Collaboration within the Puget Sound Marine and Nearshore Scientific Community

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ABSTRACT

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Scientific research is essential to supporting ecosystem recovery efforts. Given limited time and financial resources, funding entities may be interested in factors that influence the 'impact' of research findings on recovery processes. This analysis explores one characteristic of scientific research that may be linked to the impact of results: collaboration among researchers and between researchers and policy makers who use scientific information. A multi-method social network analysis describes the network of Puget Sound researchers studying Puget Sound marine and nearshore ecosystems in order to inform recovery. The collaboration network structure, derived from 253 online surveys, is explained and contextualized using 20 qualitative key-informant interviews. The scientific network involved in Puget Sound recovery consists mainly of individuals trained in natural sciences, with 60% of nodes reported to have training in ecology, 48% in biology, and 38% in fisheries

science. Human dimensions disciplines with the greatest representation of training included policy analysis (12% of all nodes), sociology (4%) and economics (4%). The discussion highlights factors reported to facilitate or inhibit success of collaborative research efforts such as leadership, incentives, and long-term adequate funding. Additionally, the degree to which a collaborative research model can be linked to 'high impact', policy-informing research outcomes is addressed. Researchers, science communicators, and policy makers are motivated to collaborate because they feel that collaborations more effectively address complex policy concerns that have social and ecological dimensions. Yet, persistent challenges to interdisciplinary, collaborative research including limited funding, institutional barriers, and disciplinary 'cultural' barriers remain. This study begs the question, given the current research effort and forms of collaboration, of whether these activities are strategically informing Puget Sound management pursuits.

1. INTRODUCTION

The Puget Sound Partnership (PSP or Partnership) is a Washington State agency tasked with restoring Puget Sound ecosystem health by 2020. As part of this effort, the Partnership is directed to encourage and support collaborative efforts that contribute to the recovery of Puget Sound (Puget Sound Partnership 2012). In the field of natural resource management, there is increasing recognition of the importance of collaborative, interdisciplinary research, which has been found to generate more complete, balanced and useful results (Omenn 2006; Christie 2011). In addition to collaboration within the scientific community, collaboration between researchers, managers and policy makers can increase the impact of scientific findings (Weber 1998; Weber et al. 2010).

This report is based on a study that was conducted between September 2012 and January 2013. The Partnership hired a team of researchers from the University of Washington to provide a description of the collaborative network within the Puget Sound research community. The team sampled primarily scientific researchers investigating topics within one priority science area of the Partnership's Biennial Science Workplan: marine and nearshore ecosystems. In recognition of the importance of collaboration beyond the scientific community itself, the sample was defined broadly to be inclusive of managers and policy makers working on marine and nearshore issues.

This report draws from multiple sources of information and methods. Using data from three distinct methods of inquiry allows for the triangulation of recurring and prominent themes from study informants (Miles and Hubermann 1994; Patton 2001). Results of an online survey provide a map of the overall network of collaboration and useful illustrations of collaborative ties within and between sub-networks such as topical focus areas (e.g. researchers working on salmon), disciplines (e.g., natural and social sciences) or institutions (state, federal, academic, and non-governmental). Throughout this report, elements of social network analysis are used to describe and illustrate characteristics of the Puget Sound science network in conjunction with an inductive, exploratory qualitative research approach (Miles and Huberman 1994; Rubin and Rubin 2005; Yin 2008.) Detailed insights from key-informant interviews and focus groups are used to expand traditionally limited and brief survey data, offering more context about topics such as incentives that lead researchers to collaborate, and barriers to collaborative efforts. In addition, interview and focus group participants spoke about characteristics of research that seem to have 'high-impact' regarding Puget Sound Recovery. The term 'high-impact' is defined below.

By comparing these insights to a framework presented by Weber (1998), the study concludes with recommendations that may help facilitate more effective and functional collaborations in a socio-ecological setting such as Puget Sound. Future analyses using these data could focus on describing the form and factors influencing the structure of the overall network and sub-networks, as well as exploring other themes that emerged from the qualitative dataset.

1.1 Definitions: 'Collaboration' and 'High-Impact Research'

For the purposes of this study (and as defined in research instruments used), 'collaboration' is defined broadly to encompass diverse interactions, which could include direct collaboration on shared research projects, consulting with researchers to discuss ideas and get feedback, sharing research findings, or participation in the same panel, committee, or volunteer program, or other group or activity. Survey respondents were asked to nominate the first 5-10 individuals that came to mind with whom they personally collaborate. Focus group participants and key-informants were asked to explain how and why they collaborate on research related to Puget Sound marine and nearshore ecosystems.

In addition to discussion of incentives and barriers to collaboration, informants were asked to comment on aspects or qualities of research that lead to results gaining traction and momentum toward Puget Sound recovery. For the purposes of this analysis, 'high-impact research' is defined as research with outcomes that directly catalyze or inform measurable recovery, restoration, or policy changes affecting Puget Sound marine and nearshore environments.

It is important to note that the research collaborations under discussion in this study are not always assumed to have 'high impact' on policy as a primary end goal; the network maps included in study results are inclusive of collaborative relationships formed with a wide range of motivations and end goals. For example, a great deal of important research collaboration is focused on the function of Puget Sound with the goal of increased scientific knowledge rather than immediate policy application. It is also important to emphasize that the focus of this research on collaborative research does not discount the contribution and high impact of the work of individual researchers.

It is helpful to clarify that during focus groups and interviews, informants often referred to two generalized forms of collaboration: 1) collaboration between several researchers to successfully complete a research project, and 2) collaboration between researchers and managers, policy makers or other end users to increase the applied utility of results. Some 'collaborative research projects' may involve both of these forms, while others involve only one. Additionally, within each of these two broad categories, a number of specific types of collaborative arrangements are possible, some of which are addressed in this report. In all cases, collaborative ties represent close working relationships between individuals in the network, but it is important to keep in mind that there are a wide variety of incentives that lead to the formation of close working relationships. A summary of the incentives cited by informants is included in the results section of this report.

