the incentives, policy contexts, and decision frameworks that create behavior change, as alternatives to regulation – that increase social-responsibility, influence self-regulation, and encourage stewardship – segmented by audience/stakeholder group (individuals and corporate resource users, and/or land owners, social demographics, resource user types). To address individual resource users, demographic information about communities and their resource use, and the relevant local regulatory structure, will inform how those groups are targeted, and how incentive programs are designed. A better understanding of the larger economic environment in the Puget Sound region, including corporate communities, how they influence resource use, and under which regulatory mandates they operate, will create opportunities to directly target

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businesses with large influence. It is necessary to understand the nuances of the Puget Sound public and private communities to design effective incentive programs and policies that result in behavior change. The PSP Sound Behavior Index currently collects some of this information for individuals.

3. **Conduct ecosystem service valuation and Define human wellbeing indicators for Puget Sound**: Further development of human wellbeing indicators and ecosystem services valuation to measure quality of life benefits associated with what and how we value the Puget Sound environment. This information will enable decision-makers to prioritize the degree to which humans value aspects or components of the environment, and prioritize appropriate recovery actions. The current ecosystem service valuation in use does not employ Puget Sound-specific data, but instead uses proxies from elsewhere. Locally specific information will improve the accuracy of this important decision tool. Human wellbeing indicators are required to evaluate the non-tangible ecosystem services from which humans benefit. The final set of indicators will fill the current 'Quality of Life Index' placeholder in the PSP Vital Signs. These indicators will also inform effectiveness monitoring of the social outcomes of restoration actions and track changes in the Puget Sound social-ecological system.

4. **Perform meta-analysis of Puget Sound social science research**: Social science research across the Puget Sound region encompasses many types of data, including survey results, economic analyses, and others, which are housed in a variety of locations. Institutional and logistical barriers limit the sharing and systematic analysis of these data. In order to track the human dimensions of the Puget Sound environment, these disparate data must be aggregated to enable meta-analysis of regional trends and comparison across areas and communities, and explore the relationships between variables.

5. **Monitor and measure land use conversion for all Puget Sound counties**: Land conversion is occurring rapidly throughout the Puget Sound region, having dramatic effects on habitat and ecosystem service provisions. It is necessary to monitor these changes and illustrate the data with GIS analysis to make the information useful for land use planning in adaptive management settings. Some counties and state agencies have historically collected and analyzed this data, while others have not.

6. **Examine contaminant impacts on physical health & ecosystem services that support human wellbeing**: The connection between upland resource contaminants and their impact on the ecosystem services that support human wellbeing is not well documented. Upland resources provide many opportunities for recreation and other physical and psychological benefits, including many hunted and foraged species. This priority is linked to the previous item describing the need for further development of social indicators and ecosystem service valuation, and specifically highlights the need to link emerging contaminants to physical health and human behaviors.

7. **Develop decision-making tools for policy-makers and funders for the use of integrated natural and social science**: This research is specifically at the science-policy interface. The continued integration of social and natural science will improve the science community's ability to inform decisions and policies. Ecosystem attributes are currently being defined for both the biophysical and human dimensions of the social-ecological system, and their pressures and stressors are being identified in a regional pressure

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assessment. Concurrently, an integration ecosystem model will be defined for use as a decision making tool. This model will be customizable to local communities, with relevant components and appropriate pressures and stressors. This and other decision science tools should be studied for how well they integrate the natural and social sciences along with political and social contexts to result in viable strategy development. Research should seek to understand how such information reflects and responds to the needs of scientists, decision makers and funders.

8. **Improve understanding of the roles of local elected officials and technical staff in implementing recovery actions**: The role of local governments and the local processes tasked with implementing Action Agenda recommendations vary from location to location. Understanding these dynamics, the roles of elected officials at each level, and how they do or do not collaborate with local technical staff, will aid regional planning efforts to design restoration priorities with actionable goals. Understanding these roles will also help PSP to adapt its programs to more effectively support local efforts.

Conclusions

The research topics listed in this section are the product of different kinds of consensus-building processes, some more exacting and conclusive than others (the social sciences process was more a sharing of ideas). It should be stressed that all are *candidates* for support as priorities, subject to confirmation from the Science Panel by a process that has yet to be determined. It is also noted that all of the original 48 PSAs are still priorities, and that all of the recommendations from individuals (Appendix E) have potential validity.

Part IV: Recommendations for improvement

To this point, the report has assessed how science is informing recovery of Puget Sound at the end of 2013, with recommendations for priority actions in the coming biennium. The purpose of this section is to identify needs relating to the mechanism by which science informs recovery, and to suggest improvements.

