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# Collaborative Ocean Acidification Mapping for a Changing Salish Sea? Transdisciplinary and Transboundary Barriers

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**Collaborative Ocean Acidification Mapping for a Changing Salish Sea?**
**Transdisciplinary and Transboundary Barriers**

By

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Accepted in Partial Completion
of the Requirements for the Degree
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# **Master's Field Project**



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# Collaborative Ocean Acidification Mapping for a Changing Salish Sea?

## Transdisciplinary and Transboundary Barriers

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# Abstract

Fragmented Ocean Acidification (OA) data and collaboration efforts between disciplines and stakeholders for the Salish Sea are barriers to a more effective transboundary ecosystem understanding and governance. While there are presently efforts to research and monitor OA, there is a significant gap of coordinated efforts throughout the entire Sea, especially around OA biological indicators. To help bridge the gaps and increase collaborative resources, I conducted an exploratory case study of OA data mapping for the changing Salish Sea. For this project, I addressed the following research questions. First, what are the most informative ecological indicators to discern critical climate risk trends from OA? Second, how can OA indicators in the Salish Sea efficiently be mapped? Through a multi-iterative process of semi-structured interviews, online survey, analytic deliberation, and participant observations from the 2018 Salish Sea Ecosystem Conference, I developed an OA online prototype story map. Unexpectedly, I found that transboundary data was unavailable and there was a surprising lack of collaboration between US and Canadian institutions and individuals. Therefore, this project has also evolved to focus on the stark differences in perceptions of collaboration, governance, and transboundary barriers in the Salish Sea. Due to this project evolution, I have additionally developed five prescriptions to address these barriers and address collaboration around OA in the Salish Sea:

1. Develop a Research Coordination Network (RCN) for the Salish Sea
2. Create a Transdisciplinary Framework with Governance Indicators for the Salish Sea
3. Expand Prototype Map with Shared Data

# Acknowledgements

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***"The naming of the Salish Sea is a timely response to the need for the governing bodies of the region to recognize their common responsibility for protecting the health of this precious ecosystem"***

**-Swinomish Chairman Brian Cladoosby (Coast Salish Gathering 2010)**

# Introduction

Fifty-Seven nations and hundreds of sub-national jurisdictions in the Western Pacific share one inland sea (Norman 2012). The Salish Sea basin encompasses nearly 5,500 square miles (or about 15,000 square kilometers) and is bordered by the Canadian Province of British Columbia and the state of Washington in the United States (US) (USGS 2009). Over 11 million people call the basin home. The region's First Nations named it in 2010 and overtime, the Salish Sea got its own map (Freelan 2009) and bi-annual conference (SSEC 2018). But this unique transboundary marine region faces fragmented coordination, especially with ocean acidification (OA) efforts (OA Toolkit 2017). Governments, academics, professionals, and organizations have called for action to address these fragments (BC Gov News 2016; OA Toolkit 2017). While alliances and goals have been established to address the fragments, there is a still a significant lack of actual effort and results to address OA in the Salish Sea region. My field project responds to these calls with an exploratory case study of the prospects for a collaborative Salish Sea OA mapping effort.

One of the alliances and efforts to address OA in the Salish Sea was the Washington State Blue Ribbon Panel on OA. The Washington State Blue Ribbon Panel has done extensive work on addressing OA and understanding its impacts in the region (figure 1). In November 2012, the Washington State Blue Ribbon Panel and governor Christine Gregoire released a report and executive order to address the threat of ocean acidification and hypoxia (OAH) for Washington (WA Blue Ribbon Panel OA 2012). Yet, five years later, the work on addressing OAH is still in its infancy. In the executive order, Gregoire addresses six overarching goals, four of which can be discussed and supported by a prototype OA mapping and data tool. The four goals are: (1) investing in OA monitoring; (2) informing and educating stakeholders; (3) increasing the ability to adapt to the changing OA conditions; and (4) promoting a sustainable and coordinated focus on OA (Executive Order 12-07). But these goals do not extend to the entire Salish Sea.

