THE 2014 PUGET SOUND PRESSURES ASSESSMENT

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Most importantly, sixty experts in aspects of the Puget Sound ecosystem and Puget Sound pressures volunteered their time to provide expert judgments related to intrinsic vulnerability in their areas of expertise. Many of these individuals also participated in workshops on model refinement, delineation of stressors and endpoints, and creation of the model interface. The pressures assessment would have been impossible without their generous contributions of time, expertise, and patience.

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This report is available at the Puget Sound Pressures Assessment website at https://sites.google.com/site/pressureassessment/.

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Acronyms

AV	Adjusted vulnerability, and AU scale result
AU	Assessment unit
CCAP	Coastal Change Analysis Program
DIN	Dissolved Inorganic Nitrogen
DNR	Washington Department of Natural Resources
DOH	Washington Department of Health
ECY	Washington Department of Ecology
GIS	Geographic Information Systems
HELCOM	Helsinki Commission
IUCN	International Union for the Conservation of Nature
IV	Intrinsic Vulnerability
LIOs	Local Integrating Organizations
NOAA	National Oceanic and Atmospheric Administration
PI	Potential Impact
POTW	Publicly Owned Treatment Works
PSNERP	Puget Sound Nearshore Ecosystem Restoration Project

PSP	Puget Sound Partnership
PSPA	Puget Sound Pressures Assessment
SI	Stressor Intensity
SLR	Sea Level Rise
USGS	United States Geologic Survey
UW CIG	University of Washington Climate Impacts Group
VECs	Valued ecosystem components
VME	Vulnerability of marine ecosystems
WDFW	Washington Department of Fish and Wildlife

Key Terms

- **Adjusted vulnerability** is an assessment unit-scale measure of the vulnerability of an endpoint to a stressor considering the stressors' current intensity in the assessment unit.
- **Assessment units** are the watersheds and marine basins in which stressor intensity and endpoint distribution are evaluated. Watersheds are the Salmon Recovery Watersheds and marine basins are as defined by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP).
- **Endpoints** are the habitats and species affected by stressors.
- **Intrinsic vulnerability** explores the response inherent to the biology and ecology of the stressor-endpoint pair to provide an estimate of how a given stressor would affect a specific endpoint under the assumptions that the stressor is acting directly on the endpoint, stressor expression is strong, and management efforts are not mitigating the stressor-endpoint interaction.
- The **IV endpoint index** sums pair-scores across stressors to rank endpoints according to their intrinsic vulnerability.
- **IV pair scores** provide an estimate of intrinsic vulnerability for each of 1,220 unique stressor-endpoint pairs. They integrate expert input on the three intrinsic vulnerability factors: functional impact, recovery time, and resistance.
- The **IV stressor index** sums pair-scores across endpoints to rank stressors according to their potential for harm.
- **Potential impact** adjusts the intrinsic vulnerability results to account for stressor intensity and endpoint presence/absence in Puget Sound watersheds and marine basins. Results are prepared at the AU-scale and then combined to create a Puget Sound-scale view.
- **Pressures** are the human actions that give rise to stress on the ecosystem, but also may provide benefits to humans.
- **Stressors** are the proximate causes of changes in the Puget Sound ecosystem.
- The **uncertainty index** summarizes expert input on uncertainty for each stressor-endpoint pair. Uncertainty is not assessed as a separate factor, but rather uncertainty information is captured directly as part of expert ratings through use of a probability scale.

Background and Introduction

The Puget Sound Pressures Assessment (PSPA) is an effort to better understand the pressures on the Sound's freshwater, marine-nearshore, and terrestrial resources and identify the critical ecosystem vulnerabilities that should be addressed to ensure sustainable long-term protection and recovery. Results are intended to guide and inform science and management priorities and include:

- The vulnerability of endpoints (i.e., habitat and species) to stressors, and based on these results, which stressors have the most potential to impact Puget Sound endpoints and which endpoints are the most vulnerable at the assessment unit and regional scales.
- The current intensity of stressors and distribution of endpoints at the assessment unit and regional scales.
- Relative certainty and uncertainty about stressor-endpoint relationships.

Origins and Intent of the Pressures Assessment

The PSPA is one of the priority science actions in the Puget Sound Partnership's 2011–13 biennial science work plan. Pressure assessment is a priority for the Science Panel because it provides the scientific input for prioritizing recovery actions, based on the assumption that understanding the biggest stressors and most vulnerable ecosystem components (endpoints) is an important consideration for recovery planning. This effort is intended to update the original Puget Sound pressure assessment (Neuman et al., 2009) and respond to concerns that we need a more systematic and robust understanding of pressures and stressors on the Puget Sound ecosystem so we can more confidently identify and focus on what is most important. The 2014 Pressures Assessment:

- Spans a broad suite of stressors and ecosystem endpoints necessary to evaluate and rank stressors across Puget Sound.
- Provides information at two spatial scales: assessment unit (watersheds and marine basins) and regional.

- **Pressures** are the human actions that give rise to stress on the ecosystem, but also may provide benefits to humans
- **Stressors** are the proximate causes of changes in the Puget Sound ecosystem
- **Endpoints** are the habitats and species affected by stressors
- **Assessment units** are the watersheds and marine basins of Puget Sound in which stressor-endpoint interactions are evaluated

- Separates evaluation of the intrinsic vulnerability of endpoints to stressors from evaluation of stressor intensity, thus addressing one of the main criticisms of the 2009 pressure assessment—that it did not provide a fair assessment of pollution and other stressors which, to some extent at least, are controlled by current management actions.
- Engaged experts from throughout the region in a structured and transparent process to support reproducibility and facilitate future updates.
- Explicitly and systematically collected information about the amount and nature of uncertainty so it can be considered and communicated as part of the assessment results.

PSPA PRODUCES FIVE MAIN RESULTS

- Intrinsic vulnerability: stressors with the most potential for harm, and endpoints that are most vulnerable to harm
- Relative certainty and uncertainty about stressor-endpoint relationships
- Current stressor intensity at the assessment unit and Puget Sound scales
- Potential impact of stressors at the assessment unit and Puget Sound scales

So far, PSPA work has been conducted in two phases. The first phase was carried out in 2012 and 2013 and involved development of the overall approach and methodology, as documented in the *Puget Sound Pressures Assessment Methodology Technical Memorandum* (Labiosa, et al., 2014). The second phase, implementation of the PSPA methodology, was carried out in 2013 and 2014 and is documented here. Phase two involved synthesizing the approach into an assessment model that allowed us to gather and analyze assessment data and produce results. Future phases may include discussions with experts to further refine the assessment of intrinsic vulnerability scores and expand expert coverage; expansion and refinement of the GIS-based analysis to more thoroughly examine stressor and endpoint distribution and coincidence; accounting for synergistic and antagonistic effects between pressures, stressors and endpoints; evaluation of stressors under various potential or predicted future scenarios; work with local areas to apply the assessment model to their geographies either as a refinement of these results or through finer-scale sub-regional assessments; and evaluation of stressors on human well-being.

Presentation of the PSPA and Navigation of This Report

The PSPA is presented first in the *Puget Sound Pressures Assessment Methodology and Puget Sound Partnership Technical Report* (Labiosa, et al., 2014), the “PSPA Technical Memo.” The PSPA Technical Memo describes the PSPA method, including detailed discussions about how the PSPA fits within and builds on related ecosystem risk assessment methods and literature, and the reasons and context for use of expert elicitation as one of the primary tools in the assessment. It is an important companion to this report.

This report describes how the PSPA methodology was implemented and the results of the assessment. Implementation required further developing the PSPA model (e.g., defining submodels, rating categories, and rate-to-score functions; delineating stressors and endpoints; defining geographic assessment units); generating tools and data to support assessment implementation (e.g., creating an expert elicitation system, recruiting and training experts, identifying relevant GIS data, and carrying out GIS analysis); and carrying out the assessment and analyzing the results. Results of the assessment are described in this report, along with key limitations, other considerations, suggestions for use of the results, and recommendations for future studies. The main report provides a brief overview of the PSPA methodology and assessment, and describes PSPA results at the Puget Sound scale. Technical appendices describe the assessment process, methods, and results in more detail.

The technical appendices, and further information on the PSPA, including the PSPA results spreadsheets, are available at the PSPA website: https://sites.google.com/site/pressureassessment/.

Relationship to Open Standards. The Open Standards for the Practice of Conservation (CMP 2013) have been, and continue to be, extensively used in the Puget Sound region for recovery planning and adaptive management. The PSPA implements a Puget Sound customization of the Open Standards practice of "rating or ranking of direct threats to identify critical threats." The PSPA does not implement the specific threat rating approach developed in Miradi, the Open Standards software, but it does cross-walk well with the Miradi approach and involves consideration of the same basic factors. In Miradi, threat rating evaluates three factors: (1) scope, which addresses the proportion of the [endpoint] that can reasonably be expected to be affected by the threat within ten years; (2) severity, which addresses the level of damage to the [endpoint] from the threat over the assessed scope; and (3) irreversibility or permanence, which addresses the degree to which the effects of a threat can be reversed and the [endpoint] affected by the threat restored. In the PSPA scope is evaluated directly using spatial analysis, severity equates to a combination of the functional impact and resistance factors, and irreversibility equates to the recovery time factor.

Peer Review

The PSPA report and appendices were reviewed by a small group of experts selected by the Puget Sound Science Panel, including several Science Panel members who had not participated directly in the assessment. Reviewers endorsed the report as describing a reasonable implementation of the PSPA methodology and representing "a considerable advancement over previous reports on [the topic pressures] for Puget Sound." Reviewers also suggested a number of improvements particularly in the areas of improving understanding of interactions of multiple stressors on the ecosystem, use of expert judgments, and presentation of the assessment and results. We have worked to address these comments in this revision, and, where needed, in suggestions for potential future studies.

Overview of PSPA Methodology

This section provides a brief overview of the PSPA methodology and how it was implemented in the assessment. The PSPA methodology was developed by a small team of Science Panel members and other experts and is documented in the PSPA Technical Memo (Labiosa, et al., 2014). The PSPA methodology builds on the "vulnerability of marine ecosystems" (VME) approach developed by Halpern et al. (2007), and similar work by HELCOM (Baltic Marine Environment Protection Commission - Helsinki Commission, ongoing). The PSPA extends these approaches in three ways by: (1) including terrestrial and freshwater aquatic ecosystems in addition to marine and nearshore ecosystems; (2) extending beyond the exclusive use of habitat-type endpoints to include species; and (3) using Bayesian probability assessment in individual intrinsic vulnerability ratings, instead of a single (score-level) factor to represent uncertainty. Implementing the PSPA methodology involved a number of steps, including: developing the PSPA model and defining submodels; delineating stressors and endpoints; defining geographic assessment units; generating assessment tools and identifying relevant data to support the assessment; creating an expert elicitation system and recruiting and training experts; identifying GIS data and carrying out GIS analysis; and carrying out the assessment and analyzing the results. These steps are briefly summarized here and described in detail in Appendices A-F.

Developing the PSPA Model and Submodels

The PSPA model describes relationships between stressors and endpoints in the Puget Sound basin. It is divided into three submodels: intrinsic vulnerability, stressor intensity, and endpoint distribution. The submodels were used primarily to separate assessment of endpoint sensitivity (intrinsic vulnerability) from evaluation of endpoint exposure (stressor intensity and endpoint distribution). They also divide the assessment into manageable components and distinguish between those elements that are spatially dependent and those which are not.

Figure 1 illustrates the relationships between the three submodels and the PSPA results. The intrinsic vulnerability submodel produces an estimate of the vulnerability of endpoints to stressors under a clear set of assumptions about exposure and stressor strength; this result is similar in concept to an ecological sensitivity or "effects" filter in site-scale risk assessments. The stressor intensity and endpoint distribution submodels develop information about the interaction of stressors and endpoints (an "exposure" filter) by exploring the amount and frequency of stressors and the distribution of endpoints in geographic assessment units. (Landis and Wiegers, 1997; Labiosa et. al, 2014 and references cited within). Together, the results of these three submodels provide information on the potential impact of a stressor on an endpoint within a particular geographic assessment unit. Intrinsic vulnerability and potential impact are considered the main results of the PSPA.

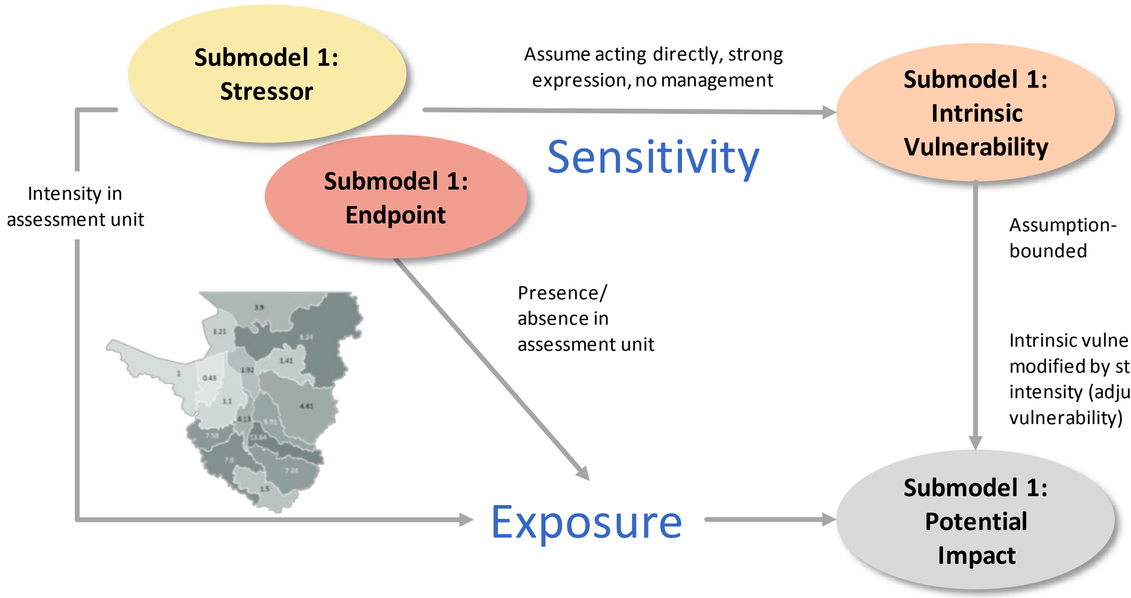

Figure 1: PSPA Implementation Framework

Intrinsic vulnerability (Submodel 1) applies to stressor-endpoint pairs, and addresses the question "how vulnerable are endpoints to stressors?" It is an estimate of how, hypothetically, a given stressor would affect a specific endpoint under the assumptions that stressor expression is strong, a stressor is acting directly on that endpoint, and management efforts are not mitigating the stressor-endpoint interaction. It is termed "intrinsic" vulnerability because the response being evaluated is that which is inherent to the biology and ecology of the stressor-endpoint pair. The intrinsic vulnerability evaluation does not consider information about actual stressor intensity or endpoint distribution in the study area. Stressor intensity and endpoint distribution information are assessed separately and then combined with the results of the intrinsic vulnerability part of the assessment to produce estimates of potential impact.

Intrinsic vulnerability explores the response inherent to the biology and ecology of the stressor-endpoint pair to provide an estimate of how a given stressor could affect a specific endpoint. Factors contributing to intrinsic vulnerability were evaluated by experts under the assumptions that the stressor is strong, acting directly on the endpoint, and management actions are not mitigating the stressor-endpoint interactions.

Intrinsic vulnerability was assessed using expert judgment on three factors related to the vulnerability of a single endpoint to a given stressor: (1) what is the impact of the stressor on the endpoint, (2) how much time is required for the endpoint to recover from the effect of the stressor, and (3) how resistant is the endpoint to the stressor. Each question had a set of defined rating categories, with each rating category describing a different "level" of the effect of the stressor on the endpoint. Experts were asked to make these assessments under the specific assumptions described above. Appendix A describes the intrinsic vulnerability submodel, its implementation, and the intrinsic vulnerability results in detail.

Stressor intensity (Submodel 2) applies to stressor-geographic assessment unit pairs, and addresses the question "how widely distributed and frequent are stressors in each geographic assessment unit?" Stressor intensity is based on an examination of the amount of a stressor present under current conditions and the frequency with which a stressor occurs in each assessment unit. Stressor amount was evaluated using readily-available GIS data. Where GIS data were not available, stressor amount was evaluated using other reference sources and literature and the expert judgment of the project team. Stressor frequency was evaluated using the expert judgment of the project team. Appendix B describes the stressor intensity submodel, its implementation, and the stressor intensity results in detail. Appendix E describes the delineation of stressors for the PSPA.

Stressor Intensity explores the relative amount and frequency of stressor occurrence in each geographic assessment unit across Puget Sound. Stressor intensity was estimated based on a combination of readily-available GIS data, other analyses, and project team expert assessment.

Endpoint distribution (Submodel 3) applies to endpoint-geographic assessment unit pairs and addresses the question "which endpoints are present in each geographic assessment unit?" It is an estimate of the prevalence of endpoints within a particular geographic assessment unit. Endpoint distribution was evaluated using readily-available GIS data, and was simplified to endpoint presence or absence in each assessment unit for this phase of PSPA implementation. Appendix C describes the endpoint distribution submodel, its implementation, and the endpoint distribution results in detail. Appendix F describes delineation of endpoints for the PSPA.

Endpoint Distribution characterizes the presence or absence of endpoints in each geographic assessment unit across Puget Sound. Endpoint distribution was estimated using readily available GIS data.

Potential impact combines the results of the three submodels to create a geographically-specific estimate of the potential impact of a stressor on an endpoint in an assessment unit. Potential impact is calculated by scaling or adjusting the intrinsic vulnerability result by the stressor intensity in the assessment unit, for any endpoint that is present in that assessment unit.

