PUGET SOUND MARINE AND NEARSHORE GRANT PROGRAM

ANALYSIS OF INVASIVE SPECIES, TOXICS, OIL SPILL, AND INTEGRATED RISK ASSESSMENT FINDINGS:

A REVIEW OF GRANT PROGRAM RESULTS, PART 2

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July 2016

This project has been funded in part by the United States Environmental Protection Agency under assistance agreement PC 00J29801 to Washington Department of Fish and Wildlife. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

The authors wish to thank grant contributors who reviewed and commented on a previous version of this report: Allen Pleus, Jennifer Lanksbury, Jeff Gaeckle, Todd Hass, and Toby Ross. Kris Symer provided design assistance.

KEY RESULTS AND RECOMMENDATIONS

INVASIVE SPECIES PREVENTION AND RESPONSE

1) Records of marine and estuarine non-indigenous species (NIS) introduction and spread in Puget Sound have increased over time. Vessel biofouling and ballast water are the most significant vectors.

2) Ballast water exchange regulations have reduced, but not eliminated, the discharge of NIS zooplankton into Puget Sound. Prioritization criteria have been developed to identify high-risk vessels for inspections and other management actions. Tankers from California are particularly high-risk, and exempt from federal regulations requiring ballast treatment system installation. Ballast water from the Columbia River is also categorized high-risk, but exchange is not required before entering Puget Sound under current regulations.

3) The vessel biofouling vector is not currently managed in Washington, but development of a biofouling program is underway. High-risk commercial vessels can be identified through the age of their anti-fouling coating (i.e., hull maintenance schedule) and length of recent lay-ups. Biofouling risk is compounded by a lack of effective in-water cleaning systems that prevent release of both invasive species and pollutants during operation.

4) Implementation of ballast water management criteria and development of a biofouling program is hindered by a lack of staff resources. Funding for WDFW's Aquatic Invasive Species and Ballast Water programs has declined in recent years, resulting in deferral of several high-priority activities.

TOXICS IN NEARSHORE BIOTA

1) Regional patterns of contamination in biota can be observed using transplanted mussels deployed and retrieved with the help of citizen volunteers.

2) Contaminant patterns in transplant mussels correspond to adjacent shoreline land-use. Weak positive correlations were observed between impervious surface/road area and concentrations of PAHs, PCBs, PBDEs, and DDTs in mussels. High levels of lead, copper and zinc in transplanted mussels were observed adjacent to designated urban growth areas.

3) It is difficult to demonstrate a cause and effect relationship between outfall effluent and eelgrass decline in Puget Sound. However, concentrations of copper, lead, and zinc in eelgrass tissue collected from Puget Sound are within ranges where adverse effects have been observed elsewhere.

OIL SPILL PREVENTION AND RESPONSE

1) Operation of three proposed maritime terminal developments—the Gateway bulk carrier terminal, the Trans-Mountain/Kinder Morgan pipeline expansion, and Delta Port terminal expansions—would increase the probability of an oil spill in US/Canadian trans-boundary waters. However, most of the POTENTIAL increased risk could be mitigated using a well-

designed portfolio of management measures such as speed limits, one-way traffic regimes, and a rescue tug. Some of these interventions should be considered for implementation even if none of the 3 terminal developments are constructed.

2) Restoration sites and other high-value habitats may not be included in the six Geographic Response Plans that are used to guide coordinated spill response in Puget Sound. These plans can be strengthened with input from Tribes, local jurisdictions, and community organizations. Having access and other logistical issues worked out before a spill should significantly improve the performance of defensive measures intended to protect habitat.

3) Community volunteers can be engaged in some elements of spill response, but regular investment in recurring training sessions is required. Keeping organizations and individuals engaged in maintaining volunteer response capabilities may prove to be challenging given the mismatch between the frequency of required trainings and the frequency of spill events.

PUGET SOUND PRESSURES ASSESSMENT

1) The rankings that emerged from the Puget Sound Pressures Assessment (PSPA) support a broad array of Puget Sound recovery decision and planning activities. They are informing the development of 5-year LIO recovery plans, as well as the 2016 Action Agenda update.

2) The PSPA stressor rankings for marine basins align well with the Grant Program's funding strategy. The largest Grant Program investments focused on several highly rated stressors, and for the most part follow the management priority categories described in the PSPA.

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1. BACKGROUND

The Washington Department of Fish and Wildlife (WDFW) and the Washington Department of Natural Resources (WDNR) together serve as the Marine and Nearshore Lead Organization (LO) responsible for developing and implementing a 6-year strategy for implementing priorities of the Action Agenda for Puget Sound. The Puget Sound Marine and Nearshore Grant Program ("the Grant Program") awards funds provided under the U.S. Environmental Protection Agency's (EPA) National Estuary Program for projects related to protecting and restoring marine and nearshore habitat. The Grant Program has organized their investments into five areas:

1) effective regulation and stewardship,
2) habitat restoration and protection (including capital investments),
3) addressing high priority threats,
4) cross cutting issues, and
5) adaptive management.

Since 2011, the Grant Program has funded more than 65 projects. Work on grants awarded during Rounds 1-4 of the current 6-year funding cycle has largely been completed. During Round 5, the grant program funded the Puget Sound Institute (PSI) to analyze and synthesize results of the first 4 years of awards. As part of an adaptive management strategy, the aim of this grant is to evaluate past results in order to inform and optimize outcomes at project, programmatic, and Puget Sound recovery levels. PSI is evaluating the Grant Program's portfolio of projects in groups by investment area.

The 10 grants reviewed in this report are grouped in the High Priority Threats and Cross-cutting Issues investment areas. The Grant Program's objectives for these grants were to:

> *"Prevent invasive species and oil spills from degrading Puget Sound and compromising on-going and future recovery efforts."*
>
> and
>
> *"Address threats to Puget Sound that cut across Lead Organizations to achieve synergistic results beyond the scope of the Grant Program."*

This report synthesizes the findings presented in the grant products listed in Table 1. Our analysis is **not** a comprehensive review of these issues in the Puget Sound region. We focus on the lessons learned and implications of these specific projects. The following analysis of project results is organized by the sub-strategies used in the Action Agenda.

Table 1: High Priority Threats and Cross Cutting Issues Grants (Rounds 1-4)

Grant Title	Project Partners	Product Citations
Ballast Water Management Assessment	WDFW and UW School of Aquatic and Fishery Sciences	Cordell et al. (2015)
Assessment of Biofouling Threats to Puget Sound	Portland State University and Smithsonian Environmental Research Center	Davidson et al. (2014)
Toxic Contamination Monitoring in Mussels (Mussel Watch Pilot Expansion)	WDFW	Lanksbury et al. (2012) Lanksbury et al. (2014)
Impacts of Outfalls on Eelgrass	WDNR	Gaeckle (2012) Gaeckle (2014) Gaeckle et al. (2015)
Assessing Threats from Large Oil Spills (Vessel Traffic Risk Assessment)	Puget Sound Partnership, George Washington University, and Virginia Commonwealth University	Van Dorp and Merrick (2014)
Community Engagement for Oil Spill Response and Readiness	Northwest Straits Foundation (NWSF)	NWSF (2015)
Swinomish Oil Spill Preparedness Project	Swinomish Indian Tribal Community	Swinomish Tribal Community (2014a-b)
Preparing COASST Post-Spill	UW Coastal Observation and Seabird Survey Team (COASST)	COAAST (2014)
Geographic Expansion of Seabird Survey and Early On-Scene Training	Seattle Audubon Society	Ross and Joyce (2014)
Puget Sound Integrated Risk Assessment[1]	Puget Sound Partnership (PSP)	McManus et al. (2014) Labiosa et al. (2014)

[1] This grant was part of the "adaptive management" investment area. It is included in this report for context.

2. INVASIVE SPECIES PREVENTION AND RESPONSE

This section provides analysis of results from grants awarded to address Action Agenda Sub-strategies **B5.3** (Prevent and rapidly respond to the introduction and spread of terrestrial and aquatic invasive species) and **B5.4** (Answer key invasive species research questions and fill information gaps).

Findings and recommendations provided in this section are based on key results of 2 Grant Program investments:

- "Ballast Water Management Assessment" grant (Cordell et al. 2015)
- "Assessment of Biofouling[2] Threats to Puget Sound" grant (Davidson et al. 2014)

These investigations were specifically designed to inform development of 6-year state ballast water and biofouling management plans. The Ballast Water Work Group[3] (BWWG), WDFW's Ballast Water Inspection and Compliance Program, and the Invasive Species Council are incorporating these results into ongoing policy processes.

These studies also address a "Priority Science Action" identified in the 2011-2013 Biennial Science Work Plan (*Assess risks imposed by marine invasive species*).

2.1 FINDINGS

Davidson et al. (2014) provided an overview of invertebrate and algal invasions in Puget Sound and Washington's Pacific Coast. Major findings are listed below.

- At least 74 marine and estuarine non-indigenous species (NIS) occur in Puget Sound. The authors concluded this estimate is likely low because NIS monitoring efforts in the region have been inconsistent, uneven, and non-standardized.
- Records of NIS introductions have increased over time, with 35 new detections in the past 20 years (Figure 1).
- The primary vectors (transport mechanisms) by which marine and estuarine NIS have been introduced into Puget Sound are: ballast water, vessel biofouling, and aquaculture.[4]

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[2] **Biofouling** refers to marine organisms that adhere to submerged surfaces. Biofouling species include sessile organisms, like barnacles and algae, that attach to surfaces as well as mobile species that inhabit a matrix of those sessile organisms.

[3] The BWWG advises WDFW on developing, revising, and implementing Washington's ballast water management law. It was established under Chapter 220-150-010(2) WAC.

[4] Shellfish aquaculture was historically a large contributor of NIS in the region. Changes in industry practices, and regulations for importation and transfer of organisms and equipment have greatly reduced risks associated with this vector.

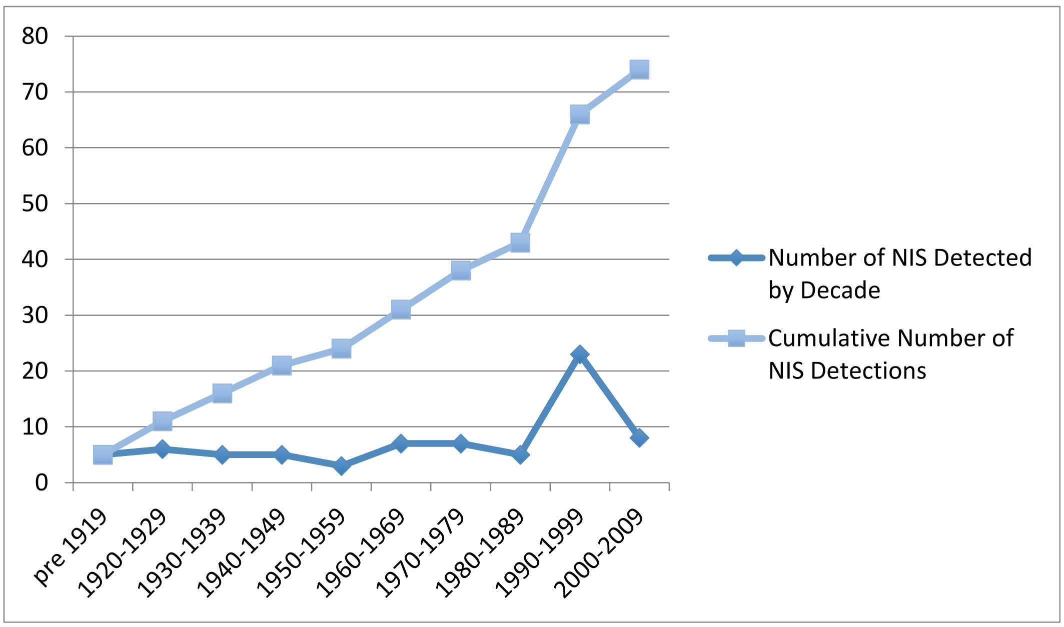
- Other potential biofouling vectors include: aquatic plant shipments, live bait, the aquarium trade, live seafood, movement of maritime infrastructure, and floating marine debris.

- Vessel biofouling has been implicated as a possible vector for the introduction of 43 NIS into Puget Sound (37 as multi-vector[5] and 7 as sole vector).

- Ballast water has been implicated as a possible vector for the introduction of 33 NIS into Puget Sound (all multi-vector).

- The lack of data on impacts of marine and estuarine NIS established in the region hampers analyses of risks associated with these species. The authors' review of the scientific literature found that impacts of only 39% of know NIS occurring in Puget Sound had been evaluated in published papers. Of the 138 papers on these species, only 13 included data collected in Washington.

Figure 1: Number of First Records for NIS in Puget Sound



2.1.1 BALLAST WATER VECTOR

Cordell et al. (2015) evaluated 13 years of ballast water samples collected from ships arriving in Seattle. They found:

[5] Multi-vector refers to those species having more than one possible vector of introduction.

- Ballast water exchange regulations[6] have reduced—but not eliminated—the discharge of NIS zooplankton into Puget Sound. The authors concluded that some vessels discharge potentially high-risk ballast water due to tank design limitations, noncompliant exchange management, or environmental factors beyond the vessel's control.

- A total of 55 non-indigenous zooplankton species were found in 816 ballast water samples collected between 2001 and 2014.

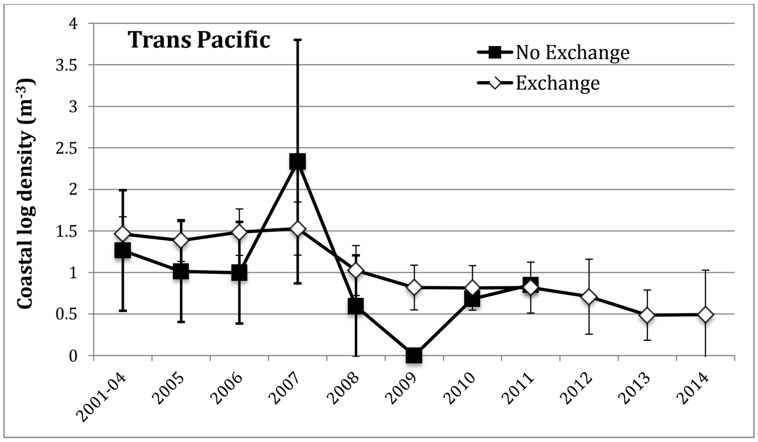
- Total estimated coastal[7] zooplankton discharged into Puget Sound declined dramatically after 2008 (Figures 2-4). The authors attribute this trend to an increase in overall ballast water management compliance resulting from WDFW's focus on ship inspections, sampling, and review of ballasting records during this time period.

- Ballast water from domestic sources had higher densities of NIS zooplankton (Figures 2-3), while those from foreign sources had higher species diversity.

- Ballast samples from California had the highest densities of species identified as high-risk NIS compared to other areas of origin.

- Tankers had the highest densities of coastal zooplankton compared to other ship types (Figure 4).

Figure 2: Coastal Zooplankton Density in Exchanged and Unexchanged Ballast from Trans-Pacific Sources (Figure 12 from Cordell et al. 2015)



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[6] Chapter 222-150 WAC requires most vessels transitioning into waters of the state to perform an open sea ballast water exchange to minimize discharge of NIS.

[7] Cordell et al. (2015) used percent composition and/or density of coastal zooplankton species (relative to oceanic zooplankton species) as a proxy for ballast water exchange efficacy.