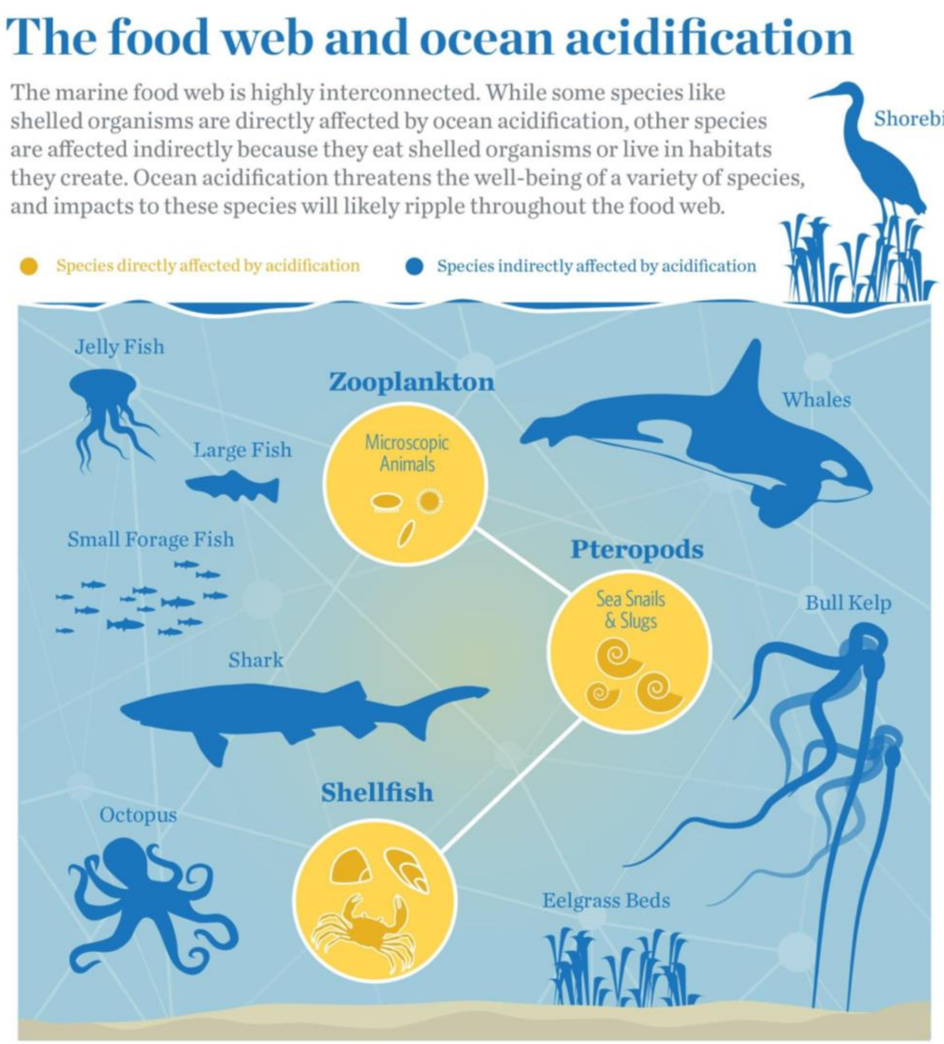



Figure 1: Infographic by the Washington State Blue Ribbon Panel on Ocean Acidification depicting that OA indicators: Zooplankton, pteropods, and shellfish, are impacting the higher trophic levels in the marine ecosystem due to their deleterious impacts from OA.

OA and Hypoxia are commonly referred to together due to the chemical properties and the combined impacts that could cause the ecosystems a more intense negative impact than OA itself. Frequently, when water temperature and nutrient loads increase, hypoxia and OA occur concurrently (Turner 2016). Hypoxia is a condition when there is low dissolved oxygen in the waters (Turner 2016). For this project, I have included OAH data, but the primary focus is around OA.

Canada and the US joined the OA International Alliance to address OA in 2016. But, the alliance has also called for better monitoring and collaboration with their allies. Moreover, there is no collaborative effort to develop a mapping platform displaying OA ecological and biological conditions and trends for the entire regions. To address this gap, I examined three questions: (1) what are the most informative ecological indicators to discern critical climate risk trends from OA; (2) how can OA ecological indicators be effectively mapped throughout the Salish Sea; and (3) what are the barriers of collaboration that the Salish Sea faces regarding OA? To address these questions, this project relied on several social science research methods. Semi-structured interviews, and an online survey were used to identify the OA indicator variables. Feedback on an online prototype map displaying OA indicators data was collected via a group process of analytic deliberation. A combination of semi-structured interviews, surveys, and participant observations were analyzed for identifying collaboration efforts. The project goal was to investigate the transdisciplinary, transboundary, and deliberative barriers that collaborative OA work faces throughout the Salish Sea.

# Chapter 1. Ocean Acidification in a Changing Salish Sea

OA is a worldwide issue due to the global increase of greenhouse gases. With increases in greenhouse gases, OA worsens due to greenhouse gases' interaction with waters around the world. OA is the process by which carbon dioxide mixes with the ocean leading the ocean to become more acidic or to have a lower pH (Feely et al. 2016; NOAA 2016a). West Coast scientists and politicians have recently begun taking steps to regionally address ocean acidification because of the changing OA levels (Ryan 2016). Between studies on impacts of OA, cruise collection, site data collections, and other physical, chemical, and biological oceanography related topics, OA research is a growing field (NOAA 2016a).

OA has been a rising concern and issue throughout the Salish Sea due to the high market value and reliance on the seafood industry (British Columbia Seafood 2013; Washington Sea Grant 2015). Shellfish in particular are susceptible to OA conditions, and have previously failed to develop and become a viable entity to sell when OA conditions are too high (Bednaršek 2012b; Washington Sea Grant 2015). While levels of OA have increased globally, perhaps the more important fact is that water nearshore where aquacultures and sensitive marine ecosystems are located, such as the waters in the Salish Sea, are more susceptible to OA as OA levels increase (Feely et al. 2016). Since OA is an ecosystem-wide issue within the Salish Sea, gathering and compiling all OA ecological indicator data within the region will bridge the gaps to better inform the public, conservationists, scientists, and policy makers on OA throughout the Salish Sea (Loreau et al. 2001; Pomeroy, Watson, Parks, and Cid 2005; Sherman 1991). Since OA is a significant threat throughout the Salish Sea, this requires more research and information. OA is studied throughout several methods of data collection and research. To make significant progress, studies and data must be additionally collected at large scales to better understand underlying impacts that OA could have. The current project explores development of such a tool to enhance understanding of how the Salish Sea is impacted by OA by compiling chemical and biological? indicator data throughout the region and producing an online map.

### *1.1 OA Indicators*

Ecological indicators are science-based tools or data that assess the ecological quality and allows analysis or a comparison between different nature sites (Turnhout 2009). Ecological indicators can give insight to various ecological issues, including OA. A recent joint effort between the Department of Environment and Climate Change Canada and the US's EPA produced a list of Salish Sea Ecosystem health indicators (SSER 2014). Yet, none of the indicators address OA conditions or trends. OA indicators allow policy makers, economic stakeholders, and environmentalists to understand what is currently occurring in terms of pH and OA levels in the waters (Bednaršek et al. 2014). While studies are continuing to grow in the field of OA ecological indicators, researchers have already identified potential OA indicators such as seagrass, pteropods, crab larva, and coral. These indicators could be found in the Salish Sea region, however, the data is usually fragmented into specific basins like the Strait of Juan de Fuca, Puget Sound, and Strait of Georgia (Bednaršek et al. 2014; Haigh, Ianson, Holt, Neate, and Edwards. 2015; Weisberg et al. 2016).

