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A boundary spanning system supports large-scale ecosystem-based management

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ABSTRACT

Boundary spanning is a focused effort to facilitate the exchange of knowledge and information between producers (i.e., analysts, scientists, researchers, etc.) and users (i.e., decision-makers, policy makers, managers, etc.) in support of evidence-informed decision-making. Here we provide specific examples of approaches and products by a boundary spanning organization as part of a regional ecosystem-based management program. These examples illustrate a range of potential boundary spanning activities while also describing a more holistic boundary system that employs several complimentary and related approaches to improve the use of knowledge in decision-making across interfaces separating different institutions. This system is supported by, and indeed requires, a larger institutional framework that provides scaffolding upon which the boundary spanning operates. As described, the institutional framework is often not supplied solely by a single boundary spanning organization, but rather by a suite of cooperating institutions. Last, we discuss approaches to evaluating the various impacts of boundary spanning.

1. Introduction

Effectively managing ecological resources requires a holistic understanding of the scientific, policy, and programmatic frameworks within which management strategies are developed and implemented in order to make informed and evidence-based decisions (Cvitanovic et al., 2016). This follows the notion that evidence-based decision-making will lead to efficient allocation of limited financial resources and improved outcomes. The idea has been formally identified in some regulations and statutes that require the use of best available science during implementation (e.g., Endangered Species Act of 1973 U.S.C. 16 § 1536(a)(2) and Copley, 1999). There are typically, however, distinct scientific, policy-making, and managerial communities that do not naturally interact. This leads to gaps that impede communication, information exchange, and the successful incorporation of science into decision-making (Francis et al., 2005; Meagher and Lyall, 2013; Murphy and Weiland, 2016). Related challenges include, for example, that ecosystem-related research activities and programs are not often aligned with the key policy questions (Sutherland et al., 2011); there is often limited translation of research findings for the policy environment

(Lawton, 2007); and research findings may be perceived as lacking legitimacy or credibility, thereby reducing their potential to be accepted and used by decision-makers (Cash et al., 2003).

In response to these challenges, there have been numerous efforts to undertake boundary spanning activities (Guston, 2001; Kirchoff et al., 2013; Meyer, 2010; Meyer et al., 2015), which can be defined as focused efforts to enable the exchange of knowledge and information between knowledge producers (i.e., analysts, scientists, researchers, etc.) and knowledge users (i.e., decision-makers, policy makers, managers, etc.) to support evidence-informed decision-making (Bednarek et al., 2018). Boundary-spanning is an extension of the use-of-evidence field that aims to improve the flow and availability of research evidence to research users (Christie et al., 2020; Sutherland et al., 2019), and can support a variety of objectives using a wide range of approaches (Bednarek et al., 2015; Carlile, 2002; Cvitanovic et al., 2015; Dey et al., 2020; Guston, 2001; Kerkhoff and Lebel, 2006; Mollinga, 2010; Pietri et al., 2011; Sutherland et al., 2009, 2006, 2011). Effective boundary work is tailored to the local context and the intended uses of knowledge (Clark et al., 2016).

The practice of boundary spanning uses, and often relies on,

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boundary objects, such as maps, reports, articles, models, or standards that serve as tools (durable products) to facilitate and reinforce communication between communities (Clark et al., 2016). Importantly for this discussion, boundary objects operate at interfaces between communities or institutions, facilitating information exchange across those interfaces (Levina and Vaast, 2005). Boundary objects are a means of representing and transferring information across institutional and practical boundaries, translating that information to account for differences in perspective and to create shared meaning, and accounting for different interests that may impede sharing or interpretation (Carlile, 2002, 2004). They should be adaptable so that they support communication within and across different communities, yet robust so as to maintain identity and meaning (Clark et al., 2016; Star and Griesemer, 1989). Boundary spanning activities and boundary objects, therefore, both operate at interfaces between distinct sectors or communities of practice, supporting communication, collaboration, and coordination (Fong et al., 2007). A given boundary object may serve one or more of those roles. Specific examples include GIS outputs used for wetland delineation (Harvey and Chrisman, 1998), emissions scenarios for climate modelling (Girod et al., 2009), water resource management models (White et al., 2010; Zagona et al., 2001), and illustrative future land-use scenarios (Sarkki et al., 2019).

A recent value proposition describes the ways in which boundary spanning supports the development of credible, relevant, salient, and legitimate science (Bednarek et al., 2018). First, boundary spanning organizations and boundary objects increase the potential for durable decision processes and policies, particularly by *facilitating the integration of new information*. That is, to establish decision processes that persist and successfully weather changes in knowledge. Second, boundary spanning increases the efficiency by which science is tailored for consideration, and the probability that it will be used in the decision-making process, by *increasing the alignment between science/investigations and policy/decision-making*. Third, boundary spanning increases the legitimacy and robustness of science and technical information used in decision-making by *increasing its acceptance among a diverse set of participants in the knowledge exchange process*. This occurs via translation of scientific results, daylighting the scientific process, and diagramming its usefulness and applicability to decisions. Last, by scanning the policy landscape and context, boundary spanners can *identify when and how research results can meet decision-making needs*. This includes supporting the potential to capitalize quickly upon open policy windows to ensure decisions are supported by evidence.

