Ranking injurious effects of humans on Puget Sound:

A non-technical summary of the 2014 Puget Sound Pressures Assessment

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A recovery strategy fashioned on expert opinion

In 2007 Gov. Gregoire challenged residents of the region to make Puget Sound "fishable, diggable, and swimmable" again, and charged recovery practitioners to define a "science-based, unified, and prioritized" recovery plan for the ecosystem. After 150 years of environmental decline on many fronts, planning the recovery of such a large and complex region could not be completed in a single step. There was no ready-made list of the most damaging effects, no obvious way to prioritize recovery targets, and no wholly objective way to order the actions needed to achieve them. The best, indeed only way to make and rank such lists is to assemble, as systematically as possible, the informed opinions of experts.

This 'expert elicitation' approach has been used in different ways to, for example, list and rate the human actions that are injurious to the Puget Sound ecosystem, identify suitable recovery targets and prioritize the actions needed to achieve them, and design the research needed to fill gaps in understanding about ecosystem processes— gaps that raise uncertainty and hinder progress (see refs. 1-3). Such lists are not fixed for the rest of time. They must be amended as knowledge is gained, methods improve, progress is made, and priorities change. The latest addition to this set arises from a second assessment of the pressures wrought by humans on the Puget Sound ecosystem. The ensuing report, produced with funding from the EPA, is entitled *The 2014 Puget Sound Pressures Assessment* (see ref. 4). This article summarizes the goals, methods, and results of the assessment, as well as some implications for Puget Sound recovery.

Box 1. A primer of recovery parlance

Human actions that are injurious to the ecosystem are called 'pressures' (for example, conversion of natural habitat to residential, commercial, and industrial uses). The direct effects of these actions, the means by which they exact change on the ecosystem, are called 'stressors' (for example, habitat conversion due to development; to forestall confusion, it is noted here that despite the title of the document, the assessment was done on stressors, not pressures). 'Endpoints' are key ecosystem components – species and habitats – that are impacted by stressors (for example, Chinook salmon, small high-gradient streams, and urban open space). They qualify by being especially valued, those that are being managed or recovered. Finally, the geographical areas within which the assessment applies are called 'assessment units'. In this case, the assessment was conducted at two geographic levels: within the entire Puget Sound region, and within each of 16 separate watersheds and 7 marine basins that together comprise the whole.

Goals

Simply conceived, the assessment had dual goals. The first was to list human actions that are injurious to the ecosystem ('stressors'; see the primer of recovery parlance in Box 1), and rank them by their capacity to cause harm. The second was to list the most valued components of the ecosystem – key species and habitats, or 'endpoints' – and rank them by their relative vulnerability to be harmed.

How the assessment was done

Careful selection attempted to ensure that the three major ecosystem domains – freshwater, marine-nearshore, and terrestrial – were represented by both stressors and endpoints. When selection was completed, a total of 47 stressors and 60 endpoints had made the cut. This gave a large number of potential stressor-endpoint pairs (47 x 60 = 2,820) for which the effects of each of the former on each of the latter were to be assessed. Because all endpoints are not affected by all stressors – for instance, *headwater wetlands* are not much affected by *sea level rise* – this number was reduced to 1,372 pairs having plausible interactions. Experts were asked to only rate stressor-endpoint pairs about which they had confidence in forming an opinion, and to consider only *direct* effects of the stressor on the endpoint. Finally, for each pair, they were asked to rate three factors relating to these effects: 1) **functional impact**, the magnitude of change in condition of an endpoint when exposed to a stressor at high intensity; 2) the **time** it would take for an endpoint to recover after exposure to a stressor; and 3) the **resistance** of an endpoint, its capacity to stay the same after exposure to a stressor, a measure of its sensitivity. Rather than select a single rating category from a range of options for each factor, experts indicated their degree of confidence in ratings by expressing each opinion as a probability distribution across all categories. For example, a hypothetical rating by expert *x* for recovery time of endpoint *y* when exposed to stressor *z* might look like the probabilities listed at right. In this example the expert thought the most likely response time was over a period years, possibly longer, and was less likely to be shorter. This novel rating approach allowed uncertainty to directly influence results (the theory underpinning this analytical approach is summarized in ref. 6).

Rating Category for Recovery Time	Expert Rating
No Impact	0.00
Months	0.15
Years	0.50
Decades	0.35
Centuries	0.00
Irreversible	0.00

For a few stressor-endpoint pairs, no expert could be found to make an assessment, but in the end, 60 experts rated 1,087 stressor-endpoint pairs (by comparison, in the 2009 assessment, a few experts rated 26 pressure classes and 11 endpoints; 1). Most pairs (61%) were rated by more than one expert, and for these the mean rating was calculated to yield final IV scores.