Potential impact explores the impact of stressor on endpoints within each geographic assessment unit. The potential impacts is a model output, based on "adjusting" the intrinsic vulnerability results to account for stressor intensity and endpoint presence or absence in Puget Sound watersheds and marine basins.

Potential impact results are calculated for every stressor-endpoint pair in every assessment unit. Those results are then combined in various ways to create both assessment unit scale results and a Puget Sound scale view of the relative potential impact of different stressors, and the relative potential harm to different endpoints.

Stressor and Endpoint Delineation

Stressors are the proximate causes of change in the Puget Sound ecosystem. The goal for stressor delineation was to create a clearly-defined suite of stressors that covers the full span of stress on the Puget Sound ecosystem at the highest level possible while still differentiating between discrete activities and processes that have different cause-effect relationships to endpoints. We used the draft Puget Sound Pressure Taxonomy (Stiles et al, in prep) and the International Union for Conservation of Nature pressure taxonomy to guide stressor delineation. Because the PSPA asked experts to assume a stressor was acting directly on an endpoint and to assume the expression of the stressor was strong, we distinguished between stressors that might have different potential for harm when strongly expressed. In other words, if we thought experts might give a different answer to the intrinsic vulnerability questions if the source of stress were different, we divided the stressor into sub-stressors. For example, the functional impact (one of the intrinsic vulnerability factors) of point source pollutants is likely different from that of non-point source pollutants when both are strongly expressed, so we divided all the pollution stressors into two sub-stressors, one for point source pollution and another for non-point. Similarly, in the stressors related to flow changes we delineated separate sub-stressors for changes in low (and peak) flows due to climate change and those due to altered land cover. Delineating sub-stressors according to source also aids consideration of management actions, since management actions are often oriented to stressor source.

The final list of 47 PSPA stressors nests completely within the Puget Sound Pressure Taxonomy; an ongoing update of this taxonomy uses PSPA stressor definitions and source/secondary source identifications. This refined and regionally-supported list of Puget Sound stressors is a significant collateral benefit/result of the PSPA. Table 1 lists PSPA stressors. Stressors are described further in Appendix E.

Table 1: Puget Sound Pressures Assessment Stressors

A1. Conversion of land cover for residential, commercial, and industrial use
A2. Conversion of land cover for natural resource production
A3. Conversion of land cover for transportation and utilities
B. Terrestrial habitat fragmentation
C. Shoreline hardening
D. Shading of shallow water habitat
E1. Dams as fish passage barriers
E2. Culverts and other fish passage barriers
F. Barriers to terrestrial animal movement and migration
G1. Terrestrial and freshwater species disturbance in human dominated areas
G2. Terrestrial and freshwater species disturbance in natural landscapes
H. Species disturbance – marine
I. Derelict fishing gear
J1. Altered peak flows from land cover change
J2. Altered peak flows from climate change
K1. Altered low flows from land cover change
K2. Altered low flows from climate change
K3. Altered low flows from withdrawals
L. Flow regulation – prevention of flood flows
M1. In-channel structural barriers to water, sediment, debris flows
M2. Other structural barriers to water, sediment, debris flows
N. Animal harvest
O. Bycatch
P1. Timber harvest
P2. Non-timber plant harvest
Q1. Predation from increased native species
Q2. Displacement by increased native species
R1. Predation from non-native species
R2. Displacement by non-native species
R3. Non-native genetic material
S1. Spread of disease and parasites to native species
S2. Introduction, spread, or amplification of human pathogens
T1. Air pollution from mobile sources
T2. Air pollution from stationary sources
U1. Point source, persistent toxic chemicals in aquatic systems
U2. Non-point source, persistent toxic chemicals in aquatic systems
V1. Point source, non-persistent toxic chemicals in aquatic systems
V2. Non-point source, non-persistent toxic chemicals in aquatic systems
W. Large spills
X1. Point source conventional water pollutants
X2. Non-point source conventional water pollutants
X3. Changes in water temperature from local causes
Y. Harmful algal blooms
Z. Changing air temperature
AA. Changing precipitation amounts and patterns
BB. Sea level rise
CC. Changing ocean condition

Endpoints are habitats, landforms, species, and communities of the Puget Sound ecosystem that are directly influenced by stressors; i.e., the level of ecological organization at which the PSPA evaluated direct impacts of stressors. Endpoint identification started from existing lists of valued ecosystem components (VECs) (as described in Schlenger et al. 2011). The initial list of VECs was broadened to more completely capture all three ecosystem domains (freshwater, marine-nearshore, and terrestrial). Habitat endpoints were then overlaid on a basic framework that divided each ecosystem domain into broad geographic/geomorphic zones, with the goal of identifying one or more endpoints for each broad area. This so-called "place-based" approach was recommended by experts during PSPA model refinement discussions and meetings. Species endpoints were identified using food webs, with the goal of delineating one or more biological endpoint in each trophic level within each domain. In general, the PSPA is biased towards endpoints that are sufficiently understood or studied such that information (and experts) are available to carry out the pressure assessment evaluation. Other considerations that influenced endpoint selection included exposure/susceptibility, ecological relevance (endpoints that are significant determinants of the system of which they are a part were considered above those that could be affected without significant ecosystem-level consequences), scale, and practicality of evaluation (Suter et al., 2007 as described in Labiosa et al., 2014).

Note that water quality is specifically captured as an attribute of appropriate endpoints. Experts were specifically asked to consider how water quality is affected by stressors for a number of habitat endpoints including rivers, streams, beaches, embayments, and other endpoints. When a stressor (such as one of the pollution stressors) is acting primarily on a water quality attribute of an endpoint, we instructed experts to consider that relationship when scoring the vulnerability of the endpoint to that stressor.

At the same time that the PSPA was working with experts to delineate endpoints, two other efforts were creating taxonomies of the Puget Sound ecosystem. The Chinook Monitoring and Adaptive Management project was working with local watershed groups and the Salmon Recovery Council to create a common framework for adaptive management of Chinook recovery. An indicators evolution project was working with experts to create a comprehensive taxonomy of the Puget Sound ecosystem, including ecosystem components and attributes, to support identification and refinement of biophysical indicators for assessing and reporting on ecosystem condition. Care was taken to coordinate the PSPA with these efforts. The final list of 60 PSPA endpoints is a combination of ecosystem components, attributes, and indicators, tailored to create the best understanding of stressor effects. It is a subset of the comprehensive Puget Sound taxonomy and nests entirely within that framework. Table 2 lists PSPA endpoints. Endpoints are described further in Appendix F.

Stressors and endpoints were paired for evaluation of intrinsic vulnerability. Pairs were delineated based on the judgment of the project team and in consultation with Science Panel members and other experts. As part of this process 1,448 of the 2,820 potential stressor-endpoint pairs were eliminated because the stressor-endpoint interactions were not known or believed to occur in the Puget Sound ecosystem (e.g., fish passage barriers do not affect the marine benthic community). When there was ambiguity, the stressor-endpoint pair was retained for further evaluation by experts. This resulted in 1,220 stressor-endpoint pairs that were carried forward for expert evaluation.

Endpoint and stressor delineation were a significant part of the PSPA effort. As discussed further in the section on potential future investigations, we received a variety of comments from experts on stressor-endpoint pairs—some in the form of “opt outs” or suggestions to remove a pair from the assessment, some in the form of “non-ranking” where the pair was simply skipped with no feedback, and some in the form of a zero rating. In other cases, experts questioned “missing” endpoints, or had comments on the ways that stressors were sub-divided or grouped. This information could be reviewed more closely and conversations with experts could further review both the stressor and endpoint lists and the stressor-endpoint pairs.

Table 2: PSPA Endpoints by Domain

Freshwater	Marine-Nearshore	Terrestrial
• Small, high-gradient streams • Headwater slope wetlands • Headwater depressional wetlands • Lakes and ponds • Large rivers • Large streams • Small, low-gradient streams • Lowland slope wetlands • Lowland depressional wetlands • Freshwater tidal wetlands • Riparian vegetation • Lotic freshwater benthic invertebrates • Lotic freshwater aquatic vertebrate communities • Freshwater aquatic plant communities • Chinook salmon* • Coho salmon* • Cutthroat trout* • Kokanee • Bald eagle* • River otter* • Freshwater mussels	• River deltas • Beaches • Embayments • Rocky shores • Open water, where sediment surface is below the euphotic zone • Eelgrass, kelp, and other submerged vegetation communities • Herring • Surf smelt • Rockfish (adult) • Marine benthic community • Marine epibenthic community • Pelagic community • Demersal fish and invertebrate community • Marine mobile benthic carnivores • Marine sessile filter feeders • Chum and pink salmon* • Rhinoceros auklet • Killer whale	• Alpine grassland and shrublands • Subalpine unmanaged forests • Subalpine managed forest • Unmanaged lower elevation forests • Managed lower elevation forests • Oregon white oak woodlands • Lowland grasslands • Agriculture areas • Urban open space • Forest interior birds • Pond breeding amphibians associated with upland forest • Forest salamanders • Bobcat • Roosevelt elk • Coopers hawk • Long-legged myotis bats and Keen's myotis bats

Note: Marine riparian vegetation, great blue heron, scoter species, butterflies of prairies/balds and oak woodlands, and streaked horned lark were dropped from the assessment because we were unable to obtain sufficient expert input to complete the assessment. Future assessments might seek to obtain expert coverage for these endpoints.

* Evaluated in both the Freshwater and Marine-Nearshore domains.

Defining Geographic Assessment Units

The vulnerability of an endpoint to a stressor is only relevant where both the stressor and the endpoint are present at the same time. Stressor/endpoint coincidence was evaluated through assessment of stressor intensity and endpoint distribution in geographic assessment units (AUs). The AUs for the freshwater and terrestrial endpoints are the watersheds profiled in the Puget Sound Salmon Recovery Plan (Shared Strategy for Puget Sound, 2007) and the AUs for the marine-nearshore endpoints are the marine basins as defined by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) (Cereghino, et al). Geographic assessment units are shown in Figure 3.

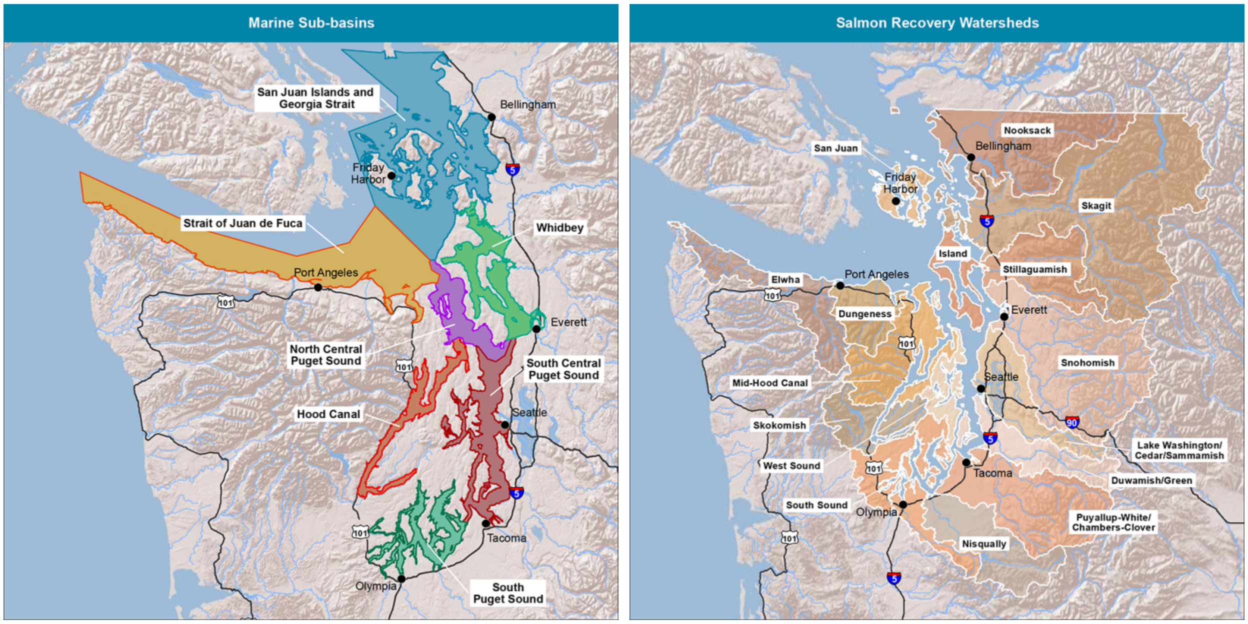

Figure 3: Assessment Units

Developing PSPA-relevant Data

Data necessary for the PSPA was developed through a combination of expert elicitation and analysis of existing spatial information.

Expert Elicitation of Intrinsic Vulnerability. Sixty experts participated in the PSPA by providing assessments of intrinsic vulnerability for stressor-endpoint pairs. Experts were identified largely by the small group of Science Panel members that led development of the PSPA, PSP science staff, and the project team. As the elicitation proceeded, some participating experts suggested other experts who should be involved. Experts were assigned stressor-endpoint pairs relevant to their expertise and asked to rate the vulnerability of individual endpoints to specific stressors using the questions and defined rating categories in the intrinsic vulnerability submodel. Experts assigned relative probabilities to the different rating categories, encoding their assessment of uncertainty at the same time they were providing ratings. Expert ratings were captured through an online interface, which also gave experts a way to "opt out" of rating pairs that they did not have the expertise to evaluate or that they believed did not exist in the Puget Sound ecosystem. There also was a way to provide comments relevant to their assessment.

Experts were oriented to the assessment model and the intrinsic vulnerability questions, assumptions, and rating categories through written instructions and materials distributed by email, in a series of webinars, and in one-on-one conversations. The online elicitation system also included a screencast that walked experts through intrinsic vulnerability assumptions and scoring. Following an initial expert elicitation in early January 2014, experts were convened in a day-long meeting to discuss their experience and ratings. Based on feedback during this meeting, the online elicitation system was streamlined to make rating faster and improve expert experience. Experts were given the option to use a custom Excel spreadsheet to record their ratings, as an alternative to the online system. Following these improvements experts were given an opportunity to refine ratings as needed. (Few experts chose to do this.) The PSPA project team reached out to additional experts to fill gaps in ratings, and provided assessment materials and one-on-one orientation to new participants similar to that provided to the experts who participated in the initial elicitation effort. Emphasis was placed on finding experts with acknowledged expertise in individual stressors and endpoints though consultation with the Science Panel team, PSP science staff, and discussions with participating experts, rather than on maximizing the number of expert participants. We are satisfied if only one expert has rated a stressor-endpoint pair, although we acknowledge that results based on a single experts' assessment may be viewed with caution by some readers and we indicate in the discussions below where overall results rely heavily on such data.

The large number of stressor-endpoint pairs presented a serious challenge to the assessment. In the initial elicitation effort, we attempted to use expert elicitation to evaluate stressor distribution and endpoint distribution, in addition to intrinsic vulnerability. This meant that many experts were asked to rate a very high number of pairs across all three submodels. Although the switch to GIS-based evaluation for stressor and endpoint distribution was made quickly after expert feedback during the initial effort, some experts had already committed the time they could to the project and did not participate further in the elicitation. Experts were not compensated for their work or time, which also presented a challenge. In the end, we received expert intrinsic vulnerability ratings for 1,087 of 1,220 unique stressor-endpoint pairs, an 89% coverage rate. Of the rated pairs, 61% were rated by multiple experts, and 39% were rated by one expert. The 11% of assessment pairs that did not receive expert ratings were assigned uniform distribution scores.

HUMAN DIMENSIONS

The PSPA considered stressors from the perspective of human health and well-being. An ecosystem services approach was used to describe both services provided by assessment endpoints and potential impacts of stressors on the ability of endpoints to provide those services. A number of regional experts in defining and evaluating human well-being participated in framing this part of the assessment and in attempting to score stressor-endpoint interactions from a human well-being perspective. Through this effort it became clear that a robust evaluation of human well-being would require additional framing, potential refinements to create a human well-being-specific model, and delineation of additional human well-being-specific stressors and endpoints. This assessment was deferred to future work.

Opportunities to increase expert coverage, improve interactions with and between experts, including reducing expert "burn out," could improve the quality of data for future PSPA-like assessments; specific suggestions for how to do this are described as part of the discussion of potential future investigations. At the same time, we emphasize that the results produced here are based on a large amount of input, systematically gathered, and provided by experts selected for their specific knowledge, and thus represent a significant improvement over past understandings of pressures on the Puget Sound ecosystem. The assessment size and the expert elicitation process are described further in Appendix A.

Analysis of Stressor Intensity and Endpoint Distribution in AUs. Where available, GIS-based information and analysis was used to evaluate stressor intensity and endpoint distribution in AUs. GIS-based analysis was used for all endpoint distribution assessments and for assessments of stressor amount for most stressors. The project and Science Panel teams identified Puget Sound-wide data layers for each stressor and endpoint. Each stressor and endpoint data layer was then overlaid with the AU boundaries to create an individual AU score for each parameter. For stressor amount, the individual AU scores were normalized to create an index of the relative amount of each stressor in each AU, consistent with the approaches used for stressor distribution in similar assessments. (Halpern et al, 2008; HELCOM, 2010) For endpoint distribution the information was simplified to endpoint presence or absence in each AU.

GIS-based information was not readily available at the Puget Sound-wide scale for about twenty stressors. For those stressors, the project team in consultation with the Science Panel team and PSP science staff estimated stressor amount using other information and analysis. These are described in Appendix B (methods) and in the discussions of results for individual stressors (Appendix H). Stressor frequency was estimated by the project team in consultation with the Science Panel team and PSP science staff.