2. METHODS

This paper is based on data collected using multiple methods, including focus groups, interviews, and an online survey. The primary sampling target was researchers focused on one priority science area of the Partnership's Biennial Science Workplan: marine and nearshore ecosystems. However, sampling was also inclusive of managers and policy makers working on marine and nearshore issues, as well as researchers focused on topics closely related to marine and nearshore environments.

A primary goal of the online survey was to capture the structure of collaborative ties within this network. In this report, results of the online survey are used to map the overall network as well as to describe factors influencing various characteristics of these maps. Focus group results helped frame this study by providing initial lines of inquiry and shaping the survey and key-informant interview guides. Focus groups and key-informant interviews generated qualitative data about informants' experience of incentives and barriers to collaborative research, characteristics of successful collaborative research, and qualities of successful collaborators. These results provide additional context to help explain patterns observed in the networks.

2.1 Sample Selection

Science and policy leaders were selected for participation in one of two focus groups (Olympia and Seattle) based on their employment, publication record and participation in recognized Puget Sound science and policy organizations. In total, 16 individuals participated in the focus groups. Focus groups were implemented before key-informant interviews and survey data collection began. Interview and survey data collection took place simultaneously. In addition to qualitative data collected during focus group conversation, focus group participants provided nominations of potential informants to be included in key-informant interviews and/or circulation of an online survey.

In total, 20 key-informants were interviewed through the course of this study. In addition to key-informants nominated during focus groups, additional potential informants were nominated by subsequent study participants in a snowball sampling approach. In order to achieve a balance of research interests, disciplinary training (natural and social science, policy/manager), and institutional affiliation (individuals representing federal, state, and tribal governments, universities, and non-profits), nominated individuals in underrepresented affiliations or disciplines were prioritized for inclusion in the study..

The list of potential survey respondents was developed by 1) soliciting suggestions of relevant researchers from focus group and interview informants, 2) review of Salish Sea Ecosystem Conference presentation records, 3) institutional and personal websites, and 4) publications. The primary target of the survey sample was scientific researchers, but all individuals suggested by senior Puget Sound policy makers and researchers consulted were included in the list of potential respondents. A unique link to the survey was emailed to a total of 388 possible respondents. At the conclusion of data collection, a total of 222 complete responses were received (57.2% response rate), along with 31 partial responses (for a total response rate of 65.2%). Data from partial responses were included in analysis.

It is also important to note that there are a total of 522 nodes in the network presented in this report. Just under half of these nodes (253) are the survey respondents themselves. The remaining 269 nodes represent individuals who were nominated as collaborators by survey respondents either chose not to respond to the survey or were not included in the original list of potential survey respondents.

2.2 Analytic Methods

Data analysis was divided into qualitative and quantitative methods of exploration. Generally, survey data were analyzed using quantitative approaches, while focus group and key-informant interview data were analyzed qualitatively. In some instances, open-ended survey data were analyzed qualitatively using the methods outlined below.

2.2.1 Quantitative Analyses

The online survey generated information about ties between actors in the network, as well as characteristics of individual actors such as their disciplinary training, employer(s), and funding sources. Ties between actors and characteristics of individual actors are illustrated using the social network analysis software UCINET. Statistical measures calculated using UCINET include network density and several measures of centrality (actor degree centrality and actor betweenness centrality). In addition to network statistics, basic correlation analysis was conducted on a small number of variables using the Statistical Package for Social Sciences (SPSS) (Field 2010).

Density is defined as the fraction of the number of ties in the network divided by the total possible ties. A graph with no ties would have a density of 0, while a graph with all possible ties would have a density of 1. Actor degree centrality is defined as the total number of ties to an individual actor. Betweenness centrality is a measure of the probability that an actor in the network will provide a communication path between other actors. The 'actor betweenness index' is a sum of the probabilities over all pairs of nodes that the actor in question will be located on the path of communication (Wasserman and Faust 1994).

Collaborative relationships in the network of Puget Sound researchers are assumed to be reciprocal – to lack 'directionality'. In a non-directional network, no distinction is made between in-degree and out-degree ties. This affects resulting measures of density and centrality, because whether or not both actors in a pair of nodes have each nominated the other, the relationship is assumed to flow in both directions. This makes sense in a study examining collaborative relationship, because by definition 'collaboration' indicates that the actors work together.

However, despite the assumed reciprocal nature of collaboration, the directional concepts of 'in-degree' and 'out-degree' ties remain important in this analysis. If an actor has a high number of in-degree ties, they are considered to have high 'prestige' in the network, having been nominated many times by other actors. If an actor nominates many others in the network, he/she will have a high number of out-degree ties. These concepts can help distinguish between those actors most frequently sought out as collaborators and those who most frequently reach out to others with the desire to collaborate.

2.2.2 Qualitative Analyses

Qualitative data analysis uses an inductive, exploratory approach that becomes more deductive as concepts become more grounded in empirical evidence (Miles and Huberman 1994; Rubin and Rubin 2005; Yin 2008). The qualitative data analysis software, ATLAS.ti v.7 (Scientific Software Development), was used for coding and organizing data from focus group and key-informant interviews. Several open-ended questions in the survey provided additional qualitative information. Narrative was coded based on a priori defined topics and major themes, which emerged repeatedly during focus groups, surveys and interviews. Throughout the coding process, theoretical memos were developed in which the meanings of themes were assessed and links to survey data identified. Potential new lines of inquiry were highlighted and pursued in subsequent key-informant interviews. Results are related to relevant frameworks describing high-impact, successful collaborative research (Cummings and Kiesler 2005, Jakobsen et al. 2004, Weber 1998, and Weber et al.