Results: a plurality of rankings

The PSPA produces two primary quantities relating to the vulnerability of endpoints and the influence of stressors, called Intrinsic Vulnerability and Potential Impact.

Intrinsic Vulnerability (IV)

Intrinsic Vulnerability estimates how much a given stressor affects a specific endpoint under limiting assumptions: that the stressor is acting directly on the endpoint, that stressor expression is strong, and that management efforts are not affecting the stressor-endpoint interaction. Results can be presented as a rectangular table, with stressors listed down the left hand side, endpoints arrayed across the top, and the body of the table filled with IV scores for each stressor-endpoint pair that has been assessed.

An index of the overall impact of each stressor was derived as the sum of IV scores in each row of the table, a function how many endpoints each stressor affects, and how severely. Likewise, an index of endpoint vulnerabilities was derived as the sum of IV scores in each column, a function of the number of stressors affecting each endpoint, and how severely. Sorting these indices into descending order yielded rankings of stressors by their potential to harm, and endpoints by their vulnerability to be harmed.

Among the most vulnerable endpoints (highest IV scores) were *cutthroat trout*, various *salmon species*, *eelgrass*, and *lotic freshwater vertebrate communities*. Among the least vulnerable were *killer whales*, *alpine plant communities*, and both *managed and unmanaged forests*. A similar sorting of stressor indices revealed that *conversion of land cover for development* (residential, commercial, transportation and utilities), *large oil spills*, *sources of pollution* and *toxic chemicals in aquatic systems*, *shoreline hardening*, *altered stream flows from climate change*, and *terrestrial habitat fragmentation* were among the stressors with the most potential for harm. Among the the stressors with least potential for harm were *species disturbance in marine, terrestrial and freshwater environments*, *bycatch*, *air pollution*, *changing precipitation amounts and patterns*, *dams as fish passage barriers*, *barriers to terrestrial animal movement including migration culverts* and *other fish passage barriers*.

In interpreting these results, it is important to remember that IV scores reflect only *direct* effects of stressors on endpoints. Thus killer whales emerged with a relatively low score, but their prey, salmon, had consistently high scores. Restoring salmon stocks should greatly improve prospects of killer whales.

Potential Impact (PI)

As the term intrinsic vulnerability (IV) implies, these results rank stressors and endpoints in the abstract, free of geographical or any other context. In reality, however, endpoint distributions and stressor intensities vary greatly across Puget Sound. It is for this reason that recovery strategies change locally across the region – for example, salmon recovery plans differ among major watersheds. To capture this local variation, IV scores for each stressor-endpoint pair were modified to yield a 'Potential Impact' (PI) score within *each* of the 16 major watersheds and 7 marine basins that together comprise the Puget Sound ecosystem (Figure 1). PI scores were derived by multiplying IV scores by 1 or 0, depending on whether a given endpoint was present or absent (respectively) in each assessment unit. This product was in turn multiplied by an estimate of 'stressor intensity' in each assessment unit, measured, where possible, from mapped (GIS) data. PI scores were averaged across endpoints, and across stressors, to yield indices of Potential Impact within each assessment unit. These assessment unit scale results were further aggregated to produce a Puget Sound scale view.