We note that the use of GIS analysis for this study has pros and cons, especially for stressor evaluation. GIS is an efficient, transparent, and easily updatable method to quantify stressors and endpoints at various scales. However, given limited time and resources, this GIS analysis was limited to readily-available, Sound-wide data sets that were available in digital form and required minimal geo-processing. Thus the analysis captures only the aspects/expressions of a stressor that are easily, and previously, mapped. For some stressors, such as shoreline hardening (C), the available shoreline armoring data allow for a fairly direct assessment of stressor amount with high confidence. We can map bulkheads with good accuracy. For other stressors, such as altered peak flow from land cover change (J1) and species disturbance-marine (H), direct estimates of stressor amount are more difficult. There are no readily available geospatial data sets for flow alterations or species disturbances, so we used proxies or surrogates to assess stressor amount. The proxy datasets are typically related to potential sources of the stress, such as developed land cover for altered flows from land cover change, and marine vessel traffic for marine species disturbance.

Use of proxy and surrogate data sets is common in geospatial analysis; however, the quality of the proxies and surrogates varies. For example, we used land cover data (developed lands) as an indirect measure of predation from non-native species (stressor R1) because we believed distribution of this stressor was linked to human-dominated landscapes. This proxy is easy to understand and gives results that seem consistent with the experience and knowledge of the Science Panel and project teams, and intuitively “make sense.” On the other hand, stressor U1 (point source persistent pollution in aquatic systems) was defined to include persistent chemical cycling (e.g., PCB and mercury cycling); V2 (point source non-persistent pollution in aquatic systems) was defined to include historic sources of small spills. However the stressor intensity analysis for both stressors is based only on current discharges from wastewater treatment plant and other current facility discharges, because only those data were readily available within the timeframe of the assessment. There are other, similar, examples of a stressor intensity evaluation potentially “missing” some of the stress that was defined as part of a stressor. These may result in under-estimation of the potential impact from some stressors. We note that this is not unique to the PSPA; all the assessments on which the PSPA method is based select available data sets to represent broad stressors. Appendix B describes the stressor intensity evaluation, data sources, and the quality of the stressor definition-data source match.

Overall there were 3 stressors for which we did not have adequate data to evaluate their intensity in marine basins. These are terrestrial habitat fragmentation (B), non-timber plant harvest (P2), and introduction and spread of non-native genetic material (R3). These stressors are not included in the potential impact results for marine basins; they are included in the intrinsic vulnerability results and in potential impact results for watersheds.

Types and Uses of PSPA Results

The purpose of the PSPA is to help the Puget Sound science community and decision makers better understand the potential impact and relative intensity of stressors in the Puget Sound region. It serves as a screening tool to inform decisions about recovery strategies and priorities. It is designed to be used in concert with other information and consideration of other factors and is not intended to pre-judge regional priority setting or other decisions. It is but one piece, albeit, we think, an important one, in understanding the Puget Sound ecosystem and helping decision makers determine how best to achieve ecosystem protection and recovery.

The PSPA produces two primary results: (1) intrinsic vulnerability, and (2) potential impact (at the AU and Puget Sound scales). Results examine the current intensity of stressor expression; future studies could use the same methodology to evaluate potential future stressor expression scenarios to consider, for example, which stressors are increasing in intensity and which are more constant.

> **When potential impact scores are low and intrinsic vulnerability scores are high, these likely are opportunities to take action to mitigate and manage stressors before their impacts are more pronounced or widespread in Puget Sound.**

As described above, the intrinsic vulnerability results describe the response of an endpoint to a stressor based on inherent biology and ecology of the stressor-endpoint pair. These results are independent of geography—that is, results are the same for all watersheds and marine basins in Puget Sound in which the stressor-endpoint pair occurs. Results are developed at the level of individual stressor-endpoint pairs to produce stressor-endpoint pair scores or "IV pair scores"; pair scores are then summed across stressors and endpoints to create the IV stressor and endpoint indices. All three types of intrinsic vulnerability results (pair scores, IV stressor indices, and IV endpoint indices) are presented in the next section. A high IV stressor index indicates that the stressor has a high potential for harm across the endpoints considered. A high IV endpoint index indicates that the endpoint is more vulnerable to harm given the stressors considered.

Potential impact results combine the intrinsic vulnerability results with stressor intensity results and endpoint presence or absence to create an AU-specific adjusted vulnerability score (AV pair score) for every stressor-endpoint pair in every assessment unit. These results reflect geographic-specific potential impact of each stressor on each endpoint present in the AU. We describe these results as "potential" impact because, as with other studies of this type, the PSPA is a model-based, ecosystem-scale evaluation. We explored the vulnerability of endpoints to stressors under a defined set of assumptions and combined this result with information on current stressor intensity and the presence/absence of endpoints in assessment units. We do not map actual encounters between stressors and endpoints but rather identify watersheds and marine basins where the stressors and endpoints are present and therefore have the potential to co-occur. Furthermore, we do not consider synergistic or antagonistic affects across stressors, nor do we consider the initial condition of endpoints (e.g.., intact, impaired, threatened, etc.). All of these factors could influence the actual impact of a stressor on an endpoint.

As with the IV pair scores, AU-specific AV pair scores are summed over endpoints to create an AU-scale result that describes the potential impact of each stressor in each individual watershed and marine basin, and over stressors to identify the endpoints most vulnerable to harm from stressors in each individual AU.

Potential impact results are presented for each AU in Appendix G. The AU-specific potential impact results are combined to create a Puget Sound-scale evaluation of the potential impact of stressors, and the potential harm to endpoints. Two types of Puget-Sound scale results are considered: a simple averaging of the potential impact scores in each assessment unit (treating each assessment unit equally), and a "count" of the number of assessment units for which each stressor has high potential impact. As discussed below, the two types of results yield similar insights.

The potential impact results are most informative when viewed in relation to the intrinsic vulnerability results. Potential impact results can give an artificially-simplified picture of stressor expression (and importance), particularly for stressors that are not widely distributed or have infrequent occurrence. Using the intrinsic vulnerability results in combination with potential impact results will illustrate this type of case. For example, large spills are rare, so they rank relatively low in the potential impact results; at the same time, a large spill could have catastrophic effects in Puget Sound and they rank among the stressors with the greatest potential for harm in the intrinsic vulnerability results. A similar case occurs with many of the climate-related stressors because their current expression in Puget Sound is relatively low (e.g., sea level rise). Even though many endpoints have high intrinsic vulnerability to strong future expressions of climate stressors, the potential impact results are relatively low, because the current stressor intensity is relatively low. When potential impact scores are low and intrinsic vulnerability scores are high, these likely are opportunities to take action to mitigate and manage stressors before their impacts are more pronounced or widespread in Puget Sound. When both potential impact and intrinsic vulnerability are low there may be opportunities to more narrowly focus management activities to mitigate stressors, or refocus on different stressors altogether.

This report presents summary results; however, we encourage users to explore application of the PSPA data to their individual decisions and contexts. To assist with this we have provided a comprehensive set of results in the Appendices, and two additional products: summaries of AU-scale results and spreadsheets.

The summaries of AU-scale results are provided in Appendix G. They compile PSPA information for each individual AU for further analysis and use by local decision makers. We recognize that as a relatively coarse-scale assessment the PSPA was not intended to develop (or replace) locally-derived pressure assessments that consider more fine-grained local data and expert judgments. Rather it is intended to help inform and, where needed, provide a starting point or a complement to locally-driven efforts. The PSPA also provides a methodology that can be tailored and replicated by local groups if a finer-scale pressure assessment is desired, perhaps using finer-scale endpoints and stressors (e.g., individual salmon lifecycle stages and more finely-defined habitat types) depending on the management questions of interest.

The PSPA intrinsic vulnerability and potential impact results spreadsheets are available at the PSPA 2014 website (https://sites.google.com/site/pressureassessment/). They contain all the PSPA data for intrinsic vulnerability and potential impact (both AU-scale and Puget Sound-scale results) and can be sorted and queried to explore the PSPA data from the perspective of individual endpoints, groups of endpoints, individual and groups of stressors, and sub-model and factor scores. We encourage use of these spreadsheets to explore results and evaluate application of the PSPA data to local decisions.

Limitations

Limitations and considerations in use of the PSPA results are described in detail in the results sections below. A few key limitations to keep in mind when reviewing the results include:

- Stressor and endpoint intrinsic vulnerability results at are based on a simple sum (or average) of IV pair scores; they do not attempt to describe how multiple stressors combine to act on endpoints or how one stressor acts on many endpoints to influence the ecosystem.
- The PSPA stressor intensity evaluation describes a snap shot in time, based on how much of a stressor has occurred so far (e.g., how much land has been converted for the habitat conversion stressors) not how much stress is likely to occur in the future.
- A significant number of stressor-endpoint pairs in the PSPA (39%) were evaluated by only a single expert. Because of timing and other considerations, we emphasized recruiting experts with acknowledged expertise in individual stressors and endpoints though consultation with the Science Panel team, PSP science staff, and discussions with participating experts, rather than on maximizing the number of expert participants. We are satisfied if only one well-qualified expert has rated a stressor-endpoint pair, although we acknowledge that results based on a single expert's assessment may be viewed with caution by some readers. With this potential concern in mind, we have highlighted where results rely heavily on the judgments of a single expert.

The discussion of potential future studies, later in this report, describes approaches that can be taken to address each of these limitations in any future iterations or updates of the PSPA.

Intrinsic Vulnerability Results

As described previously, intrinsic vulnerability examines the relationship between individual stressor-endpoint pairs to provide an estimate of how a given stressor would affect a specific endpoint under the assumptions that the stressor is acting directly on that endpoint, stressor expression is strong, and management efforts are not mitigating the stressor-endpoint interaction. The result of this evaluation equates to a sensitivity or "effects" filter in site-scale risk assessment. It is termed "intrinsic" vulnerability because the response being evaluated is that which is inherent to the biology and ecology of the stressor-endpoint pair. The intrinsic vulnerability evaluation does not consider information about actual stressor intensity or endpoint distribution in the study area; information on stressor intensity and endpoint distribution is assessed separately and then combined with the results of the intrinsic vulnerability evaluation to produce estimates of potential impact.

Intrinsic vulnerability was evaluated through expert elicitation. Sixty experts participated, providing ratings for a total of 1,086 of 1,220 stressor-endpoint pairs; a coverage rate of 89%. Within rated pairs, 61% were rated by two or more experts; 39% were rated by a single expert. For assessment pairs where we had no expert ratings, a uniform distribution of ratings was used in model calculations as a placeholder value. A summary of assessment size and coverage is provided in Table 3.

Intrinsic vulnerability explores the response inherent to the biology and ecology of the stressor-endpoint pair to provide an estimate of how a given stressor would affect a specific endpoint under the assumptions that the stressor is acting directly on the endpoint, stressor expression is strong , and management efforts are not mitigating the stressor-endpoint interaction.

Table 3: Assessment Size and Coverage

	Freshwater	Marine-Nearshore	Terrestrial	Total
Number of unique pairs retained in assessment results	526	456	238	1,220
Number of assessment pairs rated by experts	491 (93%)	366 (80%)	230 (97%)	1,086 (89%)
Number of assessment pairs where uniform distribution was used	35 (7%)	90 (20%)	8 (3%)	134 (11%)

Climate-related stressors[1] were treated differently than other stressors: experts were asked to assume that the stressor was present at the upper end of the range of predicted expressions in 100 years—that is, they were asked to evaluate the vulnerability of endpoints to predicted future, strong expressions of climate stressors.

Two types of intrinsic vulnerability results are presented here: (1) results of the evaluations of individual stressor-endpoint pairs (IV pair scores); and (2) results summed across stressors and endpoints to create vulnerability indices (IV stressor index and IV endpoint index). Methods are described in Appendix A.

Note that in each section we present results in four groups (Very High, High, Moderate, and Lower) based on the magnitude of scores. These groups reflect our belief that small differences in the exact numeric scores should not be over-interpreted: items with very high scores are distinct from those with very low scores, but items that differ in score by a small amount are not really different from each other. Grouping emphasizes the similarity of items within a group and the distinctions between items in different groups, but there will almost always be “close calls”: items in the bottom of one group that could just as easily be placed in the top of another group. Deciding where to “draw the lines” between groups is challenging and in some sense arbitrary. We explored a variety of approaches to identifying groups, and the implications of each. The groups presented in this report are based on dividing the range of scores or index values into four equal increments, and identifying which items (stressor-endpoint pairs, stressors, or endpoints) lie in each increment. This simple approach is similar to the approach used by Halpern (2008) and gave very similar results to what would be achieved by more statistically sophisticated clustering methods used elsewhere (Ban et al., 2010). Details of the various approaches are described in Appendix A.

Stressor-Endpoint Pair Results

The intrinsic vulnerability results are made up of individual stressor-endpoint “pair scores” for each of the 1,220 unique stressor-endpoint pairs in the assessment. Each intrinsic vulnerability pair score (IV pair score) was calculated by averaging all the expert ratings for the pair. If only one expert provided ratings for a pair that expert’s score is the IV pair score; if no experts provided ratings (11% of the pairs), the IV pair score is calculated from the uniform distribution placeholder values.

IV pair scores provide an estimate of intrinsic vulnerability for each of 1,220 unique stressor-endpoint pairs. They integrate expert input on the three intrinsic vulnerability factors: functional impact, recovery time, and resistance.

IV pair scores provide an indication of:

- Which individual stressors have the most potential for harm and which the least.
- Which endpoints are the most vulnerable, and which the least.
- Whether there are differences in intrinsic vulnerability between habitat and species endpoints.
- Which factors (functional impact, recovery time, or resistance) most drive intrinsic vulnerability in individual stressor-endpoint relationships.

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[1] The climate-related stressors in this assessment are: altered peak flows from climate change (J2), altered low flows from climate change (K2), changing air temperature (Z), changing precipitation amounts and patterns (AA), sea level rise (BB), and changing ocean condition (CC).

IV pair scores were divided into four groups as described above. Pair scores that define each group are shown in Table 4.

Table 4: Intrinsic Vulnerability Pair Score Groupings

Group	IV Pair Score
Very high intrinsic vulnerability	> .75 to 1
High intrinsic vulnerability	> .50 to 0.75
Moderate intrinsic vulnerability	> 0.25 to 0.50
Lower intrinsic vulnerability	0 to 0.25

Stressor-endpoint pairs with very high and high intrinsic vulnerability indicate stressors with the most potential for harm on a single endpoint. They describe situations where a stressor, when directly acting on the endpoint and strongly expressed, and without mitigation by management actions, was judged by experts to have the largest potential negative impact on the endpoint as measured by the three intrinsic vulnerability factors. Table 5 shows stressor-endpoint pairs with very high intrinsic vulnerability by domain (freshwater, marine-nearshore, and terrestrial). Groupings and associated pair-scores for all stressor-endpoint pairs are shown in Appendix A.

For eight of the twelve stressor-endpoint pairs with very high intrinsic vulnerability, ratings were provided by one expert only. Most of the individual pairs in the lower intrinsic vulnerability grouping (about 60%) also were rated by only one expert. The high proportion of one-expert pairs in the very high and lower intrinsic vulnerability groupings suggests some caution in considering these individual pair-scores.

IV pair scores also can be sorted to explore differences between habitat and species endpoints, to look only at climate-related endpoints, and to examine uncertainty. These results are described further in Appendix A.

Table 5: Stressor-Endpoint Pairs with Very High Intrinsic Vulnerability, by Domain

Stressor	Endpoint
Freshwater Domain	
A1. Conversion of land cover for residential, commercial, and industrial use	Headwater slope wetlands
A1. Conversion of land cover for residential, commercial, and industrial use	Headwater depressional wetlands
A1. Conversion of land cover for residential, commercial, and industrial use	Bald eagle*
A3. Conversion of land cover for transportation and utilities	Bald eagle*

Stressor	Endpoint
Marine-Nearshore Domain	
A1. Conversion of land cover for residential, commercial, and industrial use	Bald eagle*
A3. Conversion of land cover for transportation & utilities	Bald eagle*
A3. Conversion of land cover for transportation & utilities	Eelgrass, kelp, and other submerged vegetation communities [1]
O. Bycatch	Rockfish (adult)
CC. Changing ocean condition	Pelagic community
CC. Changing ocean condition	Demersal fish and invertebrate community
CC. Changing ocean condition	Open water, where sediment surface is below the euphotic zone
Terrestrial Domain	
Z. Changing air temperature	Alpine grassland and shrublands
A1. Conversion of land cover for residential, commercial, and industrial use	Unmanaged lower elevation forests’[1]
A1. Conversion of land cover for residential, commercial, and industrial use	Oregon white oak woodlands’[1]

* Evaluated as elements of both the Freshwater and Marine-Nearshore domains.

[1] Evaluated by more than one expert

Driving Factors

For any particular stressor-endpoint pair, it is useful to understand which, if any, of the three intrinsic vulnerability factors contribute most to the pair score. Figure 4 shows the relative contribution of each intrinsic vulnerability factor to pair scores for pairs with very high intrinsic vulnerability (these are the same pairs that are shown in Table 5, above). All three factors contribute to the IV pair score for every stressor-endpoint pair, but the relative contribution differs. For example, the recovery time and resistance factors each contribute more to the intrinsic vulnerability of the pelagic community to changing ocean conditions (CC), than the functional impact factor. For the intrinsic vulnerability of adult Rockfish to bycatch (O), recovery time contributes relatively little. These results provide information that may be useful in designing recovery strategies by identifying the factors that are most “important” to the intrinsic vulnerability of stressor-endpoint pairs.