2010). The qualitative research helped explain the general patterns described in the network analysis (Miles and Hubermann 1994; Patton 2001).

3. RESULTS AND DISCUSSION

A primary goal of this study was to characterize and illustrate the collaborative network of the Puget Sound research community. Results of data collection include maps of the network, as well as qualitative analysis of interview and focus group responses. Social network analyses are used predominantly for descriptive purposes and for comparison with more detailed qualitative data. Interview and focus group responses are analyzed to address incentives and barriers to collaboration, how collaboration can be fostered, as well as what types of research seem to have high-impact toward Puget Sound recovery. Survey data were collected from a total of 522 individuals, including the 253 survey respondents and an additional 269 individuals who were nominated as collaborators but did not personally fill out the survey. Survey respondents were asked to provide information about each of their collaborators, including discipline, topical areas of focus, and employer.

The network analysis presented in this report focuses primarily on these characteristics that are available for all 522 nodes. Survey respondents were also asked to provide detailed information about themselves. Additional variables available for analysis of the sub-sample of survey respondents include academic training, funding sources, whether or not they conduct research and/or work in policy, venue(s) in which they find the most productive exchange of scientific information, factors that influence their choice of research questions, and qualitative responses to several open-ended questions regarding incentives and barriers to collaboration. A descriptive analysis of some of these variables is presented in this report. Future analyses could utilize the larger, more detailed dataset to explore specific questions about variables that may explain the presence or absence of ties between nodes.

Qualitative focus group and key-informant data were coded into 28 themes based on topics defined *a priori* as well as major themes that emerged repeatedly (Miles and Hubermann 1994). These results serve to extend and provide explanations of network data generated by the survey. In addition, several open-ended survey questions provide qualitative data regarding incentives and barriers to collaboration. Responses to these open-ended questions were received from 178 of 253 survey respondents, and were categorized into themes based on frequency of occurrence. Details from qualitative analyses serve as the primary source of data informing the policy recommendations presented in the final section of the report.

The Results and Discussion section is divided into six sections: 1) descriptive statistics of the entire network sample, 2) descriptive statistics of the survey respondent sub-sample, 3) network maps, 4) qualitative results – incentives and barriers to collaboration as well as fostering collaboration and high-impact research, and 5) key actors and egonetworks.

3.1 Descriptive Statistics of the Entire Network Sample

Respondents were asked to identify their disciplinary training as well as the topical areas upon which their work is focused. In addition, they were asked to identify the disciplines and topical areas of their collaborators. Respondents were not restricted to selection of one discipline and topical area, and most selected multiple responses in both categories (Figure 1.).

The greatest percentages of nodes were reported to have training in natural science disciplines, with 60% of nodes trained in ecology, 48% in biology, and 38% in fisheries science. Human dimensions disciplines with the greatest representation of training included policy analysis (12% of all nodes), sociology (4%) and economics (4%) (Figure 1A). It follows that the greatest percentages of nodes reported focus on topics having to do with biological, ecological, or physical processes (natural sciences). The greatest percentages were reported to study habitat (49%), restoration (36%), water quality (35%), salmon (32%), and food webs (32%). Social science or policy-related focus areas studied by the greatest percentages of nodes included decision-making processes (19%), policy implementation (17%), policy effectiveness (16%), public awareness (15%), environmental perceptions (13%), and costs and benefits of management decisions (13%). In addition to the checklist of possible topics provided to survey respondents, topics such as algae and seagrass, climate, disease, sediments, shellfish, aquaculture, groundfish, tourism and recreation, human health, and stormwater were included within the 'other topics' focal area (Figure 1B). It is important to note that in some cases, those trained in specific natural science or social science disciplines are working within focus areas that are not distinctly natural or social science..

In addition to discipline and topical focus area, survey respondents were asked to note their employer as well as the employers of their collaborators. The greatest percentages of nodes in the network were employed by academic institutions (34%), while 23% worked for federal agencies and 16% worked for Washington State agencies. The employer categories with the least representation in the sample were industry (1%), public outreach and education (0.4%), and funders (0.2%). In addition, there were seven nodes in the network (1.3%) for which no employer was reported.

3.2 Descriptive Statistics of the Survey Respondent Sample Only

When analyzed separately from other nodes in the network, the dataset from the 253 individuals that directly responded to the survey includes a greater number of variables available for analysis. Several additional descriptive statistics are presented here that relate only to the sub-sample of survey respondents. These include whether the respondent was personally engaged in research and/or policy and management, level of education, academic institutions where survey respondents received their highest degree, breakdown of funding sources, influence of funding availability and management needs on choice of research topic, and venues where survey respondents feel they achieve the most productive exchange of scientific information.

Approximately 74% of survey respondents (187 out of 253) reported that they are personally engaged in conducting research, while 42% (107 out of 253) reported that they work in policy or management but also supervise and collaborate with researchers. Twenty-seven percent of respondents characterized their professional role to include both research and policy/management. Of the more than 64% of respondents who identified themselves as "only" working in one area or the other, a larger percentage worked only in research. Approximately 10% did not respond to either question, and are categorized as 'other'.

Respondents were asked to provide the institution(s) where they received academic training, and the type of degree they received. A majority of respondents hold Ph.D.'s, and all hold at least a Bachelor's degree. People who attended the same academic institutions may have created and maintained professional linkages. Of the total 253 survey responses considered in this dataset, 239 provided information about their institutions. When considering only where respondents received their highest degree, a total of 171 different institutions were named. The institution that was most frequently attended by respondents was the University of Washington (40% of respondents received their highest degree there). Other institutions that stood out in the sample were Western Washington University (5% of respondents attended), University of California, Davis (4%), Oregon State University (3%), Evergreen State College (2%) and University of California, San Diego (2%). All other institutions made up fewer than 1% of the total sample. A majority of these institutions were identified two or fewer times.