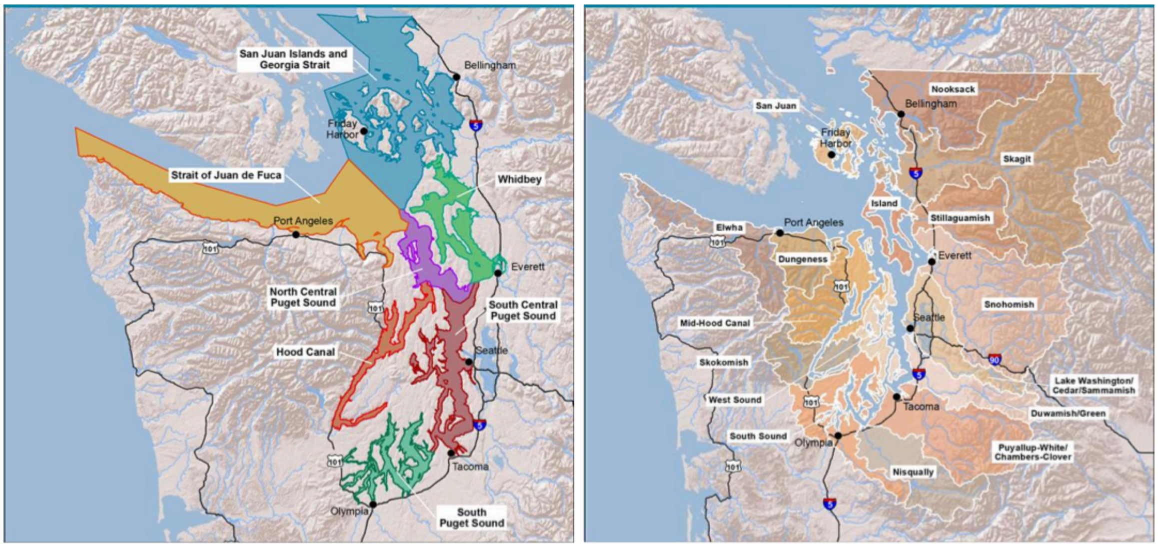

Figure 1. The 7 marine basins (left) and 16 watersheds (right) in which Potential Impacts were assessed. (Fig. 3 in ref. 4).

For watersheds in Puget Sound, among the stressors with the most potential for harm were: *conversion of land cover* for all uses, *non-point source pollutants in aquatic systems*, *timber harvest*, *shoreline hardening*, and *terrestrial habitat fragmentation*. For marine basins, they were: *conversion of land cover for transportation & utilities and natural resource production, non-point source, persistent toxic chemicals in aquatic systems*, *shading of shallow water habitat*, *shoreline hardening*, *spread of disease and parasites to native species*, and *introduction, spread, or amplification of human pathogens*.

Among the most potentially impacted endpoints, were, for freshwater habitats: *cutthroat trout*, *coho* and *chinook* salmon, *lotic freshwater vertebrate and invertebrate communities*, and *riparian vegetation*. For marine and nearshore habitats they were *eelgrass* and *kelp*, *chum* and *pink salmon*, *marine sessile filter feeders*, *rockfish* (adult), *embayments*, and *beaches*.

Rating the Pressures Assessment

This is by necessity a superficial summary of what was an intricate, exhaustive, in many ways novel, and ultimately successful attempt to rate and rank stressors and endpoints in Puget Sound. Those hoping for a single ranking of stressors (or endpoints) that could be applied universally across the region will be disappointed. Given the size and diversity of Puget Sound, theirs was a naïve hope in any case. In its final manifestation, several rankings emerged from the assessment, each with its own meaning and significance. For example, in addition to the two rankings mentioned above (IV and PI), there were different ways of calculating IV indices (mean vs. sum), and different ways of gauging overall stressor impact. This plurality of outputs is the reason that no 'definitive' ranking is included here, making an important point: anyone interested in applying the results should first read and understand the nuances of the main report (see ref. 4), the logic described in the appendices (see ref. 5), and how the various outputs are intended to be applied (they will be rewarded – these docs are well written).

Some might ask how good can an assessment be that is based on tens of thousands of 'guesses'? They might further wonder what can scores derived from these guesses, scores that are accurate to two or more significant figures, actually mean? The respective answers are 'quite good', and 'quite a lot', for several reasons. First, these were *informed* guesses by professionals, many of whom have spent most of their careers on one or a few related topics. Imagine how much better this outcome was than, say, one in which the same stressor-endpoint pairs had been assigned *at random* to the same pool of experts for assessment, or indeed to the same number of randomly chosen non-specialists. Second, the authors took pains to assess and account subjective uncertainty, and performed sensitivity analyses that together boost confidence that results are meaningful. They caution that similar IV (or PI) indices probably do not distinguish stressors (or endpoints), but that widely disparate scores probably do. Finally, the results do seem intuitively plausible. For example, the fact that some stressors (e.g. *conversion of land cover for development*) scored highly in rankings derived in different ways, or for different habitats, does enhance confidence that these are among the most injurious (e.g. Figure 2). Similarly, by choosing to tackle say the 'top 10' stressors and endpoints on any ranked list, the chance is good that the most important are among them. Even so, it is worth repeating that, to apply the results effectively, one must grasp the complexities of this assessment, rather than take any single ranking at face value.