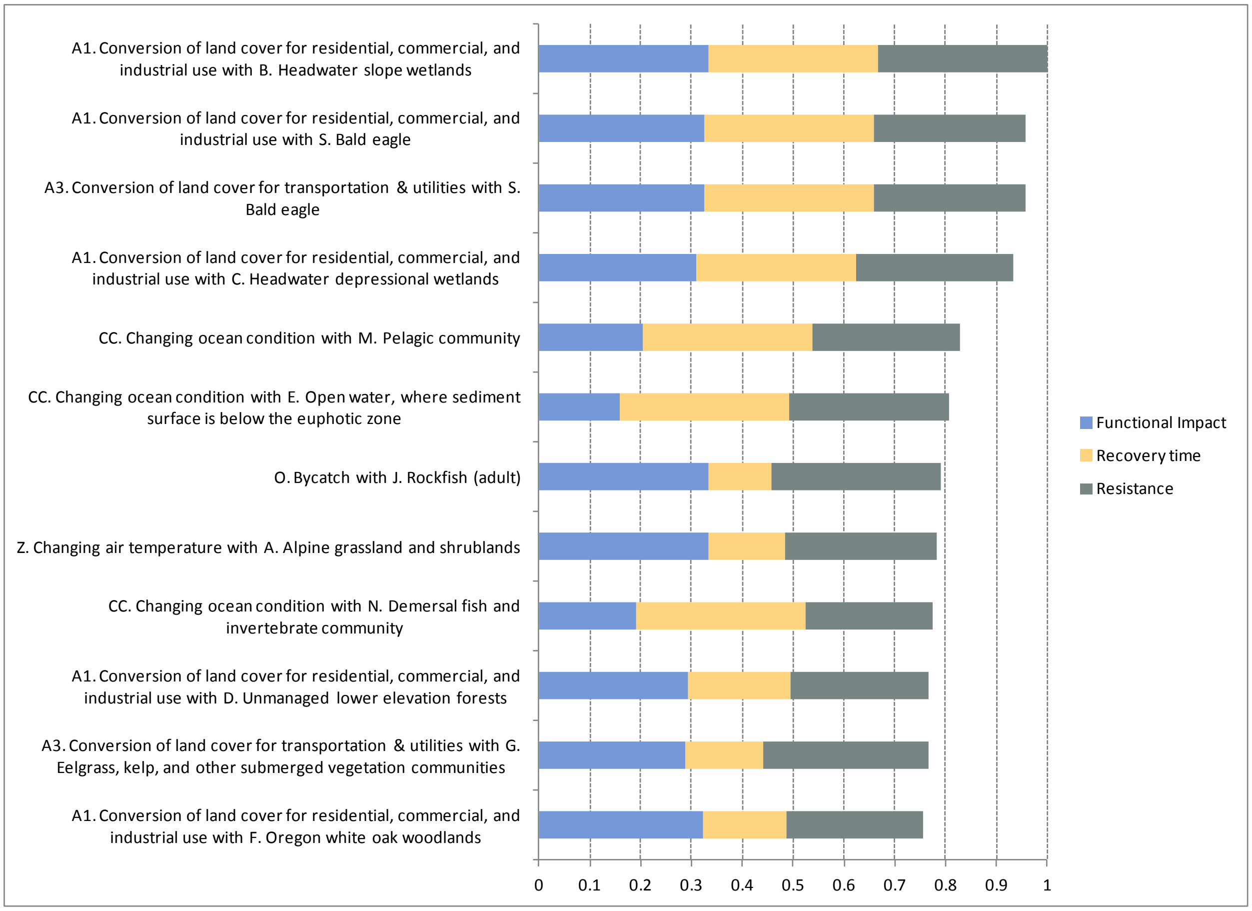


Figure 4: Pair Scores for Pairs with Very High Intrinsic Vulnerability with Contribution from Each Factor

Figure 5 illustrates the average contribution of each factor to IV pair scores across all stressor-endpoint pairs. Although the resistance factor contributes more to IV pair scores on average, all three factors play a role in most cases. There are very few stressor-endpoint pairs (less than 5% of the total number of pairs) for which one factor contributes more than the other two factors combined. On the other hand, there are a fairly large number of pairs for which recovery time contributes less than 15% of the IV pair score, although none of these are among the pairs with very high intrinsic vulnerability (see Figure 6).

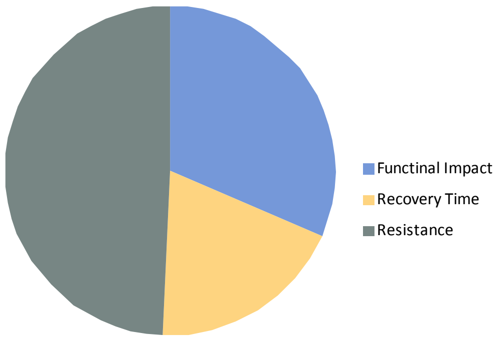


Figure 5: Contribution of Each Factor to IV Pair Score (Average over All 1,087 Rated Pairs)

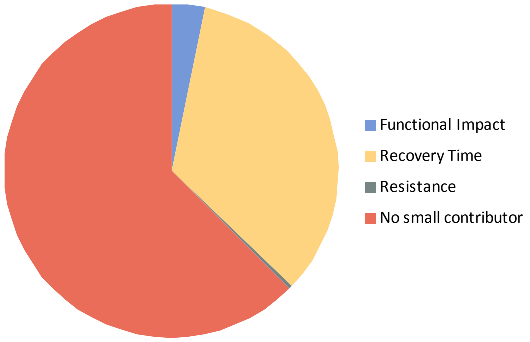


Figure 6: Pairs for which One Factor Contributes Less than 15% to IV Pair Score (Over all 1,087 Rated Pairs)

Uncertainty

One of the main differences between the PSPA and other similar assessments is treatment of uncertainty. Many of the stressor-endpoint relationships being evaluated in the PSPA are highly uncertain, and assigning a single rating category for any given intrinsic vulnerability factor to a stressor-endpoint pair may be difficult, or simply inappropriate. Instead of asking experts to select a single, best estimate for rating categories we asked experts to assign a relative likelihood, or probability, to each rating category for each intrinsic vulnerability factor. This approach encodes information on uncertainty directly in the expert ratings and allows experts to express a full range of certainty/uncertainty in the assessment.

Our approach to uncertainty is best illustrated by an example. This example is for the recovery time factor and rating categories; the other two intrinsic vulnerability factors were assessed in exactly the same way, except with their unique rating categories. Instead of asking experts to enter a single best estimate for the recovery time factor, we asked them to tell us the probability that each of the recovery time rating categories accurately describes the actual recovery time for the stressor-endpoint pair being evaluated. Instead of selecting a single rating category for recovery time, an expert’s ratings might look like the example in Table 6.

Table 6: Example Illustrating How Information on Uncertainty Is Encoded in Expert Ratings

Rating Category for Recovery Time	Expert Rating
No Impact	0%
Months	15%
Years	50%
Decades	35%
Centuries	0%
Irreversible	0%

The **uncertainty index** summarizes expert input on uncertainty for each stressor-endpoint pair. Uncertainty is not assessed as a separate factor, but rather uncertainty information is captured directly as part of expert ratings through use of a probability scale.

Uncertainty information captured directly in expert ratings can be explored to examine a number of questions. Because each expert provided his or her ratings using a probability scale (instead of a single estimate) we have a direct interpretation of their uncertainty about the stressor-endpoint relationship being evaluated. We know, for example, what experts think about how likely it is that recovery time may actually be longer or shorter than their best estimate. To provide a summary of the uncertainty information experts provided, we calculated an uncertainty "index" for each stressor-endpoint pair. The pair-level uncertainty index was calculated based on the distribution of rating categories provided by each expert, and includes consideration of differences between experts. Theoretical values range from 0 to 1. If an expert assigned a pair to exactly one rating category for each of the three intrinsic vulnerability factors the uncertainty index is 0. If an expert assigned a maximum-spread distribution for all rating categories for all three factors (e.g., a 50% chance of "no impact" and a 50% chance of "irreversible" impact on the recovery time scale), or if two highly confident experts provided diametrically opposed assessments, the uncertainty index would be 1. In the data set, uncertainty indices range from 0 to 0.93. Pairs that have placeholder values, which were assigned a uniform distribution for all three factors, have an uncertainty index of 0.71.Uncertainty results for stressor endpoint pairs are described more fully in Appendix A, along with a discussion of pairs for which there were large differences among experts about the intrinsic vulnerability.

Intrinsic Vulnerability Indices: Stressors with the Most Potential for Harm and Most Vulnerable Endpoints

Intrinsic vulnerability results can be summed or averaged across either endpoints or stressors to create intrinsic vulnerability indices (IV indices). The IV indices combine the information in the 1,220 stressor-endpoint pair scores to provide a view from the perspective of an individual stressor or an individual endpoint. Summing across stressors and endpoints was chosen as the primary method to create the IV indices because it more fully reflects both the individual pair scores and the number of stressors that might act on an endpoint (or the number of endpoints that a stressor might harm), so it more completely represents overall ecosystem effects. Differences between summing and averaging are discussed later in this section.

IV indices can be used to explore:

- Which stressors have the most potential for harm and which the least.
- Which endpoints seem the most vulnerable and which the least.
- Numbers of stressor-endpoint interactions.

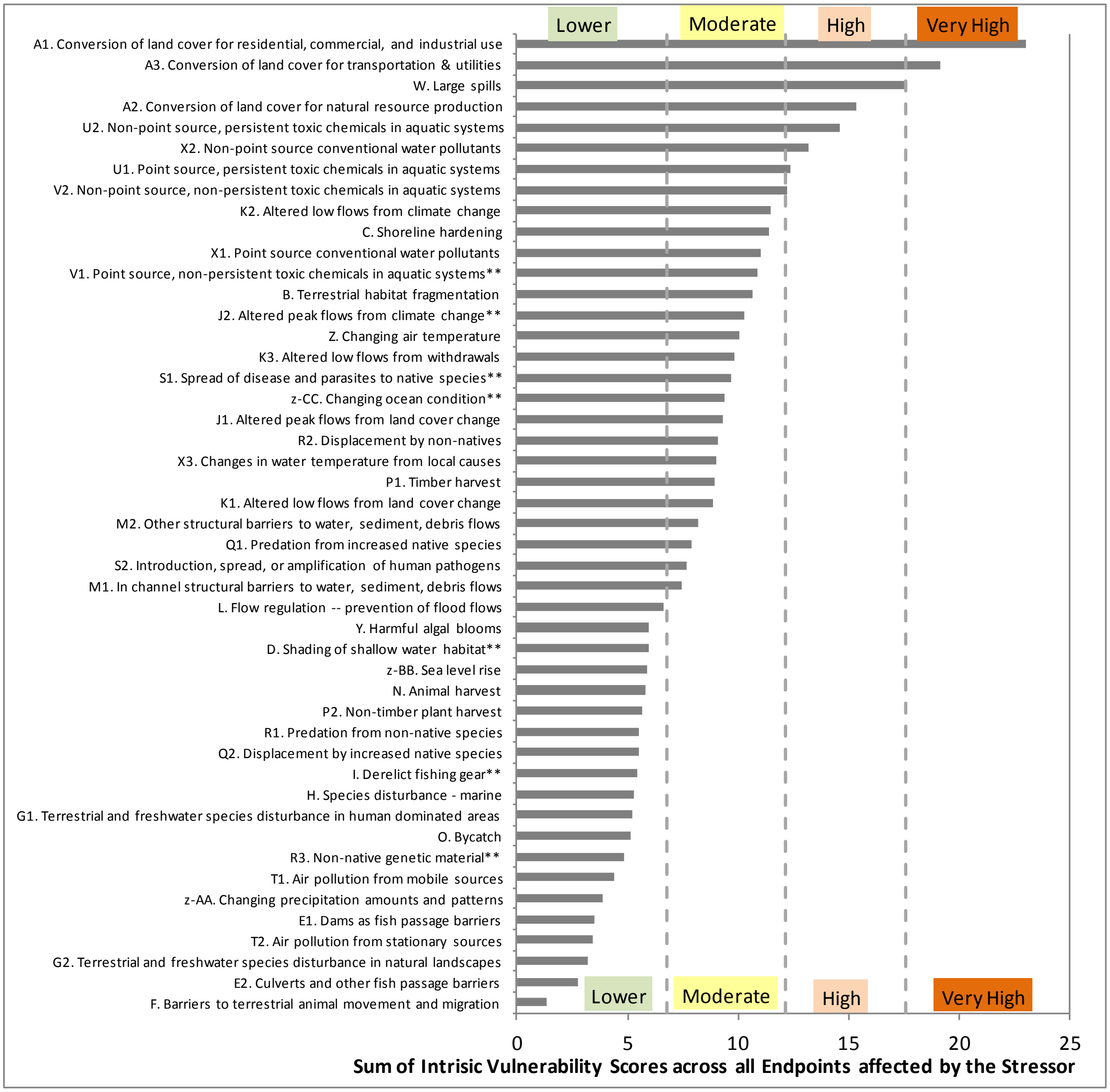
Figure 7 identifies the stressors with the most potential for harm (IV stressor Index) and Figure 8 identifies the most vulnerable endpoints (IV endpoint Index).

Intrinsic Vulnerability Stressor Index

The **IV stressor index** sums pair-scores across endpoints to rank stressors according to their potential for harm.

Figure 7 shows IV index values for all stressors. Stressors with very high uncertainty are marked. As with other results, the IV stressor index is divided into four groups, shown in Table 7.

There are eight stressors in the very high and high potential for harm groups (17% of the assessment). There are 19 stressors in the moderate potential for harm group (40% of the assessment) and 20 stressors in the low potential for harm group (43% of the assessment). Stressors with very high potential for harm are: conversion of land cover for residential, commercial, and industrial use (A1), conversion of land cover for transportation and utilities (A3), and large spills (W). Stressors with high potential for harm are: conversion of land cover for natural resource production (A2), non-point source, persistent toxic chemicals in aquatic systems (U2), non-point source conventional water pollutants (X2), point source, persistent toxic chemicals in aquatic systems (U1), and non-point source, non-persistent toxic chemicals in aquatic systems (V2). For one stressor, changing air temperature (Z), more than half of the data used to calculate the stressor index were provided by a single expert. This stressor is in the moderate group.



** Endpoint for which there was very high uncertainty in the ratings.

Figure 7: IV Stressor Index: Stressors with the Most Potential for Harm

Table 7: IV Stressor Index Groupings

Group	Index Value
Very high potential for harm	> 17.6 to 23
High potential for harm	> 12.2 to 17.6
Moderate potential for harm	> 6.8 to 12.2
Lower potential for harm	1.3 to 6.8

Intrinsic Vulnerability Endpoint Index

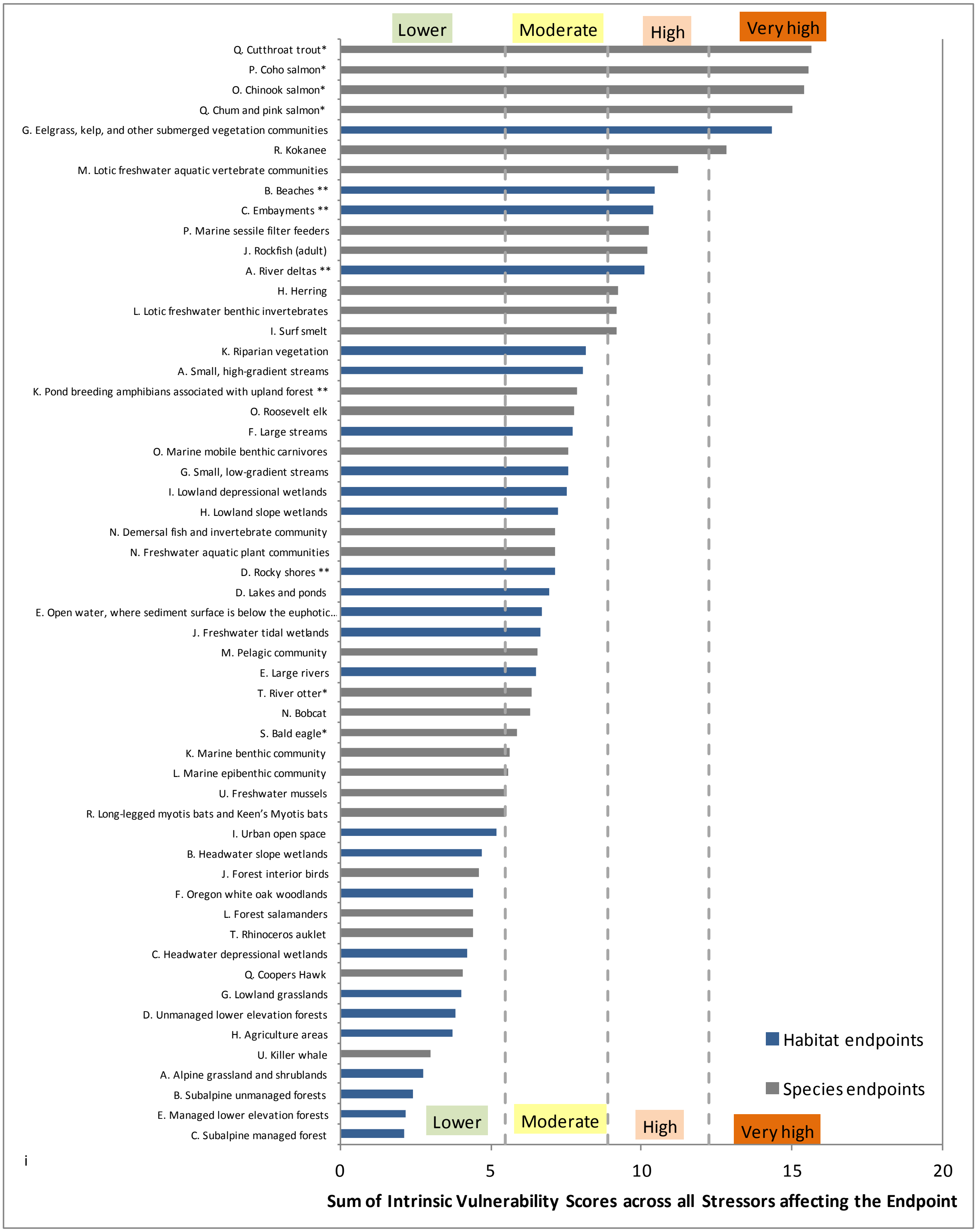
The **IV endpoint index** sums pair-scores across stressors to rank endpoints according to their intrinsic vulnerability.