Here we present a case study of a boundary spanning organization, the Puget Sound Institute (PSI), and numerous boundary objects (the products of PSI's work) in the context of a specific ecosystem-based management program (Table 1). First, we describe the system of organizations and relationships that guides and implements the ecosystem-based management and recovery program (in this case the Puget Sound National Estuary Program) as a framework for understanding the relevant interfacing communities, and the gaps between them that can inhibit information exchange. Second, we describe the system of boundary objects and boundary spanning activities that bridge these gaps, facilitating information exchange and increasing the use of knowledge in decision-making. We explore the example boundary objects and boundary spanning activities in terms of the proposed value proposition of boundary spanning, and end with a discussion about the impact of the boundary spanning organization in this case.

We focus on this example because the boundary spanning activities described herein are associated with an ecosystem management program that guides restoration and recovery in a complex environmental system. Management of complex environmental systems is a global challenge and therefore this case study may be of broad relevance to other ecosystem-based management programs. This case study provides a novel example of an organization working at many community interfaces, providing multiple functions, and producing a suite of boundary objects, which is a departure from the more-singularly focused

Table 1

Examples of boundary objects developed in support of regional ecosystem-based management planning and implementation under the Puget Sound National Estuary Program.

Boundary Spanning Value	Puget Sound Institute Boundary Spanning Objects
Increase efficiency by which science is tailored for consideration in decision-making	Lead Organization Syntheses Implementation Strategy State of Knowledge Reports Uncertainties and Knowledge Gaps Implementation Strategy Research and Monitoring needs
Increase the potential for durable decision processes and policy	Implementation Strategy Starter Packages/State of Knowledge Reports & Base Program Analyses <i>Salish Sea Currents</i> Encyclopedia of Puget Sound
Increase legitimacy and robustness of science	Lead Organization Syntheses Uncertainties and Knowledge Gaps Implementation Strategy Research and Monitoring Needs
Capitalize on policy opportunities	Lead Organization Syntheses Base Program Analyses <i>Salish Sea Currents</i> Encyclopedia of Puget Sound

boundary spanning typically presented in the literature.

2. Background to the Puget Sound recovery planning process

The Puget Sound ecosystem enjoys a rich history of science-informed restoration programs driven by water quality impairments, the presence of multiple culturally- and economically-valuable fish stocks, marine mammals protected under the U.S. Endangered Species Act, and federal trust responsibilities to uphold fishing rights reserved by Northwest Treaty Tribes.

A substantial portion of the Puget Sound ecosystem-based management program is contained within the U.S. Environmental Protection Agency (EPA) National Estuary Program (NEP); Puget Sound is one of 28 designated estuaries of national significance under the NEP. The NEP supports several institutions and processes that contribute to recovery planning and implementation (Fig. 1). Regional ecosystem recovery objectives have been identified and are tracked through a list of 25 key measures (known as Vital Signs; <https://vitalsigns.pugetsoundinfo.wa.gov/>) that collectively describe the condition of the Puget Sound ecosystem. Examples of these Vital Signs include estuary and floodplain extent and function, water quality, forage fish abundance, and sense of place. Recovery targets define the desired condition for each of the Vital Signs, and priority actions to achieve these recovery targets are laid out in a regularly-updated Action Agenda, as mandated by Washington State law.

The organizational framework of the Puget Sound NEP includes several key institutions that contribute to ecosystem management (Fig. 1). These include: the regional EPA, which provides program administration and coordination within the Federal offices; the Puget Sound Partnership and its advisory boards, which provide guidance on scientific and restoration priorities, coordination, and restoration performance evaluation; and the Strategic Initiative Lead Organizations (“Lead Organizations”), which oversee the award and administration of NEP funds and the development and management of focused recovery plans for the Vital Signs (known as Implementation Strategies). Interdisciplinary advisory committees are responsible for the development of recovery plans, with input from the broader restoration community and the public. These interdisciplinary advisory teams are comprised of a diverse array of participants from the regional recovery community, including representatives of implementing and management agencies, staff from funding and planning organizations, and researchers and academics. The Puget Sound Institute, a boundary-spanning organization