Those respondents who indicated they were personally involved in conducting research were asked to list the primary funding sources that fund their research. Of the total 189 individuals who were posed this question, 188 provided information about their funding sources (Figure 2A). The majority of funding sources reported by survey respondents were federal government agencies (56%), and the next largest category was state government agencies (19%). Respondents were also asked to rate the degree to which funding availability influences their choice of research questions, on a scale of 1 to 5, where 1 = no influence and 5 = greatest influence. Of 192 respondents who provided an answer to this question, the greatest number rated the influence of funding at level 4 (71 respondents - 37%), and the second greatest number ranked it at level 3 (60 respondents - 31.25%) (Figure 2B). Respondents were also asked to rate the degree to which policy and management needs influence their choice of research questions, on a scale of 1 to 5, where 1 = no influence and 5 = greatest influence. Of 193 respondents who provided an answer to this question, just under half rated the influence of policy and management needs at level 4 (88 respondents - 46%), while 45 respondents (23%) rated it at level 3 and 24 (18%) rated it at level 5 (Figure 2C).

Respondents were asked to select one or more different venues that they considered to provide the most productive exchange of scientific information. Of the five options presented in the survey instrument (during the normal work day; the Salish Sea

Ecosystem Conference; collaborative research projects; informal gatherings or social settings; panels, boards or working groups; other), the most frequently chosen were 1) collaborative research projects (29%), and 2) during the normal work day (25%). In addition, some respondents chose to include an open-ended 'other' response. The most common 'other' responses referred to conferences and workshops other than the Salish Sea Ecosystem conference.

3.3 Collaborative Network Maps

Using UCINET, the collaborative relationships reported by survey respondents were visualized to represent the overall network of 522 nodes. In addition, sub-networks separated from the overall network based on specific criteria can be illustrated. Figure 3A shows a map of the entire network, illustrating all nodes including the 253 survey respondents and the 269 nominated collaborators who did not personally fill out the survey. The network has an overall density of 0.007 +/- 0.0831. The density measure is primarily useful as a baseline for identifying changes over time, or to compare against collaborative networks of similar size. It is important to note that density is not expected to hold constant when comparing networks of different sizes, or types of relationships (Scott, 2000). Figure 3B limits the network to include only survey respondents who reported that they personally conduct research (189 nodes). The density of this network is 0.017 +/- 0.1299.

As can be visualized by the network maps, the overall Puget Sound science network as well as the smaller 'researcher only' network, are both dominated by natural scientists. A cluster of social scientists appears to work closely together, while some social and interdisciplinary scientists are also scattered throughout the network. This relative isolation of social scientists indicates there may be significant areas of opportunity for integration of human dimensions work with the natural science community, as well as opportunity for creating more balance in the scientific agenda. Increased interdisciplinary collaboration across this boundary could have the potential to open up whole new ways of framing issues, and solutions, that may be obscured due to the lack of communication and understanding that can be inferred from the network map.

3.4 Qualitative Results

Participants in focus groups, interviews, and the online survey were asked to identify incentives they feel contribute to collaborative research efforts as well as barriers that detract from collaboration. This study defined collaboration broadly and sampled researchers and non-researchers. Data regarding both collaborations *between researchers* and *between researchers and non-researchers* were included equally in this analysis. Responses to open-ended questions in the online survey were grouped into categories based on the number of times a particular type of response was observed. Results of interviews and focus group discussions provide an expanded understanding of the individual incentives and barriers identified by survey respondents.

3.4.1 Incentives toward Collaboration

The first of the open-ended survey questions pertains to respondents that answered "yes" to the survey question: "Are there incentives for you to collaborate with researchers?" The open-ended question is then: "If yes, what are the incentives?" The following are the most frequently stated responses in order of frequency. Many of the total 178 survey respondents who answered this question provided more than one response, for a total of 226 distinct responses:

1. Incentives regarding the need for information or other resources that are not readily available (76 respondents)
    - Unfamiliar methods made available by consulting another researcher
    - Access to complementary data
    - Access to additional areas of expertise
    - Additional field sampling access through other researchers' activities
    - Increased diversity of ideas and other ways of thinking about problems
2. Incentives regarding funding (69 respondents)
    - Increased likelihood of receiving grants
    - Increased access to funded projects
    - More efficient use of existing funding
3. Incentives regarding the increased quality or impact of project outputs (46 respondents)
    - Higher quality science
    - Increased effectiveness of scientific results
    - Better research proposals
    - Can accomplish more projects
4. Incentives regarding personal rewards or other intrinsic benefits (35 respondents)
    - Collaborative work is more interesting
    - Increased motivation and inspiration
    - Increased creativity
    - Increased excitement
    - Gaining new perspectives/learning

As a complement to the incentives identified in the survey, focus group and key-informant interview participants were asked to identify factors that help facilitate collaboration. Many focus group responses reflected similar themes of cost savings, personal motivations, and a need for information or expertise that was not readily available without collaborative efforts. Key-informants reiterated a number of the incentives raised in focus groups and surveys, such as the motivation of increased funding opportunities or cost savings. In addition, key-informants also identified personal incentives to be important drivers motivating them to collaborate. At times, the incentive was identified as a personal desire to do the best job possible and to make a difference in their field, even if their job does not necessarily require that level of dedication.

> *"Incentives [for collaboration] are few and far between. For those who just truly want to make a difference or influence policy and management, then the incentives are more personal and not often rewarded in a departmental sense."* (Independent, interdisciplinary researcher)

"I like collaborating because I am interested in science. I didn't want to [conduct natural science research] personally, but it's intriguing so I like working on big projects." (Independent social scientist)

"Necessity is not really the case. You don't need to reach out to do your job, but if you want to solve problems in real places it is a necessity." (Federal funds manager for Puget Sound restoration)

The above quotes demonstrate that diverse informants find utility and fulfillment in pursuing collaborative relationships, especially when considering how they meet their personal and professional goals.