According to the latest *State of the Sound* report (2013) we are half way to the statutory 2020 'deadline' for recovery, but most status and trends indicators ('Vital Signs') have not advanced much, if at all, towards their targets, and some, such as orcas, have lost ground. Puget Sound recovery practitioners are not alone in expending great effort and still finding recovery elusive. A recent meeting of lead scientists representing Puget Sound and six other large coastal ecosystems in the US revealed that to varying extents all were struggling not only with this, but also with other shared challenges (Table 7). Insights that stood out from proceedings as particularly instructive for the application of science to ecosystem recovery are related in Georgiadis et al. (2014), and those that pertain to Puget Sound are repeated below.

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The problem of not progressing towards recovery targets is compounded by not knowing *why*. The severity of this problem was highlighted at a recent Science Panel meeting by an observation about the Intensively Monitored Watersheds program. This program was set up specifically to understand the complex relationships controlling salmon responses to habitat changes (in Washington state), and to detect responses by salmon to a set of restoration actions, by concentrating monitoring and research efforts at a few strategically selected locations (http://www.ecy.wa.gov/programs/eap/imw/index.html). After 10 years and expending >$14 million, few responses have been detected. This observation has sobering implications for expectations of informed recovery at the level of the Puget Sound ecosystem. There is pressing need to better understand the effectiveness of recovery actions.

Table 7. Shared challenges among recovery strategies of seven coastal ecosystems.

1. *Setting priorities under uncertainty, not only among multiple recovery targets and actions, but also for the science needed to reduce uncertainty and support decision-making.*
2. *The problem of detecting and defining causal relationships between stressors, actions, and ecosystem responses.*
3. *Managing expectations about recovery: ecosystems often take so long to respond to remedial action it is hard to know if they are responding at all.*
4. *The theory of adaptive management is far easier to grasp than to apply.*
5. *Recovery science for a given ecosystem is often "fractured", proceeding without coordination among largely independent groups.*
6. *Effectively communicating science to policy and decision makers.*
7. *Applying and integrating social sciences into ecosystem restoration promise great gains, but all have struggled to achieve this goal.*

For ecosystems represented at the workshop, there were few reported instances of even partial recovery (e.g. blue crab in Chesapeake Bay), but these were instructive. For example, progress towards recovery targets tended to be more advanced in recovery strategies that focus on fewer targets. Chesapeake Bay's recovery strategy targets only three stressors (nitrogen, phosphorus, and sediment levels in rivers flowing into the Bay). By contrast, more than 20 recovery targets have been selected for Puget Sound (depending on how they are defined). Progress may be imperceptible because capacity and resources have been spread too thinly over too many targets and across too large an area for recovery gains to be detectable. A related possibility is that system responses are nonlinear and manifested only after cumulative effort surpasses threshold levels that have not yet been reached for most targets. Even if these are valid, in complex systems like Puget Sound, narrowing the scope of the recovery strategy to a feasible yet functional number of targets turns out to be one of the greatest challenges of all. This is because the number of potential targets is large, many of them interact with each other, and much of the information is lacking that is required to rank them by potential to yield greatest recovery gains.

A further difference among ecosystem recovery strategies represented at the workshop was that some were more explicitly model-based than others. For example, in the Chesapeake Bay region, management of stressors depends on sophisticated models, finely tuned systems of regulation, and tailored coordination among state and federal agencies. From the assessment in Part I above it is evident that models are reasonably prevalent among ongoing and recently completed research projects in Puget Sound, yielding critical insights into ecosystem processes. But this may be less true of recovery strategies. Too often it is left implicit how research findings (especially models) will be adapted and applied to recovery. There is great need for synthesis of research findings and assessment of their implications for recovery.

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Many of the reasons that might account for little observable progress towards recovery are symptoms of a more inclusive explanation: that Adaptive Management (AM) is difficult to apply at the ecosystem level. Practitioners at the workshop agreed that applying AM to large and complex ecosystems is challenging, but nonetheless re-affirmed unanimously that AM should remain the default approach to recovery, for three main reasons: there are too many unknowns for any alternative approach to be viable; to chart a cost-effective course towards recovery; and to demonstrate net benefits of actions in order to justify continued funding for recovery (or, if actions do not deliver desired effects, at least to understand *why*). Discussion about relative expenditure on monitoring and AM among ecosystems revealed an average of about 15% of the total spent on recovery. This was an amount limited more by what funding agencies were prepared to commit than by what is needed to address critical uncertainties.