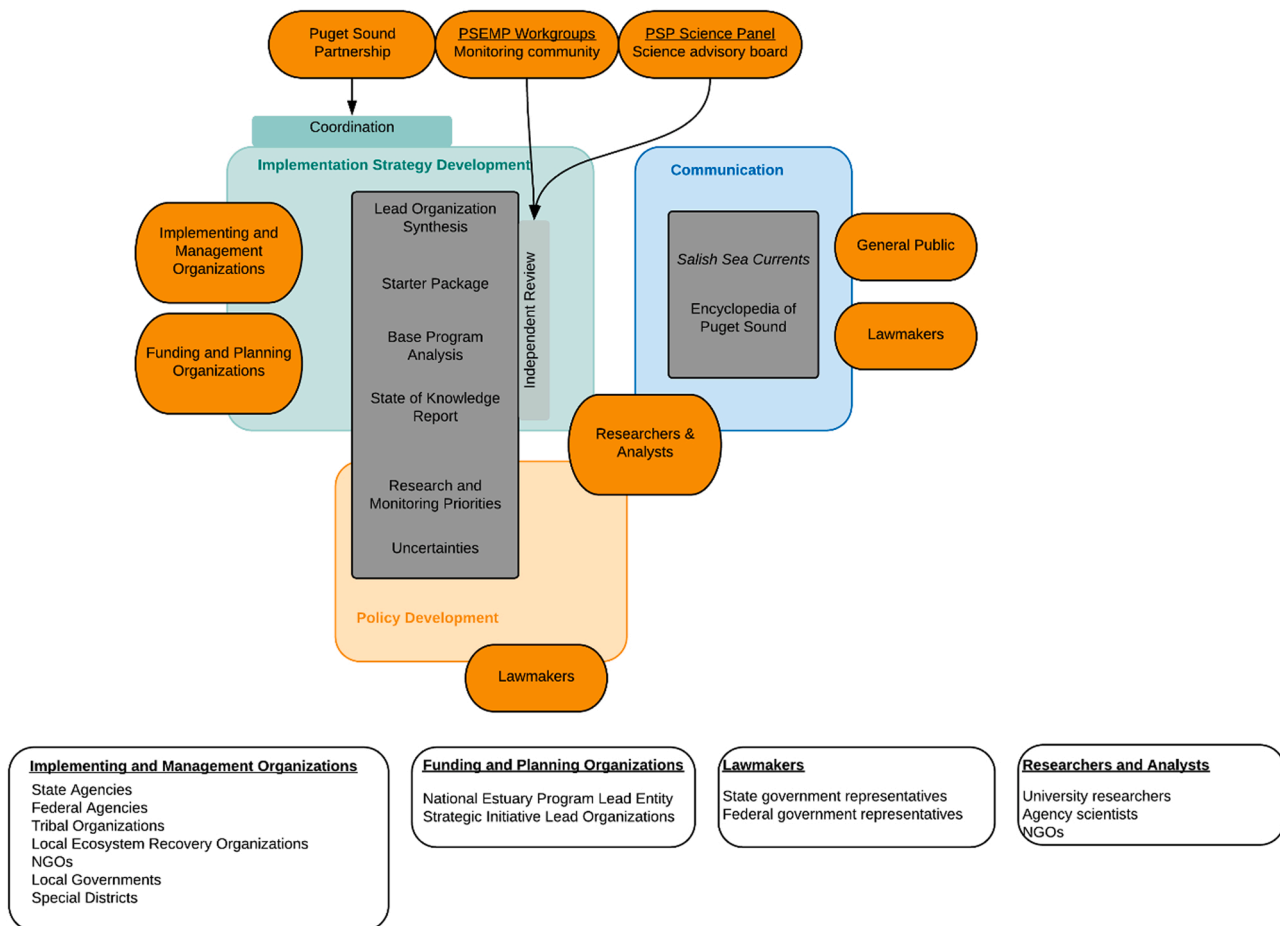


Fig. 1. The Puget Sound Institute (PSI) boundary spanning system. The figure depicts PSI's work at interfaces between Researchers and Analysts on the one hand, and multiple communities that use research and analysis results on the other (orange ovals): via Implementation Strategy Development (green box), Policy Development (pale orange box), and Communication (blue box). Boundary objects (grey boxes) are developed and employed at those interfaces to facilitate the transfer of knowledge among communities. Individual institutions support the system via coordination and independent science review. The specific constituencies of each community are listed in the white boxes.

works to ensure that scientific and technical information is considered and reflected in recovery planning and implementation. Prior to its creation, there was no independent institution with the capacity to address technical issues associated with regional ecosystem recovery and planning, or to facilitate the co-production of ecosystem-relevant knowledge. The Puget Sound Institute is a university-affiliated research institute that does not report directly to a regulatory agency. It is staffed by university researchers with a range of expertise including environmental chemistry and water quality, ecosystem ecology, computational and qualitative modeling, and environmental policy, and their respective restoration contexts, providing technical capacity across a broad array of recovery science and policy issues.

The importance of the restoration planning and management framework in the Puget Sound context is that it establishes the interfaces where boundary spanning is appropriate and necessary (Fig. 1) and provides structure for the use of boundary objects. These interfaces span communities that broadly include research and analysis, planning, program implementation, policy making, the general public, and restoration funding. This constellation of communities is common to most restoration programs, though in other programs there may be differences in connections, or bridges, across the interfaces that define the local need for boundary spanning and the use of boundary objects (Fong et al., 2007).

The Puget Sound Institute strategically engages at multiple points in the restoration planning and management framework with the aim of bridging interfacial gaps and ensuring functional links between

research, planning, and decision-making. Decision-making and implementation occur at many points in the recovery system, which requires spanning boundaries of many types. There are multiple Federal agencies (e.g., Puget Sound Federal Task Force, 2016) that coordinate with sovereign Tribes, Washington State agencies and the Governor's office, county- and city-level implementing organizations, and special purpose districts creating a decentralized decision-making framework, with multiple opportunities and needs for boundary spanning. Additionally, many of the participants in this recovery environment may be affected by institutional burdens associated with limits on jurisdictional authority, regulatory focus or constraints, and/or political or management influence. This creates the scenario of organizational missions that, while not necessarily in conflict, are not always well aligned. This further highlights the need for an independent organization that can operate across institutional boundaries, and help maintain focus on specific and common goals. Due to this complexity, which is likely a common feature of large-scale ecosystem-based management programs, there is a need for boundary-spanning activities that are broadly applied, and boundary objects that are broadly used. A selection of case studies describing the application of boundary objects at different institutional interfaces is described in more detail below.