The Intrinsic vulnerability endpoint index (IV endpoint index) can be presented for all endpoints combined or sorted by ecosystem domain or by endpoint type. Figure 8 differentiates habitat and species endpoints with different colored bars. Endpoints with very high uncertainty are marked.

The IV endpoint index also is divided into four groups based on index values shown in Table 8.

There are 15 endpoints in the very high and high intrinsic vulnerability groups (27% of the assessed endpoints). There are 23 endpoints in the moderate group (42% of the assessed endpoints) and 17 endpoints in the low group (31% of the assessed endpoints). Considering all endpoints, endpoints with very high vulnerability are: cutthroat trout, coho salmon, Chinook salmon, Kokanee, chum and pink salmon, and eelgrass, kelp, and other submerged vegetation communities. Endpoints with high vulnerability are: lotic freshwater aquatic vertebrate communities, beaches, embayments, marine sessile filter feeders, adult rockfish, river deltas, herring, lotic freshwater benthic invertebrates, and surf smelt. No terrestrial endpoints are in the very high or high groups when all endpoints are considered. For the freshwater and terrestrial domains, the endpoints with the highest vulnerability are species endpoints. For the marine-nearshore domain, the endpoints with the highest vulnerability are a mix of habitats and species. Note that a number of the highly ranked marine-nearshore endpoints also have significant uncertainty and rely on a relatively high number of placeholders in the IV pair scores.

For several endpoints, the endpoint index is strongly influenced by the assessments of a single expert (more than half of the data used to calculate the index was provided by one expert). This includes one endpoint in the very high category (eelgrass, kelp, and other submerged vegetation communities). Other endpoint results highly dependent on a single expert include 4 terrestrial and 1 freshwater habitat endpoint (subalpine managed forests, subalpine unmanaged forests, freshwater aquatic plant communities, headwater depressional wetlands, and headwater slope wetlands,) and 11 species endpoints (bald eagle, bobcat, Coopers Hawk, forest interior birds, forest salamanders, freshwater mussels, Killer whale, pond breeding amphibians associated with upland forests, Rhinoceros auklet, river otter, and Roosevelt elk).



* Evaluated in both freshwater and marine-nearshore domains.
** Endpoint for which there was very high uncertainty in the ratings.

Figure 8: IV Endpoint Index: Vulnerability of Endpoints

Table 8: IV Endpoint Index Groupings

Group	Index Value
Very high vulnerability	> 12.3
High vulnerability	> 8.9 to 12.3
Moderate vulnerability	> 5.5 to 8.9
Lower vulnerability	2.1 to 5.5

Summing Versus Averaging in Index Creation

As described earlier, summing across stressors and endpoints was selected as the primary method to create the IV indices because it more fully reflects both the individual stressor-endpoint pair scores and the number of stressors that might act on an endpoint (or the number of endpoints a stressor might harm). An endpoint that is affected by a large number of stressors is more vulnerable than one affected by few stressors, all other things being equal. Similarly, a stressor that acts on many endpoints has greater potential for harm than a stressor that acts on fewer endpoints, all other things being equal; the sum reflects this. At the same time, there may be cases where a stressor affects only a few endpoints, but those endpoints are highly vulnerable. These results are not easily seen when the summing approach is used, but can be explored by considering the average of the IV pair scores. The average of IV pair scores will highlight stressors that have a significant potential for harm on fewer endpoints, and endpoints that are strongly affected by only a few stressors.

In general, there is good agreement between the IV index ranking of stressors and endpoints by sum and by average. There are five stressors and eight endpoints (see Table 9) that would fall into the very high or high groups if averaging were used but which are in the lower group when summing is used. Differences between sum and average IV indices are described more fully in Appendix A.

Table 9: Changes in IV Index Rankings Based on Method Used to Create Indices

Stressors that rank very high or high by average but low by sum of pair scores	Endpoints that rank very high or high by average but low by sum
D. Shading of shallow water habitat (16) E1. Dams as fish passage barriers (7) E2. Culverts and other fish passage barriers (7) N. Animal harvest (14) BB. Sea level rise (15)	• Headwater slope wetlands (11) • Headwater depressional wetlands (10) • Alpine grasslands and shrublands (7) • Unmanaged lower elevation forests (10) • Subalpine unmanaged forests (7) • Oregon white oak woodlands (13) • Lowland grasslands (12) • Forest interior birds (13)

*Numbers in parentheses show the number of endpoints (out of 55) that are potentially affected by the stressor or the number of stressors (out of 47) that potentially affect the endpoint.

Applying the Intrinsic Vulnerability Results

As discussed above, the intrinsic vulnerability evaluation produces a model-based, assumption-bounded, estimate of vulnerability. It allows comparison of the potential for harm when stressors act directly on endpoints, stressor expression is strong, and management efforts are not mitigating stressor-endpoint interactions. The IV indices can be used to help identify and refine Puget Sound recovery priorities and strategies, and the stressor-endpoint pair-level results can be used to inform management decisions about individual stressors and endpoints. The intrinsic vulnerability results also complement the potential impact results (discussed in the next section of this report), and provide insights into potential research and monitoring needs and gaps.

Using the Intrinsic Vulnerability Results to Help Identify and Tailor Recovery Strategies and Priorities

Stressors or endpoints that score very high and high in the IV indices should be considered when recovery strategies are identified and priorities are set.

The stressor-endpoint pair-level results can be used to further explore the IV indices. Pair-level results might be used to tailor recovery strategies to ensure protection of the endpoints most vulnerable to a particular stressor and explore opportunities for coordination of recovery strategies to address multiple needs. For example, when looking at the endpoints most vulnerable to the stressors with the highest IV index rankings, wetland types occur six times. Similarly, dams as fish passage barriers are the highest or second highest stressor for all salmonid endpoints based on the intrinsic vulnerability pair scores; and those endpoints are, overall, among the most vulnerable in the IV endpoint index. We recommend, however, that care be taken to focus on patterns and trends rather than hinge decisions on any individual IV pair scores when using the stressor endpoint pair-level results in this way. The PSPA is a relatively coarse-scale assessment and it was designed primarily to evaluate stressors on Puget Sound. As the results are disaggregated into smaller and smaller pieces, decision makers should be attentive to the fact that they are seeing only a very small slice of the assessment picture. Put another way: the aggregated results reflected in the IV pair scores rankings and the IV stressor and endpoint indices are likely more meaningful to decision making than any individual IV pair score considered in isolation.

Stressors that rank low on the IV stressor index and that do not have a high potential impact on any individual endpoints in the pair-level results do not have high potential for harm and might be considered lower priority for management; however, our results did not identify any such stressors. Even barriers to terrestrial animal movement and migration, the lowest ranked stressor in the IV stressor index, is an important stress on forest salamanders and pond breeding amphibians associated with upland forest. IV pair scores for stressors that rank low in the IV index can be used to tailor management strategies to target the most vulnerable endpoints over endpoints with less vulnerability, but based on our results it appears that all stressors warrant some management to prevent adverse effects on at least one endpoint.

Using the Intrinsic Vulnerability Uncertainty Results to Inform Research, Monitoring and Future Assessment Priorities

Stressors or endpoints that have high uncertainty indices should be considered when research and monitoring priorities are set. A high uncertainty index can result from the use of placeholder values, from high expressed uncertainty by experts, or by high disagreement between multiple experts. Any of these may be an indication that additional research or monitoring is needed to better understand stressor-endpoint relationships.

As with the other intrinsic vulnerability results, the uncertainty indices for stressors and endpoints can be used in concert with the pair-level uncertainty index values. Tables 10 and 11 show the stressors and endpoints with the highest uncertainty index values, as well as the associated highest uncertainty stressor-endpoint pairs. Use of placeholder values is noted. Future work could seek to reduce the uncertainty represented by placeholder values by bringing more experts into the assessment and reducing or eliminating use of placeholder values. Where experts expressed a high level of uncertainty, that uncertainty could reflect either lack of personal knowledge or confidence, or lack of knowledge within the scientific community. The former might be reduced by undertaking a Delphi-like process where experts discuss and share the information they relied on for their ratings. This approach could help individual experts reduce their own uncertainties and would also serve to identify why experts have different ratings, in cases where there is large between-expert variance. The latter issue—uncertainty inherent in the current state of the science—indicates areas where more research, monitoring, and assessment may be necessary to better understand the relationships before they can be better characterized.

Table 10: Stressors with Very High Uncertainty and Associated High-uncertainty Endpoints

Stressor	Endpoints with the Highest Uncertainty Index
z-CC. Changing ocean condition	5 of 18 endpoints use placeholder values River deltas; Beaches; Embayments
D. Shading of shallow water habitat	6 of 16 endpoints use placeholder values Kokanee; Cutthroat trout
I. Derelict fishing gear	0 of 15 endpoints use placeholder values Rhinoceros auklet; Pacific herring
R3. Non-native genetic material	6 of 14 endpoints use placeholder values Kokanee; Chum and pink salmon
S1. Spread of disease and parasites to native species	8 of 30 endpoints use placeholder values Pond breeding amphibians associated with upland forest; Killer whale
J2. Altered peak flows from climate change	10 of 29 endpoints use placeholder values Pond breeding amphibians associated with upland forest; Lowland depressional wetlands
V1. Point source, non-persistent toxic chemicals in aquatic systems	1 of 36 endpoints use placeholder values Freshwater mussels; Lakes and ponds; Open water, where sediment surface is below the euphotic zone
L. Flow regulation – prevention of flood flows	4 of 24 endpoints use placeholder values Lakes and ponds; Pond breeding amphibians associated with upland forests

Table 11: Endpoints with Very High Uncertainty and Associated High-uncertainty Stressors

Endpoint	Stressors with High Uncertainty for the Endpoint
River deltas	9 of 28 stressors use placeholder values Z. Changing ocean conditions U2. Non-point source, persistent toxic chemicals in aquatic systems V1. Point source, non-persistent toxic chemicals in aquatic systems V2. Non-point source, non-persistent toxic chemicals in aquatic systems
Embayments	9 of 28 stressors use placeholder values Z. Changing ocean conditions V1. Point source, non-persistent toxic chemicals in aquatic systems V2. Non-point source, non-persistent toxic chemicals in aquatic systems
Beaches	9 of 28 stressors use placeholder values Z. Changing ocean conditions V1. Point source, non-persistent toxic chemicals in aquatic systems Y. Harmful algal blooms
Pond breeding amphibians associated with upland forest	No placeholder values used R2. Displacement by non-natives L. Flow regulation – prevention of flood flows M1. In channel structural barriers to water, sediment, debris flows M2. Other structural barriers to water, sediment, debris flows S1. Spread of disease and parasites to native species
Rocky shores	8 of 27 stressors use placeholder values U1. Point source, persistent toxic chemicals in aquatic systems U2. Non-point source, persistent toxic chemicals in aquatic systems
Open water, where sediment surface is below the euphotic zone	7 of 20 stressors use placeholder values V1. Point source, non-persistent toxic chemicals in aquatic systems V2. Non-point source, non-persistent toxic chemicals in aquatic systems

Considerations and Limitations

The intrinsic vulnerability part of the PSPA evaluates individual stressor-endpoint relationships and then sums (or averages) across assessments of those individual relationships to create indices of stressors with the most potential for harm and the most vulnerable endpoints. The intrinsic vulnerability results presented here do not consider pressure networks (relationships between stressors and sources that may amplify impacts) or synergistic (or antagonistic) interactions when multiple stressors act on the same endpoint. These sorts of evaluations could be supported by the PSPA intrinsic vulnerability data; however they were beyond the scope of this phase of the project.

Endpoint delineation was systematic, following the approach and applying the criteria laid out in the PSPA Technical Memo (Labiosa et al., 2014) and informed by Suter 2007. While care was taken to delineate endpoints systematically to cover the full range of habitats and species in each ecosystem domain, the actual endpoints were selected at least in part based on a valued ecosystem component consideration. That is, when faced with selecting between two endpoints that both might represent a particular habitat or species niche, we selected the endpoints that were sufficiently understood or studied such that there would be information (and experts) available to evaluate them. Often the most studied/well understood endpoints are also among the most valued ecosystem components. This approach has many advantages, including the practical advantage of supporting assessment; however when results are used to inform management strategies it also introduces potential bias towards strategies that address what we already know and care about now, potentially at the expense of other (perhaps even more vulnerable) endpoints. In this regard, our evaluation is no different than any other evaluation which relies on VECs.

Finally, these results reflect the initial application of the PSPA Methodology. There was limited time to facilitate interactions between experts and experts were both learning the method and applying the method at the same time. There are opportunities to improve expert coverage and likely refine the quality of expert ratings in future studies.

Potential Impact Results

Potential impact combines the results of the three PSPA sub-models. Intrinsic vulnerability results for stressor-endpoint pairs (IV pair scores) (submodel 1) are combined with stressor intensity results (submodel 2) to create an assessment-unit specific adjusted vulnerability score for every stressor-endpoint pair. AU scale adjusted vulnerability pair scores (AV pair scores) are "filtered" by endpoint presence or absence (submodel 3) to eliminate scores for endpoints that are not present in the AU, and are then summed over the remaining endpoints to create an AU-scale result that describes the potential impact of each stressor in each watershed and marine basin. The AU-scale potential impact results are combined to create a Puget Sound-scale estimate.

Potential impact adjusts the intrinsic vulnerability results to account for stressor intensity and endpoint presence/absence in Puget Sound watersheds and marine basins. Results are prepared at the AU-scale and then combined to create a Puget Sound-scale view.

Adjusted vulnerability is an assessment unit-scale measure of the vulnerability of an endpoint to a stressor considering the stressors' current intensity in the assessment unit.

We describe these results as potential impact because we did not evaluate actual impact. Rather, we explored the vulnerability of endpoints to stressors under a defined set of assumptions and then combined this result with information on current stressor intensity and the presence/absence of endpoints in assessment units. Our finest-scale results are at the AU-scale, and we do not map actual encounters between stressors and endpoints but rather identify watersheds and marine basins where the stressors and endpoints are present and therefore may co-occur. Furthermore we do not consider synergistic or antagonistic affects across stressors, nor do we consider the initial condition of endpoints (i.e., intact, impaired, threatened, etc.). All of these factors could influence the actual impact of a stressor on an endpoint.

Puget Sound scale potential impact results for watersheds and marine basins are presented here. Methods and supplemental results, including endpoint-focused results, are described in Appendix D. Assessment unit scale potential impact results for each watershed and marine basin are presented in Appendix G, and discussions of results for each individual stressor are presented in Appendix H.

Assessment units are the watersheds and marine basins in which stressor intensity and endpoint distribution are evaluated. Watersheds are the Salmon Recovery Watersheds and marine basins are as defined by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP).

Calculating Potential Impact

The potential impact results combine the intrinsic vulnerability pair scores with geographic information on stressor intensity and endpoint distribution. Because they rely on geographic information, potential impact results are determined at the AU scale, and then combined to create a Puget Sound scale view.

Following the PSPA Technical Memo, the potential impact results are calculated from the intrinsic vulnerability scores for each stressor- endpoint pair, the stressor intensity index for each stressor in each assessment unit, and the presence or absence of each endpoint in each assessment unit. Mathematically, $\mu_{i,j}$ represents the intrinsic vulnerability score for each stressor (*i*) endpoint (*j*) pair (calculation of this score is described in Appendix A); $P_{i,c}$, represents the stressor intensity index for each stressor in each assessment unit (c) (see Appendix B); and endpoint distribution information is represented by a 1-or-0 presence/absence score, $E_{j,c}$ for each endpoint in each assessment unit (see Appendix C).

The factors are combined in two steps. First, an AU-specific "adjusted vulnerability" score is calculated for each stressor-endpoint pair ($\mu_{i,j,c}$):

$$\mu_{i,j,c} = E_{j,c} \times P_{i,c} \times \mu_{i,j} \tag{1}$$

The adjusted vulnerability scores represent the potential impact of a stressor on an endpoint in the assessment unit being considered. Thus they represent the potential impact of a specific stressor on a specific endpoint in a specific assessment unit. Adjusted vulnerability scores are calculated only for endpoints that are present in the assessment unit being considered. (I.e., the results are "filtered" to remove calculations for endpoints that are not present.) If the endpoint is not present, the adjusted vulnerability for all pairs involving that endpoint is 0; if the stressor is not present, the adjusted vulnerability for all pairs involving that stressor is 0.

In the second step, the adjusted vulnerability scores are summed (separately) over endpoints and over stressors to provide individual AU-scale "potential impact indices" for each assessment unit. These are similar to the IV indices described in Appendix A.

$$Potenial\ impact\ of\ stressor\ i\ in\ AU\ c = \sum_{j=1}^{m} E_{j,c} \times P_{i,c} \times \mu_{i,j} \tag{2}$$

$$Potenial\ impact\ on\ endpoint\ j\ in\ AU\ c = \sum_{i=1}^{n} E_{j,c} \times P_{i,c} \times \mu_{i,j} \tag{3}$$

As with the intrinsic vulnerability stressor and endpoint indices, we also calculate a second index using an averaging approach. In this case we average the adjusted vulnerability pair scores across individual endpoints and stressors. This secondary set of AU-scale index values is used to identity individual stressors that have high potential impact on only a few endpoints, and to identify endpoints that can suffer high potential harm from only a few stressors.