In Puget Sound, Adaptive Management was nominally adopted as the default approach (Puget Sound Partnership 2010, Redman et al. 2013). But AM has been applied in a patchy and incomplete manner, partly because of insufficient resources. Since recovery strategies for threatened and endangered species are availed greater resources, it is no coincidence that AM is better developed for, say, Chinook salmon than for *non*-endangered targets in Puget Sound (viz. *Framework for development of Monitoring and Adaptive Management Plans*, the Intensively Monitored Watersheds program, and the budget of project no. 29 in the inventory of projects). It follows that resources on a similar scale would be required to apply AM to every recovery target, endangered or not. Because funding at that scale for all targets remains improbable, questions need to be revisited of what is an appropriate number of recovery targets for Puget Sound, and what is the level of funding that would be required to make measured progress towards them.

‘Implementation strategies’ and ‘recovery groups’

Two recent developments offer promising ways to identify, prioritize, and achieve research priorities for recovery that improve upon approaches used to date. The first is resurgent support for creation of ‘implementation strategies’ for each recovery target. Also called ‘results chains’, ‘theories of change’, or ‘pathways of effects’, all refer to conceptual models that describe the mechanistic theories, causal pathways, and actions by which recovery targets will be met. Creating an implementation strategy is a key step in the programmatic cycle of Adaptive Management (Conservation Measures Partnership 2013). They are useful because they make assumptions explicit, promote communication and coordination, facilitate implementation and adaptation, and ensure continuity (among other reasons outlined below). In Puget Sound’s recovery program, many implementation strategies have been sketched, but not completed or applied, largely because, once again, resources and therefore capacity were lacking to tackle so many at once.

The second promising development arose during a recent workshop designed to explore the feasibility of creating implementation strategies for recovery targets in Puget Sound. Those focusing on Pacific herring discussed how a ‘recovery group’ comprised of applied scientists, experienced managers, and other experts could develop and advance a recovery strategy for herring, much as ‘recovery teams’ do for endangered species. Given funding constraints, recovery groups could fill only a few of the roles that are typically performed by recovery teams, but defining implementation strategies should be included. This notion is not entirely new, since clusters of scientists, resource managers and recovery practitioners already exist within the

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Puget Sound restoration community for many of the recovery targets (e.g. shoreline armoring, forage fish, floodplains). The key feature of this approach is that creation of implementation strategies would proceed 'in parallel' for each target, rather than one group being responsible for defining all of them. Recovery groups would need appointment, guidance, management, coordination, and funding.

Implementation strategies should have a catalyzing effect on progress not only for the general reasons listed above, but also for reasons that address many of the difficulties relating to identification and selection of decision-critical research that were highlighted in Part I of this report. Once an implementation strategy is designed and documented it becomes possible to add additional layers showing the junctures at which 1) research is needed to fill a critical uncertainty (including models and social science), 2) monitoring is needed to assess effectiveness of actions, 3) policy changes are required; 4) costs can be estimated to assess cost-effectiveness, and 5) time expected for these elements to be delivered. For any given time and purpose (such as the preparation of a BSWP), the list of research priorities can be drawn up simply by combining the 'research layers' from each implementation strategy. The list of monitoring and policy priorities would be similarly derived. It becomes at least conceivable to estimate and compare the cost and cost-effectiveness of alternate paths and actions, order actions into a logical time frame, and expose common and conflicting goals within and among strategies.

There is no process that guarantees achievement of recovery goals. Adaptive management is the approach that, more than any other, improves the likelihood that progress can be made towards recovery under uncertainty. The Science Panel endorses application of Adaptive Management, and recommends that it be supported accordingly. Initial emphasis should be on completion of implementation strategies for each target by separate recovery groups. Once implementation strategies have stabilized, funds should be awarded largely to projects – be they for research or implementation of recovery-related actions – that explicitly describe how topics featured in and justified by implementation strategies will be addressed. The next BSWP should summarize progress in the design and use of implementation strategies, including the identification of recovery research priorities, and descriptions of criteria by which attainment of research objectives will be assessed.

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This section concludes with a list of needs relating to recovery science that were expressed in this BSWP (Table 8).

Table 8. A list of needs relating to recovery science that were expressed in this BSWP.

1	For a process to be developed by which the inventory of recovery research projects can be continuously updated (as opposed to recreating it anew every biennium) using a dedicated online database. Once operational, funding agencies should require grantees to enter project data into the database as funds are awarded.
2	For the BSWP to be published as far in advance of other work plans (including LO plans and Action Agenda Updates) as necessary to allow research recommendations to be acted upon, and funding provisions made (>6 months).
3	For results and findings of completed research projects to be synthesized and their implications for recovery assessed.
4	For effectiveness of recovery actions to be assessed, where appropriate, through effectiveness monitoring.
5	For *cost effectiveness* to guide planning and implementation of recovery priorities and actions.
6	For research recommendations and 'candidate' research priorities listed in Part III to be selected and confirmed as actual research priorities.
7	For Priority Science Actions and their goals to be made sufficiently specific to permit assessments of progress.
8	For the scope of Puget Sound's recovery strategy (e.g. number of recovery targets) to be reduced, and / or funding to be increased, such that resources are sufficient to allow Adaptive Management to be operational for every target.
9	For 'implementation strategies' to be defined and documented for every target by a separate 'recovery group'.
10	For RFPs relating to recovery science to require proposers to describe how their projects will address PSAs (and elements of implementation strategies), and how results will be applied to recovery.
11	Where appropriate, for scientists conducting recovery research to be actively involved in the process of transforming their research results to actions.