Figure 3: Coastal Zooplankton Density in Exchanged and Unexchanged Ballast from West Coast Sources (Figure 12 from Cordell et al. 2015)

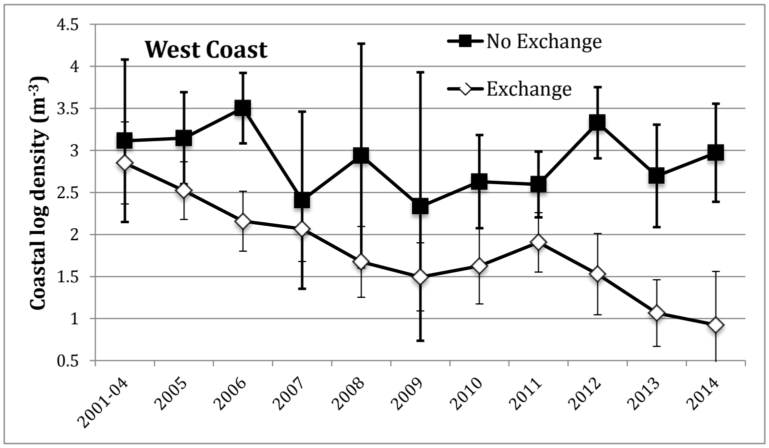
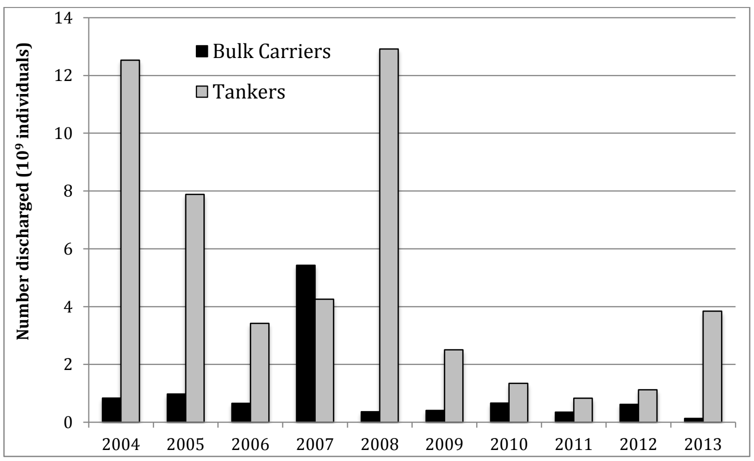


Figure 4: Estimated Total Coastal and NIS Zooplankton Propagules Discharged into Puget Sound for Two Main Ship Types (Figure 15 from Cordell et al. 2015)



MANAGEMENT OF BALLAST WATER RISKS:

- An objective of the Cordell et al. (2015) assessment was to develop recommendations for threshold(s) that could be used to determine when there is sufficient evidence for identifying high-risk vessels that should be prioritized for management action.[8] Their analysis of post-2008 sampling data revealed that ballast water samples could indeed be used as a tool to identify arrivals with poor exchange efficacy or non-compliant exchange management.

[8] WAC 220-150-035 directs WDFW to "identify, publish, and maintain a list of vessels that pose an elevated risk of discharging ballast water or sediment containing non-indigenous species into waters of the state." Vessels on this list will be prioritized for evaluation and boarding, and may require completion of an approved temporary compliance plan and/or temporary alternative strategy.

- The authors concluded that the most valuable post-arrival metrics for evaluating relative risk of NIS introduction are: (1) percent composition of coastal zooplankton species, (2) density of coastal zooplankton species, and (3) ballast age. They established risk criteria for each metric to allow WDFW to group ballast water samples into high, moderate, and low management priority levels.

- Currently, exchange is not required for ballast originating in the Columbia River because it is designated a "common waters zone." However, most of the un-exchanged Columbia River samples analyzed as part of this study would be categorized as high-risk using the prioritization scheme developed by the authors. This suggests the inclusion of Columbia River and Puget Sound in the same common water zone should be reconsidered.

2.1.2 VESSEL BIOFOULING VECTOR

Davidson et al. (2014) evaluated vessel biofouling risks and potential management measures. They found:

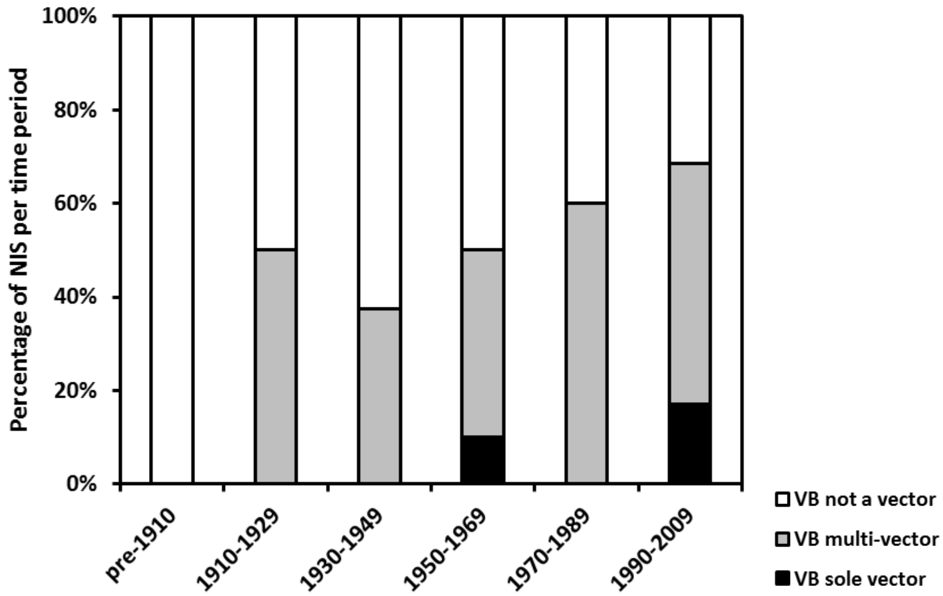
- Vessel biofouling is a potentially significant vector for NIS introduction and spread in Puget Sound.

- The proportion of NIS introductions and spread attributed to biofouling has increased over time (Figures 5 and 6).

- Vessel movement and maintenance patterns are integral to identifying and managing biofouling invasion threats. Factors that affect biofouling accumulations include: age of coatings[9] intended to reduce biofouling, vessel speed, freshwater transits, and port residence duration.

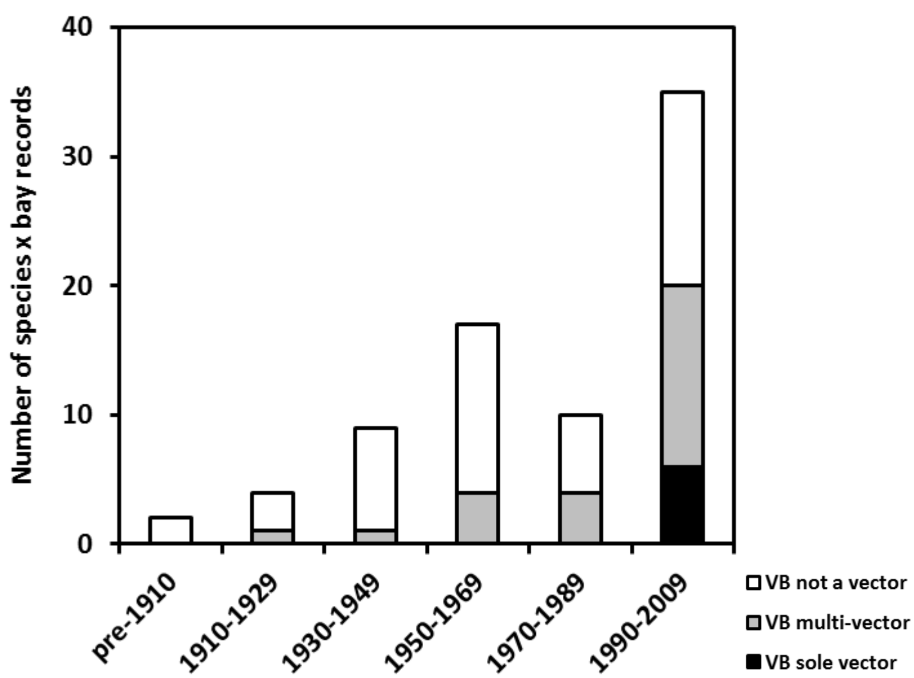
[9] There are two types of coatings applied to vessels to reduce biofouling. **"Soft" anti-fouling paints** are designed to slowly wear away, revealing a fresh layers of chemicals toxic to marine species (e.g., biocides like copper). The continual renewal of the toxic surface layer prolongs the efficacy of the coating. **"Hard" foul-release paints**, which are often silicone-based, create a smooth surface that does not allow organisms to remain on the vessel once it moves.

Figure 5: Role of Vessel Biofouling in NIS Initial Introduction (Figure 1.4 from Davidson et al. 2014)



Vector refers to a NIS transfer mechanism. **Multi-vector** NIS have more than one possible vector of introduction, while **sole** vector NIS have only one.

Figure 6: Role of Vessel Biofouling in NIS Spread (Figures 1.5 from Davidson et al. 2014)



VESSEL MOVEMENT AND MAINTENANCE DATA (FROM DAVIDSON ET AL. 2014):

- Approximately 50,000 commercial, fishing, and recreational vessels enter Puget Sound every year.

- On average, 920 commercial vessels make 3,200 arrivals to Puget Sound each year (based on U.S. Coast Guard 2008-2011 data). Review of commercial arrival data indicated that: (1) 56% of these arrivals were coastwise traffic, with the most ports of origin in British Columbia, California, and Alaska; (2) tankers generally had the longest port residence times; (3) container ships traveled faster than other ship types; and (4) 40% of lay-ups occurred in bays along the U.S. west coast.

- Review of commercial vessel maintenance data (n=404) indicated: (1) 80% of ships used biocide-based anti-fouling paint; (2) 56% of ships reported application of anti-fouling or foul-release coatings within the past 2 years; and (3) most vessels had not conducted in-water cleaning since dry-docking or delivery, though 20% did report in-water propeller polishing.

- 1,584 fishing vessels made at least 105,494 arrivals in Washington harbors between 2005-2008. A small number of fishing vessels frequently transited between Puget Sound and Grays Harbor/Willapa Bay on Washington's southwest coast, providing a means for biofouling organisms to be mixed among these areas.

Recreational vessels likely play a stronger role in secondary spread of NIS along coasts or within regions, rather than between regions, due to their limited range. The authors surveyed and/or interviewed 145 recreational boat owners and 8 fishing/other boat owners:

- 86% reported they had taken steps to reduce fouling within the past 2 years.

- 88% reported using some type of antifouling paint.

- 54% reported having cleaned their boats since last haul out. Notably, 55% of this group reported doing so in-water despite Washington's ban[10] on in-water cleaning for vessels with biocidal paints. Several of the boaters interviewed in-person acknowledged they were aware of being in violation of state regulations.

- 67% of boaters indicated they had made overnight stays at marinas other than their homeport in the past 12 months. Only 6% of these overnight stays were outside the Salish Sea (mostly southeast Alaska).

[10] Pollutants generated during in-water cleaning of hulls with copper-based coatings can cause an exceedance of the water quality standard for copper. Ecology prohibits in-water cleaning of recreational vessels with soft coatings. EPA requirements for in-water cleaning of commercial vessels ≥79 feet in length are found in the Vessel General Permit (Section 2.2.23). Operators are required to: (1) employ methods that minimize discharge of fouling organisms and antifouling hull coatings, (2) minimize release of copper from antifouling paint into the water column when they clean their vessel, and (3) not clean the hull in copper impaired waters within the first 365 days after paint application unless documented as absolutely necessary. Ship operators are also required to notify WDFW and Ecology prior to in-water cleaning of vessels covered under EPA general permits.

MANAGEMENT OF BIOFOULING RISKS (FROM DAVIDSON ET AL. 2014):

- Washington does not require vessels to remove biofouling at regularly defined intervals.[11] WDFW does not have a formal biofouling management program, but rather deals with heavily fouled vessels and in-water cleaning requests on a case-by-case basis.

- The authors suggest Ecology's prohibition of in-water cleaning of recreational vessels with soft coatings likely increases the risk of NIS spread.

- The referenced report describes policies for managing vessel biofouling that have been implemented in other regions. These include: (1) requiring antifouling coatings be in good condition and renewed before the expiration of the paint manufacturers' recommended replacement period; (2) submittal of activity logs and/or questionnaires, with inspections or treatment required if vessels are determined to be high risk; and (3) requiring vessels to remove biofouling at regular, defined intervals.

- Improperly managed in-water cleaning can increase the risk of invasion by assisting in propagule release from vessels into surrounding habitats. The authors suggest managing this risk by considering the travel history of a vessel along with proposed cleaning methods.

- The authors suggest Ecology's restrictions on in-water cleanings may be a deterrent for development and use of cleaning technologies in the region.

- In 2011, the Washington legislature passed a bill to ban the use of copper anti-fouling paints on recreational boats under 65 feet by 2020.

- Age of anti-fouling coating and time in port are the 2 most important risk factors associated with biofouling abundance and richness on commercial vessels, according to a risk factor analysis conducted by the authors.

- The authors suggested WDFW identify high-risk vessels entering Puget Sound by evaluating proxies for these factors. Their suggested triggers for management action are: (1) time since dry-docking, either 4 years or 400 days[12] and (2) lay-up periods of ≥ 10 days within the past 12 months.

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[11] In 2014, WDFW was granted authority to conduct vessel inspections, set up mandatory check stations, and issue decontamination orders (RCW Chapter 77.135.135). However, funding needed to fully implement this law has not been provided to WDFW.

[12] The typical recommended life span of antifouling paints is 3-5 years. However, literature indicates biofouling accumulations increase substantially ~400 days after paint application. The authors attribute this discrepancy to the likely effect of niche areas (non-hull submerged areas like rudders, propellers, and thrusters) as biofouling hotspots. Under normal conditions, coatings probably work well on relatively homogeneous hull surfaces after 400 days but organisms begin to accumulate in niche areas after this time.

- The authors recommend Washington develop a biofouling policy using an advisory group process to ensure rulemaking decisions consider the best available science, feasibility and economic considerations, and implementation information.

2.2 IMPLICATIONS

Davidson et al. (2014) conclude that the lack of management of the biofouling vector in Washington may undermine the impact of ongoing ballast water management efforts. This conclusion is supported in the literature. Williams et al. (2013) argued that management of ballast water is not sufficient to prevent future invasions; they also identified biofouling of all vessel types as a high priority for management action.

WDFW can apply the risk criteria developed as part of these 2 grants to prioritize inspections and other management actions. The Cordell et al. (2015) sample prioritization criteria are not currently being applied as part of daily inspection operations conducted by WDFW's Ballast Water Program, though the intent is to move the program in that direction (A. Newsom, WDFW Ballast Water Specialist, personal communication, October 2015). This is because the ballast water program does not currently have the budget for sample analysis or management oversight (A. Pleus, WDFW Aquatic Invasive Species and Ballast Water Unit Lead, personal communication, October 2015).

2.3 RECOMMENDATIONS

1) Incorporate prioritization thresholds and other management recommendations from Cordell et al. (2014) and Davidson et al. (2014) into the 6-year strategic plans currently under development for the state's ballast water program and a new biofouling management program.[13] In the interim:

    - Prioritize inspections of tankers from California, which appear to pose particularly high risk for NIS introductions via the ballast and biofouling vectors. Notably, crude oil tankers engaged in coastwise trade are exempt[14] from federal regulations requiring ballast treatment system installation by 2021.

    - Determine whether changes to the state's Common Water Zone area are warranted.

    - Continue to collect ballast water samples.

2) Collaborate with Ecology to identify biofouling management measures that balance the risks associated with invasive species and the risks associated with introduction of toxins into the marine environment. The Puget Sound Pressures Assessment (McManus et al. 2014) described in Section 6 could be a useful tool for this type of assessment. The "Potential Impact" of

[13] This work is being funded through a Round 5 grant awarded to WDFW's Aquatic Invasive Species and Ballast Water Unit in December 2015.

[14] 33 CFR Part 151 Subpart D §151.2015(b)(1)

stressors involving toxic chemicals was ranked higher than stressors associated with non-native species.

3) Consider the Puget Sound Ecosystem Monitoring Program (PSEMP) as a venue to coordinate NIS research and monitoring efforts.

   - Cordell et al. (2014) recommend more ambient zooplankton research and monitoring to establish a baseline for detecting future invasions. The invasive Asian copepod Oithona davisae was of particular concern for them. The PSEMP Forage Fish and Food Webs Workgroup could help foster collaboration between NIS investigators and researchers involved with ongoing and recommended future zooplankton sampling and time series analysis being conducted as part of the Salish Sea Marine Survival Project.

   - PSEMP could also play a role in reviewing existing monitoring efforts, compiling data, and providing recommendations on research and monitoring needs for WDFW programs.

4) Communicate Aquatic Invasive Species Program funding needs to executive-level managers through the Ecosystem Coordination Board. Funding for the program has declined in recent years, resulting in deferral of several high-priority activities (WDFW and Washington State Patrol 2015). Crucial program components are being funded through grants. This lack of budget consistency is likely to make development of a new marine biofouling management program a challenge.