The AU-scale potential impact indices can be considered individually, and they can be combined to support consideration of potential impact at the sound-wide scale.

Puget Sound Scale Potential Impact Results for Watersheds and Marine Basins

The Puget Sound scale potential impact results are calculated by averaging the AU-scale potential impact results for each stressor. Note that we did not evaluate Puget Sound scale potential impact across assessment unit types; results were developed and are presented separately for watersheds and marine basins.

At the Puget Sound scale, the potential impact results can be used to explore:

- Which stressors have the most potential impact and which the least.
- Where stressors have the most potential impact, and where the least.

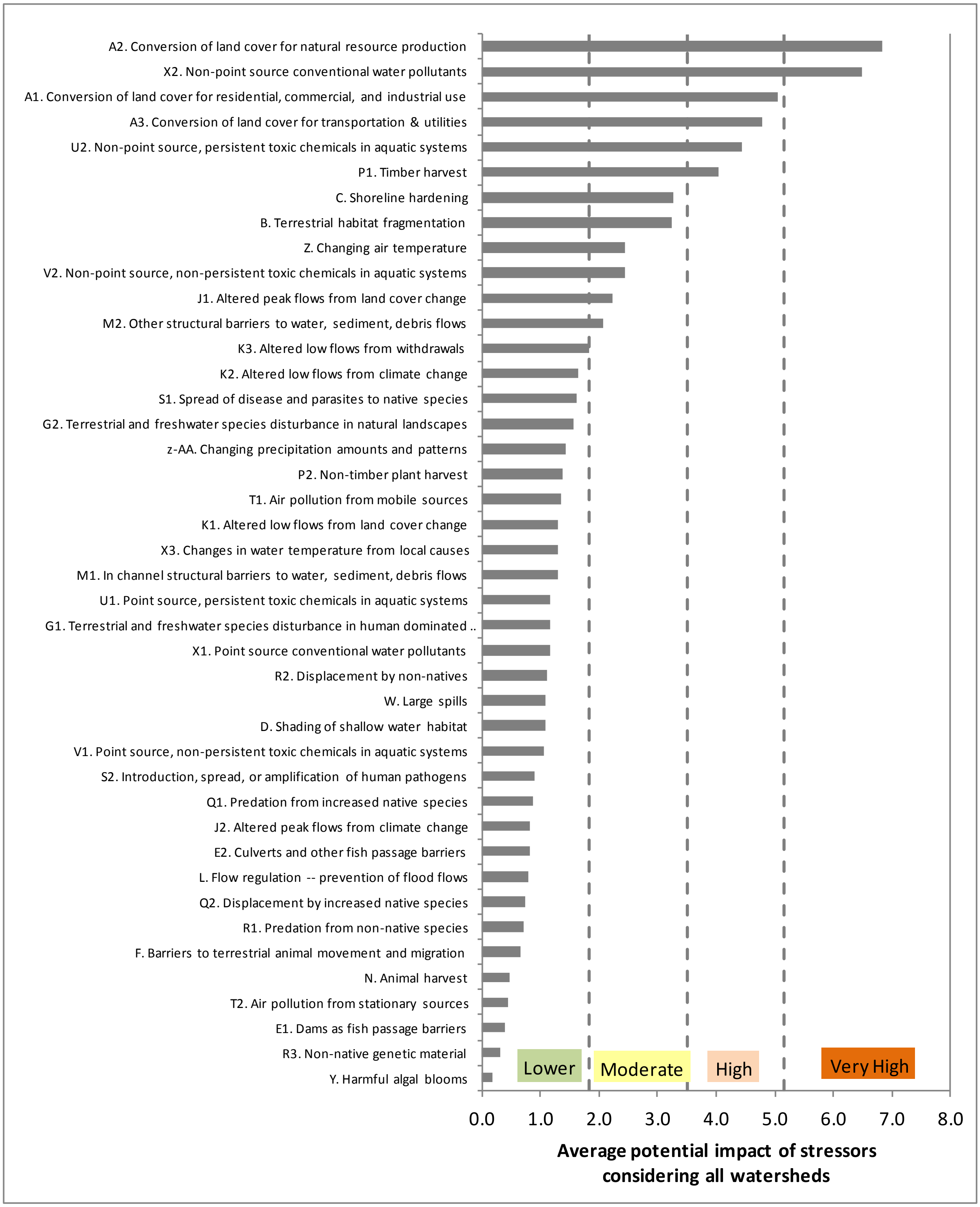
Stressors with the Most Potential Impact

Figure 9 shows Puget Sound scale potential impact for stressors in watersheds; Figure 10 shows Puget Sound scale potential impact results for stressors in marine basins. Figure 11 highlights which stressors have very high and high potential impact in both watersheds and marine basins, and which have very high and high potential impact results on only one type of assessment unit

Just like the intrinsic vulnerability results, we divided the potential impact results into four groups: very high, high, moderate, and lower, based on the magnitude of the scores. Table 12 shows the divisions for watersheds and the divisions for marine basins; the numeric values of the potential impact indices span different ranges for the two types of assessment units because fewer endpoints were evaluated for marine basins than for watersheds. The method used for defining groups is the same method used for defining the intrinsic vulnerability groups, and is described in more detail in Appendix A.

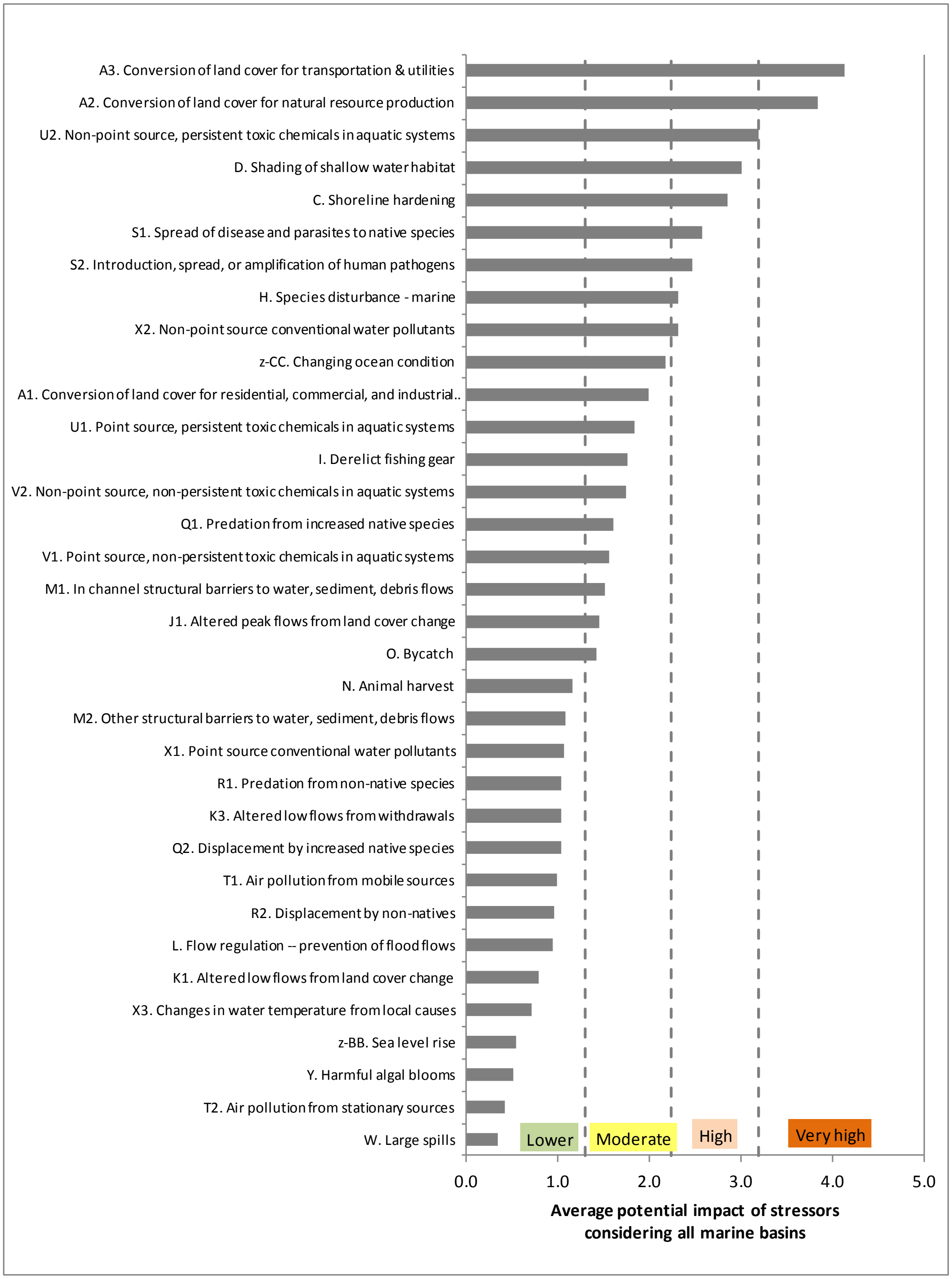
In considering the potential impact results, it is important to keep in mind the differences in stressor intensity assessment. As described more fully in Appendix B and the sections on individual stressors in Appendix H, stressor intensity estimates were based on readily available spatial information. Sometimes this spatial information describes how much of a stressor has occurred so far (a cumulative amount). This is the case with the habitat conversion stressors, where stressor intensity is a measure of how much habitat has been converted to residential or commercial development, or natural resource production, to date. Results can describe how much stress these stressors are currently placing on the ecosystem but they do not describe how these stressors might be expressed in the future. Future studies could evaluate these stressors under a variety of future “build out” scenarios to better inform current and future management priorities. Other times, stressor intensity describes only what is occurring now, and may miss some stress from cumulative effects. This is the case for the pollution stressors, where stressor intensity is a measure of how much pollution is occurring based on current discharges and land-cover based load estimates. It does not address legacy pollution or pollution loads that may already be present and dispersed in the environment. Future studies could evaluate this.

As discussed further below, it also is important to avoid considering potential impact results in isolation. The intrinsic vulnerability results are an important complement to the potential impact results in part because they evaluate all stressors under the same set of assumptions and therefore can signal which stressors have more or less potential for harm independent of measures of current stressor intensity.



*Potential Impact as shown here is the average of the Potential Impact of each stressor in each watershed. Potential impact of a stressor in each watershed incorporates intrinsic vulnerability, stressor intensity, and endpoint presence or absence, summed across all endpoints; it is described in detail Appendix D.

Figure 9: Puget Sound Scale: Stressors with the Most Potential Impact in Watersheds



*Potential Impact as shown here is the average of the Potential Impact of each stressor in each marine basin. Potential impact of a stressor in each marine basin incorporates intrinsic vulnerability, stressor intensity, and endpoint presence or absence, summed across all endpoints; it is described in detail Appendix D.

Figure 10: Puget Sound Scale: Stressors with the Most Potential Impact in Marine Basins

Table 12: Puget Sound Scale Potential Impact Groupings in Watersheds and Marine Basins

Group	Puget Sound Scale Index Value Watersheds	Puget Sound Scale Index Value Marine Basins
Very high potential impact	>5.16 to 6.83	>3.19 to 4.14
High potential impact	>.5 to 5.16	>2.24 to 3.19
Moderate potential impact	>1.83 to 3.5	>1.29 to 2.24
Lower potential impact	< =1.83	<= 1.29

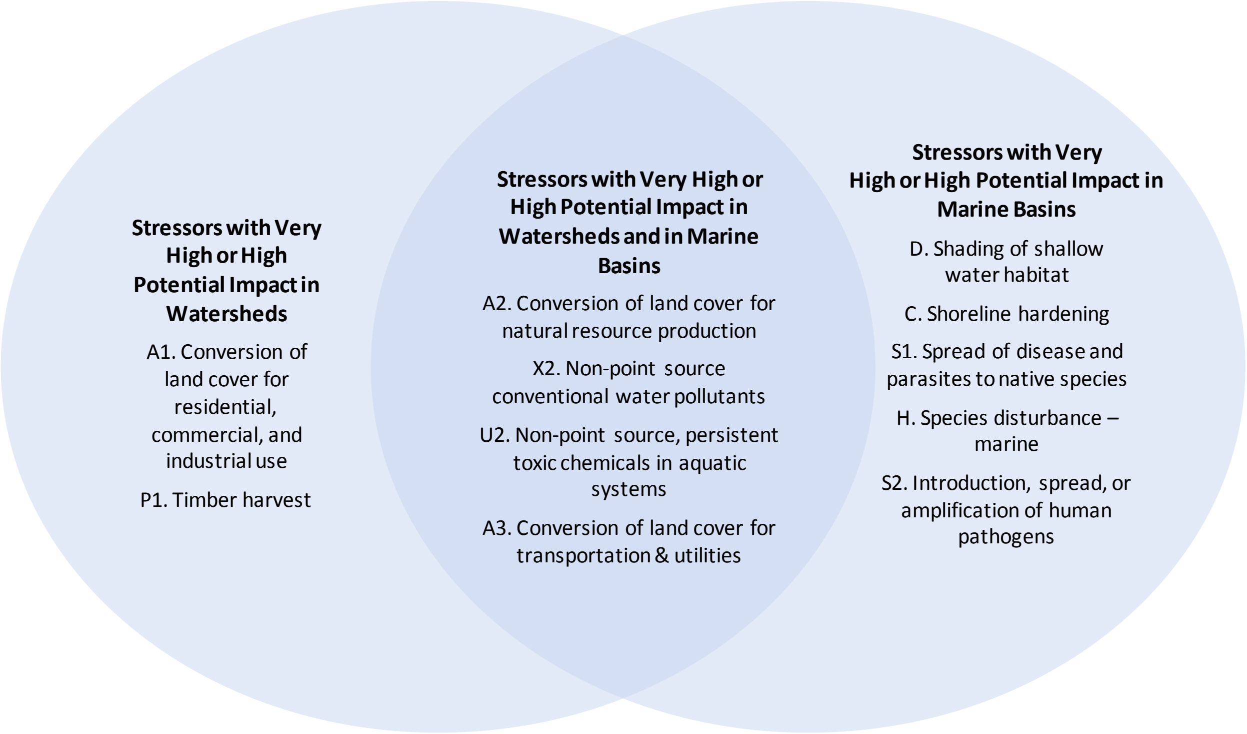


Figure 11: Puget Sound Scale Stressors with Very High or High Potential Impact by Assessment Unit Type

Using Sum vs. Average Adjusted Intrinsic Vulnerability Pair Scores to Create the Puget Sound Scale Potential Impact Results

The potential impact results displayed in Figures 9, 10, and 11 aggregate AU-scale results that are produced by summing across AU scale AV pair scores. AU-scale potential impact results also can be created by averaging across AU scale AV pair scores. As discussed more fully in Appendices A and D, we use summing as a primary method to create results because it more fully reflects both the number of endpoints that a stressor might harm and the vulnerability of each affected endpoint to that stressor; however, to ensure stressors that have a disproportionately high potential impact on relatively fewer endpoints are not masked, we produce complementary results using averaging. Averaging highlights stressors that have a high potential impact on fewer endpoints.

For watersheds, there are two stressors in the lower potential impact group when summing is used which jump to the very high or high potential impact groups if averaging is used. For marine basins, there are no stressors in the lower potential impact group which jump to the very high or high potential impact groups if averaging is used. Table 13 summarizes these results. Appendix D includes tables showing the potential impact results calculated both by summing and by averaging.

Table 13: Changes in Puget Sound Scale Ranking Based on Method Used to Calculate Results

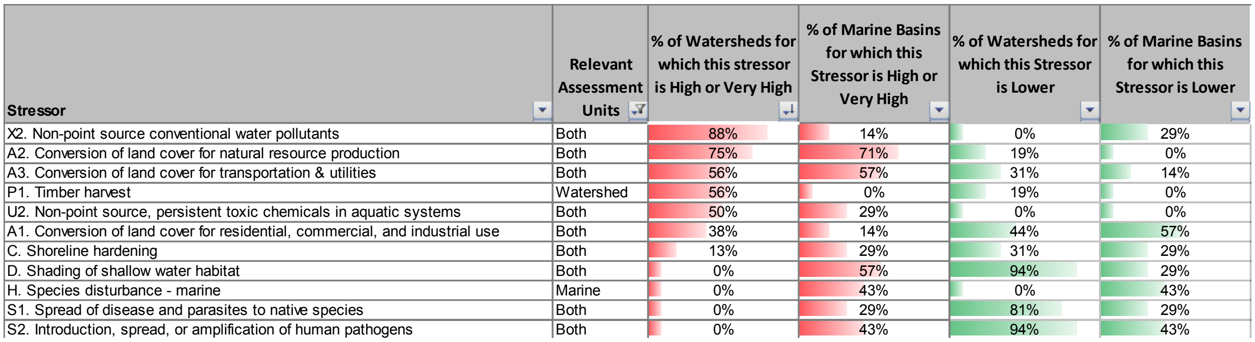
Watersheds: stressors that rank high by average but low by sum of AV pair scores	Marine Basins: stressors that rank high by average but low by sum of AV pair scores
D. Shading of shallow water habitat F. Barriers to terrestrial animal movement and migration	None

AU-Scale Results for Watersheds and Marine Basins

Appendix G presents AU-scale potential impact results for each watershed and marine basin. Results are intended for further analysis and use by local decision makers. The PSPA was not intended to develop (or replace) locally-derived pressure assessments that consider finer-scale more local data and expert judgments. At the same time, results are initially prepared at the AU-scale, producing a view that allows for local exploration. At the AU-scale, the PSPA is intended to help inform and, where needed, provide a starting point or complement to locally-focused efforts. Please see Appendix G for further discussion of AU-scale results.