3.4.2 Barriers to Collaboration

The second open-ended survey question states: "What are challenges or barriers to collaboration with researchers?" The most frequently stated responses to this question follow. Some of the total 148 survey respondents who answered this question provided more than one response, for a total of 167 distinct responses:

1. Challenges associated with time constraints (75 respondents)
    - Time spent maintaining collaborative relationships
    - Respondents are generally overworked
    - Time spent researching potential collaborative projects
    - Time spent learning about others' areas of expertise
    - Difficulty in coordinating schedules
2. Challenges with funding (68 respondents)
    - Funding is generally lacking for long-term collaborative projects
    - Institutional funding structure does not lend itself to collaboration
    - Costs associated with travel for meetings with collaborators
    - Lack of funds to support the effort of seeking collaborations
3. Challenges with varied institutional cultures or vision (24 respondents)
    - Varied agency mandates and expectations can lead to poorly-focused studies
    - Researchers and policy-makers have different purposes for their work
    - Generally incompatible institutional policies or "red tape"
    - Competing long-term and short-term goals

When focus group participants were asked to identify challenges and barriers to collaboration, their responses strongly corroborated survey data describing barriers associated with time constraints, lack of funding, and variable priorities. Funding seems to be a particularly complex subject, as it can act both as an incentive and a barrier to collaboration. In the cases where collaborative funding is available, it incentivizes researchers to collaborate. However, the general lack of these types of funds, or the lack of funding structures that permit creative collaborations, also prevents the collaborative process from occurring freely. Key-informant interview participants were not specifically asked to comment on their perceived barriers to collaboration, however, a number of respondents voluntarily identified barriers to collaboration through the course of conversation. Many of these barriers pertain to information already learned from the survey and focus groups, such as time and funding challenges, but a few interesting points differed, such as challenges caused by the inherent transaction costs associated with starting new interdisciplinary collaborations.

> *"…it's risky due to the opportunity and transaction costs that come with collaboration when you're working with new disciplines, and there's always a long start up speaking the same language due to jargon in some new collaborations."* (Independent, interdisciplinary researcher)

> *"The lingo, literally the language and terms are not well understood between disciplines."* (Federal agency policy maker and science supervisor)

Indeed, transaction costs, particularly costs involving time constraints, are an important point that has been highlighted as a defining feature of collaborative projects involving researchers and policy makers and interdisciplinary research teams (Cummings and Kiesler 2005, Jakobsen et al. 2004, and Weber 1998). Ideally, collaborative arrangements in which various skills, knowledge, or resources are combined should decrease the overall transaction costs of conducting effective research, otherwise there would be little to no incentive to participate. However, transaction costs are not the only factors that influence collaborative processes, and as Weber (1998) noted, reduction of costs alone may not be sufficient incentive to participate in successful collaborations. As noted in the survey data, key-informants also remarked upon frustrations experienced due to varied institutional cultures and lack of recognition as additional barriers to collaboration. Additionally, as has also been noted by Jakobsen et al. (2004) and Cummings and Kiesler (2005), respondents mentioned problems of generalized institutional failures in establishing collaborative relationships and commitments.

> *"Having people be self-aware enough to place themselves in a collaboration is something we don't teach, and it doesn't get recognized."* (Academic interdisciplinary researcher and science supervisor)

> *"You didn't get the feeling that the Partnership was really looking for partners among scientists."* (Academic natural science researcher)

> *"…there were a lot of internal staff management problems [at the PSP]….there was no feedback like there was in the Shared Strategy [for salmon recovery] where we would give science, then they would implement it, then they would come back with another follow-up question and we would analyze that."* (Independent, interdisciplinary researcher)

Fostering sustained collaborations is complex and difficult. The creation of incentives, norms and mechanisms to foster collaboration are essential. While there is clearly considerable communication and collaboration taking place in the realm of Puget Sound nearshore science, various informants are concerned that mechanisms to sustain collaborations are lacking. Researchers and policy makers frequently feel challenged to meet the demands of their appointed positions, as well as Puget Sound recovery. Sustained collaborations suffer as personnel are stretched thin in the workplace.

3.4.3 Researcher-specific incentives and barriers to collaboration

During the analysis of collaborative incentives and barriers, it became clear that active researchers have specific collaborative circumstances that differ from non-researcher constituents of the Puget Sound nearshore science community. This is particularly true for researchers working within the academic community, where differences in the cultures of academic research and applied research became readily apparent. Some respondents felt that the incentives to collaborate outside normal institutional boundaries were present and growing.

> *"I think NOAA science benefits from having a connection to academic science because I think it keeps the science more up to date. Then academics strongly benefit from being able to work on applied research because it makes our research more relevant."* (Academic natural science researcher)

> *"As a scientist, [it is becoming] clearer and clearer that human activities are driving changes, and it is good for me to work with people understanding the drivers of human dynamics. The applied ecology literature is increasingly moving toward interdisciplinary science, so the bar for getting papers published is getting higher and higher for actually doing interdisciplinary work."* (Federal agency natural science researcher)

However, many respondents also felt that these institutional challenges remained problematic in promoting cross-institutional, interdisciplinary collaborations. There are barriers of language, norms, and prestige, particularly in an academic setting.