Each of the OA indicator species have different levels of sensitivities to the changing pH levels in the water. Pteropods are calcium calcifiers and rely on the available calcium carbonate to produce and maintain healthy shells. As OA increases, the calcium carbonate shells dissolute, and this dissolution can be measured and analyzed with relation to OA (Bednaršek et al. 2012a; Bednaršek et al. 2014). The dissolution of shells is measured into three categories: Type 1, 2, and 3. Type 3 is the highest shell dissolution damage category, whereas type 1 is the lowest and considered to be healthy pteropods (Bednaršek et al. 2012b).

Seagrass is another potential OA indicator. Seagrass summer production rates decrease as the OA levels increase (Koch, Bowes, Ross, and Zhang 2013). Thus, seagrass photorespiration rates are the measurement for OA indicators. However, while abundant throughout the region, the summer production rate data is limited.

Crab larva, similar to pteropods, use calcium carbonate to produce the shells or instars (Gibson, Atkinson, and Gordon 2011). Unlike pteropods, the crab larva as an OA indicator is measured by fitness (Walther 2016). It is typically measured by the time of the crab larva developments through key growth stages (Gibson, Atkinson, and Gordon 2011; Walther 2016). Particular species such as the Svalbard crab is highly sensitive to such changing conditions in the water (Walther 2016).

Finally, coral is an identified as a potential OA indicator located in the Salish Sea. As OA levels increase, the calcification rates of corals decrease, causing a more fragile, smaller, and increased amount of bleached coral (Anthony, Kline, Diaz-Pulido, Dove, and Hoegh-Guldberg 2008; Hoegh-Guldberg et al. 2007). However, there is significant variability on what and how the data was measured for coral changes in the Salish Sea. For OA, coral is measured typically by the aragonite saturation of the coral.

Overall, there is OA ecological indicator data available for these variables, but each data set has significant limitations on measurements and data availability in terms of location and time. The concept of OA indicators is relatively new, with most research taking place in the past decade. The available data tends to be located in high tourist areas such as the San Juan Islands and are not extensive throughout time. Nonetheless, by utilizing OA indicators, an online map of conditions and trends can inform stakeholders on current and changing water chemistry occurring throughout the Salish Sea.

### *1.2 Salish Sea History and Collaboration Context*

The Salish Sea was officially given its name in 2010 by both Canadian and US governments to recognize and honor the Coast Salish First Nation tribes of the land and water (Wong & Rylko 2014). Home to 57 nations including Canada and the US, the Salish Sea contains a unique transboundary location (Norman 2012). However, this transboundary ecosystem faces the challenge of environmental cooperation from First Nations, US, and Canada.

> *"Although the Coast Salish communities recognize themselves as a connected group, the realities of border crossing serve as a harsh reminders of the politics of occupation and colonially constructed space"*
> -Emma Norman (2012)

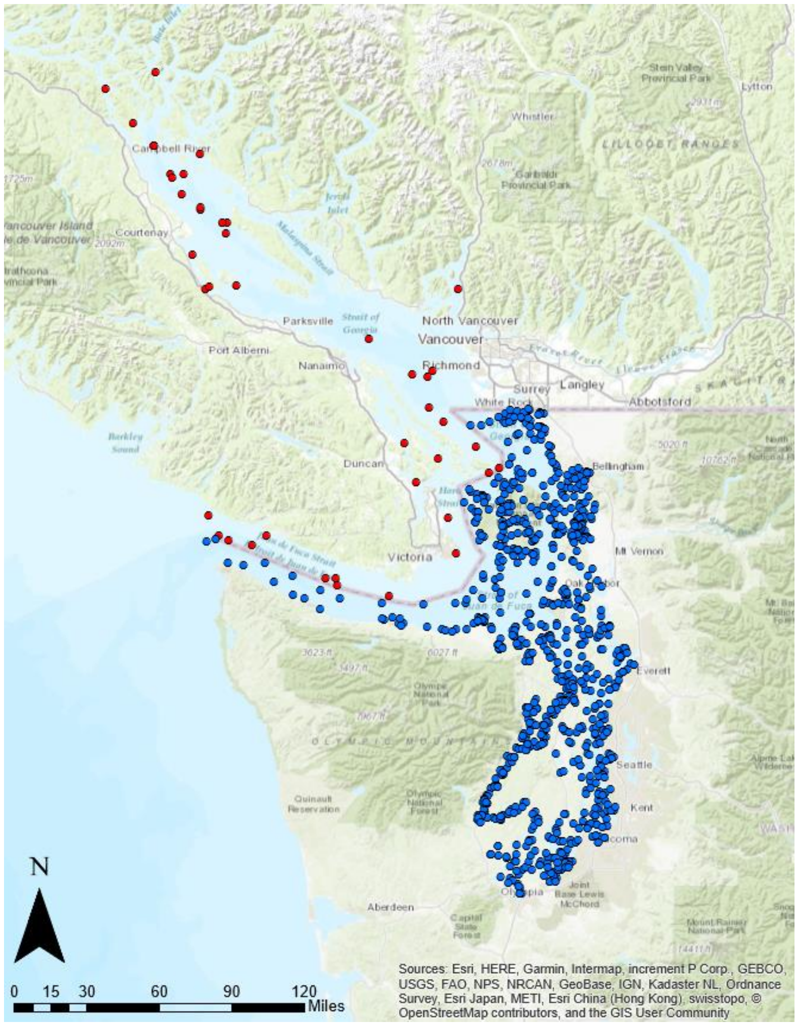
The Environmental Cooperation Agreement (ECA) from 1992 is one such agreement between the BC and Washington State governments to bridge collaboration efforts throughout land and water in the Salish Sea region (ECA 1992). Specifically, it looks to focus on water quality, flooding, air quality, water resource management, and wetland protection (ECA 1992).