The AU scale results also can be examined for Puget Sound-wide implications. The potential impact results calculated for each AU can be looked at together to facilitate comparisons across and between AU types. Table 14 shows the percentage of watersheds and marine basins in which each stressor is in the very high or high potential impact group and corresponding information about the percentage of assessment units in which each stressor is in the lower potential impact group. This helps to show Puget Sound-wide patterns of stressors and reiterates the variability of potential impact across assessment units. Except for non-point source persistent toxic chemicals in aquatic systems (U2) all stressors that are in the very high or high potential impact groups in some individual AUs are in the lower potential impact group in other AUs.

Table 14: AU-Scale Ranking of Stressors with Very High or High Potential Impact in either Watersheds or Marine Basins



Stressor	Relevant Assessment Units	% of Watersheds for which this stressor is High or Very High	% of Marine Basins for which this Stressor is High or Very High	% of Watersheds for which this Stressor is Lower	% of Marine Basins for which this Stressor is Lower
X2. Non-point source conventional water pollutants	Both	88%	14%	0%	29%
A2. Conversion of land cover for natural resource production	Both	75%	71%	19%	0%
A3. Conversion of land cover for transportation & utilities	Both	56%	57%	31%	14%
P1. Timber harvest	Watershed	56%	0%	19%	0%
U2. Non-point source, persistent toxic chemicals in aquatic systems	Both	50%	29%	0%	0%
A1. Conversion of land cover for residential, commercial, and industrial use	Both	38%	14%	44%	57%
C. Shoreline hardening	Both	13%	29%	31%	29%
D. Shading of shallow water habitat	Both	0%	57%	94%	29%
H. Species disturbance - marine	Marine	0%	43%	0%	43%
S1. Spread of disease and parasites to native species	Both	0%	29%	81%	29%
S2. Introduction, spread, or amplification of human pathogens	Both	0%	43%	94%	43%

Summary Results for Individual Stressors

Appendix H presents summary results and discussion for each stressor evaluated in the PSPA. This includes maps comparing the potential impact rankings of each stressor across watersheds and (separately) across marine basins, such as the comparison of the potential impact rankings of X2 (non-point source conventional water pollutants) in Figure 12, below.

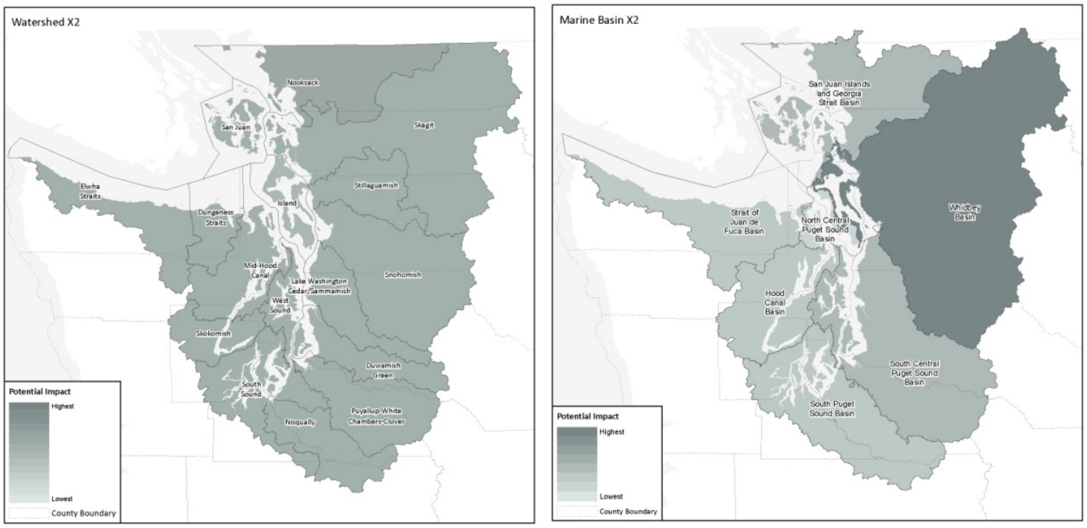


Figure 12: Comparison of Potential Impact Rankings of X2 (Non-point Source Conventional Water Pollutants)

Application of Potential Impact Results and Relationship Between Potential Impact and Intrinsic Vulnerability

The potential impact results give a sense of which stressors have the most potential impact on Puget Sound at the AU and Puget Sound scales. They are intended to help decision makers identify and refine Puget Sound recovery priorities and strategies.

The potential impact results are most informative when viewed in relation to the intrinsic vulnerability results. Potential impact results alone give an incomplete picture of stressor expression (and importance) particularly for stressors that are not widely distributed or have infrequent occurrence. Using the intrinsic vulnerability results in combination with potential impact results will illustrate this type of case. For example, large spills are rare, so they rank relatively low in the potential impact results; at the same time, a large spill could have catastrophic effects in Puget Sound and they rank among the stressors with the greatest potential for harm in the intrinsic vulnerability results. A similar case occurs with many of the climate-related stressors because their current expression in Puget Sound is relatively low (e.g., sea level rise). Even though many endpoints have high intrinsic vulnerability to strong future expressions of climate stressors, the potential impact results are relatively low, because the current stressor intensity is relatively low. When potential impact results are low and intrinsic vulnerability is high, these likely are opportunities to take action to mitigate and manage stressors that have a high potential for harm before they are fully expressed. When potential impact is high and intrinsic vulnerability is low there may be opportunities to focus stressor management more closely on vulnerable endpoints. This relationship can be illustrated in a simple two-by-two table (Figure 13).

Intrinsic Vulnerability (IV) >>>

Higher IV/Lower PI	Higher IV/Higher PI
The potential for harm is high, but the stressor may be rare (infrequent) and/or the current stressor intensity may be relatively low. • These stressors should be priorities for action. • Consider potential opportunities to mitigate stressor before impacts are more fully felt.	**Stressor has high potential for harm and likely affects many endpoints; current stressor intensity is relatively high.** • These stressors should be priorities for action. • Where possible strategies should emphasize overall stressor reduction.
Lower IV/Lower PI	**Lower IV/Higher PI**
The potential for harm is relatively low across endpoints and/or the stressor affects relatively fewer endpoints; the stressor is rare and/or the current stressor intensity is relatively low. • These stressors may have high potential for harm in certain places or for certain endpoints; IV results should be checked to identify any particularly vulnerable endpoints. • Consider targeted management strategies and/or de-emphasize depending on local context.	**The potential for harm is relatively low across endpoints and/or the stressor affects relatively fewer endpoints, but stressor intensity likely is high.** • These stressors could be priorities for action. If stressor reduction is not possible, consider targeted management strategies to reduce or mitigate harmful stressor-endpoint relationships.

Potential Impact (PI)>>>

Figure 13: Relationship Between Potential Impact Results and Intrinsic Vulnerability Index

PSPA results can be plotted in a similar way. Figure 14 plots the IV stressor index results against the Puget Sound-scale potential impact results for watersheds. Figure 15 shows the same information for marine basins.

We note that the two values are not independent: both the intrinsic vulnerability stressor index (the y-axis) and the potential impact index (the x-axis) are calculated from the intrinsic vulnerability pair scores. The potential impact index also incorporates the spatial intensity and distribution of the stressor and its affected endpoints, information not captured in the stressor IV index. As discussed above, inclusion of those factors adds an important dimension to the PSPA results, potentially helping to identify stressors for which overall reduction may be important (e.g., high IV, high PI), stressors where early mitigation might avoid future impacts (e.g., high IV, lower PI), and areas where mitigation of particular stressor-endpoint relationships might be useful (e.g., lower IV / high PI).

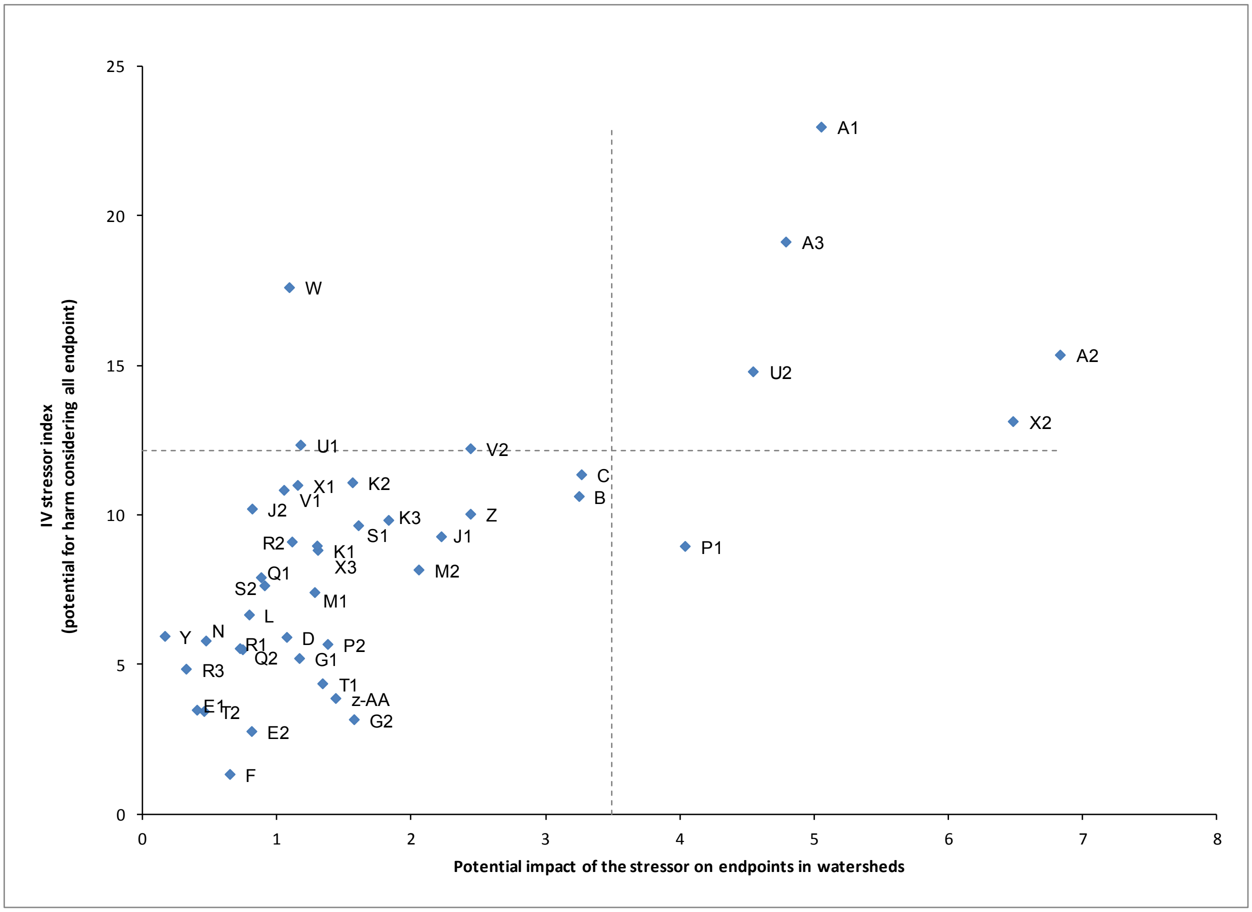


Figure 14: Puget Sound Scale: Comparison of IV Index and PI Index Rankings for All Stressors in Watersheds

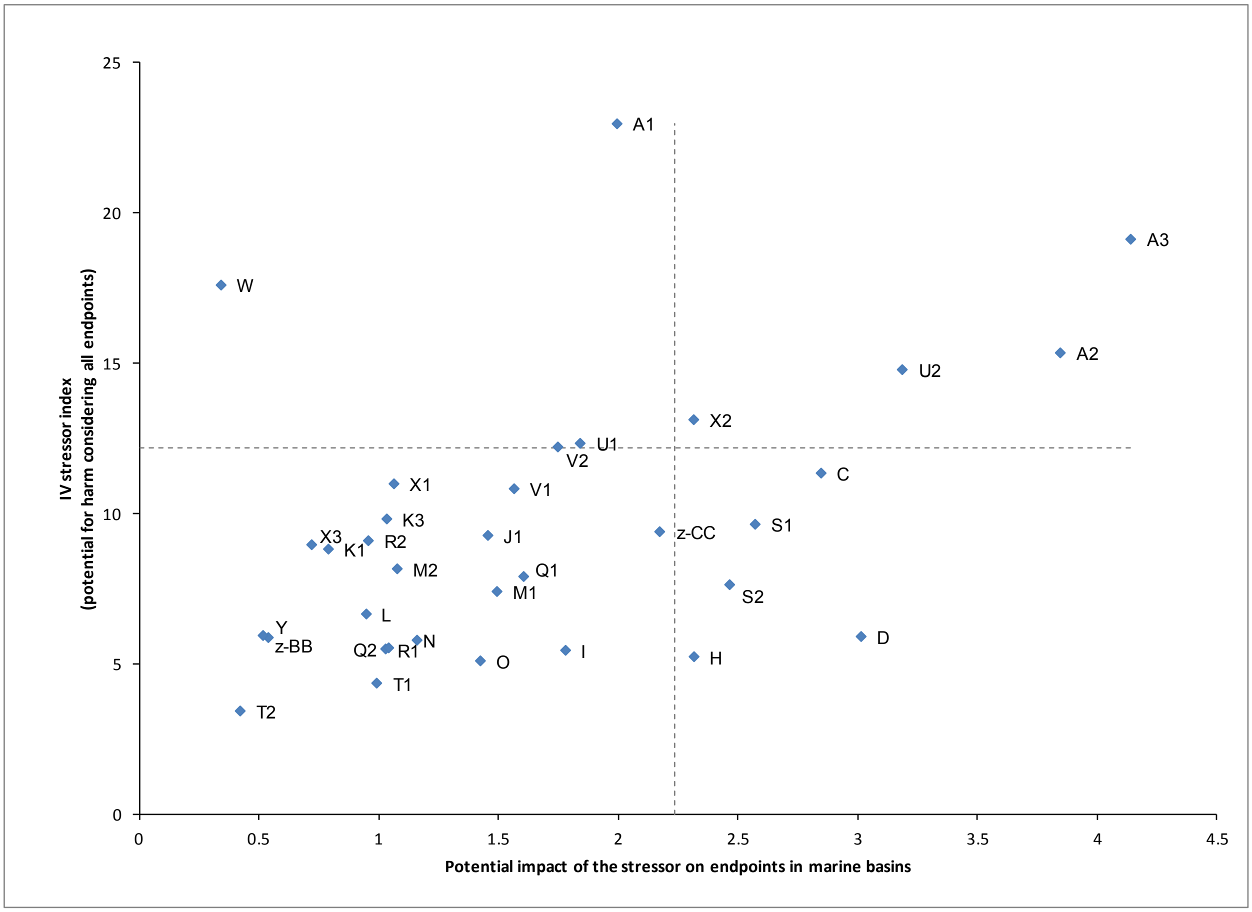


Figure 15: Puget Sound Scale: Comparison of IV and PI Index Rankings for All Stressors in Marine Basins

Relationship of PSPA Results to Past Puget Sound Pressure Assessments

It is difficult to compare PSPA results with the previous assessment of pressures on Puget Sound, *Identification, Definition and Rating of Threats to the Recovery of Puget Sound, A Technical memorandum to the State of the Sound 2009* (Neuman et al., 2009). The 2009 assessment used different stressors (termed "threats") and endpoints, and presented results in a more aggregated fashion.

Table 15 compares the results of the 2009 assessment with PSPA results. In general, stressors associated with land use change (residential, commercial, natural resource production, and utility-related development) are identified as very high or high threats (2009) or very high or high potential impact (PSPA). Shoreline hardening also has a high rating in both assessments, as do non-point water pollutants, which were assessed as surface water runoff in the 2009 assessment and as U2, V2, and X2, non-point source persistent toxics, non-persistent toxics, and conventional water pollutants, in the PSPA. (V2 does not have a very high or high potential impact result, but does have a high intrinsic vulnerability result.)

The 2009 assessment rated invasive species and unsustainable fisheries and harvest as high threats. These stressors do not have very high or high potential impact results in the PSPA. This may have to do with threat/ stressor definitions and the difference in assessment methods. Spread of disease and parasites to native species (S1) which is related to invasive species does have a high potential impact result in the PSPA. Animal harvest has an intrinsic vulnerability result in the PSPA, but the potential impact result is not high, reflecting the current management of harvest activities. Climate change has a very high threat rating in the 2009 assessment; stressors associated with climate change have high intrinsic vulnerability results in the PSPA but do not have high potential impact results, reflecting their current (relatively low) expression. When potential impact of climate change stressors is calculated using scenarios of potential future expression, they have high or very high potential impact.