3. Boundary spanning case studies

The Puget Sound Institute has employed several approaches and strategies to link knowledge to decision-making in support of Puget

Sound restoration programs. We illustrate these with several specific examples centered around the development and use of Implementation Strategies, the regional recovery plans focused specifically on the Vital Signs (regional recovery goals). The Implementation Strategy recovery plans identify approaches and activities that are expected to achieve recovery targets and, importantly, are developed under processes that engage the above-mentioned interdisciplinary advisory teams of subject matter experts, including researchers, research users, planners, natural resource managers, and other stakeholders, to co-produce each recovery plan. This venue provides explicit opportunities for the application of boundary objects to span interfaces between these disparate communities. The development of an Implementation Strategy provides a mechanism for the incorporation of scientific and technical information into planning, decision-making, and implementation, and the programs and plans identified therein are supported via focused NEP funding.

In this section we describe boundary objects (Table 1) developed to span different interfaces, including the processes within which they are developed and their use, and then link them to the boundary spanning value proposition.

3.1. Boundary object – Program synthesis: addressing interface between analysts and funders

The Puget Sound Institute produces synthesis documents that summarize and analyze completed and ongoing NEP-funded recovery projects with the intention of identifying and communicating the best available knowledge and lessons learned to support recovery planning and funding decisions. Synthesis results are aimed at informing Lead Organizations, the regional coordination agency (PSP) and its boards, and the scientific community, and intended to be incorporated into strategic planning. These syntheses are scoped and developed in coordination with the Lead Organizations but are independent products.

One such synthesis focused on a set of 25 individual grants for the restoration and protection of watersheds throughout Puget Sound (Wright, 2020), a grant program led from 2011 to 2017 by one Lead Organization. The grants supported local governments to incorporate environmental needs into land use planning, urban development, climate adaptation planning, and critical areas protection in priority watersheds. PSI analyzed over 350 grant-related documents, including project activity and financial reports, maps, meeting notes, economic analyses, and presentations; conducted 23 semi-structured interviews; and administered questionnaires co-created with the Lead Organization.

Recommendations in the synthesis report included updating feasibility studies of the transfer of development rights programs (a zoning technique to conserve lands by redirecting development) to better reflect recent urban and rural population growth trends, investing in paid facilitators of stakeholder meetings, and improving data management, stewardship and access. Another finding was that a lack of publicly accessible data and narratives made it difficult to communicate the results of watershed modeling, land-use planning, and GIS mapping to policy makers and the public. More than a dozen projects produced maps of some type; however, only four were available online, and most had data quality and replicability issues. Importantly, an analysis of grantee perspectives on successes, challenges, and next steps resulted in recommendations back to the Lead Organization for future funding that builds directly on past investments and therefore are more likely to lead to recovery targets being met.

The intention of syntheses is to integrate across different information sources and data types to identify key methods, concepts, and lessons learned (Rodrigo et al., 2013), to distill disparate results into a coherent understanding of broader systems, and help improve the design of future research (Akasofu, 2007). Consistent with these notions, the programmatic syntheses performed by the Puget Sound Institute, of which the watershed program synthesis is one example, are boundary objects that facilitate information exchange across the interface between researchers on the one hand, and implementers, funders and planners on the other,

by highlighting and bringing forth the lessons learned by the former to the latter. They serve as boundary objects in that they support the transfer and translation of information between communities (Carlile, 2004). The intentional scoping of the syntheses with partners at funding and implementing agencies, the Puget Sound Partnership, and resource managers increases the alignment between research results and research use, and the synthesis development helps create a shared understanding of the work from the perspective of all parties. The syntheses result in clear, communicable next steps (improving transfer and translation) that, because they were scoped with many of the institutions involved in the recovery processes, can provide useful information that aligns with diverse organizational objectives. They capture information that may otherwise have been lost and, in this particular case, improved access to research products, specifically through the categorization and summarization of a variety of documents from disparate sources – a majority of which were not available digitally and had never been shared outside of intra-department networks. At its most basic level, this synthesis made information more widely available. In addition, the funding agencies used the findings from the synthesis to support the adoption of best practices identified in the report (Habitat Strategic Initiative, 2021), including those associated with technology, data management, storage stewardship, and digital communications materials, showing that the boundary-spanning activities increased the potential for uptake of research results, which is one of the posited values of boundary spanning (Bednarek et al., 2018).

3.2. Boundary object – Technical and programmatic knowledge base: addressing interface between research, planners and implementers

Ecosystem recovery plans are most effective when they are based on a solid foundation of technical information, including the best available research and monitoring results, as well as a comprehensive understanding of the regulatory and programmatic environment within which solutions might operate. A technical foundation helps ensure that proposed strategies, approaches, and solutions will have the desired ecosystem effect and are technically sound. A regulatory and programmatic background provides an understanding of ongoing programs across jurisdictions that are relevant to ecosystem recovery, as well as regulatory opportunities and restrictions within which ecosystem recovery operates. Such a foundation may include the evaluation of current approaches and identify where existing strategies are most likely to succeed or new strategies could add capacity and/or address gaps. Developing a shared understanding of this technical and policy landscape provides a vital context for researchers and research users to jointly produce recovery strategies.