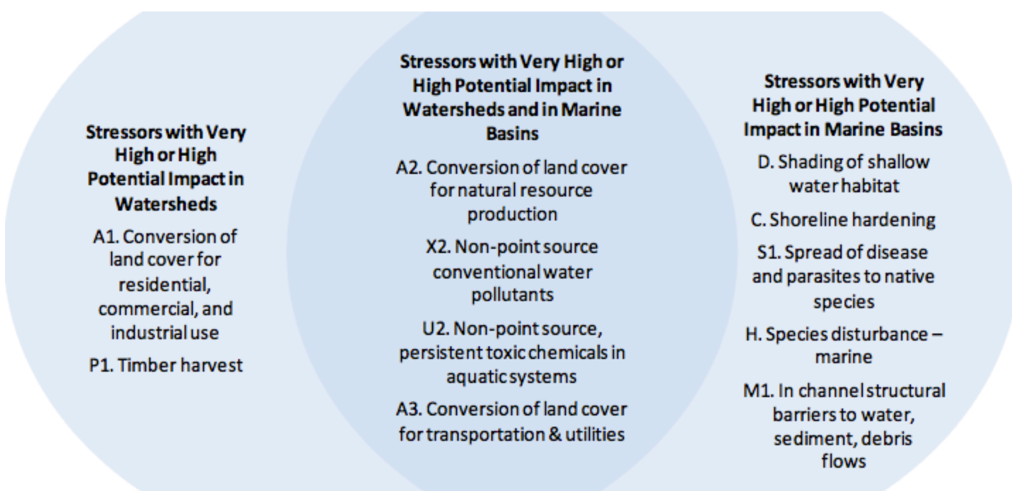

Figure 2. Stressors with *Very High* or *High* Potential Impact within many Assessment Units (Fig. 11 in ref. 4).

How is this assessment expected to make a difference?

The stated purpose of the PSPA is to help members of the Puget Sound science community and decision makers better understand the potential impact and relative intensity of stressors in the Puget Sound region, and to inform decisions about recovery strategies and priorities. It was *not* intended to replace existing local pressure assessments, or those that consider finer-scale data.

However, it may complement or provide a starting point for locally focused efforts, where none currently exist. More specifically, the authors suggest how *Potential Impact* (PI) scores can be used in conjunction with *Intrinsic Vulnerability* (IV) scores to guide decisions and action in four contrasting scenarios (Fig. 3).

The PSPA is already beginning to influence recovery in several ways: PSP staff have discussed how results may be used by local implementers (LIOs), as supporting information for groups developing Implementation Strategies, in steelhead recovery planning, and in the next phases of Chinook monitoring and adaptive management (S. Redman, personal communication). Assessment results will also help sponsors prioritize decisions about recovery support.

This list of early applications is instructive in illustrating how the PSPA will make an impact: not by causing everyone to fall into lockstep with a single ranking, but by guiding many separate, independent and measured applications of results at appropriate scales. Propagation of that process over time and space will result in convergence of recovery effort and direction that would otherwise be hard to achieve.

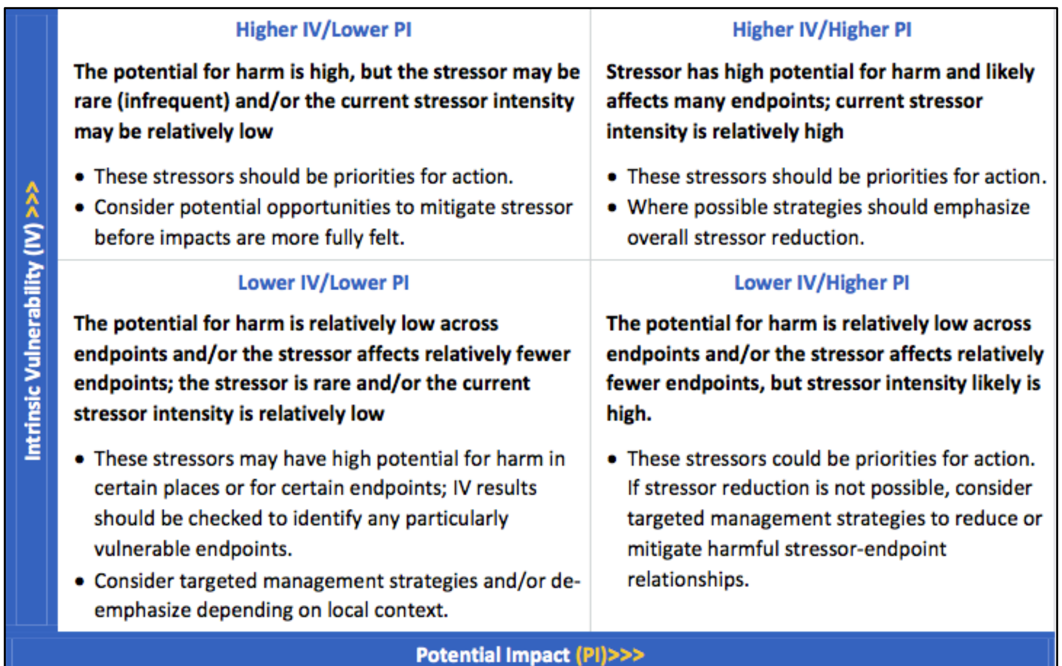

Figure 3. Suggestions as to how combinations of IV and PI scores may help to guide decision making (Fig. 13 in ref. 4).

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