> *"…if you want to collaborate and write a paper, you're an economist, and you want to collaborate with an ecologist or behavioral scientist, then maybe your department will look at a paper that you publish in a weird journal that they don't recognize and not value it as much."* (Independent interdisciplinary researcher)

> *".....[academics] have a different rewards system since they are generally looking for peer-reviewed pubs, which are slightly less valued in the government system."* (State agency natural science researcher)

> *"[The] academic model keeps you fairly insular without a lot of credit for reaching across institutional boundaries and unit boundaries."(*Academic natural science researcher)

There are also challenges of meeting financial and professional goals through interdisciplinary collaborations that involve institutions with distinct expectations and cultures. Funding structures within research disciplines often do not accommodate novel, or innovative collaborative project designs.

> *"[Many] academics are living on soft money, so it's harder to engage them in a substantive way unless there is a project or funding source."* (State agency natural science researcher)

> *"I think the scientists there like having external collaborators but the funding structure doesn't allow it very well."* (speaking of agency scientists) (Academic natural science researcher)

In summary, while many academic scientists are interested in collaborative scientific relationships, incentives, funding, and institutional structures within the academy, and among affiliated academic scientists, do not always foster collaboration and may not be keeping pace with the demand for collaborative scientific pursuits beyond academic boundaries.

3.4.4 Fostering High Impact Research

Interview informants were asked to reflect on the kinds of research projects they felt had the most traction and momentum toward making significant impact on Puget Sound recovery. As stated in the introduction to this report, 'high-impact research' is defined as a research project with outcomes that directly catalyze or inform measurable recovery, restoration, or policy changes affecting Puget Sound marine and nearshore environments.

Research programs that engage the public and directly include policy makers and resource managers were frequently identified by key-informants as high impact. Through the semi-structured interviews, it became clear that collaborative arrangements in Puget Sound spanned a far more diverse network of people than just those involved with, or connected to, primary research.

When asked what qualities had contributed to the impact of their chosen projects, a number of respondents spoke of collaborations with citizens groups, stakeholders, and county or higher level government representatives. Additionally, a number of respondents commented that projects producing particularly useful outputs were successful as a result of effective interdisciplinary collaborations or cross-discipline communication that often included these kinds of groups.

> *"…has a lot of traction because her research combines so many aspects of physical drivers dealing with oceanography, chemical drivers, and biological drivers that actually impact people with toxic shellfish."* (Federal agency natural science researcher)

In some cases, these collaborations were actually a defining feature of the project's initial design. They were conceptualized in such a way that they would ultimately be useful to a broader audience than simply the scientific community.

> *"Our approach is to mindfully work with the end user from the beginning. [We] try to talk to people who use the information and they help constrain the question. Sometimes it's a NGO or government entity and then [we] make sure the academic information can be used."* (Independent, interdisciplinary researcher)

> *"…[projects that] produce results that are usable, very applied, and very applicable….They were modeling studies done in consultation with the people who were going to use the results."* (Tribal researcher and science supervisor)

> *"It was a high-level political leadership call for good science, and that brought all the scientists. It really motivated everybody….these political leaders said they were going to take this seriously and adjust their decisions based on the analysis, and they did."* (Independent, interdisciplinary researcher)

> *"It's not necessarily the best research that has an impact, but it is designed so that it will work for people."* (Tribal researcher and science supervisor)

In other cases, respondents described participatory collaborative processes that enhanced the nature and effectiveness of projects. These also often spanned across traditional organizational and institutional boundaries.

> *"The big one is having an iterative relationship between science and policy…"* (Independent, interdisciplinary researcher)

> *"We met with agencies every six months and they provided input and asked questions … They were really good about listening to what we were finding…"* (Independent, interdisciplinary researcher)

> *"Hood Canal Coordinating Council's Regional Watershed Plan has the potential for a lot of traction because a lot of stakeholders are at the table and they have had them there for a while....also a good team of scientists to inform that plan."* (Non-profit natural science researcher)

> *"There was that circle-back that brought back the problems of Puget Sound to the public eye, a social political management dynamic."* (Federal natural science researcher)

Respondents were also asked to identify obstacles or barriers to impactful research in Puget Sound. Not surprisingly, lack of funding was the most frequently identified barrier to impactful research, but many collaborative barriers, particularly between the research and policy communities, were also noted. Often times this barrier was caused by a lack of communication between researchers or individuals immersed in diverse disciplines.

> *"The technical basis for this stuff is complex, and we who understand it somewhat are not good communicators…and there's some resistance from politicians too in getting to the essence of the problem."* (Tribal researcher and science supervisor)

Although the role is not always promoted or recognized, the importance of skilled "science liaisons" has been identified in the literature (Weber et al. 2010). A number of respondents spoke of the need to better communicate information between disciplines, institutions, and policy makers.

> *"There is a very strong disconnect between policy makers and scientists."* (Independent social science researcher)

> *"…the impact comes from people who can tell stories….Barriers to understanding Puget Sound are getting things digested and used to the point that they impact policy…."* (Academic interdisciplinary researcher and science supervisor)

> *"…it takes a constant drumbeat [from a] science leadership person who knows what's going on [with] the Puget Sound policy side to sort of be that translator and just talk to people and network…"* (Independent, interdisciplinary researcher)

> *"[The work is] very solid fundamentally, but it's translated, through [the researcher's] efforts, into products that the policy community understands. That work presented at fisheries meetings is state of the art and can also be communicated successfully to policy folks….What's missing is the people who are good at translating research, and good researchers are not compensated for their efforts in that area."* (Academic interdisciplinary researcher and science supervisor)

Several respondents mentioned leadership roles as highly important in promoting impactful research. The role of leadership in successful collaborations was also noted by Weber (1998) and Christie (2011). Interview respondents noted that this was especially true of projects that involved volunteered time or resources from collaborators who might have little or no incentive to participate.