To establish this shared understanding, Puget Sound Institute staff produce a document at the outset of the Implementation Strategy development process, termed the “Starter Package,” that provides a foundational baseline of technical and programmatic information. This document is scoped collectively by the interdisciplinary advisory team, and the results are subsequently presented back to the full team responsible for developing each recovery strategy so that all team members have a shared base of knowledge to supplement their individual areas of expertise, and to establish a common context among recovery practitioners. This has been identified as a fundamental value of boundary objects (Fong et al., 2007).

During the course of Implementation Strategy development, this knowledge base is expanded according to specific requests and needs identified by the interdisciplinary team, focusing on information that would support decision-making and planning (e.g., ecosystem dynamics, stress-response relationships, available analytical tools, previous management interventions and their effects, etc.), often resulting in additional analysis or a literature review. The initial Starter Package is expanded by Puget Sound Institute staff throughout the development of the Implementation Strategy to ultimately form two separate and intentionally aligned documents: a State of Knowledge report, focusing

on technical research and monitoring, and a Base Program Analysis, focusing on programs, policies, and regulations. For example, if a State of Knowledge report provides detailed technical information describing the relationships between water quality, land use, and land use changes, the Base Program Analysis might describe regional land use regulations. The documents incorporate input from the full interdisciplinary advisory team and undergo public and independent peer review (see Fig. 1), thereby increasing their legitimacy. The result of this effort is a comprehensive and co-produced knowledge base that supports informed decision-making. These reports serve to anchor the process of Implementation Strategy development and adaptive management by basing restoration actions and future research on the best available information, and by providing opportunities for communities to collaborate, coordinate, and communicate informational needs. Importantly, they are intended to be regularly reviewed and updated with new information as it becomes available, such as via new research results. As boundary objects, they sit at the interfaces between researchers and analysts, implementing and management organizations, and funders and planners.

The development and updating of these documents increase the potential for durable decision-making processes, another value of boundary spanning. By simultaneously establishing a foundation of technical information and the governance landscape within which recovery planning occurs, and by intentionally identifying cross-system linkages, understanding about the transdisciplinary aspects of the system is increased. As such, the resulting recovery strategies are more likely to reflect multiple perspectives. Our experience suggests that the co-development of a technical and programmatic knowledge base increases participant awareness of opportunities for restoration and the limitations of existing approaches, which leads to improved products and increased flexibility to new evidence or changes in the governance landscape during the adaptive management process. The documents serve as boundary objects that facilitate these processes and outcomes.

3.3. Boundary object – Technical and programmatic knowledge base: addressing the interface between research and policy makers

The Base Program Analysis and State of Knowledge reports also function at the interface between researchers/analysts and policy makers (Fig. 1) by serving as foundational work designed, in part, for the utilization of policy windows. The ability to quickly respond to the appearance of policy windows with actionable information increases the likelihood that information will inform decision-making (Bednarek et al., 2018), supporting the case for ongoing evaluation of the decision landscape and preparation of relevant boundary objects to allow for rapid response to opportunities.

In a first example, the Puget Sound Institute prepared a set of materials over a period of several years that were designed to be ready-for-use by decision-makers. The documents focused on the restoration of shorelines through the removal of shoreline stabilization structures (e. g., bulkheads, seawalls, revetments, known collectively as armor); the existence of such structures was identified as a contributing factor in the decline of Puget Sound Chinook salmon (NOAA, 2005). Chinook salmon recovery is a priority for conservation of a group of orcas known as Southern resident killer whales, a population of great concern in the Puget Sound region. A Puget Sound Institute synthesis and analysis of NEP-funded projects (another example of a Lead Organization synthesis described above) highlighted opportunities to improve shoreline regulatory outcomes through improved permit application review and enhanced enforcement under the Washington State Hydraulic Code and Shoreline Management Act (Kinney et al., 2016). This synthesis work subsequently informed the content of the Base Program Analysis and State of Knowledge reports for a Shoreline Armoring Implementation Strategy (Habitat Strategic Initiative, 2018). Both the early synthesis and the Implementation Strategy were developed based on an awareness of the policy landscape associated with shoreline armor, the removal of

which was expected to support Chinook salmon and orcas in Puget Sound; this information was therefore expected to potentially be invoked as part of policies to recover either population.

The Shoreline Armoring Implementation Strategy, and specifically its regulatory recommendations, provided a readily available and credible source of policy options for a Southern Resident Orca Task Force created by the Washington State governor in March 2018 to develop a long-term action plan for orca recovery and sustainability. In July 2018, a Puget Sound orca known as Tahlequah carried her dead calf for 17 days while traveling with her pod. Widespread media coverage of Tahlequah “grieving” the calf captivated the public and created a clear policy window. Late pregnancy failure and perinatal loss has been associated with low availability of Chinook salmon prey (Wasser et al., 2017) and this event led Washington’s Legislature to take several decisive actions to bolster the supply of Chinook salmon to orcas. Bills passed during the 2019 state legislative session were in line with the recommendations of the Orca Task Force, which based its habitat protection recommendations on the Shoreline Armoring Implementation Strategy, including increased agency operating budgets to improve compliance with shoreline regulations and increased civil penalties for permit violations.