5) Update National Exotic Marine and Estuarine Species Information System (NEMESIS) records with distribution information provided in Cordell et al. (2015) regarding copepod species that have become established in Puget Sound. The Davidson et al. (2014) species list was obtained through a query of the NEMESIS database and we noted two missing species: *Labidocera jollae* and *Oithona davisae*.

3. TOXICS IN NEARSHORE BIOTA

This section provides analysis of results related to Action Agenda Sub-strategy **C1.1** (*Implement and strengthen authorities and programs to prevent toxic chemicals from entering the Puget Sound environment*).

Findings and recommendations provided in this section are based on key results of 2 Grant Program investments:

- "Toxic Contamination Monitoring in Mussels" grant (Lanksbury et al. 2014)
- "Impacts of Outfalls on Eelgrass" grant (Gaeckle 2012, Gaeckle 2014, and Gaeckle et al. 2015)

These investigations address top priorities for 2 PSEMP Workgroups (Toxics and Stormwater), as well as a "Priority Science Action" identified in the 2011-2013 Biennial Science Work Plan (*Develop integrated monitoring and assessment of toxic chemical sources, exposure, and effects*).

3.1 FINDINGS

3.1.1 TOXIC CONTAMINATION IN MUSSELS

Blue mussels (*Mytilus* spp.) are effective indicators of nearshore water and sediment quality, and have been used for decades to track contaminant levels in many areas across the United States (Lanksbury and West 2011). Since 1986, the National Oceanographic and Atmospheric Administration's (NOAA) "Mussel Watch" Program has tracked status and trends in environmental quality by measuring contaminant levels in bivalve tissue.

Lanksbury et al. (2014) piloted a large-scale synoptic survey of contaminant levels in Puget Sound mussels during winter 2012-2013. With the help of citizen volunteers, native mussels (*Mytilus trossulus*) spawned and reared in an aquaculture facility were transplanted to 108 locations[15] and collected about 2 months later. Concentrations of several major contaminant classes were measured in the mussel tissue. Contaminant patterns were then compared with adjacent shoreline land-use metrics.

This project differs from other existing mussel monitoring programs in Puget Sound (Table 2) in a few important ways:

- A much larger number of sites were sampled—77% to 95% more than in other studies (Figure 7).
- Transplanted mussels were used instead of wild mussels. This change reduced the potential effects of other factors (e.g. mussel species, size, age, and condition) on contaminant burdens.
- Sample sites were located adjacent to a wide range of land-use types (undeveloped, rural, agricultural, urban, and industrial). NOAA's Mussel Watch program was designed to represent average conditions away from contaminant hotspots.

Using data from this intensive survey effort, the authors investigated relationships between concentrations of a suite of contaminants in mussel tissues, and metrics of urbanization.

- Contaminant classes
  - polycyclic aromatic hydrocarbon (PAHs)
  - polychlorinated biphenyls (PCBs)
  - polybrominated diphenyl ethers (PBDEs)
  - dichlorodiphenyl-trichloroethane (DDTs)

[15] Sixty sites were funded by the Grant Program. Outside partners sponsored an additional 48 sites in Admiralty Inlet, the San Juan Islands, and Hood Canal. Wherever possible, sites were located in areas where eelgrass, forage fish, or shellfish beds were present; areas with a history of contaminant monitoring; and areas with a need for Natural Resource Damage Assessment (NRDA) baseline data.

- Proxies for land-use in adjacent watershed catchment areas
    - percent impervious surface
    - percent road area
    - within/outside designated Urban Growth Areas (UGAs)
- Biological endpoints
    - mortality
    - growth (mm/day)
    - condition index (dry weight of soft tissue/shell length x 100)

Results (Table 3 and Table 5) provide data on the current geographic extent and magnitude of contamination in nearshore environments, and offer insight into how contamination in nearshore biota may be related to upland land-use patterns.

- The highest concentrations of organic contaminants were observed in the most urbanized embayments, particularly Elliott Bay, Salmon Bay, Commencement Bay, and Sinclair Inlet.
- Statistically significant but weak positive correlations were observed between impervious surface/road area and concentrations of PAHs, PCBs, PBDEs, and DDTs in mussel tissues.
- Levels of lead, copper and zinc in transplanted mussels were significantly higher adjacent to designated urban growth areas (UGA), but this relationship was not as strong as it was for organic contaminants. There were no significant relationships between mercury, arsenic, or cadmium concentrations in mussel tissues and UGA designation.
- PAH concentrations were also elevated in mussels from some non-urban shorelines where they may have been exposed via marinas, ferry terminals, roadways, or other point sources.
- The authors had success inferring sources of PAHs to the nearshore using “fingerprints” characteristic of certain inputs (unburned petroleum or combustion sources). This technique holds promise for future source identification efforts.

Lanksbury et al. (2014) compared their contaminant concentration results with data from NOAA’s Mussel Watch Program. They found general patterns of contaminant distribution in Puget Sound were similar between the two datasets, but in some cases contaminant concentrations differed substantially. Both projects measured contaminants in mussel tissue collected from sites in Elliott Bay (Four-Mile Rock and Myrtle Edwards). PAH concentrations in the wild mussels sampled by NOAA were *ten-fold higher* than concentrations in transplanted mussels from this study. The authors attribute this to differences in study methods (e.g., wild vs. transplant, tidal height sampled, proximity to substrate, and different analytical labs). They caution against direct comparisons between their results and results of other regional mussel monitoring efforts (Table 2).

Table 2: Comparison of Puget Sound Mussel Monitoring Efforts

Program	# of Sites	Location of Sites	Contaminants Measured	Time Frame	Mussel Type
WDFW Toxic Contaminant Monitoring in Mussels (Subject of present analysis)	108	Throughout Puget Sound, across a wide range of upland land uses	PAHs, PCBs, and PBDEs; 8 chlorinated pesticides; 6 metals	2012-2013	transplant
NOAA Mussel Watch	14	Throughout Puget Sound, but away from industrial areas	More than 140 compounds, including 17 metals, PAHs, PCBs, and pesticides	1986-present (biennial)	wild
Department of Ecology Pesticide Monitoring Program	5	Padilla Bay, West Duwamish Waterway, Hylebos Waterway, Chamber Creek, Lower Budd Inlet	43 pesticides/breakdown products and PCBs	1995	wild
Snohomish Marine Resources Committee	9	Snohomish County	More than 140 compounds, including 17 metals, PAHs, PCBs, and pesticides	2007-present	wild
ENVEST Partnership (Navy, EPA, and Department of Ecology)	24	Sinclair Inlet, Dyes Inlet, Port Orchard Passage, Rich Passage, Agate Passage, Keyport, Liberty Bay	Metals, PAHs, and PCBs	2009-2011	wild
Mussel Watch Gradient Project (Tacoma-Pierce County Health Department)	18[16]	Hylebos Waterway, Ruston Waterfront	PAHs, PCBs, and PBDEs; 8 chlorinated pesticides; 6 metals	2012-2013	transplant

[16] The Mussel Watch Gradient Project (Hanowell et al. 2014) was a companion study to Lanksbury et al. (2014). These 18 sites are included in the the Mussel Watch Expansion Project's 108 sites. However, since the mussel cages were deployed at a higher density than the rest of the study sites, data were averaged within the study areas and assigned to a central point along each of the two 9-cage distributions.

Figure 7: Mussel Monitoring Sites in Puget Sound

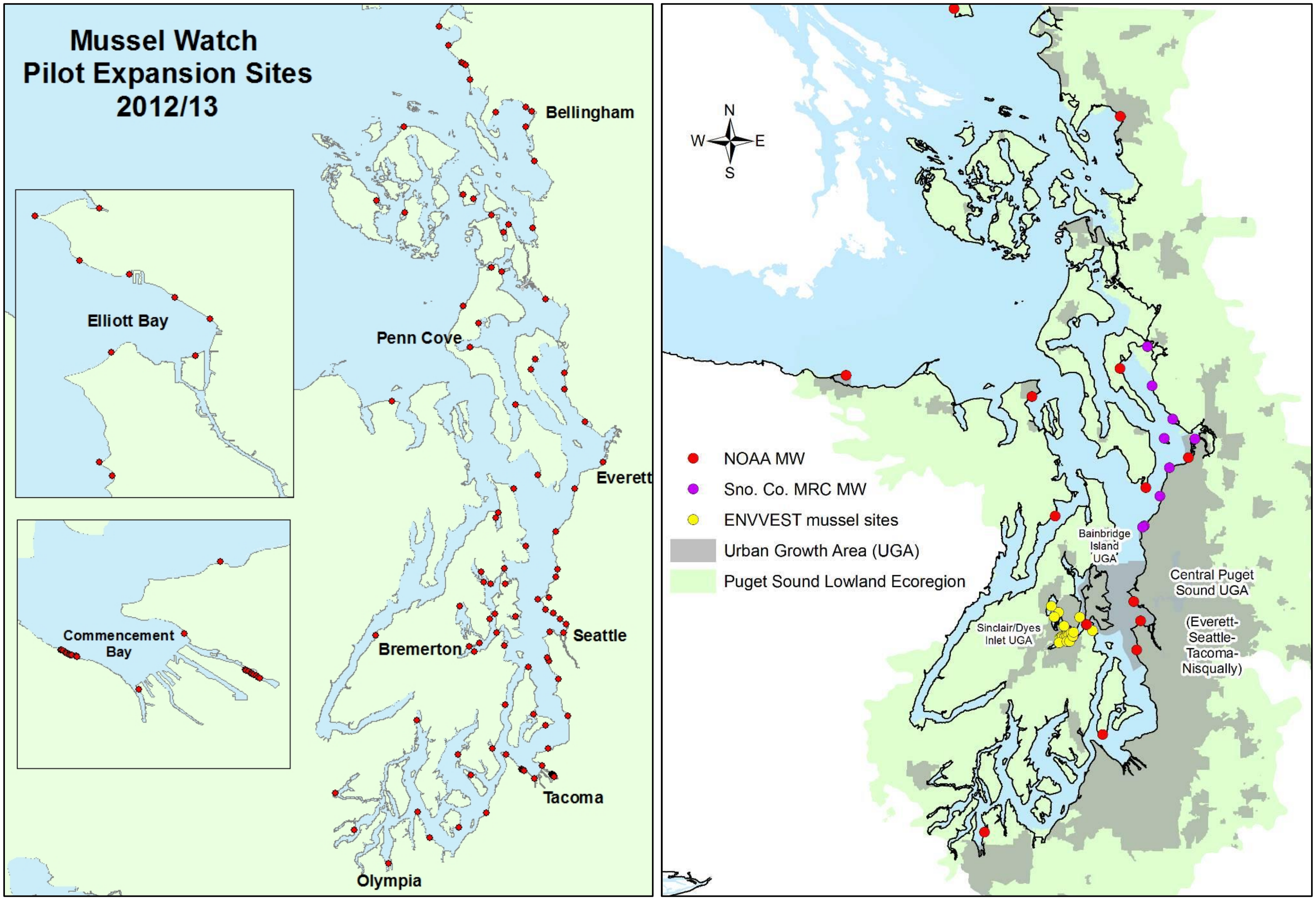

Table 3: Mussel Contaminant Concentration Results from Lanksbury et al. (2014)

	Mean concentration at Penn Cove (baseline)	Concentration range at transplant sites	Mean concentration within UGAs	Mean concentration outside UGAs
Σ_{42}PAHs	71.4 (±20.4)	29 – 5030 (ng/g dry weight)	857 (±1065.7) *	285 (±277.6)
total PCBs	19.3 (±6.8)	4.1 – 216 (ng/g dry weight)	60.3 (±96.6) *	24.2 (±12.3)
Σ_{11}PBDEs	2.8 (±1.4)	1.7 – 35 (ng/g dry weight)	12.3 (±17.7) *	5.9 (±4.4)
Pesticides				
Σ_{6}DDTs	1.1 (±0.05)	1.1 – 46 (ng/g dry weight)	6.9 (±15.0) *	2.3 (±1.0)
Σ_{8}Chlordanes	below LOQ	0.9 – 11.4 (ng/g dry weight)	low number of detects	low number of detects
Dieldrin	not detected	1.0 – 2.6 (ng/g dry weight)	low number of detects	low number of detects
Hexachlorobenzene	not detected	1.5 – 1.8 (ng/g dry weight)	2 detects	2 detects
Mirex	not detected	1.6 (ng/g dry weight)	1 detect	1 detect
Aldrin	not detected	below LOQ	low number of detects	low number of detects
endosulfan 1	not detected	below LOQ	low number of detects	low number of detects
hexachlorocyclohexanes	not detected	below LOQ	low number of detects	low number of detects
Metals				
Lead	0.1 (±0.02)	0.1 – 1.4 (μg/g dry weight)	0.4 (±0.2) *	0.3 (±0.2)
Copper	5.0 (±0.6)	4.1 – 10.5 (μg/g dry weight)	6.3 (±1.7) *	5.9 (±1.5)
Zinc	74.8 (±8.1)	68 – 137 (μg/g dry weight)	93.3 (±27.7) *	83.1 (±10.8)
Mercury	0.03 (±0.002)	0.03 – 0.1 (μg/g dry weight)	0.04 (±0.01)	0.05 (±0.03)
Arsenic	5.3 (±0.3)	4.8 – 8.0 (μg/g dry weight)	5.9 (±0.6)	5.9 (±0.6)
Cadmium	2.0 (±0.3)	1.6 – 4.1 (μg/g dry weight)	2.1 (±0.4)	2.2 (±0.6)

UGA = Urban Growth Area   LOQ = limit of quantification   * significantly higher than sites outside UGA

Table 4: Relationships between Proxies for Urbanization and Contaminant Concentrations

	% Impervious Surface			% Road Area		
	r^2	$F_{,1,\ 87}$	p-value	r^2	$F_{,1,\ 87}$	p-value
Σ_{42}PAHs	0.372	53.035	<0.0001	0.358	49.981	<0.0001
total PCBs	0.193	21.979	<0.0001	0.157*	17.373	<0.0001
Σ_{11}PBDEs	0.215	25.161	<0.0001	0.254	30.971	<0.0001
Σ_6DDTs	0.248**	29.963	<0.0001	0.187	21.257	<0.0001
Lead	0.198	22.749	<0.0001	0.274	34.224	<0.0001
Copper	0.098	10.603	<0.0001	0.054	6.026	0.016
Zinc	0.055	6.073	0.016	not significant		
Mercury	not significant			not significant		
Arsenic	no correlation			no correlation		
Cadmium	no correlation			no correlation		

* Lipid content was a significant covariate (p = 0.04, r2 = 0.188)
** Lipid content was a significant covariate (p = 0.005, r2 = 0.295)

Table 5: Relationships between Proxies for Urbanization and Biological Endpoints

	Mortality	Growth	Condition Index
% Impervious Surface	significant p = 0.003, adjusted r^2 = 0.087	no correlation	no correlation
% Road Area	significant p = 0.002, adjusted r^2 = 0.097	no correlation	no correlation

3.1.2 EFFECTS OF OUTFALLS ON EELGRASS

LITERATURE REVIEW

Gaeckle (2012) summarized available literature on the effects of outfalls and effluent on both seagrasses generally and eelgrass (*Zostera marina*) specifically.

- Effluent likely alters physical processes—hydrology, salinity, and temperature—associated with seagrass beds.
- Nutrient loading has detrimental impacts on seagrasses. These include: prolific growth of macroalgae, epiphytes, and phytoplankton on seagrass blades; low dissolved oxygen; light attenuation; and toxic levels of nitrogen that can limit uptake of other essential nutrients.
- Seagrasses take up metals and organic compounds from marine waters and sediments.

- Elevated concentrations of seven metals (aluminum, cadmium, copper, lead, mercury, nickel, and zinc) have been associated with reduced growth rates in *Zostera marina*.

SPATIAL ANALYSIS

Gaeckle et al. (2015) evaluated the spatial proximity of *Zostera marina* L. and outfalls in Puget Sound to identify areas where anthropogenic inputs may affect eelgrass. This spatial analysis included only major rivers and outfalls permitted under the National Pollutant Discharge Elimination System (NPDES). Several other sources of nutrient and/or contaminant loading (e.g., septic systems, vessel discharges, metal sloughing from vessel anti-fouling paints, and non-point source pollution associated with agriculture and urbanization) were not evaluated due to a lack of data.