This ECA agreement has supported work to identify Salish Sea Ecosystem Indicators and the Health of the Salish Sea Ecosystem Report (SSER). The foundation of the SSER is on the identification and current state of the ecosystem indicators which include Chinook salmon, air and freshwater quality, marine species at risk, marine water quality, shellfish harvesting, streamflow, southern resident killer whales, swimming beaches, and toxins in the food web (SSER 2014). Only two of these indicators reflect the social system, shellfish harvesting and swimming beaches. The other eight indicators reflect on specific species recovery such as the

Southern Orca Whale, and then air and water quality (SSER 2014).

Moreover, this framework as applied in the Salish Sea is mostly a purely biophysical framework, the Drivers-Pressures-State-Impact-Response (DPSIR) (SSER 2014; Wong & Rylko 2014). The reliance on a biophysical framework overlooks institutional drivers and ignores the fragmentation of scientists and the spatial reach of environmental studies throughout the entire region. This therefore results in significant barriers and fragmentation in the region, especially in terms of collaboration (Breslow 2015). Also, despite growing research on climate change and OA, especially in the Salish Sea, the SSER has no indicators, mentions, or focus on OA.

Conversely, the Puget Sound Partnership's Action Agenda and Report Card includes several social system indicators such as good governance, economic vitality, shellfish beds, local foods, and sound stewardship (PSP 2017). The inclusion of social system indicators starts to display a more socio-ecological systems and transdisciplinary frameworks. These types of frameworks rather than the DPSIR framework, reduces the barriers between society and the environment, which is required especially regarding OA.




Map 1: The data mapped in the image is OAH data collected for the Salish Sea. This is one of the more extensive maps publicly available to access OAH data. However, most of the data collected are chemical indicators. Credit to Oregon Ocean Acidification and Hypoxia Council and their OAH Inventory Map, which can have accessed on ArcGIS Online.

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In 2016, both Washington State and BC governments joined the International Alliance to Combat Ocean Acidification (OA Alliance) with over other 50 governments and affiliations (BC Gov 2016; OA Alliance 2016). The OA Alliance looks to bridge governmental sectors with taking political action against OA. These efforts include providing resources such as the OA toolkit to provide recommendations on how to address OA. Some of these recommendations are applicable to Collaborative OA mapping for the Salish Sea in particular and bolded in the following list (OA toolkit 2016). However, as map 1 illustrates, there is a paucity of Canadian

OA monitoring that challenges collaborative efforts. Illustrated in map 1, there are major gaps of OA data collected throughout the Salish Sea, specifically in Canadian Waters. Additionally, it is evident that there are significantly less data collecting efforts in Canada for OA versus in the US.

1. Utilize and expand existing environmental quality laws and policies to promote best practices, permanent improvements (i.e. **support participation in programs that leverage national or regional infrastructure and collaborations**).
2. Manage resources and human activities to reduce co-occurring stressors that exacerbate the impacts of OA (i.e., precautionary fisheries policies, support marine protected areas, climate-smart human development, etc.).
3. Develop budget mechanisms, funding mechanisms to support research and monitoring.
4. **Support development and incorporation of acidification indicators and thresholds to guide adaptive management action for species and places at varying scales.**
5. Communicate OA issues and science developments to stakeholders, regulators, and the general public.
6. Collaborate with key stakeholders, audiences, and impacted communities by sharing knowledge on the causes, impacts, and responses to OA by attending conferences, symposiums, workshops, and other events.
7. **Support and join existing international science and monitoring activities such as the Global Ocean Acidification Observing Network (GOA-ON) and the Ocean Acidification international Reference User Group (OAiRUG), or the UN's IOC Sub-Commission for the Western Pacific (WESTPAC)**.
8. Request and support the inclusion of OA, ocean health indicators, and OA work plans by national governments within UN FCCC NDC at COP23.

9. Promote scientific collaboration across agencies and organizations to coordinate and implement recommendations with other ocean and coastal actions.
10. **Coordinate integrating OA science into adaptation frameworks and policy by incorporating the most current findings into mitigation and resilience planning**.

While the tool kit provides over 40 policy recommendations and actions that governments could take action on, little progress on addressing OA in the Salish Sea is occurring especially in terms of OA indicators, management, and transboundary collaboration in the region as is suggested in the recommendations stated above.

Additionally, to the already given recommendations by the OA International Alliance, this project also envisioned that Marine Protected Areas would be important elements of a collaborative mapping platform because of their potential for anchoring adaptive OA management. MPAs are defined by any areas in the marine environments that have been protected and include sanctuaries and state marine preserves (Agardy 1997). In the Salish Sea, MPAs are areas that policy makers in both Canada and the US believe needs to be protected to preserve marine habitat, species, and to prevent further degradation of the ecosystem (Agardy 2000; BCMOE 2007; Stevenson, Christie, Fluharty, Warren, and Pollnac 2014). MPAs are commonly a vehicle of long-term conservation due to their economic, humanitarian, habitat, and ecological values (Agardy 2003; NOAA MPA 2016b).