> *"A lot has to do with leadership, I think, and a couple of people who are just tireless in their efforts."* (Academic natural science researcher)

> *"In a lot of cases, it takes a champion, someone who feels strongly that it needs to happen. They have to be diligent. Everyone is short on resources and time, so they have to make it worth people's time. There have to be incentives."* (Independent social science researcher)

> *"…there are a lot of bridges to build and you need to have good people… [You] need at least one good person in each group to bring good information to the table. A pragmatic*

> *scientist is going to make things happen in any situation."* (Non-profit natural science researcher)

> *"…a lot of work gets done and a lot of things actually get accomplished because there are a few either very intense people that really kind of keep pressure on everybody else to keep moving, or really charismatic leaders where everybody wants to follow…"* (State agency natural science researcher)

Based on these data, informants in this study agreed that cross-boundary collaborations have a potential to deliver high-impact outcomes. In addition to the already-mentioned incentives necessary for individuals to develop and maintain functional collaborative relationships, these partnerships can also be enhanced by increased leadership, as well as enhanced communication among players within a collaborative effort.

3.5 Key Actors and Egonetworks

It is helpful to examine the networks of ties of individual key actors to identify patterns and trends in their collaborative relationships. The number of in-degree ties to an actor is considered to represent that individual's 'prestige' in the network. High prestige is a term used to suggest that an individual is highly sought out as a collaborator, and as such, is considered a key node in the collaborative network. However, this term should not be used as an indication of an individuals' overall value or contribution to the scientific community. Numerous factors may influence an actor's prestige in the network, including the length of time an individual has been active in the network. Correlation analysis of the data for all survey respondents reveals a weak, but statistically significant positive correlation between the number of years an individual has worked in Puget Sound and the level of prestige of the actor in the network ($r = 0.228$, $p < .001$, $N = 247$).

Interview data are available for several individuals identified as key nodes with high prestige in the network. This sub-section of the paper brings together an analysis of egonetworks with the qualitative results presented in sub-section 3.4 to help uncover some of what may personally motivate these key-informants to collaborate or prevent them from engaging in collaborative efforts. Egonetworks are presented for three individuals along with important themes that emerged in their interviews regarding incentives and barriers to collaboration (Figure 4).

The key actor in Figure 4A is an academic natural scientist who began working on Puget Sound issues almost 50 years ago during undergraduate training. This actor has the 3^{rd} highest overall degree centrality in the network, and also ranked 3^{rd} in terms of prestige (number of times nominated by other actors). As discussed above, this actor's high centrality and prestige in the network is at least partly explained by the duration of the informant's research efforts in Puget Sound. Results from the interview with this individual reveal a preference for previous mechanisms for collaborative science and policy-making that pre-dated the Puget Sound Partnership, such as the Shared Strategy for Puget Sound and the Puget Sound Action Team (PSAT). In particular, this actor was frustrated that the Partnership has not prioritized funding for monitoring and did not maintain the monitoring framework developed by PSAT. When asked to addresses barriers to collaborative research, the individual stated, "the academic model keeps you fairly insular without a lot of credit for reaching across institutional boundaries and unit boundaries." Based on this individual's egonework, it is obvious that this scientist is embedded in a relatively dense network in which many collaborators are also linked to each other. This individual collaborates primarily with scientists from federal agencies and academia, as well as several from state agencies, one from a research institute, and one from a non-profit organization.

The key actor in Figure 4B is an independent social scientist who began working on Puget Sound issues slightly less than 30 years ago, and ranks 16^{th} in the network with regard to degree centrality and 17^{th} in terms of prestige. Personal interest in the science was mentioned as an important incentive to engage in collaborative projects. This informant also emphasized the importance of a champion who feels strongly that collaboration needs to happen, and works diligently to provide incentives that make it worth the time of participating collaborators. As mentioned in sub-section 3.4.4 on 'Fostering High Impact Research,' this actor reiterates the importance of leadership. This individual's egonetwork shows that this actor most frequently works with individuals from consulting firms, federal agencies, and research institutes. This egonetwork illustrates the disconnect between many of this individual's collaborators to one another (low density network).

Finally, the key actor in Figure 4C is an independent, interdisciplinary scientist who has worked on Puget Sound issues for 21 years, and currently has a job that is by its nature highly collaborative. This individual ranked 15th in the network in terms of degree centrality, but ranked more highly in terms of prestige (8th overall with 11 nominations). During the interview, this respondent reported the impression that incentives for collaboration are few and far between. The primary incentives for collaboration noted by this individual were personal reward and personal desire to make a difference and influence policy. According to this informant, the highest-impact research is generated by working with the end-user of the information from the beginning. Having an "iterative relationship between science and policy" leads to greater impact from academic information. This informant also noted the lack of direct reward in the workplace for the extra effort required to engage in collaborative efforts. As summarized in the previous sub-section on qualitative data, related results from the open-ended survey questions show that 35/178 respondents reported personal rewards as their main incentive to engage in collaboration, while 46/178 respondents echoed this actor's view that increased quality or impact of project outputs is an important incentive for collaboration. This individual's egonetwork shows that this independent, interdisciplinary scientist primarily collaborates with individuals from federal agencies, academic institutions, tribes, and non-profit organizations. Some of the collaborators linked directly to this individual are also tied to each other.

4. SUMMARY AND POLICY RECOMMENDATIONS

Many researchers and policy makers collaborate to improve the understanding and management of Puget Sound's marine and nearshore environment. It is important to note that the nature of collaborative efforts between informants can vary significantly depending on the specific types of collaborations in which they are involved. The network of researchers currently consists mainly of natural scientists, perhaps a manifestation of how natural resource and environmental problems have been framed historically in the United States (Christie 2011). Particular topics (e.g., habitat, restoration and salmon research) are most commonly cited as focus areas by survey respondents. The network of Puget Sound-focused human dimension researchers (i.e., applied social scientists) is much less developed and research focused on human populations, behavior, and management effectiveness is far less common. The following recommendations are intended to apply to the majority of collaborative relationships identified throughout this study, however recommendations regarding unique collaborative arrangements and their specific challenges can only be identified through increased exploration.