- The total number of anthropogenic surface/stormwater outfalls discharging into Puget Sound is unknown. Carmichael et al. (2009) estimated there were over 4,500.
- In 2015, roughly 7% (331) of the estimated 4,500 outfalls had NPDES permits.[17]
- 21% of the NPDES-permitted outfalls that discharge within 100 meters of shore are located in areas where patchy or continuous eelgrass has been documented by DNR (n=24).
- Municipal outfalls discharge a higher volume and more diverse suite of chemicals than industrial sources. Surface runoff/stormwater from developed areas tends to have some of the highest loading rates of chemicals.
- The 15 largest wastewater treatment facilities by discharge volume are responsible for 76% of the total volume of wastewater discharges to Puget Sound. The Central Puget Sound basin receives 65% of the effluent volume discharged from wastewater treatment plants.
- River discharge is a significant source of dissolved inorganic nitrogen (DIN) for Puget Sound. A 2011 study estimated that riverine DIN loads contributed 51% of total non-oceanic DIN to greater Puget Sound and the Southern Strait of Georgia (Mohamedali et al. 2011).

While there is evidence that effluent from outfalls can degrade water quality, the authors conclude it is difficult to demonstrate a cause and effect relationship between eelgrass decline and outfall effluent in Puget Sound due to the number of variables involved (e.g., tidal circulation, hydrodynamics, and other confounding stressors).

The authors identify the following as areas where eelgrass is likely most at risk from negative impacts associated with anthropogenic loading:

- major municipal outfall discharge points, though they typically discharge at or beyond the deepest extent of eelgrass;

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[17] NPDES data was obtained from Department of Ecology water quality permit databases, such as the Permit and Reporting Information System (PARIS).

- combined Sewer Overflows (CSOs) and stormwater outlets; and
- major river deltas.

FIELD EVALUATION

Gaeckle (2014) collected *Zostera marina* L. from 15 sites in Puget Sound. The sites represented a wide range of shoreline types and likely contaminant levels. Fourteen of the sample sites were co-located with the Lanksbury et al. (2014) Mussel Watch Expansion Project sites. Four sites were located in WDNR Aquatic Reserves.

Several chemical analyses were conducted on each sample:

- nutrient concentrations ($\delta^{15}N$ and $\delta^{13}C$)
- organic contaminants (PAHs, PCBs, and PBDEs)
- metals (mercury, arsenic, cadmium, chromium, copper, iron, lead, nickel, vanadium, and zinc)

Results of these analyses were compared to results of previous studies that observed adverse effects in eelgrass associated with elevated metal concentrations in leaf tissue (Table 6).

Table 6: Comparison of Leaf Metal Concentrations in Eelgrass (*Zostera marina*)

	Copper (ppm)	Lead (ppm)	Zinc (ppm)
Range from Gaeckle (2014)	16.0 – 74.1	0.1 – 0.5	56.6 – 106.6
Evidence of toxicity from review by Lewis and Devereux (2009)	>10 pp dose 10 days ↓ growth rate	>100 ppm dose 5 days ↓ N2 fixation	>10 ppm 10 days ↓ growth rate

3.2 IMPLICATIONS

- Lanksbury et al. (2014) describe regional patterns of contamination in nearshore mussels, filling in areas not covered by the smaller network of NOAA Mussel Watch Program sites. Limited spatial coverage of mussel tissue contaminant levels had been identified as a priority data gap by both the PSEMP Toxics Work Group (2014) and Puget Sound Stormwater Work Group (2010).
- Lanksbury et al. (2014) also established that it is feasible to sample an expanded network of sites over a short period of time using transplanted mussels and volunteer assistance for cage deployment/retrieval.

- Since completion of this pilot effort, monitoring of contaminant levels in transplanted mussels has been incorporated into Ecology's Regional Stormwater Monitoring Program (RSMP).[18] In October 2015, WDFW deployed 40 mussel cages at RSMP sites selected by Ecology. Cages were also deployed at an additional 25 sponsored sites; most of these locations were also sampled during the 2012-2013 monitoring effort. Another RSMP deployment is planned for October 2017 (WDFW and Ecology 2015).
- Although results of the eelgrass study did not identify a cause and effect relationship between eelgrass and outfalls, this work provides baseline data against which future information can be compared.

3.3 RECOMMENDATIONS

1) Map stormwater outfalls. Gaeckle et al. (2015) found there was little available information on the hundreds of stormwater outfalls that discharge into Puget Sound without NPDES permits. They recommended compiling information on key characteristics of these outfalls—including location, volume discharged, and drainage area—to enable analysis of their effects on nearshore biota.
2) Coordinate with the PSEMP Toxics Work Group regarding recommendations from Lanksbury et al. (2014) on possible future enhancements to the program:
    - Evaluating and potentially adding a range of contaminants of emerging concern (CECs) to the list of contaminants measured in mussel tissue.
    - Exploring the use of biomarkers to help answer questions regarding mussel health and exposure to toxics.
    - Development of a study to compare contaminant concentrations in wild mussels to evaluate transplanted mussels as a predictive tool for the former.

4. OIL SPILL PREVENTION

This section provides analysis of results related to Action Agenda Sub-strategy **C8.1** (*Prevent and reduce the risk of oil spills*). Findings and recommendations provided in this section are based on:

- "Assessing Threats from Large Oil Spills" grant (Van Dorp and Merrick 2014)

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[18] The **Regional Stormwater Monitoring Program** (RSMP) is a coordinated monitoring effort funded in part by municipal stormwater permitees. Ecology administers **National Pollutant Discharge Elimination System** (NPDES) municipal stormwater permits in Washington. In accordance with federal Clean Water Act regulations, municipal NPDES permits include conditions requiring status and trends monitoring as well as studies on the effectiveness of local stormwater management programs. Ecology designed the RSMP to meet these permittee stormwater monitoring needs. The PSEMP Stormwater Work Group provides prioritized recommendations for elements of the RSMP; in early 2014 they formally endorsed inclusion of transplant mussel monitoring at 40 sites.

This investigation addresses a "Priority Science Action" identified in the 2011-2013 Biennial Science Work Plan (Evaluate existing oil spill risk assessments and complete additional risk analyses of higher risk industry sectors to ensure there are appropriate levels of investment in reducing risk).

4.1 FINDINGS

Vessel traffic associated with proposed maritime terminal developments has the potential to increase the risk of large oil spills in US/Canadian trans-boundary waters. Van Dorp and Merrick (2014) applied the Vessel Traffic Risk Assessment (VTRA)[19] model to evaluate:

1) changes in relative risk, or probability of an oil spill, associated with 3 proposed maritime terminal developments in the advanced stages of permitting, and

2) actions to mitigate the POTENTIAL effects of increased vessel traffic that would result from these projects.

One baseline and four "What-If" scenarios were simulated in the VTRA model:

- **2010 base case**: Traffic levels, routes, and speed distributions from 2010 calendar year re-constructed from regional Vessel Traffic Operational Support System records. Includes ~6400 cargo vessel and ~1400 tank vessel transits entering and leaving the Strait of Juan de Fuca annually, as well as transits within the system.

- **Gateway bulk carrier terminal at Cherry Point, WA**: adds 487 bulk carriers to 2010 traffic levels

- **Trans-Mountain/Kinder Morgan pipeline expansion in Vancouver, BC**: adds 348 crude oil tankers to 2010 traffic levels

- **Coal, grain, and container terminal expansions at Delta Port, BC**: adds 348 bulk carriers and 67 container vessels to 2010 traffic levels

- **All three projects built**: adds 1,250 additional arrivals to 2010 traffic levels

Results of the simulations indicate that vessel traffic associated with the proposed terminal developments would significantly increase risk compared to 2010 traffic levels. If all 3 projects were operational at the same time:

- The potential frequency of collisions and groundings could rise by 18% across the entire US/Canada trans-boundary study area (Table 5).

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[19] This peer-reviewed VTRA model has been refined over the past decade and applied to several other maritime risk assessment projects, including previous studies in Washington. Four components of the analysis model—**maritime simulation**, **incident and accident probability**, and **oil outflow**—together represent the chain of events that could potentially lead to an oil spill. Risk reduction measures are introduced into model simulations to block the causal pathways that can result in a spill. This enables the modelers to quantify the effectiveness of interventions such as enhanced escort requirements, traffic rule changes, and double hull requirements.

- Potential oil loss (i.e., volume spilled in the event of an accident) could increase by 68% system-wide (Table 5 and Figure 8).

- The largest increase in relative spill risk is concentrated west of the San Juan Islands. Some waterway zones experience little to no increase in accident frequency or potential oil loss.

- Haro Strait and Boundary Pass would be expected to see the largest increase in potential accident frequency, and potential oil loss is 3 times higher than base case levels there. In the eastern Strait of Juan de Fuca, the additional traffic could more than double potential oil loss (Figure 8).

- Two waterway zones east of the San Juan Islands, Guemes Channel and Rosario Strait, are also large contributors to system-wide potential oil loss (Figure 8).

The next step of the VTRA modeling effort was to simulate risk mitigation measure (RMM) scenarios. Van Dorp and Merrick (2014), in coordination with the study's Steering Committee,[20] developed 11 RMM scenarios involving single or multiple interventions, such as:

- 100% double hull fuel tank protection
- human error reduction (to approximate second watchstander)
- maximum speed of 17 knots
- one-way Rosario Strait traffic regime
- secondary escorts (to approximate rescue tug)
- exclusion of bunkering[21] operations (to approximate maximum benefit)

Four of the RMM scenarios involved measures currently under consideration or partially implemented. Others targeted specific classes of vessels, or geographic locations observed to have increased accident frequency under a What-If scenario.

For 9 of the 11 RMM scenarios evaluated, risk reductions were significant. An additional RRM scenario was created to simulate the benefit of a set of 6 RMMs being operational at the same time. A simulation of the 1,250 additional arrivals with this 6 RMM scenario resulted in:

- A 29% reduction in accident frequency and a 44% reduction in potential oil loss as compared to the 1,250 additional arrivals scenario with no RMMs.

- Notably, this accident frequency result was 11% below the 2010 baseline accident frequency.

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[20] The Steering Committee included representatives from state/federal regulatory agencies, tribes, industries, NGOs, and other stakeholders. Many steering committee representatives were members of the pre-existing PSP Oil Spill Workgroup and Puget Sound Harbor Safety Committee.

[21] **Bunkering** refers to provision of fuel to vessels, including storage, transport, and loading onto ships. The What-If scenarios included transits of laden bunkering tug-barges from Seattle and Cherry Point to the new Canadian facilities.

Table 7: VTRA Results – Changes Associated with 1,250 Additional Arrivals

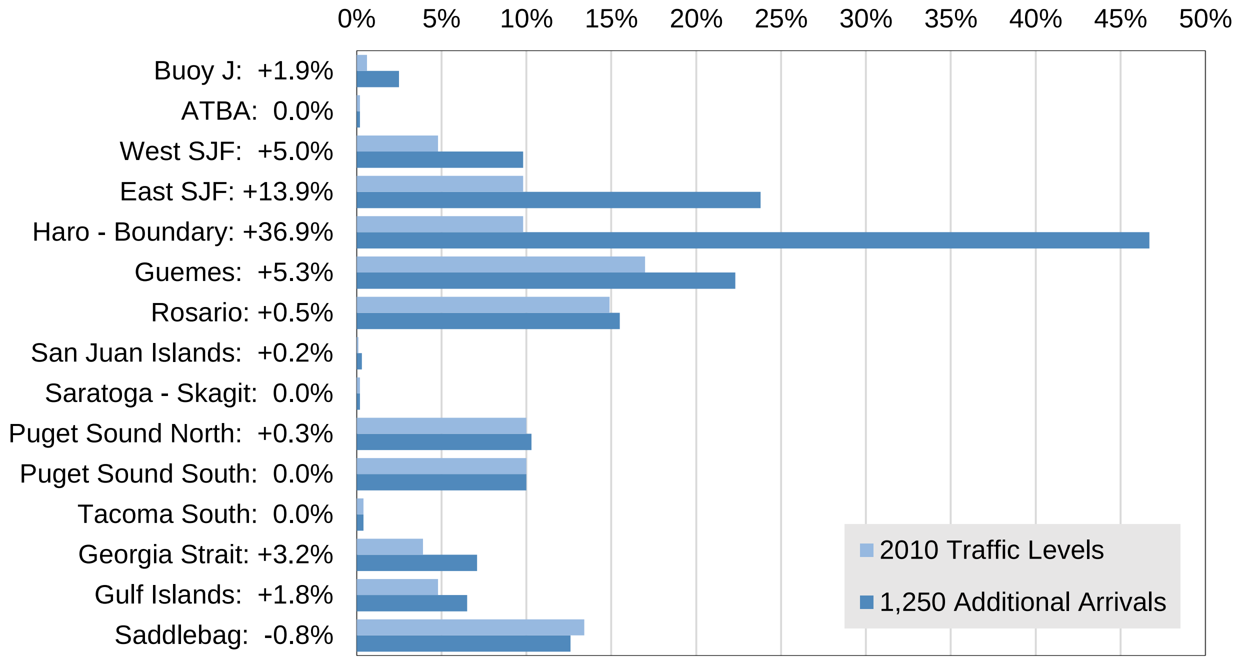
Waterway Zone	Potential Accident Frequency	Potential Oil Loss
Buoy J[22]	+0.2%	**+1.9%**
ATBA[23]	0.0%	0.0%
West SJF	+1.4%	**+5.0%**
East SJF	**+1.6%**	**+13.9%**
Haro/Boundary	**+4.4%**	**+36.9%**
Guemes	**+2.9%**	**+5.3%**
Rosario	+1.2%	+0.5%
San Juan Islands	0.0%	+0.2%
Saratoga - Skagit	-0.1%	0.0%
Puget Sound North	+0.5%	+0.3%
Puget Sound South	+1.1%	0.0%
Tacoma South	0.0%	0.0%
Georgia Strait	**+3.7%**	**+3.2%**
Gulf Islands	+0.4%	+1.8%
Saddlebag	+1.2%	-0.8%
System Total	**+18%**	**+68%**

Note: Values represent percent increase over 2010 levels.

[22] **Buoy J** is a lighted Traffic Separation Scheme (TSS) structure located northwest of Cape Flattery to direct Strait of Juan de Fuca traffic. This waterway zone encompasses the area west of the entrance to the Strait and west of the ATBA (see below).

[23] **ATBA** is an "Area To Be Avoided" designated by the International Maritime Organization (IMO) for protection of the Olympic Coast National Marine Sanctuary. Map provided in Vessel Traffic Service Puget Sound.

Figure 8: VTRA Results – Waterway Zone Contributions to Total Potential Oil Loss



SYSTEM TOTAL: +68% (REPRESENTS PERCENT INCREASE OVER 2010 LEVELS)

4.2 IMPLICATIONS

The results of these VTRA simulations indicate that:

1) Most of the increased risk associated with the new projects could be mitigated using a well-designed portfolio of risk management measures.

2) Some risk reduction interventions should be considered for implementation even if none of the 3 terminal developments are constructed.

4.3 RECOMMENDATIONS

- The Puget Sound Harbor Safety Committee, Department of Ecology, and U.S. Coast Guard should continue to examine new ways to manage vessel traffic and reduce risk, whether new projects move forward or not.

- Van Dorp and Merrick (2014) recommend that the 17-knot speed limit and second watchstander risk mitigation measures be considered for system-wide implementation even if none of the 3 terminal developments are constructed.

- Van Dorp and Merrick (2014) recommend implementing the interventions associated with the 6 RRM scenario if the proposed maritime terminal projects are built.

- Consider funding updates to the VTRA model. Base case traffic levels are now more than 5 years old, and “What If” scenarios may change as proposed terminal developments move through the permitting process. Previous work has established it as a valuable tool resulting in actionable recommendations to reduce oil spill risk. A complementary analysis of the economic costs and benefits associated with implementation of mitigation measures could be useful for decision-makers.

- The Grant Program and regional response agencies should also use VTRA results to inform investments in community preparedness programs and regional response planning.

- VTRA results help target geographic areas that would benefit most from the types of oil spill response efforts described in Section 5. The San Juan Islands and Clallam County should remain high-priority areas for Grant Program investments.