Due to such values and conservation efforts, MPAs are also considered to be areas that are generally more sensitive to changes in the environment (Agardy 2003). Due to their inherent political foundation, MPAs are also areas that are commonly monitored and researched to ensure that the regulations, enforcement, and protection of the area is sufficient and beneficial (Agardy 2000; 2003). Given Bert Webber’s highly cited definition of the Salish Sea (see Map 1), there are

85 MPAs located in the project area (BCMOE 2007; Freelan 2009; Stevenson et al. 2014). However, while the MPAs in this region have already been identified, the data and mapping efforts for MPAs throughout the Salish Sea are fragmented due to the presence of the US/Canada border. Policies, monitoring efforts, governance, and research efforts in general for this region are fragmented according to Clauson & Trautman (2015). Thus, this fragmentation is a growing concern and becoming more critical to study, especially due to the Sea's sensitivity to the changing marine conditions. Fragmentation in OA efforts can already be seen in data throughout the Salish Sea (map 1).


Map 2: Stefan Freelan 2009 of the Salish Sea. Includes the basins of the Strait of Juan de Fuca, Strait of Georgia, and the Puget Sound for Bert Webber's definition.

### *1.3 Common Pool Resources in the Salish Sea*

OA and other environmental and social threats to the Salish Sea exemplify a Common Pool Resource (CPR) dilemma. In CPR theory, scholars from this tradition have theorized that there are resource and institutional conditions that allow appropriators to overcome the tragedy of the commons (Schlager 2004). First, there are four key resource attributes needed for the emergence of cooperation: (1) feasible improvement; (2) indicators; (3) predictability; and (4) spatial extent. These resource conditions are discussed in the next section. Second, there are key institutional attributes: (1) principle of exclusion; (2) appropriation rules restricting time, place, technology, and quantity of resource units; (3) affect individuals can modify rules; (4) monitoring; (5) graduated sanctions; (6) conflict resolution; (7) rights to devise their own institutions; and (8) nested enterprises (Schlager 2004).

This shared inland sea ecosystem of Washington State and British Columbia faces increasing pressures from population growth, habitat losses to urbanization, toxic pollution, overfishing, ocean acidification and hypoxia (OAH), and other risks posed by a warming climate (Fraser, Gaydos, Karlsen, and Rylko, 2006). For instance, a panel of scientists from North America's West Coast have called for regional responses to climate change impacts, including the increasing risks of OAH (Ryan, 2016). As a result, researchers have recommended several actions to mitigate OAH impacts including: (1) inventorying areas where local pollutants exacerbate OAH; (2) inventorying locations where aquatic vegetation conservation and restoration can successfully mitigate OAH; (3) inventorying the co-location of protected areas and other sites vulnerable to OAH; and (4) defining gaps between monitoring efforts and management needs. Moreover, they called for the expansion and integration of knowledge about OAH because it is "already posing a substantial threat, even if it's just beginning to enter the public consciousness" (Chan et al. 2016, p. 14).

This unique ecosystem and resource is threated and expected to become increasingly more endangered. Other emerging studies also forecast that the transboundary Salish Sea ecosystem in British Columbia and Washington State will face the impacts of OAH earlier and more severely (Boehm et al. 2015; Somero et al. 2016). Consequently, Washington's governor and British Columbia's (BC) Premier are supporting more efforts to research and mitigate OA (Nair 2017). Nonetheless, the Salish Sea ecosystem has most of the key attributes supportive of the emergence of cooperative behavior.

However, my research will show that there are institutional barriers that have undermined cooperation. Yet, based on the current policies and institutions in place, there is room for improvement to make these policies more efficient and less likely to fall into a scenario of the "tragedy of the commons." There is currently efforts to create a Salish Sea Model by the Pacific Northwest National Laboratory, which will help support research coordination efforts, predictability, monitoring indicators, and provide improvement in OA in the region. All of the key resource attributes described by Schlager (2004) are present in the Salish Sea with OA.

First, this ecosystem can feasibly be improved.  Second, there are reliable and valid indicators characterizing the conditions of the resource. Third, with recent modeling advances, key resource flows are relatively predictable. Fourth, the spatial extent of the resource and its internal microenvironments are well understood. However, as my research revealed, the Salish Sea still faces  fragmented governance and policies that blocked my attempts to collect and map OA data for the entire ecosystem.

While most CPR research focuses on localized conservation cases (Anderies & Janssen 2013; Ostrom 1999; Schlager 2002), a growing body of work explores regional and larger scales of natural resource governance (Basurto 2013; Berkes 2008; Heikkila, Schlager, and Davis 2011;

da Silveira and Richards 2013) like the Salish Sea ecosystem. Dietz, Ostrom and Stern (2003) identified three promising governance strategies for successful CPR outcomes: (1) policy diversity; (2) multi-level institutional nesting; and (3) analytic deliberation. The first two have been conceptualized as polycentrism. Polycentrism is a governance regime in which there are high cooperation/coordination and distribution of power (Pahl-Wostl & Knieper 2014). Whereas analytic deliberation was described as a "well-structured dialogue involving scientists, resource users, and interested publics, and informed by analysis of key information about environmental and human - environment systems. . ." (Dietz, Ostrom, and Stern, 2003, p. 1910).