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Appendices

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Appendix A

Legislation relating to role of the PSP Science Panel and Biennial Science Work Plan

RCW 90.71.290 Science panel — Strategic science program — Puget Sound science update — Biennial science work plan.

(1) The strategic science program shall be developed by the panel with assistance and staff support provided by the executive director. The science program may include:
   (a) Continuation of the Puget Sound assessment and monitoring program, as provided in RCW 90.71.060, as well as other monitoring or modeling programs deemed appropriate by the executive director;
   (b) Development of a monitoring program, in addition to the provisions of RCW 90.71.060, including baselines, protocols, guidelines, and quantifiable performance measures, to be recommended as an element of the action agenda;
   (c) Recommendations regarding data collection and management to facilitate easy access and use of data by all participating agencies and the public; and
   (d) A list of critical research needs.

(2) The strategic science program may not become an official document until a majority of the members of the council votes for its adoption.

(3) A Puget Sound science update shall be developed by the panel with assistance and staff support provided by the executive director. The panel shall submit the initial update to the executive director by April 2010, and subsequent updates as necessary to reflect new scientific understandings. The update shall:
   (a) Describe the current scientific understanding of various physical attributes of Puget Sound;
   (b) Serve as the scientific basis for the selection of environmental indicators measuring the health of Puget Sound; and
   (c) Serve as the scientific basis for the status and trends of those environmental indicators.

(4) The executive director shall provide the Puget Sound science update to the Washington academy of sciences, the governor, and appropriate legislative committees, and include:
   (a) A summary of information in existing updates; and
   (b) Changes adopted in subsequent updates and in the state of the Sound reports produced pursuant to RCW90.71.370.

(5) A biennial science work plan shall be developed by the panel, with assistance and staff support provided by the executive director, and approved by the council. The biennial science work plan shall include, at a minimum:
   (a) Identification of recommendations from scientific and technical reports relating to Puget Sound;
   (b) A description of the Puget Sound science-related activities being conducted by various entities in the region, including studies, models, monitoring, research, and other appropriate activities;
   (c) A description of whether the ongoing work addresses the recommendations and, if not, identification of necessary actions to fill gaps;
   (d) Identification of specific biennial science work actions to be done over the course of the work plan, and how these actions address science needs in Puget Sound; and
   (e) Recommendations for improvements to the ongoing science work in Puget Sound.

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Appendix B:

Institutions at which staff were contacted to request information about ongoing and recently completed projects, and recommendations for needed research.

County, State, and Federal Agencies
King Co. Science Section
Northwest Fisheries Science Center
Pacific Northwest National Labs
Puget Sound Partnership
USDA Forest Service – Pacific Northwest Research Station
USGS Forest and Rangeland Ecosystem Science Center
USGS Pacific Coastal and Marine Science Center
USGS Washington Water Sciences Center
USGS Western Fisheries Research Center
USGS Western Geographic Science Center
Washington Sea Grant
Washington State Department of Commerce
Washington State Department of Ecology
Washington State Department of Fish and Wildlife
Washington State Department of Health
Washington State Department of Natural Resources (Aquatics & Forestry)
Institutes
Center for Urban Waters
Center for Wildlife Ecology at Simon Fraser University
Coastal Watershed Institute
Pacific Shellfish Institute
Padilla Bay National Estuarine Research Reserve
Port Townsend Marine Science Center
Puget Sound Institute
Non-profit organizations
Long Live the Kings
Nature Conservancy
Olympic Coast National Marine Sanctuary
Skagit River Systems River Cooperative
Colleges and Universities
University of British Columbia Fisheries Centre
University of Washington College of the Environment, Tacoma
University of Washington Friday Harbor Labs
University of Washington SAFS
Washington State University Puyallup including the Washington Stormwater Center
Washington State University Puyallup Research & Extension Center
Western Washington University Shannon Point Marine Science Center

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Appendix C

Appendix C1:
Inventory of Ongoing and Recently Completed Projects.

Appendix C2:
Descriptions of Ongoing and Recently Completed Projects.

Appendix D:
Summary of the total number and total budgets of projects assigned to each of the 48 Priority Science Actions.

Appendix E:
Inventory of Recommended Studies.

Appendix F:
Scientific reports and paper published since 2011 of relevance to Puget Sound recovery

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