- Likewise, future updates of the Northwest Area Contingency Plan[24] could prioritize improvements to Geographic Response Plans[25] (GRPs) for these high risk areas. Rigorous pre-spill shoreline segmentation[26] could strengthen GRPs by identifying specific locations where oil is likely to accumulate; access points and staging areas for responders; and high quality habitats where defensive measures can be prescribed. Tribes, local jurisdictions, and community organizations could contribute valuable knowledge to significantly increase the level of detail provided in the current GRPs.

5. OIL SPILL RESPONSE

This section provides analysis of results related to Action Agenda Sub-strategies **C8.2** *(Strengthen and integrate spill response readiness of the state, tribes, and local government)* and **C8.3** *(Respond to spills and seek restoration using the best available science and technology)*.

Outcomes of 4 community oil spill preparedness and response projects funded by the Grant Program are summarized below:

- “Swinomish Oil Spill Preparedness Project” grant (Swinomish Tribal Community 2014a-b)

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[24] The **Northwest Area Contingency Plan (NWACP)** documents the region’s plan for a unified and coordinated response to spill events by federal, state, tribal, local, responsible party, contractor, and community agencies/businesses/organizations. It is developed by the joint federal/state Regional Response Team-Northwest Area Committee.

[25] **Geographic Response Plans (GRPs)** are an element of the NWACP. They are used as a guide to minimize the impact of oil on natural, cultural, and certain economic resources at risk during spills. Each plan covers a specific geographic area and contains information meant to aid the response community in managing the incident. For example: site descriptions, reference maps, recommended response strategies, shoreline information, resources at risk, and logistical information.

[26] **Shoreline Segmentation** is a process described in detail in Section 9422 of the NWACP.

- “Geographic Expansion of Seabird Survey and Early On-Scene Training” grant (Ross and Joyce 2014 via Seattle Audubon Society)

- “Preparing COASST Post-Spill” grant (COASST 2014)

- “Community Engagement for Oil Spill Response and Readiness” grant (NWSF 2015)

5.1 OUTCOMES

5.1.1 SWINOMISH OIL SPILL PREPAREDNESS

This grant funded development of local oil spill response capability for the Swinomish Reservation. The Tribe:

- Identified 15 high-value salt marsh areas at risk from potential oil spills, along with techniques and equipment that could be used to reduce spill effects on those habitats. Areas where oil spill damage could potentially be avoided or minimized through timely action in the early stages of a spill event, such as closing tide gates or placing booms at the mouth of small inlets, were prioritized.

- Developed a *Marine Oil Spill Response Standard Operating Procedures Manual* to document: methods to protect these high-value habitats; procedures for equipment deployment; safety procedures for tribal personnel and volunteers; and communications strategies.

- Recruited and trained tribal staff and community volunteers who could be mobilized in the event of a spill threatening Reservation waters. A total of 13 observers and 7 responders were recruited and trained. Spill response procedures and communication strategies were described and practiced during 7 training sessions. Participants were able to practice deploying and setting boom with anchor at several of the sites identified in the manual.

- Participated in a regional tabletop drill at the Shell refinery on March Point.

5.1.2 VOLUNTEER RESPONSE TRAINING AND DATA COLLECTION PROGRAMS

The three remaining grants in this group involved efforts to engage community volunteers in oil spill response and pre/post spill data collection. Community volunteers can be the closest field observers and provide useful information on reported spills (Ecology and PSP 2011). Local knowledge may be particularly useful in areas where the coastline is not easily accessible (NRT 2012). There is a strong desire among many in the region, particularly in the birding community, to get involved in a project addressing concerns about oil spills (Ross and Joyce 2014).

However, oil is a hazardous substance that poses health and safety risks. Volunteer participation in spill response is limited by the extensive training, equipment, and medical surveillance requirements associated with exposure to oil (National Response Team 2012). The minimum amount of training

required under applicable regulations[27] depends on a person's role and responsibilities during response operations. Untrained or improperly trained community members could also increase wildlife impacts by frightening oiled wildlife away from the shorelines where they attempt to escape the oil or cold water (Pacific States – British Columbia Oil Spill Task Force 2008).

These grants funded training for volunteers to assist with three elements of spill response:

1) Early on-scene reconnaissance
2) Baseline and post-spill data collection
3) Oiled wildlife care

The grantees were able to develop volunteer capacity by developing organizational protocols and offering training classes. However, due to annual recertification requirements, these programs are not sustainable without additional grant funding.

EARLY ON-SCENE RECONNAISSANCE

Early On-Scene Reconnaissance (EOSR) is intended to increase the number of "eyes on the water" for intelligence gathering in the event of a marine disaster (Ross and Joyce 2014). Survey teams capture data about the condition of a beach: the extent of oiling, fish and wildlife presence, and on-scene conditions. This information is then provided to regional spill response agencies to help coordinate response efforts.

Two grants in this group leveraged successful, long-term citizen science programs—University of Washington's Coastal Observation and Seabird Survey Team (COASST) and Seattle Audubon's Puget Sound Seabird Survey (PSSS)—to prepare their highly trained volunteers to perform EOSR in the event of a spill.

The result of these grants is a geographically distributed[28] and coordinated network of observers trained to recognize and characterize oil spills, then quickly report their observations to responsible agencies.

- 49 PSSS volunteers were trained to make observations from existing survey sites after a spill has been reported but not confirmed. If a spill has been confirmed, they can make standardized observations regarding the presence of oil using a quantitative data sheet based on NOAA and U.S. Coast Guard standards (Ross and Joyce 2014). Volunteers were instructed to avoid hazardous areas and make observations from safe a location.

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[27] Includes federal and state **Hazardous Waste Operations and Emergency Response (HAZWOPER)** standards 29 CFR §1910.120(q), 40 CFR §311, and Chapter 296-843-20020 WAC, as well as Incident Command System training (e.g., FEMA ICS-100).

[28] COASST has collected data on beached bird carcasses for over 15 years, and currently has 125 monitoring sites in northern Puget Sound and along the Strait of Juan de Fuca. PSSS has collected data on wintering seabird density and distribution in central and south Puget Sound for almost 10 years; the program expanded into northern Puget Sound and the Strait of Juan de Fuca as part of this grant (see below).

- 81 COASST volunteers were trained[29] to assess existing survey sites for oil after a spill, and to keep themselves safe while working around oil. Training also provided information on the Incident Command System oil spill management structure. This level of training allows these volunteers to work on the beach even if oil is present (COASST 2014).

- 2 COASST staff completed additional training and were certified to teach HAZWOPER courses for volunteers. They developed "volunteer friendly" HAZWOPER and EOSR training materials, enabling COASST to continue to train volunteers for EOSR until their teacher certifications expired.

- Grantees coordinated their work with the Northwest Area Committee, a group of federal and state agency personnel charged with coordinating response actions with tribal and local governments and the private sector.

These relationships and response procedures were tested during the grant period. PSSS conducted a drill to check the availability of volunteer observers and test the functionally of the response plan (Ross and Joyce 2014). COASST responded to a request from Ecology to survey sites after a February 2014 spill at Naval Base Kitsap Bangor (COASST 2014). Four teams of trained volunteers were mobilized and provided data for 5 sites within 96 hours of notification.

These programs have been incorporated into Ecology's spill response volunteer coordination system (oilspills101.wa.gov). This site allows COASST and PSSS volunteers to register with the state, and provides a list of trainings (e.g., HAZWOPER refresher courses) that volunteers can register to attend.

COASST does not currently have staff certified to teach HAZWOPER courses, though they are interested in continuing the program developed as part of this grant if future funding allows (E. Frost, COASST Volunteer Coordinator, and Julia Parrish, COASST Executive Director, personal communication, January 2016).

BASELINE AND POST-SPILL DATA COLLECTION

The PSSS and COASST grants also included tasks to augment their existing data collection programs. This work addressed a "Priority Science Action" identified in the 2011-2013 Biennial Science Work Plan (*Evaluate information on baseline conditions for key species at risk from oil spills and improve these as necessary so that baselines exist that can be used in assessments of natural resource damages*[30]).

[29] Consistent with "First Responder Operations Level" under 29 CFR §1910.120(q)(6)(ii). 8-hour HAZWOPER training provides instruction on health and safety; use of personal protective equipment; site characterization and control; and spill management.

[30] Occurs through the **Natural Resources Damage Assessment (NRDA)** process. Total damages from a spill are estimated based on habitats and organisms impacted. This damage estimate is then used to negotiate legal settlements with the responsible party. State and/or federal NRDA evaluations may occur depending on the magnitude and type of spill.

- The PSSS grant funded expansion of their program to the Strait of Juan de Fuca and Admiralty Inlet, an area thought to be at high risk for a major oil spill. They established 26 new survey sites, and trained 49 volunteers to conduct monthly surveys at these new sites for 1 year. The new sites have been incorporated into the general PSSS program and continued to be surveyed (T. Ross, Seattle Audubon Science Manager, personal communication, June 2016).

- PSSS data from these new sites provides baseline information on seabird density and distribution in the Strait of Juan de Fuca and Admiralty Inlet. In addition, the program's EOSR-trained volunteers are ready to mobilize to survey sites at the first daylight high tide window after a spill event. Surveys during this 4-hour window will provide real-time information and supplemental data to Incident Command.

- One step in the NRDA process is to quantify damage to natural resources, including seabirds. The COASST grant funded the development of protocols and training of volunteers needed for participation in post-spill NRDA beached bird surveys (with direct field oversight by state and/or federal agency staff). To adapt standard COASST survey protocols to meet court admissibility standards, evidence numbers and tags are used instead of colored cable ties and all carcasses are collected as evidence.

OILED WILDLIFE CARE TRAINING

As part of the NWSF grant, the Islands Oil Spill Association provided three 2-day basic oiled wildlife care class for citizen volunteers in Clallam/Jefferson, Island, and San Juan Counties. 69 volunteers participated.

The sessions included 8-hour HAZWOPER training plus information on species characteristics and identification, effects of oiling, and hands-on field exercises. Classes included time to examine dead frozen birds, as well as instruction on safe handling, examination steps, and hydration methods with live ducks.

5.1.3 LOCAL GOVERNMENT AND COMMUNITY ENGAGEMENT WORKSHOPS

NWSF held workshops in Whatcom, Skagit, Island, San Juan, Jefferson, and Clallam Counties to facilitate community engagement in oil spill preparation and response.

- The first series of 6 workshops informed 184 citizens about spill response organization and chain of command, as well as volunteer opportunities. Speakers included representatives from Ecology, WDFW, Coast Guard, industry, and community groups.

- NWSF observed these communities had very different spill response needs. Private sector resources are available in counties with refineries (e.g., Whatcom and Skagit), while there is a greater need for citizens to be extensively trained in more remote counties (e.g., Clallam).

- The second series of 6 workshops targeted emergency responders, local and tribal government managers, as elected officials. Different counties were able to choose different focus areas based on their specific concerns. 145 people attended.

5.2 IMPLICATIONS

- Volunteers can play a valuable role in oil spill response. A review of the 2010 Deepwater Horizon oil spill response found that volunteers provided the Incident Management Team with useful real-time and verifiable on-scene information, such as presence/absence of new oiling, presence of tar balls, oiled wildlife, and broken or malfunctioning boom (NRT 2012).

- However, building and maintaining a community's capacity for meaningful action in the event of a spill requires regular investment in recurring training sessions (NWSF 2015a). Annual HAZWOPER refresher courses are required[31] for spill responders, so single training sessions may have limited value (NWSF 2015a).

- Keeping organizations and individuals engaged in maintaining volunteer response capabilities may prove to be challenging given the mismatch between the frequency of required trainings and the frequency of spill events. Recertification training is time-consuming for the volunteers and expensive for the volunteer organization (NWSF 2015b).

- In the absence of consistent funding for volunteer training, organizations should carefully consider different HAZWOPER training strategies to optimize costs and benefits of their preparedness programs.

5.3 RECOMMENDATIONS

1) Strengthen Geographic Response Plans (GRPs) with input from Tribes, local jurisdictions, and community organizations.

    - Swinomish Tribal Community (2014a) found that restoration sites and other high-value areas were not designated in the GRP covering their Reservation.

    - GRP updates are an opportunity to incorporate local knowledge into regional response priority planning. Ecology's volunteer coordination website provides information on GRPs under development.

    - Physically protecting important habitats from oil contamination should be the top priority for local planning efforts. The Swinomish Tribe's strategy could be encouraged in other high-risk areas where high-quality habitats are present. During their drills, they found that hauling boom and setting anchor points was difficult in areas with steep rocky terrain. In the future, they hope to install preset anchor points, identify how much boom each priority site would require, and house the appropriate amount of boom at each site as boom is acquired. Having these types of logistical issues worked out before a spill should significantly improve the performance of defensive measures intended to protect habitat.

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[31] Per 29 CFR §1910.120(q)(8).

2) Consider alternative training strategies for volunteer activities like early on-scene reconnaissance to reduce costs and volunteer attrition associated with annual recertification requirements.

   - Certifying organization staff to deliver HAZWOPER training to their volunteers could be explored as a way to provide more training at a lower cost. COASST employed this strategy by enrolling 2 staff members in 48 hour HAZWOPER teacher training, then conducting volunteer training in-house.

   - Individual organizations could develop a comprehensive "just-in-time" training[32] program for use in the event that volunteers must be trained in a short amount of time. Ecology and the Olympic Coast National Marine Sanctuary had this capability at one time (Pacific States/British Columbia Oil Spill Task Force 2011). The Island County Beach Watchers applied this model in response to the 2012 sinking of the DV Deep Sea in Penn Cove (Bennett et al. 2014). The Makah Tribe maintains this type of program, with specific training requirements included in Section 4326.9 of the Northwest Area Contingency Plan.

3) Disseminate resources developed during these grants to other Tribes, MRCs, and Local Implementing Organizations (LIOs) with an interest in developing or improving community oil spill response capabilities. Resources that could be useful for other communities looking for opportunities to provide support for first responders include:

   - The Swinomish Tribe's Marine Oil Spill Preparedness Project Standard Operating Procedures manual

   - COASST's "volunteer friendly" HAZWOPER an EOSR training materials, and Early Assessment Team protocols

   - Seattle Audubon's Oil Spill Early On-Scene Reconnaissance User Manual and oil observation form

6. PUGET SOUND PRESSURES ASSESSMENT

This section provides analysis of results supporting Action Agenda Sub-strategy **D1.2** (*Maintain and update the Action Agenda as the shared recovery plan*). Findings and recommendations provided in this section are based on:

- "Puget Sound Integrated Risk Assessment" grant (McManus et al. 2014, Labiosa et al. 2014)

The Puget Sound Pressures Assessment (PSPA) was developed to guide decisions about recovery priorities, and is supporting the Action Agenda update process. It also addresses a "Priority Science

[32] Four hours of training is generally considered to be sufficient for beach surveillance, consistent with "First Responder Awareness Level" under 29 CFR §1910.120(q)(6)(i).

Action" identified in the 2011-2013 Biennial Science Work Plan (*Conduct integrated risk assessments of the impacts of different pressures on the Puget Sound ecosystem*).

STRATEGIES FOR SETTING PRIORITIES DURING RECOVERY PLANNING

The large number of anthropogenic pressures affecting National Estuary Program (NEP) and other large-scale restoration sites makes development of management plans a challenge. Identifying and ranking threats to primary conservation targets is a key part of the NEP planning process. However, prioritization exercises are often constrained by a lack of data (Samhouri and Levin 2012, Labiosa et al. 2014, Smith et al. 2015).

Different techniques for prioritization of environmental stressors have both advantages and drawbacks (Smith et al. 2015). A comparative review of methods used in Puget Sound and other regions reveals an apparent trade-off between rigorous use of quantitative data and assessment scope (Table 8). The number of stressors evaluated tends to be limited where data-driven approaches are applied, while use of expert elicitation[33] methods can expand the breadth of an assessment.

Labiosa et al. (2014) determined that an expert elicitation-based approach was appropriate for a Puget Sound integrated risk assessment given the desire for comprehensiveness. Before we summarize PSPA results, we present a caveat advocated by Schwartz et al. (2012): the PSPA draws on scientific knowledge but not measured results. It reflects a conceptual model of cause and effect rather than understanding gained by testing hypotheses. Schwartz et al. (2012) characterize this as a valuable shortcut, but an imperfect one. Labiosa et al. (2014) acknowledged this distinction, and PSPA users should keep it mind when applying results.

[33] **Expert elicitation** is a systematic process to formalize and quantify the judgments of experts. This method usually includes an assessment and representation of the uncertainty underlying expert judgments (Labiosa et al. 2014). In this way, subjectivity is incorporated explicitly as a form of uncertainty in the analysis (Samhouri and Levin 2012).