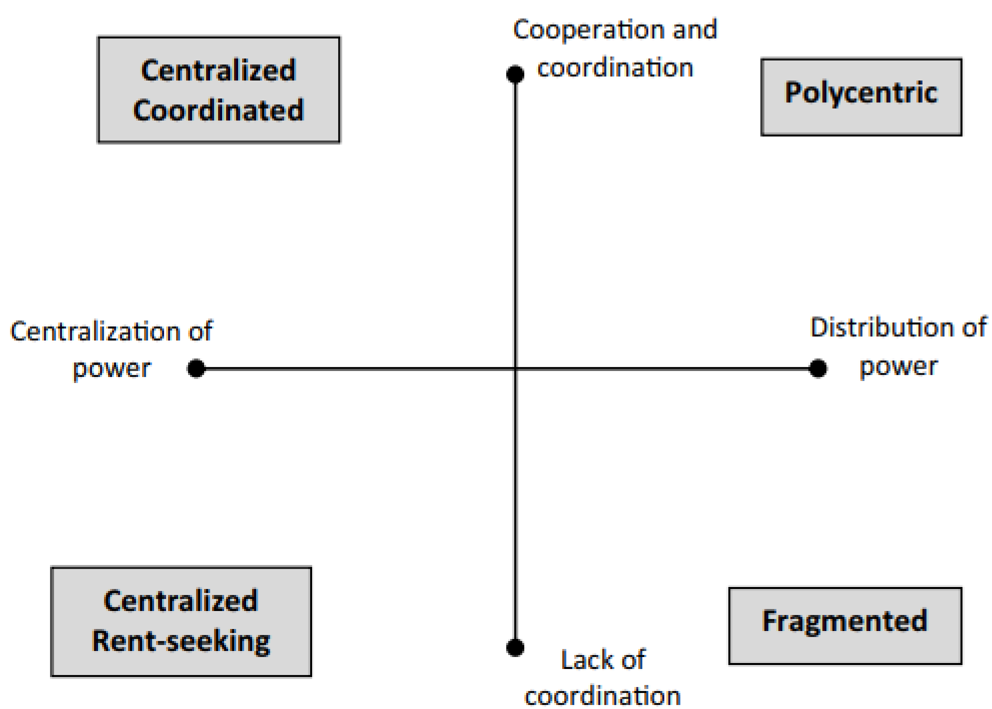


Figure 2: Figure from Pahl-Wostl and Knieper 2014 article. In the grey boxes are the idealized governance regimes in which are described into two dimensions of degree of coordination and distribution of power.

Since the Salish Sea is a trans-national marine ecosystem, the policies and the institutions surrounding this region can't be more centralized. Moreover, the current decentralized approach seems inadequate as well. Instead, a more polycentric approach seems promising, rather than trying to address the problem from their own territories as British Columbia, First Nations, and Washington State. According to McGinnis and Ostrom (2011, p. 15):

> *"Polycentricity conveys more than just federalism as it typically is understood. A federal system may consist only of a sequence of neatly nested jurisdictions at the local, state or provincial, and national levels, but a polycentric system also includes cross-cutting jurisdictions specializing in particular policy matters, such as an agency managing a river basin that cuts across state lines."*

While Washington State and British Columbia environmental officials established a bi-national cooperative agreement, it's no longer directing bi-national collaboration. Therefore, the Salish Sea is an exemplary case of a classic CPR governance dilemma Based on the current coordination and power distribution in the Salish Sea, the governance regime falls into the fragmented area as conceptualized by  Pahl-Wostl and Knieper (2014) seen in figure 2.

My field project joins this growing body of work and responds to the ecosystem health challenges facing the Salish Sea by addressing Fraser's et al.'s (2006) call to enhance collaborative knowledge management (e.g., data sharing and web accessibility), increase public education, and develop decision-making tools to help government, the private sector, and individuals to make decisions and take actions to protect and preserve our shared marine ecosystem. I argue that an online OA mapping platform can both bring key stakeholders together and help address the fragmented OA data conditions that will impede effective ecosystem management for the Salish Sea.

## *1.4 Input of Stakeholders:*

The study of the ecological environment and stakeholder perceptions are an increasing field of research and implementation (Reed 2008). The involvement of stakeholders with research allows not only an increase in participation and engagement, but also provides local and expertise insights that are limited to those stakeholders (Reed 2008). This study relies on the input from key stakeholders such as marine ecologists to inform the research on OA, its ecological indicators and collaboration effects, and from geography practitioners to create a user-friendly map. Having the input of stakeholders from OA impacted occupations and academic backgrounds is valuable to this project, but also having the difference national perspectives from Canada and the US creates a more inclusive insights.

Gathering stakeholder inputs typically includes a variety of methods such as semi-structured interviews, online surveys, and analytic deliberation groups (Clifford, Cope, Gillespie, and French. 2016). Semi-structured interviews follow the framework of having a predetermined list of questions, but also allows the conversation to deviate from the topic as the interviewee desires (Clifford et al. 2016). The conversations and responses to semi-structured interviews allow a more conversational and flexible tone and nature, thus allowing the conversation to shed new light and perspectives on the topic (Berg 2008; Clifford et al. 2016).

Online surveys are a stand-alone data collection method that is widely used and is fast and low cost (Dillman 2014). Dillman (2014), the suggested an implementation timeline for a high response rate of an online survey is twenty-two days between the distributions of the survey to sending final follow up communications (Dillman 2014). Based on the Leverage-Saliency theory for surveys, the survey provides a positive outcome of a beneficial OA map for those who took the survey. The stakeholders that respond to the survey are more likely to see their inputs implemented and taken into consideration versus those who do not respond (Dillman 2014).