A second recommendation from the Shoreline Armoring Implementation Strategy Base Program Analysis (Kinney, 2018) was to encourage armor removal by increasing financial incentives in the form of a loan program for landowners. As the result of the analysis and subsequent boundary work (see below), the author, a PSI staff member, was invited to deliver a U.S. congressional brief on the topic and provide input to two related bills. One recommendation was included as language in a bill that passed in the United States House of Representatives. These examples show that ongoing preparation of boundary objects and translation of technical information can facilitate the uptake of research during a policy window. Importantly, they demonstrate that having research-informed and pre-vetted policy solutions at the ready allows for a quick response to unexpected opportunities to influence policy making.

3.4. Boundary object – Research and monitoring priorities: addressing the interface between research, managers, and funders

As described above, in the Puget Sound NEP framework, focused ecosystem recovery plans (Implementation Strategies) are co-developed via interdisciplinary teams and describe a set of priority strategies to achieve established recovery targets. During the strategy development process, priority information needs, research and monitoring gaps, and technical uncertainties are identified. This is done by: first, cataloging all questions, uncertainties, and knowledge gaps identified by the interdisciplinary team during the strategy development process; second, reviewing and categorizing the questions/uncertainties based on the amount of information currently available and/or scope of investigation required to resolve them; and third, evaluating each question/uncertainty/knowledge gap according to the extent to which it is relevant to recovery and/or the effectiveness of the recovery strategy. Examples include understanding the effectiveness of management interventions, identifying priority ecosystem stressors, or understanding landscape patterns in critical habitats.

The systematic identification of priority uncertainties and curation of uncertainty lists are conducted by the Puget Sound Institute with input from members of the interdisciplinary team, who not only identify the full suite of uncertainties, but also contribute directly to the prioritization process, which may culminate in a simple voting exercise to define a final short list of 4–6 research and monitoring priorities for each recovery plan. This participation helps ensure that knowledge users (implementers, managers, funders, and planners) and knowledge producers (researchers and analysts) work together across the institutional interfaces on the co-identification of key information needs which may, subsequently, receive priority for funding. It is also a means of capturing

and evaluating research needs that align with different areas of institutional focus. As an example, the interdisciplinary team for an Implementation Strategy focused on toxic contaminants in marine fish indicated that understanding the occurrence and impacts of anthropogenic organic compounds (e.g., pharmaceuticals and vehicle fluids) was a priority for effectively recovering fish health and fish populations; a set of projects investigating the issue was subsequently funded via NEP. In contrast, understanding the effectiveness of wood stove replacement programs, which likely had little regional impact on contamination of the marine environment, was deemed to be a low programmatic priority and so this research question was archived. As with the above-described State of Knowledge Reports and Base Program Analyses, these uncertainty lists are intended to be regularly updated as new information closes individual knowledge gaps; the Puget Sound Institute serves this function to bring new information from the research community to the Implementation Strategy teams via these uncertainty lists. The ranked list of priority uncertainties thus serves as a boundary object connecting researchers/analysts with recovery planners, implementers, and funders by facilitating information exchange between the community of researchers, who are often unaware of the restoration planning process, and planners and implementers, who are often disconnected from the research enterprise. The list is robust in each community, in that the uncertainties are simultaneously described in terms of scientific knowledge gaps, a concept that resonates with researchers, and policy or implementation needs, which speaks to the policy, planning, and implementation communities. The uncertainties lists also serve the shared purpose of directing research activities towards their most effective use in achieving restoration goals.

Identifying research and monitoring priorities in this way leads to durable decision processes by facilitating knowledge exchange across a network of stakeholders within an adaptable system, which encourages working relationships beyond this activity. A living, co-produced list of research questions and needs serves as an avenue for the incorporation of new information into decision-making, which ultimately makes the restoration planning process more consistent and robust. Additionally, it increases the legitimacy of research by transparently discussing and addressing key knowledge gaps that, through an open process, can improve and contextualize both policy needs and research results, thereby improving the legitimacy of research results across a broader range of actors (Gibbons, 1999).

3.5. Boundary object – Encyclopedia of Puget Sound and Salish Sea Currents: addressing the interface between researchers, policy makers, and the general public

The complexity of restoring and managing an ecosystem such as Puget Sound poses an immense informational challenge. Additionally, the interdisciplinary nature of relevant science requires broad understanding and collaboration among disparate stakeholders (Hoelting et al., 2014). Technical information must be translated for non-experts, including policy makers (Fig. 1), and must be conveyed rapidly to take advantage of policy windows (Cvitanovic et al., 2015; Hoelting et al., 2014; Ruckelshaus et al., 2010). These challenges are addressed in the current context in two ways: through the online Encyclopedia of Puget Sound, which is a baseline information resource focusing on the Puget Sound ecosystem, and through the regular publication of magazine-style stories focused on the science driving ecosystem recovery; both of which are produced by the Puget Sound Institute.