Table 8: Overview of Stressor Assessments Intended to Support Prioritization Efforts

Expert elicitation	Puget Sound Pressure Assessment (PSPA)	Evaluated 47 stressors (Table 7) and 60 endpoints (Table 8).	164 subject matter experts were invited and 60 participated (37%).
	Mobile Bay National Estuary Program Assessment of Stressor Impacts to the Estuaries and Coast (2011)	Evaluated 13 stressors, 10 coastal habitat types, and 14 recognized ecosystem services.	About 30 scientists, ecologists, and resource managers participated.
	A Quantitative Assessment of 50 Stressors Affecting the Great Lakes (Smith et al. 2015)	Evaluated 50 stressors and 6 ecosystem zones for each lake.	787 experts were invited and 141 participated (18%).
Synthesis of available data	Massachusetts Bays Program Estuary Delineation and Assessment project (2012)	Evaluated 15 stressors and 7 resource metrics.	Spatial analysis using existing quantitative data (high intensity land use, stormwater discharge, impervious area, population, wastewater discharge, septic systems, 303(d) impairments, tidal restrictions, fish passage barriers, stream crossings), normalized by watershed size.
	Lower Columbia River and Estuary Habitat Restoration Prioritization Framework (Thom et al. 2011)	Evaluated 20 stressors and 8 controlling factors (hydrology, sediment quality, water quality, light, sediment dynamics, physical disturbance, depth/slope, non-native species)	Spatial analysis to evaluate restoration potential. Stressor impacts to controlling factors evaluated at local and landscape scales.

Three other recent investigations of human stressors on marine/estuarine ecosystem components included Puget Sound. They all relied on existing datasets. Halpern et al. (2009) mapped cumulative impacts associated with 25 human activities on 19 marine ecosystems. Samhouri and Levin (2011) assessed risk associated with 4 stressors on 7 indicator species. Greene et al. (2014) developed a Composite Stressor Index metric for 196 estuaries nationwide.

Table 9: PSPA 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

Harmful algal blooms

Changing air temperature

AA. Changing precipitation amounts and patterns

BB. Sea level rise

CC. Changing ocean condition

Table 10: PSPA Endpoints by Domain

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

* Evaluated in both the Freshwater and Marine-Nearshore Domains

6.1 FINDINGS

- The PSPA was a systematic evaluation of the relative impact of anthropogenic pressures on habitat/species endpoints at local and regional scales.[34]

- McManus et al. (2014) first evaluated relationships between 47 stressors (Table 9) and 60 endpoints (Table 10) using ratings from 60 technical experts. The output was **intrinsic vulnerability (IV)** scores for 1,220 stressor-endpoint pairs. The IV scores reflect how much a given stressor affects a specific assessment endpoint.

- IV pair scores were summed to develop index values for all stressors (Figure 9) and all endpoints (Figure 10). Ranked lists of relative index values identify the most vulnerable species and habitats, and the stressors with the highest potential for harm.

- Note that IV scores reflect only *direct* effects of stressors on endpoints. Killer whales emerged with a relatively low score, while their salmon prey had consistently high scores. So actions to mitigate stressors on salmon would indirectly benefit killer whales.

- The next step was to evaluate **stressor intensity** and **endpoint distribution** within each of Puget Sound's 16 watersheds and 7 marine sub-basins. The distribution and frequency of stressors, as well as presence/absence of endpoints, within each geographic unit was assessed using readily available GIS data.

- Finally, a **potential impact (PI)** metric was calculated for each stressor-pair in every geographic unit. The PI results combine the outputs of the IV, stressor intensity, and endpoint distribution sub-models. Ranked lists of PI reflect the relative impacts of stressors on endpoints within a given geographic area. Figure 11 provides a ranked list of average PI of stressors in all the 7 marine basins.

- McManus et al. (2014) explain that the PI results are most informative when viewed in relation to the IV results. This is because PI results alone give an incomplete picture of stressor expression and/or importance, particularly for stressors that are not widely distributed or have infrequent occurrence. For example, large oil spills are rare so they they rank relatively low in the PI result. However, oil spills rank among the stressors with the greatest potential for harm in the IV results. Figure 12 provides a comparison of IV and PI rankings in marine basins, while Figure 13 explains the relationship between these values and their management implications.

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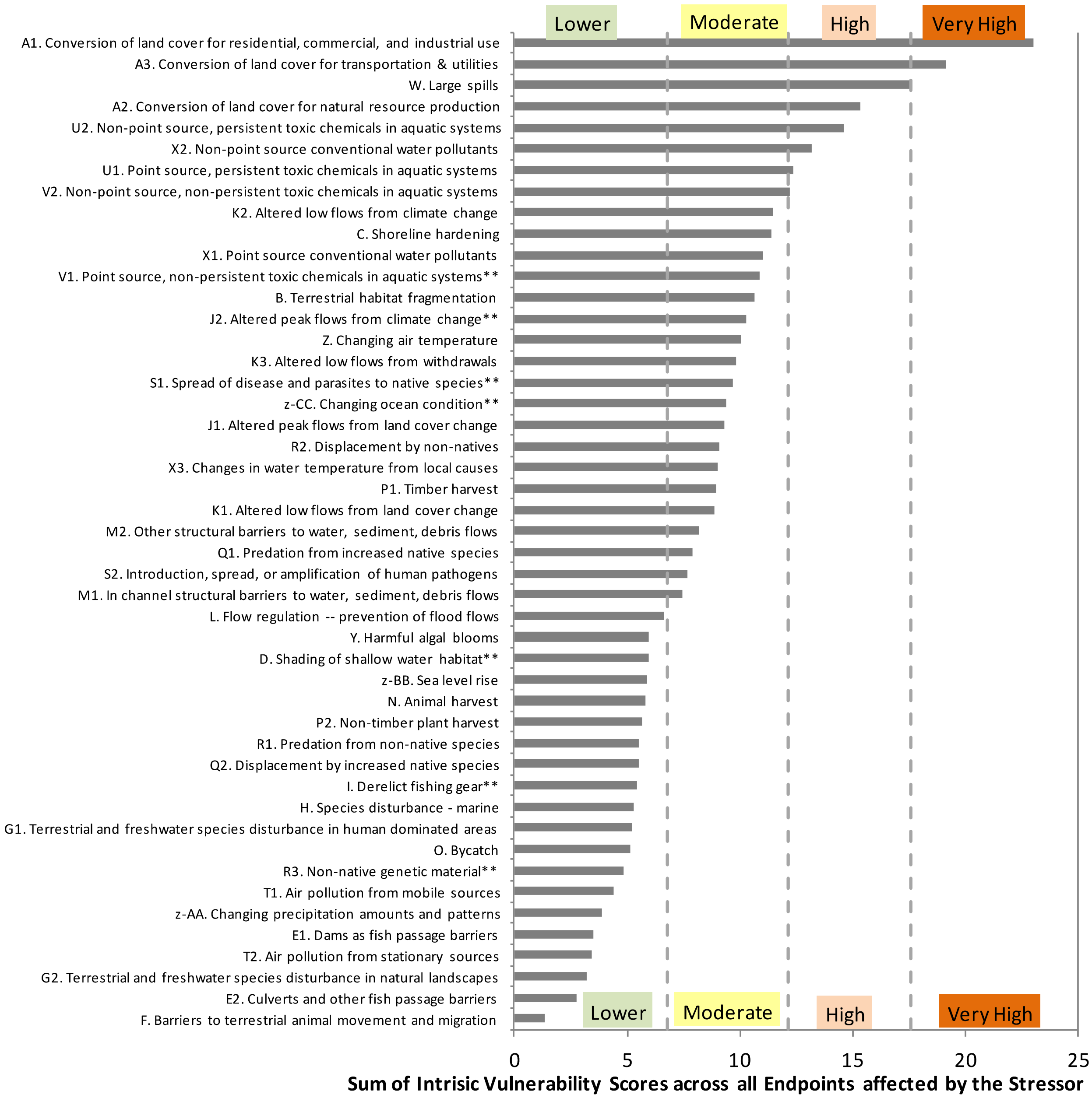
[34] The PSPA draws from the terminology and concepts used in the *Open Standards for the Practice of Conservation*. **Pressures** are human actions that are sources of stress on the ecosystem. **Stressors** are the proximate causes of ecosystem changes (i.e., the direct effects of pressures). **Endpoints** are the species and habitats affected by stressors.

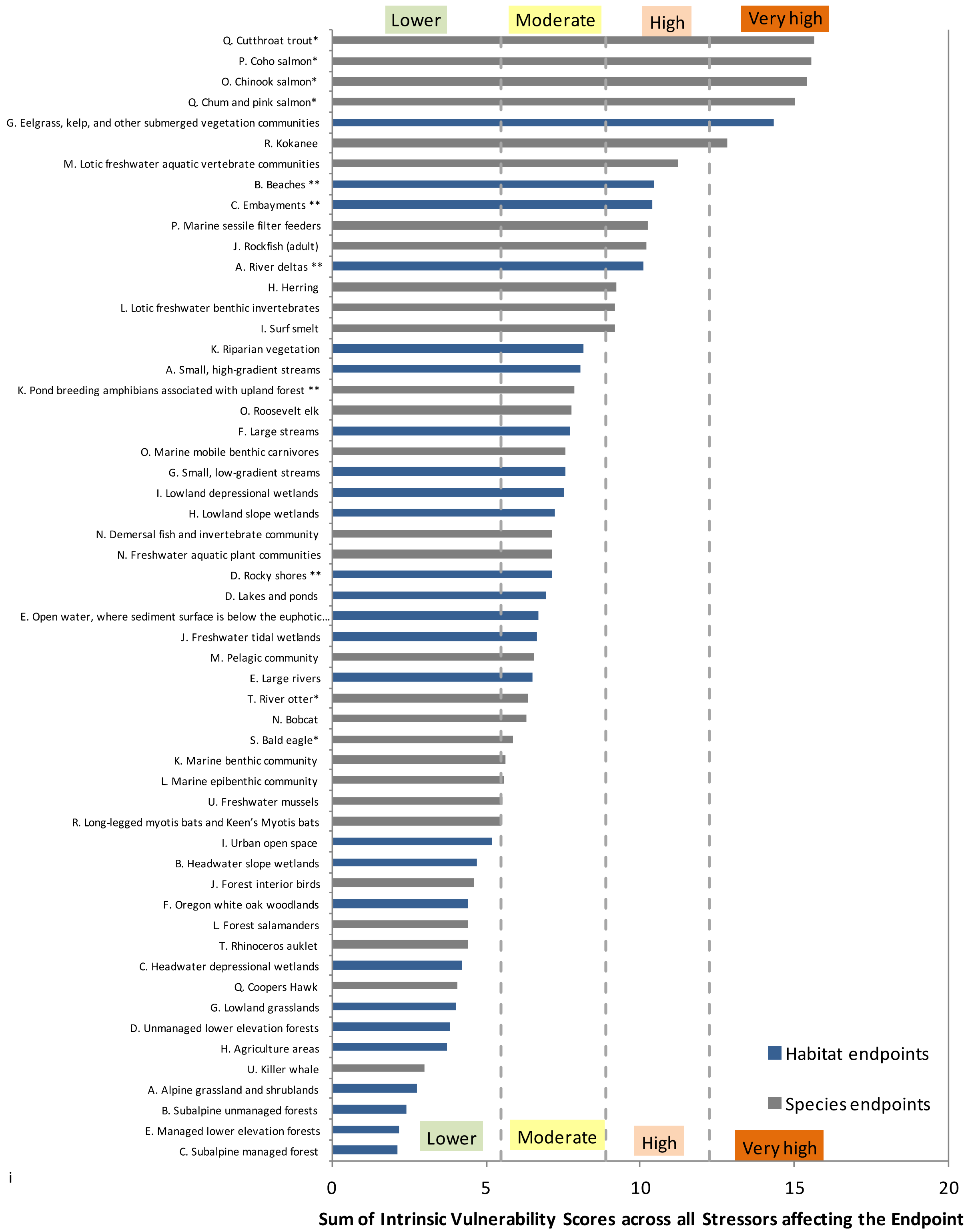
Figure 9: Stressors Ranked by IV Stressor Index Values (Figure 7 in McManus et al. 2014)



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

Note that this ranked list reflects ***summed*** IV pair scores. McManus et al. (2014) also ***averaged*** scores to highlight stressors that have a significant potential for harm on fewer endpoints. **Sea level rise** and **shading of shallow water habitat** are two stressors that rank *very high* or *high* by average index scores, but *low* by the summed scores. **Shoreline hardening** also ranked higher when averaging was used (value moved from *moderate* to *high*).

Figure 10: Endpoints Ranked by IV Endpoint Index Values (Figure 8 in McManus et al. 2014)



* Evaluated in both freshwater and marine-nearshore domains.

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

Figure 11: Ranked Potential Impact of Stressors in Marine Basins (Figure 10 in McManus et al. 2014)