Table 15: Comparison of 2009 Assessment with PSPA Results

2009 Very High or High Threat Rating	PSPA Very High or High Potential Impact	PSPA Very High or High Intrinsic Vulnerability
• Climate change • Residential, commercial, port, and shipyard development • Dams, levees, and tidegates • Invasive species • Roads, transportation, and utility infrastructure • Shoreline armoring • Surface water loading and runoff from the built environment • Unsustainable fishing and harvest	Watersheds and Marine Basins • A2. Conversion of land cover for natural resource production • A3. Conversion of land cover for transportation & utilities • U2. Non-point source, persistent toxic chemicals in aquatic systems • X2. Non-point source conventional water pollutants Watersheds Only • A1. Conversion of land cover for residential, commercial, and industrial use • P1. Timber harvest Marine Basins Only • C. Shoreline hardening • D. Shading of shallow water habitat • M1. In channel structural barriers to water, sediment, debris flows • S1. Spread of disease and parasites to native species S2. Introduction, spread, or amplification of human pathogens	• A2. Conversion of land cover for natural resource production • A3. Conversion of land cover for transportation & utilities • U2. Non-point source, persistent toxic chemicals in aquatic systems • X2. Non-point source conventional water pollutants • A1. Conversion of land cover for residential, commercial, and industrial use • U1. Point source, persistent toxic chemicals in aquatic systems • V2. Non-point source, non-persistent toxic chemicals in aquatic systems • W. Large spills

A more in-depth analysis could further compare the 2009 results to PSPA results, evaluating the various rating factors and scores. This type of assessment was beyond the scope of this effort.

Considerations and Limitations

The PSPA potential impact results sum (or average) across adjusted vulnerability scores for stressors and endpoints in assessment units to create AU-scale indices of potential impact. These AU-scale potential impact index values are further aggregated to produce the (separate) Puget Sound scale indices for watershed and marine basins. These indices are highly aggregated results. As described throughout this report and the Appendices, policy makers should not rely on one view or perspective on the PSPA results for decisions; rather, they should explore the results to understand how stressors perform in the intrinsic vulnerability and the potential impact analyses and using the sum and the average calculation approaches. The two-by-two matrix of potential impact and intrinsic vulnerability results above and the discussion of stressors that rank significantly higher if results are calculated by average, instead of sum, provide two examples of how the different types of PSPA results can be brought together to inform decisions.

The spatial analysis on which the stressor intensity evaluation relies was not originally scoped as part of the PSPA and was added to the assessment mid-way. It was performed quickly. While all stressor intensity results present a “snap shot” of current stressor expression and therefore, we believe, allow for comparisons between stressors, the potential of spatial analysis to capture stressor intensity has not been fully explored and the evaluations are likely incomplete in some ways. For example, stressor U1 (point source persistent pollution in aquatic systems) was defined to include persistent chemical cycling (e.g., PCB and mercury cycling); V2 (point source non-persistent pollution in aquatic systems) was defined to include historic sources small spills. However the stressor intensity analysis for both stressors is based only on current discharges from wastewater treatment plant and other current facility discharges, because only those data were readily available at a Puget Sound-wide scale within the timeframe of the assessment. There are other, similar, examples of a stressor intensity evaluation potentially “missing” some of the stress that was defined as part of a stressor. These may result in under-estimation of the potential impact from some stressors. (We note that this is not unique to the PSPA; all the assessments on which the PSPA method is based select available data sets to represent broad stressors.) We describe the quality of the “match” between each stressor definition and the data used to evaluate stressor amount in Appendix B.

Similarly, as described above, the PSPA stressor intensity evaluation describes a snap shot in time. For stressors that are continuing to exert stress on the Puget Sound ecosystem, our snapshot measures how much of a stressor has occurred so far (e.g., how much land has been converted for the habitat conversion stressors) not how much stress is likely to occur in the future. Results describe how much stress these stressors are currently placing on the ecosystem but they do not describe how these stressors might be expressed in the future or whether they are increasing or decreasing. Future studies could address this issue through use of scenario analysis to consider changes in stressor intensity and recovery/management options.

Conclusions and Potential Future Investigations

The Puget Sound Pressures Assessment has engaged experts from throughout the region to create a better understanding of pressures on the Sound's freshwater, marine-nearshore, and terrestrial resources. Results will help inform science and management decisions about Puget Sound recovery priorities and can be used to focus management strategies.

PSPA results address:

- Which stressors have the most potential impact in Puget Sound at the watershed/marine basin and Puget Sound scales.
- Differences in potential impact among watersheds and marine basins.
- The endpoints that are most vulnerable at the watershed/marine basin and Puget Sound scales.
- Relative certainty and uncertainty about stressor-endpoint relationships.

The PSPA process confirmed the utility of the PSPA assessment model and methodology, improved understanding of how to better conduct all or parts of an assessment in the future, and thus created a firm foundation for future assessment iterations and finer-scale sub-regional assessments. The PSPA also produced a regionally-vetted list of stressors, providing an important update to the ongoing process of defining a pressure taxonomy for Puget Sound, and a systematically delineated list of endpoints that cover habitat types and species in each of the three assessment domains (freshwater, marine-nearshore, and terrestrial).

The PSPA produces two primary results: (1) intrinsic vulnerability of endpoints to stressors and (2) potential impact of stressors at the AU (watershed and marine basin) and Puget Sound scales. The intrinsic vulnerability results evaluate all stressors under a uniform set of assumptions and therefore can signal which stressors have more or less potential for harm independent of current stressor intensity. Potential impact results combine the intrinsic vulnerability results with AU-specific measures of current stressor intensity and produce an estimate of which stressors currently have the most potential impact in Puget Sound. Viewed alone the potential impact results can give an artificially simplified picture of stressor expression (and importance) particularly for stressors that are not widely distributed or have infrequent occurrence. For example, large spills are rare, so they rank relatively low in the potential impact results; at the same time, a large spill could have catastrophic effects in Puget Sound and they rank among the stressors with the greatest potential for harm in the intrinsic vulnerability results. When potential impact results are low and intrinsic vulnerability is high, these likely are opportunities to take action to mitigate and manage stressors that have a high potential for harm before they are fully expressed. When both potential impact and intrinsic vulnerability are low there may be opportunities to re-focus management strategies; however our analysis indicates that all stressors are important and likely require attention for at least some endpoints.

HIGHLIGHTS OF PSPA RESULTS

Stressors with Very High or High Potential Impact in Watersheds and Marine Basins and Very High or High Intrinsic Vulnerability

- A2. Conversion of land cover for natural resource production
- A3. Conversion of land cover for transportation & utilities
- U2. Non-point source, persistent toxic chemicals in aquatic systems
- X2. Non-point source conventional water pollutants

Additional Stressors with Very High or High Potential Impact

Watersheds

- A1. Conversion of land cover for residential, commercial, and industrial use
- P1. Timber harvest

Marine Basins

- C. Shoreline hardening
- D. Shading of shallow water habitat
- M1. In channel structural barriers to water, sediment, debris flows
- S1. Spread of disease and parasites to native species
- S2. Introduction, spread, or amplification of human pathogens

Additional Stressors with Very High or High Intrinsic Vulnerability

- A1. Conversion of land cover for residential, commercial, and industrial use
- U1. Point source, persistent toxic chemicals in aquatic systems
- V2. Non-point source, non-persistent toxic chemicals in aquatic systems
- W. Large spills

Stressors that Rank Significantly Higher When Averaging Is Used

Potential Impact – Watersheds

- C. Shoreline hardening
- D. Shading of shallow water habitat
- F. Barriers to terrestrial animal movement and migration

Potential Impact – Marine Basins

- A1. Conversion of land cover for residential, commercial, and industrial use

Intrinsic Vulnerability

- B. Terrestrial habitat fragmentation
- C. Shoreline hardening
- D. Shading of shallow water habitat
- E1. Dams as fish passage barriers
- E2. Culverts and other fish passage barriers
- N. Animal harvest
- Z. Changing air temperature
- BB. Sea level rise
- CC. Changing ocean condition

The PSPA produces intrinsic vulnerability and potential impact indices in two ways: by summing over stressors and endpoints and by averaging over them. Summing is used as primary method to create results because it more fully reflects both the number of endpoints that a stressor might harm and the vulnerability of each affected endpoint to that stressor. Some stressors, such as dams as fish passage barriers have high potential for harm for only a few endpoints; these stressors emerge most clearly when indices are calculated by averaging. In both the intrinsic vulnerability and the potential impact results a few stressors are identified as having very high potential for harm or high potential impact on a few endpoints.

Differences in potential impact results between geographic AUs flow from differences in current stressor intensity and endpoint presence/absence across the AU. For the most part all of the high ranking stressors are present to some extent in all of the watersheds and marine basins. Some stressors are high ranking in both watersheds and marine basins; these include many of the habitat conversion and non-point source pollution stressors. Timber harvest ranks high across watersheds in Puget Sound. Shading of shallow water habitat and shoreline hardening are high-ranking stressors in marine basins.

We believe the main utility of the PSPA results is in the index rankings, patterns, and trends rather than individual IV pair scores. Put another way: the aggregated index results reflected in the IV stressor and IV endpoint indices and the potential impact indices are likely more meaningful to decision making than any IV pair score considered in isolation. The PSPA was designed primarily to evaluate stressors at the Puget Sound scale. As the results are disaggregated into smaller and smaller pieces, decision makers should be attentive to the fact that they are seeing only a very small slice of the assessment picture.

Potential Future Investigations

The PSPA was a significant investment for the Puget Sound region and is intended to serve as the updated Puget Sound-scale pressure assessment into the future. At the same time, it also was the first attempt to carry out an evaluation using this methodology in Puget Sound and it does leave room to consider future studies, a number of which are described below.

Future Investigations Related to Intrinsic Vulnerability

Explore variation among experts and provide opportunities to refine expert ratings. Stressor-endpoint pairs for which there was the greatest (and least) variation in individual expert ratings were identified and are indicated in Appendix A. Pairs where there is greater variation in individual expert ratings may point to areas where experts relied on different information, have a fundamentally different view of the stressor-endpoint relationship, or where assessment assumptions and instructions were interpreted differently. Future work should explore and attempt to resolve the sources of expert disagreement, and provide experts an opportunity to adjust scores, if warranted. It also could refine expert coverage to ensure each expert has a manageable assessment size and that the most appropriate experts rate each stressor-endpoint pair. Stressor-endpoint pairs with both high inter-expert variation and high uncertainty could prove the most fruitful for further analysis; however this work need not be limited in that way. If experts were to meet by domain, endpoint, or even stressor expertise and discuss the basis for their ratings it is possible that it might reveal qualitative differences between approaches to rating, assumptions used, or simply thinking about the meaning of a “severe” functional impact rating. This type of conversation might lead some experts to refine their ratings and, over time, may improve confidence in the PSPA results and result quality.

Explore opportunities to expand expert coverage. Several limiting factors for expert coverage were identified throughout the course of the assessment. As mentioned previously, expert participation in the PSPA was confined to a relatively short timeframe which precluded participation by some experts due to other commitments. Some experts approached for participation noted that the time needed to adequately provide judgment would require an extensive non-reimbursable commitment. A related issue was feedback on the number of stressor-endpoint pairs assigned to experts; several experts said they were overwhelmed with the number of assigned pairs. This resulted in a number of stressor-endpoint pairs for which we had to use placeholder values and a larger number of stressor-endpoint pairs where we are relying on a single expert rating. As discussed in the main PSPA report, we are not troubled by reliance on a single expert rating, provided the expert that participated was very knowledgeable; however, over time it may be beneficial to expand expert coverage to eliminate placeholder values and as a way to expand the involvement and—ideally—the convergence and support of the scientific community around the PSPA results.

Comprehensive review and update of the expert elicitation. This entire PSPA elicitation of the intrinsic vulnerability results—from model synthesis, to creation of the online elicitation interface, to identification and orientation of experts, to gathering of expert judgments—took place over only a matter of months. Experts had access to the online interface from January 2014 to mid-May 2014; however the vast majority of expert rankings were gathered during a three-week period in January. Few experts revisited or added to their rankings after that. The expert community in Puget Sound was simultaneously learning the pressure assessment method and model, understanding the stressors and endpoints delineated, and providing expert judgments. Experts had questions about the assessment method and suggested revisions and clarifications to the assessment interface, definitions, assumptions, and instructions. Some of these could be implemented during the assessment process and others were not. Comments from experts during and after the elicitation indicate that the various factor rating categories may have been difficult to understand or may have been interpreted differently by different experts. Moving forward, input and lessons from this first elicitation effort could be used to create a refined assessment process and better engage more experts. This could be done for certain priority areas (by domain or another grouping) and alone or in concert with other work, such as expanding the geographic coverage of the assessment as discussed below. Any future evaluation also should address other potential barriers to expert participation including "expert fatigue" brought on by multiple requests for participation in Puget Sound recovery-related studies over the past five years as the Puget Sound recovery plan and indicators were developed and the difficulties associated with volunteer (versus paid) experts. One option might be to leverage an existing gathering of expertise, such as the Salish Sea Ecosystem Conference, to facilitate and encourage expert participation in future studies.

Future Investigations Related to Potential Impact

Additional geospatial analysis and exploration. The PSPA implementation work undertaken here was originally scoped to contain no geospatial analysis. Geospatial analysis was added about half way through the project and was carried out quickly to serve project schedule needs. There is ample opportunity for more extensive exploration of geospatial data to characterize stressors, including the potential to create networked assessments that account for inter-relationships among pressures and use additional information to more fully characterize stressor strength as well as stressor amount. There also is the potential to combine spatial information on stressors with spatial information on endpoints to create more robust estimates of the potential for stressor-endpoint interactions to occur in the real world. This work likely could be carried out in a way that both provides information to update the potential impact indices and further supports finer-scale sub-regional assessments.

Scenario-based analysis for additional stressors. The climate stressors were evaluated under two scenarios: current expression and a predicted future expression. Similar analysis could be conducted for other stressors that may change in intensity over time, such as habitat conversion. These analyses could then inform consideration of which stressors may have the most potential impact in the future, which could color current stressor management strategies and priorities. The habitat conversion stressors and stressors related to land cover (e.g., flow stressors, non-point source pollution stressors) particularly lend themselves to these scenario-based analyses.

Consider alternative or expanded models for calculating potential impact. One of the limitations of the PSPA, like other assessments of its kind, is that it does not consider pressure networks or synergistic (or antagonistic) interactions when multiple stressors act on the same endpoint; another is that it does not explicitly consider differences in the current condition of endpoints. The current approach calculates the AU-scale stressor PI index as the sum of the AU scale AV pair scores for each endpoint the stressor affects, and calculates endpoint PI index as the sum of the AU scale AV pair scores for all stressors that act on an endpoint. Similarly, the Puget Sound-scale results are calculated as a simple average of the AU-scale results for stressors, and the sum of AU-scale potential impacts for endpoints. Other ways of creating the indices could and should be explored. Three potential modifications are:

- *Consider alternative ways of combining adjusted vulnerability scores*, including weighted sums or other combinations that better reflect pressure networks and the cumulative effects of multiple stressors, and an area-weighted average to combine across assessment units.
- *Create a combined potential impact index covering both watersheds and marine basins*. The PSPA presents the Puget Sound scale results for watersheds and marine basins separately. While the results can be looked at next to each other to facilitate comparison and to help identify stressors with high potential impact in both types of assessment units, the results are not combined. This flows from how the work to evaluate stressor intensity was done in the upland portions of marine basins, and the complications associated with endpoints that are present in both types of assessment units. In many cases, stressor intensity in the upland portions of marine basins was estimated using the same spatial information that was used to estimate stressor intensity in watersheds. If the watershed and marine basin results are combined there is danger of "double counting" this stressor intensity, especially for endpoints which were assessed in both the freshwater and marine-nearshore domains. This challenge likely could be solved mathematically; however, it was beyond the scope of this effort.
- *Build an endpoint condition sub-model and use it to further modify the IV pair scores.* The potential impact results are created by adjusting IV pair scores by a value for stressor intensity in each AU. Because the IV pair scores were developed under the assumptions that a stressor is acting directly on an endpoint, stressor expression is strong, and management is not mitigating stressor-endpoint interactions, the stressor intensity factors serve, essentially, to "discount" vulnerability in AUs where stressor expression is not strong. There is no similar adjustment made to attempt to account for endpoint condition in AUs. Endpoint condition (e.g., intact, impaired, threatened, etc.) likely influences the sensitivity of an endpoint to a stressor, making some endpoints more or less sensitive due to their condition, and accounting for it would improve assessment results.

Future Investigations Related to the Scope of the Assessment

Use the assessment methodology to carry out finer-scale geographic assessments. Finer-scale geographic assessments could be carried out for priority areas or for priority stressors and endpoints. This would necessitate the identification and development of finer-scaled AUs that seamlessly span the freshwater, marine-nearshore, and terrestrial domains, which is a significant endeavor in and of itself. Nevertheless, the development of such an AU network would provide a means for a more thorough examination of the finer-scale variations and stratifications inherent in the distribution of endpoints and stressors.

Expand the assessment to cover the entire Salish Sea. The Puget Sound pressure assessment scope was limited to the Puget Sound; however, we seek to manage Puget Sound in concert with the broader Salish Sea. Expanding the pressure assessment to cover the full ecosystem would bring in additional expertise, build and reinforce collegiality and understanding in scientific disciplines, and equip managers in the U.S. and Canada with consistent, mutually supporting information.

Refine endpoints and stressor lists and stressor-endpoint pairs. The PSPA asked experts to evaluate direct effects of stressors on endpoints. In delineating stressor-endpoint pairs for evaluation we sought to err on the side of inclusion and rely on expert advice to eliminate pairs that are not important. We received a variety of comments from experts on stressor-endpoint pairs—some in the form of “opt outs” or suggestions to remove a pair from the assessment, some in the form of “non-ranking” where the pair was simply skipped with no feedback, and some in the form of a zero rating. This information could be reviewed more closely and conversations with experts could further review both the stressor and endpoint lists and the stressor-endpoint pairs. This type of work could be combined with evaluations of pressure/stressor networks (described above), incorporated into either a finer-scale geographic assessment or an expansion to the Salish Sea, and would be also be incorporated into any update and reassessment of intrinsic vulnerability.

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