The Encyclopedia of Puget Sound (eopugetsound.org) is a boundary object created to improve access to the best available science in support of Puget Sound policy and decision-making. It grew out of a series of peer-reviewed syntheses describing key ecosystem components and relevant restoration approaches (Ruckelshaus et al., 2010) and has since been expanded and regularly updated with topical articles and research summaries. It is overseen by an editorial board, a group of technical experts who provide peer review and content through a topic editor

system (Parr et al., 2014). The Encyclopedia of Puget Sound offers a big-picture view of the Puget Sound recovery enterprise, provides factual details, such as lists and descriptions of species of concern, and collates reference materials that might otherwise be difficult to access. Because we operate at the interface between researchers, and policy makers and the general public, content is intentionally made accessible: material is focused, written in plain style, and not hidden behind pay walls. Such curation ensures that information is comprehensive, accurate, relevant and resonant with a broad audience.

To further support information exchange across this interface, the Puget Sound Institute creates a variety of online communication products including fact sheets, magazine articles (the *Salish Sea Currents* series), short-form blogs and social media posts focusing on the latest Puget Sound recovery-related science and policy news. These products synthesize important facts and provide compelling stories that are meant to engage and inspire. They are written to be accessible and timely in ways that peer-reviewed scientific articles or policy papers may not be. Communication products are aligned with ongoing recovery work and describe the science driving recovery strategy development and implementation. These stories often reach thousands of readers and in some cases have catalyzed regional and national press coverage, further expanding their impact. Examples include international coverage of PSI's report on the discovery of traces of opioids in blue mussels in Puget Sound (<https://www.pugetsoundinstitute.org/2018/05/psi-research-on-opioids-in-mussels-receives-international-coverage/>), and a PSI blog post on the above-referenced need for financial incentives to support shoreline restoration. The latter was a catalyst for eventual congressional testimony and policy change (<https://www.pugetsoundinstitute.org/2019/09/psi-study-will-look-at-potential-of-low-interest-loans-for-armor-removal/>). These communication products are boundary objects in this context as they transfer and translate information and knowledge between different communities in the recovery space (Carlile, 2004). This translational effort increases the acceptance of scientific results and information across a diverse set of users and so supports the boundary spanning enterprise by facilitating the integration of new information into decision processes.

4. Discussion

The Puget Sound ecosystem recovery framework and the diverse set of boundary objects described herein contribute to our understanding of the role of boundary spanning and boundary objects in ecosystem restoration programs, and the conditions within which boundary spanning can be effective, in several ways. First, it demonstrates that boundary spanning often operates within a broader framework that links distinct communities by a common program or purpose, drawing into sharp relief the interfaces between them. Second, programmatic boundary spanning may be comprised of a suite of activities and objects that often overlap and reinforce one another, resulting in a boundary spanning system. Last, there are a broad range of measures required for understanding the impact and value of a boundary spanning enterprise beyond observable uses of research results in policy.

The case studies highlight the framework and related interfaces that are essential for effective boundary spanning. In the present case, the Implementation Strategy development process under the regional NEP provides the scaffolding that supports boundary spanning activities, including the production of boundary objects. Our experience suggests that this particular institutional structure is not determinant in the success of boundary spanning, but rather that there are several key functionalities that are necessary, and that could be met through alternative arrangements. The functionalities include: a focused program or initiative that sets context, goals, and targets; a collaborative space where the recovery community can participate in discussions and planning relevant to the program; coordination across stakeholder groups; and an outlet and/or destination, such as recovery strategies or a funding program, that can respond to recommendations and support

programs, projects, and research, even to a limited extent. In the example of the Puget Sound NEP program, many of the elements that are needed for boundary spanning are supported by organizations other than the Puget Sound Institute (Fig. 1). For example, the recovery planning framework was initially defined by a multi-institutional group including the PSP, EPA, the Lead Organizations, and Puget Sound Institute. The interdisciplinary team for each Implementation Strategy is convened and supported by a regional coordinating body (PSP) and the relevant Lead Organization.

Taken together, the case studies describe a boundary spanning system consisting of a boundary spanning organization and related boundary objects, that overlays onto the scaffolding of the ecosystem recovery program. The range of engagement and products illustrated here provide an example of an overarching boundary spanning system that aims to produce relevant, salient, and legitimate science and then facilitate the incorporation of that information into regional decision- and policy-making processes. It is a system consisting of a suite of boundary spanning objects and activities that are related and span multiple interfaces (Fig. 1). This is a departure from many examples of boundary objects, often described as individual products developed to address singular issues (Fabbe-Costes et al., 2020; Harvey and Chrisman, 1998; Sarkki et al., 2019; White et al., 2010). However, such focus is rarely applicable for ecosystem-based programs, which are often obliged to consider multiple stressors affecting a range of ecosystem services while engaging the broad suite of communities involved in protection and restoration (Imperial and Hennessey, 1996). As such, we suggest there is value in recognizing opportunities for a system of boundary spanning.