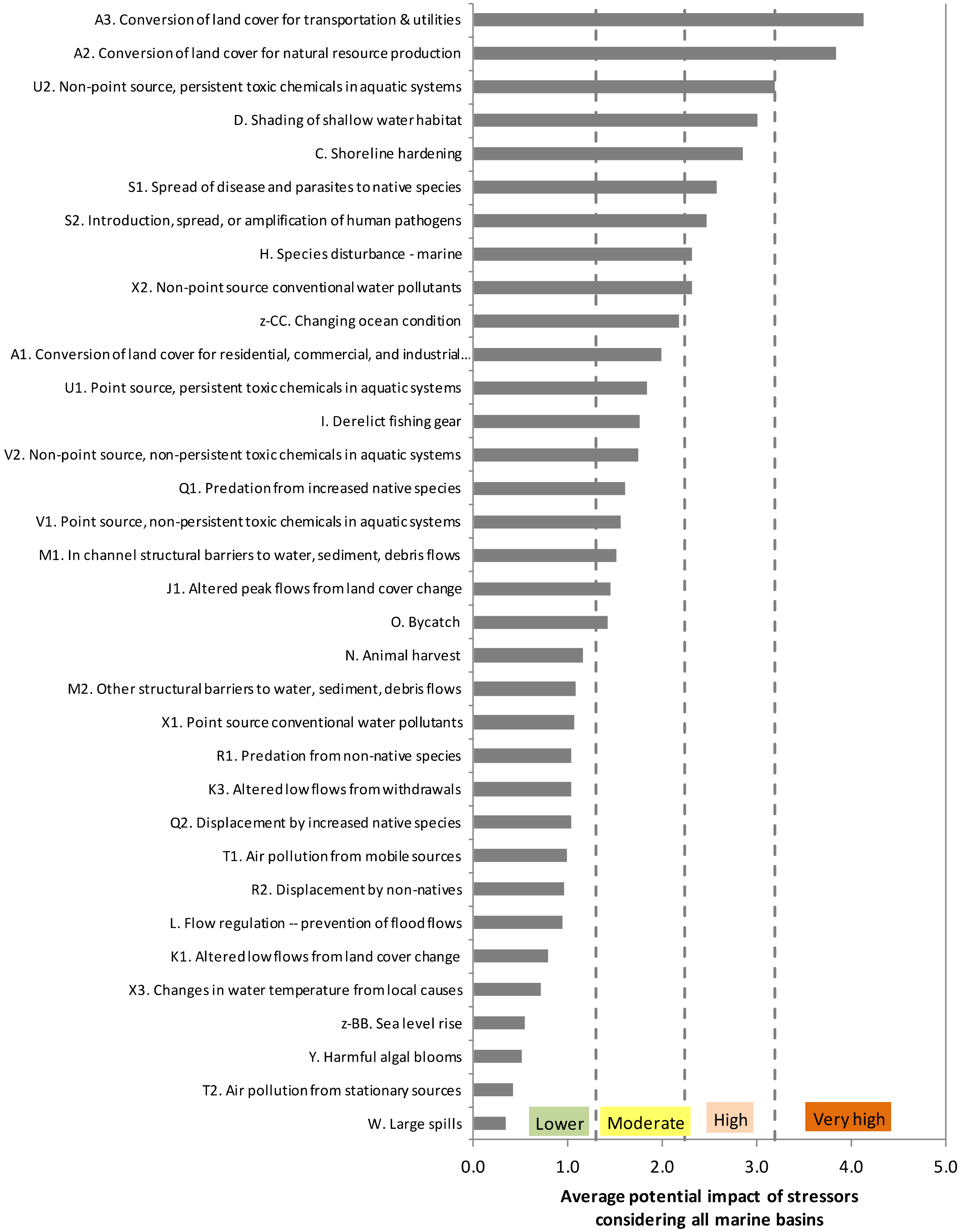
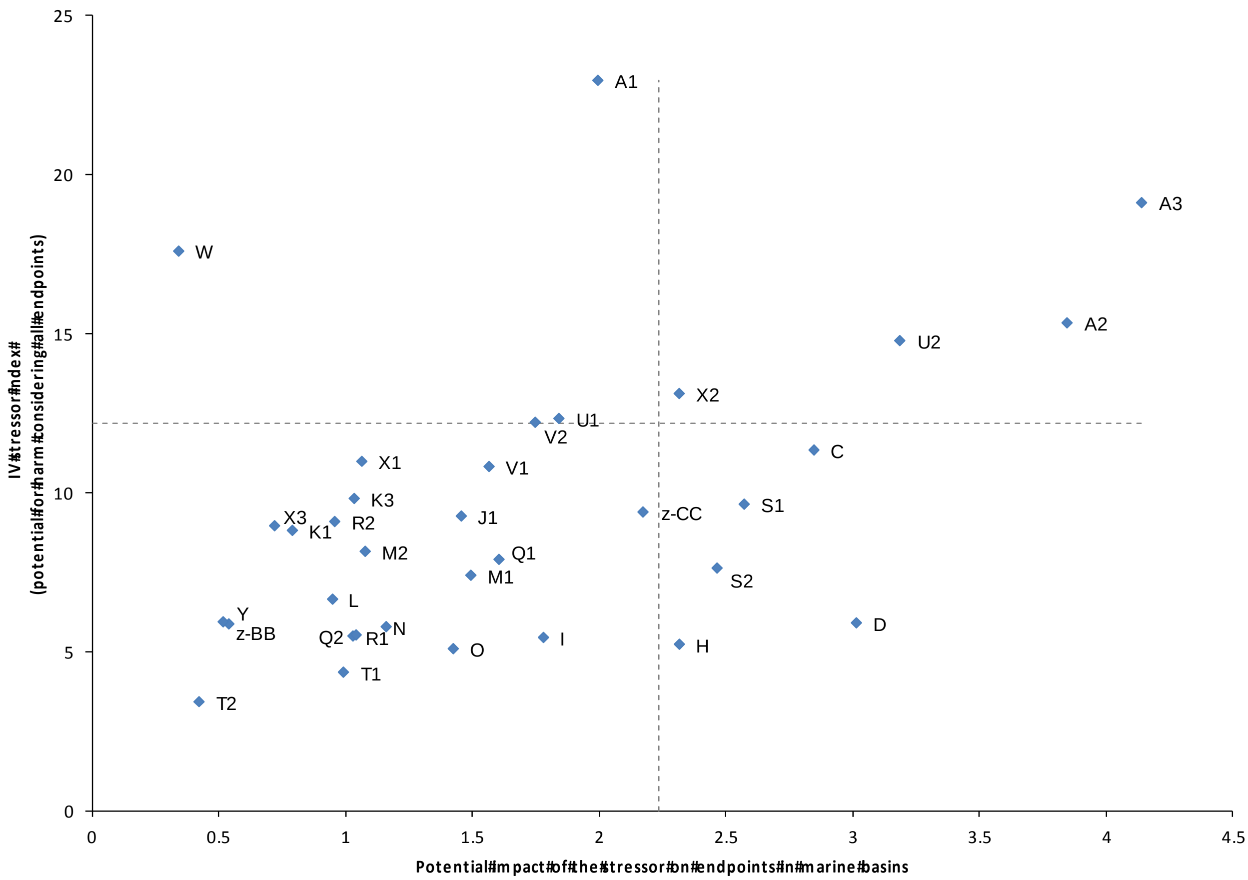


Figure 12: Comparison of IV and PI Index Rankings in Marine Basins (Figure 15 in McManus et al. 2014)



Below is a key for: (1) stressors with the highest IV scores and (2) stressors that have been priorities for the Marine and Nearshore Grant program during previous funding rounds. See Table 7 to identify the remaining stressors. Figure 7 describes the authors' thoughts on how to interpret these relationships for prioritization purposes.

A1.	Conversion of land cover for residential, commercial, and industrial use
A3.	Conversion of land cover for transportation and utilities (includes dredging)
W.	Large spills
A2.	Conversion of land cover for natural resource production (includes agriculture)
U2.	Non-point source, persistent toxic chemicals in aquatic systems
X2.	Non-point source conventional water pollutants
C.	Shoreline hardening
R2.	Displacement by non-natives
M1.	In-channel structural barriers to water, sediment, debris flow
M2.	Other structural barriers to water, sediment, debris flow (includes levees)
BB.	Sea level rise
I.	Derelict fishing gear

Figure 13: Relationship between PI Results and IV Index Scores (Figure 13 in McManus et al. 2014)

Intrinsic Vulnerability (IV) >>>		
	Higher IV/Lower 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.	**Higher IV/Higher PI** **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 **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.	**Lower IV/Higher PI** **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)>>>	

The PSPA included six stressors explicitly related to climate change. During the IV evaluation, experts were asked to rate current stressor intensity as well as predicted future stressor intensity based on UW Climate Impacts Group and other analyses for the year 2100. In the future expression scenario, changing ocean condition (includes water temperature; patterns and magnitude of upwelling events; nutrient and oxygen levels; and decreases in pH) became the highest ranked stressor for marine basins. Sea level rise also increased in rank.

PSPA STRESSOR RANKINGS RELATIVE TO GRANT PROGRAM INVESTMENTS

Table 11 compares Marine and Nearshore grants awarded between 2011-2014, the stressors these grants addressed, and total award value. This retrospective analysis shows that the PSPA stressor rankings for marine basins align well with the Grant Program's funding strategy.

The largest Grant Program investments focused on several highly rated stressors, and for the most part follow the management priority categories above. For example, oil spills had a lower PI but very high IV scores so they were funded at a level higher than the PI score alone would indicate. The relatively low investment in the four highly ranked toxics stressors is due to the cross-cutting nature of toxics work, lead by the Toxics and Nutrients Lead Organizations (administered by Ecology).

Table 11: Grant Program Investment Levels Compared to Stressor Potential Impact Rankings

Grant Program Investments	Stressors Addressed		Potential Impact Ranking	Rounds 1 - 4 Investment Value
6 property acquisitions to permanently protect nearly 307 acres of habitat, including 2.3 miles of shoreline. 4 estuary restoration projects to restore riverine and tidal processes to 360 acres, and enhance an additional 74 acres. 7 armor removal projects to restore more than 7 acres of beach habitat.	A1.	Conversion of land cover for residential, commercial, and industrial use	Moderate	$6,386,000
	A2.	Conversion of land cover for natural resource production	Very high	
	A3.	Conversion of land cover for transportation and utilities	Very high	
	C.	Shoreline hardening	High	
	M1.	In-channel structural barriers to water, sediment, debris flow	Moderate	
	M2.	Other structural barriers to water, sediment, debris flow	Lower	
WRIA 9 Marine Shoreline Monitoring and Compliance Pilot Project Targeted Outreach to Reduce Impacts from Shore Hardening in the PSMA Protecting Nearshore and Marine Habitat in Mason County Nearshore Permitting Effectiveness through T.A.C.T. Protecting the Strait of Juan de Fuca Nearshore Puget Sound Shoreline Master Program Improvement Marine Shoreline Design Guidelines Puget Sound Feeder Bluffs Mapping Compliance Assessment Social Marketing Strategy to Reduce Shoreline Armoring Quantifying the Impacts of Shoreline Armoring	A1.	Conversion of land cover for residential, commercial, and industrial use	Moderate	$2,643,000
	C.	Shoreline hardening	High	
	M2.	Other structural barriers to water, sediment, debris flow	Lower	

Puget Sound Derelict Net Removal and Pilot Response	I.	Derelict fishing gear	Moderate	$668,000
Toxic Contaminant Monitoring in Mussels Impacts of Outfalls on Eelgrass	U1.	Point source, persistent toxic chemicals in aquatic systems	Moderate	$402,000
	U2.	Non-point source, persistent toxic chemicals in aquatic systems	High	
	V1.	Point-source, non-persistent toxic chemicals in aquatic systems	Moderate	
	V2.	Non-point source, non-persistent toxic chemicals in aquatic systems	Moderate	
	X1.	Point source conventional water pollutants	Lower	
	X2.	Non-point source conventional water pollutants	High	
Ballast Water Management Assessment Assessment of Biofouling Threats to Puget Sound	R1.	Predation from non-native species	Lower	$290,000
	R2.	Displacement by non-natives	Lower	
Vessel Traffic Risk Assessment Community Engagement for Oil Spill Response and Readiness Preparing COASST Post-Spill Geographic Expansion of Seabird Survey and Early On-Scene Training Swinomish Oil Spill Preparedness Project	W.	Large spills	Lower	$696,000
Sea Level Rise and Cumulative Effects Management Tools	BB.	Sea level rise	Lower	$153,000

6.2 IMPLICATIONS

The rankings that emerged from the PSPA support a broad array of Puget Sound recovery decision and planning activities. They have informed ongoing development of 5-year LIO recovery plans, as well as prioritization of recovery strategies and sub-strategies for the 2016 Action Agenda update.

There are acknowledged limitations in the structure of the PSPA analysis that should be considered when interpreting results:

- McManus et al. (2014) point out that the PSPA does not map actual encounters between stressors and endpoints, only areas but where stressors and have the potential to co-occur.

- The authors stress that the PSPA did not consider synergistic or antagonistic affects across stressors, nor the initial condition of endpoints (e.g., intact or impaired). As a result, the PSPA stops short of being able to evaluate cumulative impacts of multiple stressors on endpoints, which may be very important for identifying management actions likely to have positive effects on key endpoints.

- Expert ratings are inherently subjective, with the perspectives and expertise of the participants having heavy influence on the results. PSPA results are not qualified by the identified expertise of the associated respondents. So it is unknown whether the high ranking of pollutants among the stressors is the result of a high number of specialists in this field among the respondents. The authors evaluated whether the results were biased by inherently optimistic or inherently pessimistic experts, by assessing the calculated intrinsic vulnerability scores by expert. They found significant overlap in the range of intrinsic vulnerability scores, providing confidence that there are not subsets of experts who are systematically different in their judgments than others.

- Bias in expert elicitation processes can be minimized with larger sample sizes. However, nearly 40% of the PSPA's intrinsic vulnerability scores were rated by a single individual. A review of the rating data by the authors found that both the highest and lowest scoring pairs were often those evaluated by only one expert. Using simple linear regression analyses, they determined the number of experts providing scores is a weak (but statistically significant) predictor of the pair score, with higher pair scores associated with higher number of scorers.

It is also important to keep in mind that prioritizing management actions depends on more than identifying stressors that have the most impact. Social and economic considerations, such as likelihood of success and perceived costs/benefits, must also be incorporated into these types of decisions (Samhouri and Levin 2012).

6.3 RECOMMENDATIONS

1) Continue to use the PSPA as a starting point for finer scale analyses by local integrating organizations (LIOs). It provides a common framework for more detailed local assessment efforts. At this scale it also becomes possible to integrate other types of knowledge from local stakeholders.

2) The Grant Program should consider placing additional emphasis on those stressors expected to become higher ranked in the future, given projected climate change scenarios. Given the very

high potential impact of and degree of scientific uncertainty associated with changing ocean conditions, more research and monitoring is warranted. Likewise, the significant coastal zone planning implications of sea level rise should make it a high priority at both the regional and local levels.

3) The PSPA authors suggest stressors or endpoints with high uncertainty in their ratings could be used to focus research and monitoring priorities. High uncertainty ratings are an indication of high expressed uncertainty by experts, or disagreement between multiple experts. NEP Lead Organizations/Strategic Implementation Leads and PSEMP Work Groups can use PSPA results to prioritize investments. Collection of quantitative research data can strengthen future PSPA amendments.
    - River deltas, embayments, beaches, rocky shores, and open water were endpoints with very high uncertainty.
    - Changing ocean conditions and shading of shallow water habitat were stressors with very high uncertainty, particularly as related to Pacific herring and surf smelt.

7. SUMMARY OF RECOMMENDATIONS AND RELATED NEAR TERM ACTIONS

This group of projects is generally well-integrated with ongoing programs and regional recovery efforts. Below is an overview of suggestions contained in this report for consideration during future funding rounds. Proposed Near Term Actions (NTAs)[35] relating to individual recommendations are noted.

1) Continue to support WDFW Aquatic Invasive Species and Ballast Water programs so that they can implement the risk criteria developed by Cordell et al. (2015) and Davidson et al. (2014). Additionally, policy issues involving changes to the state's Common Water Zone and the tradeoffs between invasive species and toxins management measures need to be resolved.

    - NTA 2016-0301, Copper-free boat paint implementation, Ecology, ranked 7 (Stormwater Strategic Initiative)

    - NTA 2016-0367, Puget Sound-wide zooplankton monitoring program, Long Live the Kings, ranked 66 (Habitat Strategic Initiative)

    - NTA-2016-0030, Assessing changes in marine water quality related to antifouling paints, Ecology, ranked 58 (Habitat Strategic Initiative)

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[35] **NTAs** are new programs, projects, investigations, or other actions intended to advance priority recovery sub-strategies. They are the core of the Implementation Plan component of the 2016 Action Agenda Update. Information on the fall 2015 solicitation, subsequent review process, and ranked lists of NTAs can be found on the Puget Sound Partnership's 2016 Near Term Action Proposals website.

2) Disseminate resources developed during the community oil spill preparedness grants to other Tribes, MRCs, and Local Implementing Organizations (LIOs) with an interest in developing or improving community oil spill response capabilities.

3) Encourage updates to Geographic Response Plans (GRPs). Identify specific locations where oil is likely to accumulate; access points and staging areas for responders; and high quality habitats where defensive measures can be prescribed. Tribes, local jurisdictions, and community organizations could contribute valuable knowledge to significantly increase the level of detail provided in current GRPs.

    - NTA 2016-0239, Shoreline segmentation: citizens improving oil spill response data, Northwest Straits Commission, ranked 66 (Habitat Strategic Initiative)

4) Use VTRA results to inform future investments in community preparedness programs and regional response planning. The San Juan Islands and Clallam County should remain target geographic areas.

    - NTA 2016-0138, Oil spill trainings to increase preparedness of the local communities, Clallam Marine Resources Committee, ranked 66 (Habitat Strategic Initiative)

5) Continue to support community preparedness programs, but consider encouraging alternative training strategies for volunteer activities. Certifying organization staff to deliver HAZWOPER training to their volunteers and/or moving to a "just-in-time" model could help reduce costs and volunteer attrition.

    - NTA2016-0322, Evaluate the status of marine birds at greatest risk from oil spills, Seattle Audubon Society, ranked 48 (Habitat Strategic Initiative)

6) Implement recommendations from and update the VTRA model. Previous work has established it as a valuable tool resulting in actionable recommendations to reduce oil spill risk.

    - NTA 2016-0400, Higher volume port area evaluation, Makah Tribe, ranked 8 (Habitat Strategic Initiative)

    - NTA 2016-0219, Puget Sound Vessel Traffic Risk Assessment update, Ecology, ranked 11 (Habitat Strategic Initiative)

    - NTA 2016-0362, Trans-boundary vessel safety summit, Makah Tribe, ranked 22 (Habitat Strategic Initiative)

7) Consider placing additional emphasis on stressors expected to become more impactful under projected climate change scenarios, such as changing ocean conditions and sea level rise.