The Puget Sound Partnership has created an ambitious science agenda. Striking a balance between basic and applied, monitoring and exploratory research is difficult, but there appears to be consistent interest in sustained research collaborations that are strategic and dynamic. Institutional evolution is underway—for example the creation of the College of Environment at the University of Washington is an example of institutional integration and growing appreciation of policy-relevant research. Researchers are likely to invest the time necessary to be part of sustained groups of research-policy collaborations that draw in adequate financial support. The Partnership, as well as other regional science leaders, may be able to play a catalytic role in the formation and maintenance of such collaborations. Additionally, there is frequent discussion of interdisciplinary NCEAS (National Center for Ecological Analysis and Synthesis)-like working groups, which draw complementary research programs together. This model is worthy of investigation.

Other studies similarly note that cross-boundary and interdisciplinary collaborations are becoming more and more important across a number of different scientific communities, while challenges remain difficult to overcome (Cummings and Kiesler 2005, Ruckelshaus and McClure 2007, Weber 1998, and Weber et al. 2010). Overcoming these challenges, creating incentives, and fostering meaningful, successful collaborations are the keys to unlocking the potential in these types of interdisciplinary endeavors.

Weber (1998) studied the nature of collaborative research in policy efforts and provides a framework of “assurance mechanisms” that lead to successful collaborations in an environmental and political setting. Three of his five assurance mechanisms are particularly pertinent to this discussion:

1. *Transaction-specific conditions must be met*

Weber (1998) discussed transaction costs in a context of policy implementation, however, the impact of a diverse range of transaction costs can be identified for collaborative research in the Puget Sound science arena. The transaction costs (time and resources) of developing, implementing and communicating research to a broad audience for higher impact are high. As has been shown, cross-boundary, collaborative processes often notably increase the overall impact of research outcomes; however, the transaction costs of maintaining these collaborations is, at times, prohibitive. Significant savings could be achieved by employing collaborative methods, if there was incentive for the creation and maintenance of long-term collaborations. This seems to have the potential to lead to higher-impact project outcomes. Considerations of the time and logistics required to establish and maintain effective collaborations in funding allocations would greatly incentivize this type of work, making collaborative projects more attractive.

In the current Puget Sound research arena, transaction costs without clear fiscal support mechanisms for these kinds of long-term, sustained, and strategic collaborations may be prohibitive. Those who are capable of communicating across disciplinary divides are often under-recognized for their efforts and successes, and funding structures do not accommodate time and transportation needs that would promote effective cross-boundary collaborations (Cummings and Kiesler 2005). Noted by respondents in this study, as well as by Weber et al. (2010), is the value of skilled "science liaisons," which could potentially be employed to fill a networking and communication gap. Again, the role of these individuals would be one that ultimately reduces the transaction costs of maintaining lively, effective collaborations. Science liaisons help lessen the time and communication constraints that inherently exist between scientific disciplines, policy and management, and perhaps even citizens and stakeholders. Ideally, these individuals would be valued and accounted for in the fiscal planning processes during the design phase of collaborative research projects.

In short, while the above social network diagrams document considerable collaboration and communication within the marine and nearshore science-policy network, the creation of sustainable and strategic collaborations is important, needed and welcome.

2. *Credible commitment to collaboration by "entrepreneurial" political leaders must be present*

As was noted by respondents, political leadership is essential for successful collaborations that span across science and policy. When applicable, this kind of leadership helps keep participants motivated and feeling like their work is directed toward a real outcome or impact. Although in Weber's (1998) study, he specifically noted the need for these kinds of "entrepreneurial *political* leaders," the presence of committed and charismatic leaders even outside the political scope, has been shown to greatly enhance collaborative processes. Efforts such as the Shared Strategy for Puget Sound were highly valued by informants in part due to the high-level political leadership that was committed to maintaining ongoing dialogue with the technical side of the project (Weber et al. 2010).

> *"If there isn't a call from people who can actually influence decisions, it's not really going to go anywhere."* (Independent, interdisciplinary researcher)

Identifying and supporting leaders who will foster and shepherd collaborative programs is clearly a useful investment.

3. *A reputation for commitment to the collaborative processes by the agency in charge of the rules*

From this study, it seems that increasing the support of innovative and collaborative research projects is likely to lead to an increase in the overall impact of funded projects. This appears to be particularly true of collaborations that include end users, researchers, and policy makers in design and implementation activities. A commitment to collaborative efforts from a governing organization would also encourage public support, as it proves the agency is flexible and willing to consider cooperative arrangements. For Puget Sound, a demonstration of this commitment to collaboration could manifest itself as increased funding specifically for collaborative, interdisciplinary projects such as NCEAS-type working groups, or other creative collaborative arrangements.

4.1 Conclusions

Analyses of interviews presented in this paper raise the question as to whether such extensive research efforts are, in fact, strategically informing Puget Sound management activities. There is a growing interest in 'high impact' research that is explicitly designed to improve policy. Researchers, science communicators, and policy makers are motivated to collaborate because they feel it is effective to address complex policy concerns that have social and ecological dimensions. Successful interdisciplinary collaborations in the Puget Sound marine and nearshore science community are clearly recognized as valuable components of high-impact, meaningful research projects. Additionally, these kinds of collaborative activities tend to be fulfilling, educational, and productive for involved members. However, successful interdisciplinary collaborations also require tangible, participatory incentives such as access to increased funding and adequate professional recognition for collaborative pursuits. There remain persistent challenges to interdisciplinary, collaborative research including limited funding, institutional barriers, and disciplinary 'cultural' barriers. Mechanisms that may improve the success of collaborative efforts include reduction of transaction costs between participants of collaborative projects, increased leadership in support of collaborative efforts, and an ongoing organizational reputation for promoting collaborative activities.

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