The boundary objects and activities illustrating this systematic approach, and described herein, can be linked to the elements of the value proposition of the boundary spanning enterprise (Bednarek et al., 2018) in singular and overlapping ways (Table 1). That is, they increase the efficiency by which research is aligned with decision-making, support and maintain the knowledge exchange systems and framework, improve the salience and legitimacy of science, and provide timely information to active policy development processes. The approach of generating a suite of interacting products provides multiple opportunities to address key barriers to knowledge exchange including accessibility, relevance, and timeliness (Hering, 2016). Information accessibility is increased through communication and direct interactions in interdisciplinary team meetings and other decision-making venues, establishing shared language for knowledge to be expressed, taken up, and jointly transformed, and for differences across boundaries to be expressed, understood, and bridged (Carlile, 2002). The continual involvement of the boundary spanning organization with the environmental management and policy communities helps ensure that key information is responsive. The diverse products and boundary spanning activities center the role of the boundary-spanning organization, which may have the result of increasing – if only through repetition – long-lasting, trusted relationships that contribute to the effectiveness of the overall boundary spanning enterprise.

A challenge associated with understanding the value of boundary spanning and boundary objects is directly linking activities to measurable or instrumental impacts, where research and research activities directly influence policy and decision practices (Nutley et al., 2009). A more comprehensive evaluation should also consider non-instrumental impacts (Lyll et al., 2004; Meagher and Lyall, 2013), which can include: changed thinking or increased awareness; increased capacity and technical understanding, resulting from education, training, and collaboration; changed attitudes, especially towards knowledge coproduction and exchange; and enduring connectivity, especially between researchers and knowledge users.

Non-instrumental impacts can be seen in the translation of research results presented in the Encyclopedia of Puget Sound and *Salish Sea Currents* (Section 3.5), which provide information in digestible forms to a broad range of stakeholders in the recovery community. While it is

difficult to map these translational articles directly to policy outcomes, the readership statistics and robust conversations associated with publications strongly suggest an increased awareness of the issues raised. Another example stems from the Shoreline Armoring Implementation Strategy where the uncertainty prioritization (Section 3.5) process identified the relationship between shoreline armor removal and near-shore fish population health as a key barrier to strategy development. The process of identifying and documenting this uncertainty raised awareness in researchers and led to a focused nearshore research project that was subsequently funded (https://pugetsoundestuary.wa.gov/wp-content/uploads/2019/12/SOS-HabitatSI_NEP_Factsheet_v2-002-2.pdf). Similarly, the Watershed Lead Organization synthesis (Section 3.1) raised awareness among recovery program funders about the need to support publicly available data and mapping in order to effectively communicate with key stakeholders.

Capacity building is another non-instrumental impact of the boundary spanning enterprise that results from co-learning between researchers and research users about research design and analytical approaches on the one hand, and designing actionable research questions on the other (Francis et al., 2018). In the present case, this co-learning occurs specifically during the exercise focusing on identifying research and monitoring priorities (Section 3.4). The exercise requires research users to develop capacity in experimental design and implementation to better understand which questions can be reasonably addressed. It also requires that researchers and analysts broaden their understanding of programmatic needs. This process likely also leads to changed attitudes among participants about the value of knowledge co-production.

Enduring connectivity, especially between researchers and knowledge users, is another non-instrumental impact of boundary spanning activities. In the present case, the boundary spanning organization represents the research community, through the State of Knowledge Reports (Sections 3.2 and 3.3), syntheses (Section 3.1), and uncertainty lists (Section 3.4). The scaffolding of the recovery planning system and the system of activities and products of Puget Sound Institute provide one pathway for continued engagement, but there are additional ongoing activities that demonstrate enduring connectivity. PSI staff are routinely called upon to provide technical consultation to the implementing and research community on a variety of fronts, such as the production of additional synthesis products for the implementing organizations, advising the science advisory panel and the backbone organization on developing future scenarios and the use of models in evaluating management scenarios, and providing expert testimony during discussions of legislation. All of these reflect enduring connectivity between knowledge producers and users.

In many ways, boundary spanning is a field in its nascent phase. While individual researchers have long histories of engaging in applied research, or use-inspired basic research (Stokes, 2011), there is recognition that a far more in-depth and involved process is needed to bring research results to bear on decision-making, and that efforts by individuals and organizations engaged in this practice go well beyond those typical of applied researchers. The need to invest in such organizations and individuals is accepted in some fields, e.g., education and human health (Coburn et al., 2013; Penuel et al., 2015), but the environmental sector lags behind in building a community of practice and value proposition for boundary-spanning. Because engaging boundary spanners requires additional investment, making the case for the effectiveness and impact of boundary spanning is a priority.

5. Conclusions

Recent work has presented specific value propositions for boundary spanning (e.g., facilitating the integration of new information, increasing the alignment between science/investigations and policy/decision-making, increasing its acceptance among a diverse set of participants in the knowledge exchange process, etc.). Here, we offer a

series of examples from one boundary spanning organization at work in a complex ecosystem-based management context to highlight practical examples against these theoretical constructs. We suggest that boundary spanning need not be depicted by stand-alone activities, but rather as a connected system of objects and engagements that, taken as a whole, have the effect of increasing the relevance of research and technical information for recovery and restoration planning, and more broadly, policy and decision-making. Additionally, we highlight the aspects of an institutional framework that provide key processes and enabling conditions for boundary spanning, and which set the stage on which boundary spanning is more likely to succeed. We argue that, while these processes are fundamental for boundary spanning to satisfy the value propositions, it is not necessary that they be provided by the boundary spanning organization, or any single organization in particular. Our experience suggests that there is value in recognizing these in the development and application of boundary spanning activities, particularly in complex systems.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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