    - NTA 2016-0089, Community-scale sea level rise and coastal hazard assessment in Puget Sound, Climate Impacts Group, ranked 2 (Habitat Strategic Initiative)

    - NTA 2016-0369, River sediment delivery to Puget Sound delta and nearshore environments, USGS, ranked 37 (Habitat Strategic Initiative)

- NTA 2016-0293, Puget Sound integrated coastal inundation modeling and mapping, USGS, ranked 37 (Habitat Strategic Initiative)

- NTA 2016-0405, Ocean acidification hotspots and sources of shellfish resilience, Department of Natural Resources, ranked 66 (Habitat Strategic Initiative)

- NTA 2016-0366, Encourage BMPs and behaviors that address nutrient-driven ocean acidification, Washington Sea Grant, ranked 93 (Stormwater Strategic Initiative)

- NTA 2016-0408, Add acidification parameters to Ecology monitoring network, Department of Ecology, ranked 132 (Habitat Strategic Initiative)

- NTA 2016-0063, Samish Bay and Padilla Bay oxygen, acidification, and bacterial submodels, Department of Ecology, ranked 189 (Habitat Strategic Initiative)

8) Map stormwater outfalls. Gaeckle et al. (2015) found there was little available information on the hundreds of stormwater outfalls that discharge into Puget Sound without NPDES permits. They recommended compiling information on key characteristics of these outfalls—including location, volume discharged, and drainage area—to enable analysis of their effects on nearshore biota.

    - NTA 2016-0193, Map stormwater outfalls in unpermitted MS4 areas, WDNR, ranked 10 (Shellfish Strategic Initiative)

8. ACRONYMS AND ABBREVIATIONS

BWWG	Ballast Water Work Group
COAAST	Coastal Observation and Seabird Survey Team
EAT	Early Assessment Team
Ecology	Washington Department of Ecology
EOSR	Early On-Scene Reconnaissance
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
HAZWOPER	Hazardous Waste Operations and Emergency Response
IV	Intrinsic Vulnerability
LIO	Local Implementing Organization
LO	Lead Organization
MLLW	Mean lower low water
MRC	Marine Resources Committee
NEP	National Estuary Program
NIS	Non-indigenous species
NOAA	National Oceanographic and Atmospheric Administration
NRDA	Natural Resources Damage Assessment
NTA	Near Term Action
NWACP	Northwest Area Contingency Plan
NWSF	Northwest Straits Foundation
PI	Potential Impact
PSEMP	Puget Sound Ecosystem Monitoring Program
PSP	Puget Sound Partnership
PSSS	Puget Sound Seabird Survey
RMM	Risk Mitigation Measures
RRT/NWAC	Region 10 Regional Response Team - Northwest Area Committee
RSMP	Regional Stormwater Monitoring Program
UGA	Urban Growth Area
VTRA	Vessel Traffic Risk Assessment
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WSP	Washington State Patrol

9. REFERENCES

9.1 MAJOR GRANT PROGRAM PRODUCTS

COAAST. 2014. Final Report: Preparing COASST Post Spill, WDFW Contract #12-1938. Deliverable to the Washington Department of Fish and Wildlife, and Department of Natural Resources.

Cordell, J., O. Kalata, A. Pleus, A. Newsom, K. Strieck, and G. Gersten. 2015. Effectiveness of Ballast Water Exchange in Protecting Puget Sound from Invasive Species: Results from WDFW/UW Ballast Water Sampling, 2001-2014. Report to the Washington Department of Fish and Wildlife and Washington Department of Natural Resources.

Davidson, I. C. Zabin, and G. Ruiz. 2014. An Assessment of Biofouling Introductions to the Puget Sound Region of Washington State. Report to the Washington Department of Fish and Wildlife and Washington Department of Natural Resources.

Gaeckle, J. 2012. Effects of Outfalls and Effluent on Eelgrass (*Zostera marina* L.): A Literature Review. Washington Department of Natural Resources, Nearshore Habitat Program. Olympia, WA.

Gaeckle, J. 2014. The Assessment of Nutrient, Metal, and Organic Contaminant Concentrations in Eelgrass (*Zostera marina* L) in Puget Sound, WA (USA): A Project Overview. Presentation at the 2014 Salish Sea Ecosystem Conference.

Gaeckle, J., L. Ferrier, and K. Sherman. 2015. Spatial Evaluation of the Proximity of Outfalls and Eelgrass (*Zostera marina* L.) in Greater Puget Sound. Washington Department of Natural Resources, Nearshore Habitat Program. Olympia, WA.

Labiosa, W., W. Landis, T. Quinn, R. Johnston, K. Currens, S. Redmond, and R. Anderson. 2014. Puget Sound Pressures Assessment Methodology. Puget Sound Partnership Technical Report 2014-02. Tacoma, WA.

Lanksbury, J.A., J.E. West, and L.A. Niewolny. 2012. Quality Assurance Project Plan: Mussel Watch Pilot Expansion Project. Prepared for the Washington State Department of Ecology.

Lanksbury, J.A., L.A. Niewolny, A.J. Carey, and J.E. West. 2014. Toxic Contaminants in Puget Sound's Nearshore Biota: A Large-Scale Synoptic Survey Using Transplanted Mussels (*Mytilus trossulus*). WDFW Report Number FPT 14-08.

McManus, E., K. Jenni, M. Clancy, K. Ghalambor, I. Logan, S. Redman, B. Labiosa, K. Currens, T. Quinn, W. Landid, K. Stiles, J. Burke. 2014. The 2014 Puget Sound Pressures Assessment. Puget Sound Partnership Publication #2014-04. Tacoma, WA.

Northwest Straits Foundation. 2015a. Community Engagement for Oil Spill Response and Readiness: Final Report for Project #12-9040. Deliverable to the Marine and Nearshore Grant Program.

Ross, T. and J. Joyce. 2014. Geographic Expansion of the Puget Sound Seabird Survey and Volunteer Training for Early On-Scene Reconnaissance Final Project Report. Deliverable to the Marine and Nearshore Grant Program.

Swinomish Tribal Community. 2014a. Final Report for Grant #12-1937, Swinomish Marine Oil Spill Response. Deliverable to the Marine and Nearshore Grant Program.

Swinomish Tribal Community. 2014b. Swinomish Marine Oil Spill Preparedness Project Standard Operating Procedures. Deliverable to the Marine and Nearshore Grant Program.

Van Dorp, J.R. and J. Merrick. 2014. Preventing Oil Spills from Large Ships and Barges in Northern Puget Sound & Strait of Juan de Fuca: VTRA 2010 Final Report. Prepared for the Puget Sound Partnership.

9.2 OTHER LITERATURE CITED

Bennett, B., E. Brooks, R. Walker. 2014. Deep Sea Incident: Oil Spill Response Capacity Enhancement Using Local Volunteers. Salish Sea Ecosystem Conference Paper 109.

Carmichael R., L. Green, C. O'Meara and M. Yarrow. 2009. Project documentation report: Public stormwater outfalls to Puget Sound. People for Puget Sound and UW Extension.

Department of Ecology and Puget Sound Partnership. 2011. Improving Oil Spill Prevention and Response in Washington State: Lessons Learned from the BP Deepwater Horizon Oil Spill. Publication Number: 11-08-002.

Halpern, B., C.V. Kappel, K.A. Selkoe, F. Micheli, C.E. Ebert, C. Kontgis, C. Crain, R.G. Martone, C. Shearer, and S.J. Teck. 2009. Mapping cumulative human impacts to California Current marine ecosystems. *Conservation Letters*. 2(3): 138-148.

Hanowell, R., C. Callahan, and J. Jensen. 2014. Final Report for the Mussel Watch Gradient Project. Ecology Grant Number G1200564. Tacoma-Pierce County Health Department, Tacoma, WA.

Greene, C.M., K. Blackhart, J. Nohner, A. Candelmo, D.M. Nelson. 2014. A National Assessment of Stressors to Estuarine Fish Habitats in the Contiguous USA. *Estuaries and Coasts*. 38(3):782-799.

Lanksbury, J. and J. E. West. 2011. Blue Mussels as Indicators of Stormwater Pollution in Nearshore Marine Habitats in Puget Sound. Olympia, WA. Washington Department of Fish and Wildlife/Puget Sound Assessment and Monitoring Program.

Mohamedali T., M. Roberts, B. Sackmann and A. Kolosseus. 2011. Puget Sound Dissolved Oxygen Model – Nutrient Load Summary for 1999-2008. Washington State Department of Ecology, Olympia, WA. Publication No. 11-03-057.

National Response Team. 2012. Use of Volunteers Guidelines for Oil Spills.

Northwest Straits Foundation. 2015b. Oil Spill Readiness and Response in Clallam County. Interview with Clallam County Marine Resources Committee members Mike Doherty, Arnold Schouten and Ed Bowlby. Accessed December 2015. <http://www.clallamcountymrc.org/media/1283/mrcclallam-interview-final.pdf>

Occupational Safety and Health Administration. Training Marine Oil Spill Response Workers under OSHA's Hazardous Waste Operations and Emergency Response Standard. Publication OSHA 3172.

Pacific States/British Columbia Oil Spill Task Force. 2008. Planning Guidelines for Convergent Volunteer Management. Guidance document prepared by L. Iwamoto, G. Knox, D. Byers, D. Pettit, C. Murphy, C. Martin, and C. Woodley.

Pacific States/British Columbia Oil Spill Task Force. 2011. The Stakeholder Workgroup Review of Planning and Response Capabilities for a Marine Oil Spill on the U.S./Canadian Transboundary Areas of the Pacific Coast Project Report.

PSEMP Toxics Work Group. 2014. Puget Sound Ecosystem Monitoring Program Toxics Workgroup Monitoring Priorities and Gaps. January 2014 Revision. Prepared by Davis, J., K. Dinacola, M. Dutch, J. Gaeckle, K. Godtfredsen, J. Hardy, C.A. James, D. Lester, L. Loehr, A. Markiewicz, D. Norton, S. O'Neill, S. Redman, C. Sullivan, and J. West.

Puget Sound Stormwater Work Group. 2010. 2010 Stormwater Monitoring and Assessment Strategy for the Puget Sound Region.

Region 10 Regional Response Team and Northwest Area Committee. 2015. Northwest Area Contingency Plan.

Samhouri, J.F. and P.S. Levin. 2012. Linking land- and sea-based activities to risk in coastal ecosystems. *Biological Conservation*. 145: 118-129.

Schwartz, M.W., K. Deiner, T. Forrester, P. Grof-Tisza, M.J. Muir, M.J. Santos, L.E. Souza, M.L. Wilkerson, and M. Zylberberg. 2012. Perspectives on the Open Standards for the Practice of Conservation. *Biological Conservation*. 155: 169-177

Smith, S. D. P., P.B. McIntyre, B.S. Halpern, R.M. Cooke, A.L. Marino, G.L. Boyer, A. Buchsbaum, G.A. Burton, L.M. Campbell, J.J.H Ciborowski, P.J. Doran, D.M. Infante, L.B. Johnson, J.G. Read, J.B. Rose, E.S. Rutherford, A.D. Steinman, J.D. Allan. 2015. Rating Impacts in a Multi-Stressor World: A Quantitative Assessment of 50 Stressors Affecting the Great Lakes. Ecological Applications. 25(3):717-728.

Susan L. Williams, S.L., I.C. Davidson, J.R. Pasari, G.V. Ashton, J.T. Carlton, R.E. Crafton, R.E. Fontana, E.D. Grosholz, A. Whitman Miller, G.M. Ruiz and C.J. Zabin. 2013. Managing Multiple Vectors for Marine Invasions in an Increasingly Connected World. *BioScience*. 63(12): 952-966.

Washington Department of Fish and Wildlife and Washington Department of Ecology. 2015. Quality Assurance Project Plan for Status and Trends Monitoring of Marine Nearshore Mussels for the Regional Stormwater Monitoring Program and Pierce County. WDFW Publication No. FPT 15-04.

Washington Department of Fish and Wildlife and Washington State Patrol. 2015. 2015 Report to the State Legislature. Washington State Aquatic and Invasive Species Prevention and Enforcement Program.

APPENDIX A: HIGH PRIORITY THREATS AND CROSS CUTTING ISSUES GRANTS

Table 12: High Priority Threats and Cross Cutting Issues Grants

Grant Title	Partners	Major Product(s)	Related 2014/15 Action Agenda Recovery Sub-Strategy
Ballast Water Management Assessment	WDFW and UW School of Aquatic and Fishery Sciences	Cordell et al. (2015) Effectiveness of Ballast Water Exchange in Protecting Puget Sound from Invasive Species	B5.3 – Prevent and rapidly respond to the introduction and spread of terrestrial and aquatic invasive species. B5.4 – Answer key invasive species research questions and fill information gaps.
Assessment of Biofouling Threats to Puget Sound	Portland State University and Smithsonian Environmental Research Center	Davidson et al. (2014) An Assessment of Marine Biofouling Introductions to the Puget Sound Region of Washington State	B5.3 – Prevent and rapidly respond to the introduction and spread of terrestrial and aquatic invasive species. B5.4 – Answer key invasive species research questions and fill information gaps.
Vessel Traffic Risk Assessment – Assessing Threats from Large Oil Spills	Puget Sound Partnership, George Washington University, and Virginia Commonwealth University	Van Dorp and Merrick (2014) Vessel Traffic Risk Assessment 2010 Final Report: Preventing Oil Spills from Large Ships and Barges in Northern Puget Sound and the Strait of Juan de Fuca	C8.1 – Prevent and reduce the risk of oil spills.
Community Engagement for oil Spill Response and Readiness	Northwest Straits Foundation	Northwest Straits Foundation (2015a) Final Report for Grant #12-9040	C8.2 – Strengthen and integrate spill response readiness of the state, tribes, and local government. C8.3 – Respond to spills and seek restoration using the best available science and technology.

Geographic Expansion of Seabird Survey and Early On-Scene Training	Seattle Audubon Society	Ross and Joyce (2014) Geographic Expansion of the Puget Sound Seabird Survey and Volunteer Training for Early On-Scene Training: Final Project Report	C8.3 – Respond to spills and seek restoration using the best available science and technology.
Preparing COASST Post-Spill	UW Coastal Observation and Seabird Survey Team	COAAST (2014) Final Report for Grant #12-1938	C8.3 – Respond to spills and seek restoration using the best available science and technology.
Swinomish Oil Spill Preparedness Project	Swinomish Indian Tribal Community	Swinomish Tribal Community (2014) (a) Final Report for Grant #12-1937 (b) Swinomish Marine Oil Spill Standard Operating Procedures Manual	C8.2 – Strengthen and integrate spill response readiness of the state, tribes, and local government. C8.3 – Respond to spills and seek restoration using the best available science and technology.
Toxic Contamination Monitoring in Mussels	WDFW	Lanksbury et al. (2014) Toxic Contaminants in Puget Sound's Nearshore Biota: A Large Scale Synoptic Survey Using Transplanted Mussels (Mytilus trossulus)	C1.1 – Implement and strengthen authorities and programs to prevent toxic chemicals from entering the Puget Sound environment
Impacts of Outfalls on Eelgrass	WDNR	Gaeckle et al. (2012) Literature Review - Effects of Outfalls and Effluent on Eelgrass (Zostera marina L.) Gaeckle (2014) The Assessment of Nutrient, Metal, and Organic Contaminant Concentrations in Eelgrass (Zostera marina L) in Puget Sound, WA (USA): A Project Overview. Gaeckle et al. (2015) Spatial Evaluation of the Proximity of Outfalls and Eelgrass (Zostera marina L.) in Greater Puget Sound	C1.1 – Implement and strengthen authorities and programs to prevent toxic chemicals from entering the Puget Sound environment
Puget Sound Integrated Risk Assessment	Puget Sound Partnership	McManus et al. (2014) The 2014 Puget Sound Pressures Assessment	D1.2 – Maintain and update the Action Agenda as the shared recovery plan

APPENDIX B: HIGH PRIORITY THREATS AND CROSS CUTTING ISSUES INVESTMENTS

Table 13: Advancing Priorities Identified in the 2011-2013 Biennial Science Work Plan

Action Agenda Strategy	Priority Science Action	Grant Product(s)
B5	Assess risks imposed by marine invasive species.	Cordell et al. (2015) Davidson et al. (2014)
C1	Develop integrated monitoring and assessment of toxic chemical sources, exposure, and effects.	Lanksbury et al. (2014) Gaeckle et al. (2014) Gaeckle et al. (2015)
C8	Evaluate existing oil spill risk assessments and complete additional risk analyses of higher risk industry sectors to ensure there are appropriate levels of investment in reducing risk.	Van Dorp and Merrick (2014)
C8	Evaluate information on baseline conditions for key species at risk from oil spills and improve these as necessary so that baselines exist that can be used in assessments of natural resource damages.	COAAST (2014) Ross and Joyce (2014)
D1	Conduct integrated risk assessments of the impacts of different pressures on the Puget Sound ecosystem.	McManus et al. (2014)