Analytic-deliberation is a decision-making approach described by the US National Research Council (NRC 1996) to address controversial and complicated risk governance issues (Chess, Dietz, and Shannon 1998; Dietz and Stern 1998; Renn 1999; Stern 2005). Through an iterative, stepwise process, analysis of scientific and local knowledge is brought together through facilitated conversations to produce the best understanding of evidence-based and value-based claims that can inform public decision-making (Dietz, Fitzgerald, and Shwom; Dietz 2013). Using the Objective, Reflective, Interpretive, and Decision (ORID) framework for the facilitated conversation allows the conversations to follow a natural thinking and analytic process so that the group can reach conclusions based on a foundational understanding and evidence. Additionally, this framework allows the group to develop shared understanding and perspectives despite the wide variety of backgrounds from each individual (Hogan 2003). ORID focuses on four categories of questions: objective, reflective, interpretive, and decision (Hogan 2003). These categories of questions can be focused to the topic of accomplishing a given task or tool. The analytic deliberation process proposed gathered perspectives between various groups and individuals.

Analytic deliberation is commonly tied with consensus workshop methods. In Brewer (2013), she used analytic deliberation to get public participants to engage and develop effective communication strategies and common political agendas. Hennessey & Sutinen (2005) suggest that analytic deliberation is a research method that actively engages participants in addressing challenging environmental problems. For this proposed project, analytic deliberation is a form of both consensus workshop, and evaluating the user experience with the proposed mapping tool. As Paddington (2009) points out, evaluating the user experience with GIS and other geographical platforms is necessity to provide an effective, efficient, and beneficial product.

### *1.5 Addressing the Fragments:*

Based on literature reviews and examination of existing tools available to marine ecologists and other OA stakeholders, it is evident that there is data fragmentation for OA indicators in the Salish Sea region. While there is data available to gather OA indicator information, there has been little to no effort to collaboratively compile and coordinate data. Furthermore, there has been no effort to create a tool to assist marine ecologists and other OA stakeholders to better research and study the OA and climate impacts throughout the Salish Sea region as a whole, not just waters in the US or Canada. OA in particular is a threat to the Salish Sea due to its location and currents.

To bridge the gap of shared data and efforts for MPA and OA data, I set out to create a prototype mapping tool. To better inform this project and to gather the perceptions of the stakeholders who are most likely to use the tool, I relied on multiple methods, supported by the literature: semi-structured interviews, online surveys, analytic deliberation groups, and participant observation. The interactive mapping tool could serve as a bridge to close the information gap between the public, government, scientists, and stakeholders, and foster future studies around the Salish Sea. By bridging this gap, an understanding of the Salish Sea's changing conditions due to climate change could increase. Thus, this leads to the potential of improved adaptive management and improved insights on OA and climate risks in the Salish Sea.

# Chapter 2. Research Design

## *2.1 Exploratory Case Study*

The project relied on a mixed methods approach to collect qualitative and quantitative data. Using semi-structured interviews, online surveys, analytic deliberation, and an online mapping platform, I created a map of the OA indicators and MPAs data for the Salish Sea.

When studying complex environmental issues, using a mixed method approach brings to light what one or the other research methods could not produce individually, (Kanazawa 2017). Furthermore, the integration of mix methods can provide new insights to multiple disciplines, especially when the research revolves around interdisciplinary or transdisciplinary research (Poteete, Janssen, and Ostrom 2010)

## *2.2 Research Design Context:*

Based on previous studies and the research design for this project, the methods used for this project included semi-structured interviews, online surveys, analytic deliberation, and participant observations (figure 3).

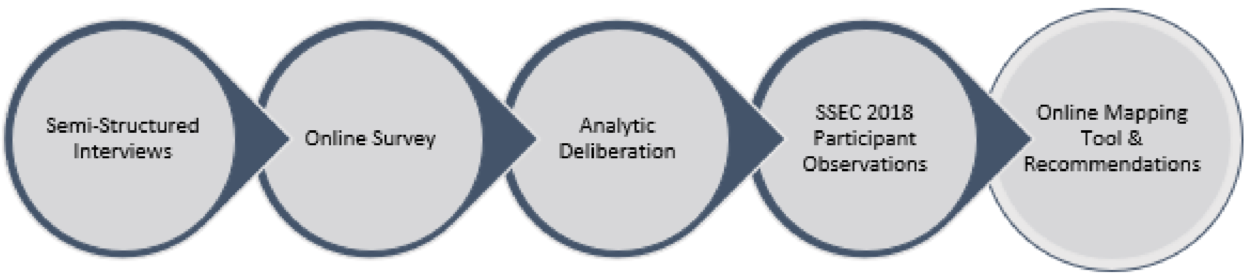


Figure 3: The process of methods and then outcome for this project. 1. Semi-structured interviews with marine ecologists. 2. Online surveys distributed to marine ecologists. 3. Analytic deliberation with geography practitioners. 4. 2018 SSEC Participant Observations. These methods all led to the outcome of an online mapping tool and recommendations.

The use of mixed methods, especially those utilized for this project, has been commonly done for similar case study designs. For example, Lesser, Abel, and Stephan (2012) utilized an iterative consensus workshop facilitation process to develop an interactive mapping tool to display information from the Toxics Release Inventory (TRI) and the EPA's Risk-Screening Environmental Indicators (RSEI) project. Available at toxictrends.org, Lesser et al. (2012) implemented an iterative and User Centered Design (UCD) software development process (Haklay and Nivala 2010) that involved two consensus workshop facilitation. GIS and cartography professionals were convened for two 1.5-hour sessions to review and suggest changes to the online mapping design.

Likewise, Clauson and Abel (2015) created an online participatory map that involved the input of the community and in turn, the map provides the community with an aggregated way of viewing the information they provided. Similar to this project, Clauson and Abel (2015) utilized an iterative participatory GIS method combining the Focused Conversation and Consensus Workshop methods developed by The Institute of Cultural Affairs (ICA 2000). They also developed and utilized a survey informed by prior work by Abel on environmental citizenship seen first in Stern, Dietz, Abel, Guagnano, and Kalof (1999). Scheuette and Laninga (2016) used surveys and interviews, combined with spatial analysis, to examine food insecurity issues in north-central Idaho. Moroney, Laninga, and Brooks (2016) used surveys and interviews to gauge stakeholder knowledge and support for wood-based biofuels projects. And Dr. Laninga worked extensively with the US Bureau of Land Management to collect visitor preferences for recreation management using focus groups and interviews (Laninga and Watt 2012). Semi-structured interviews, surveys, and analytic deliberation are common methods to engage with various stakeholders and gathering their insights.

Semi-structured interviews are not new to the field of marine science and management studies. Engagement through semi-structured interviews can be similarly found in Stevenson et al., (2014) where they engaged with marine scientists to understanding policies regarding marine protected areas in the Puget Sound. In Tarmidi, Shariff, Ibrahim, Mahmud, and Hamzah (2014), they used semi-structured interviews to gather a foundation of knowledge about geography and marine aspects around Malaysia’s marine ecosystem like my effort building a foundation of knowledge about OA indicators in the Salish Sea.

Online surveys are also a common method for research. In Jean-Pierre, Mach, and Morgan 2013, they incorporated an online survey distributed to expert climate change and marine scientist to inform research on the impacts and perceptions of ocean acidification. While the survey implemented in Jean-Pierre et al., (2013) consisted of mostly open-ended questions, the research was informed on both scientific and political information regarding the research topic, much like what the goals of this project. I used the online survey structure design found in Dillman (2014), where they describe a contact window of 22 days, with communication occurring on days 1, 4, 10, and 18, and ending on day 22. This structure has been identified by Dillman to receive the most respondents to the survey.

Analytic deliberation is commonly tied to consensus workshop methods. In Brewer (2013), she used analytic deliberation to get the public involved with geography and to engage with the participants to develop effective communication strategies and common political agendas. Hennessey & Sutinen (2005) suggest that analytic deliberation is a research method that actively engaged participants in an environmental problem, such as ocean acidification. For this project, analytic deliberation is a form of both consensus workshop and evaluating the user experience with the proposed mapping tool.

Participant observations also are a common method for qualitative research. While utilized in various disciplines, most commonly it is a utilized for social sciences (Filstead 1970). In a study by Bansal (2003), they found that utilizing participant observations helped to understand the current atmosphere of how organizations approached environmental issues, and the context of the situation. Participant observations are a key methodology for studies, such as this, to gather an insight on context, people, and insight on the problem being studied (Kanazawa 2017).

### *2.3 Shifting the Project Trajectory*

The initially proposed project study focused on creating an online interactive and collaborative OA map prototype as a case study with mixed methods. However, the unexpected lack of coordination, especially the transboundary coordination and the scarcity of Canadian OA data, caused the project to evolve into a focus on the collaboration of this region around OA. Without more available data, the online map prototype is less informative than initially planned. While the online story map is still functional, provides information about OA in the Salish Sea, and has limited publicly accessible data links, the project has refocused on barriers to collaboration efforts. While still utilizing a case study and mix methods approach, the project creates not only an initial prototype online map but also a recommendation on improving the lack of collaboration in the Salish Sea regarding OA.

### *2.4 Human Subject Protections*

This study involved human subjects for interviews, online, analytic deliberation groups, and participant observations. To minimize risks and to comply with federal law, I applied for IRB certification using the exempt form due to low risks to the study's subjects. When the IRB form was approved, interviews with marine scientists were initiated. Additionally, I provided consent forms for all interviews, online surveys, and analytic deliberation subjects to ensure that participants were fully informed and acknowledged their human subject rights and voluntary participation.

I ensured that privacy and confidentiality were given; however, anonymity cannot be provided for the interviews. Any interview recordings that might have inadvertently included names or other identifying information were not shared with anyone outside of the research team. When the study was completed, all recordings were destroyed. During the study period, records of interviews were stored on a personal, password protected computer in a locked folder. Each interview was sequentially numbered (ex. Interview 1). Portions of the interviews (sans any identifying information) were transcribed. I then de-identified the transcriptions and all recordings.

For the online survey, no identifying information such as name, email address, phone number was collected. Thus, anonymity and privacy were ensured throughout this process. The survey was distributed via a link through email. The participants of the survey were not able to access previously answered results or see other respondent answers. The survey results were then aggregated together, so no single individual was attributed to a given response or outcome. To ensure participant protection, the Qualtrics platform was invitation-only, making it blocked from indexing by a search engine, and I used the "Secure Participants Files" feature.

Like the interview process, I ensured that privacy and confidentiality were given throughout the analytic deliberation process. Any deliberation recordings that might have inadvertently included names or other identifying information was not shared with anyone outside of the research team. All recordings were destroyed after the study was completed. During the study period, records and notes of the deliberation were stored on a personal and remote password protected the computer in a locked folder. All notes and recordings during this process were destroyed after the study ended.

Since the participant observations occurred at a public venue, the 2018 Salish Sea Ecosystem Conference, my observations of public presentations did not pose any additional risks for my subjects. However, I did deidentify subjects when reporting my observations. No names or institutions were named with any given individual or presentation.

# Chapter 3. Methods & Results

## *3.1 Semi-Structured Interviews*

For the first stage, I conducted semi-structured interviews with stakeholders (marine ecologists). This stage was primarily for gathering information and context of the current OA indicators, management and coordination, and policies throughout the Salish Sea region. I used the Salish Sea Ecosystem Conference 2016 Roster with a focus on Climate Change and OA to identify Salish Sea marine ecologists for the interviews. A minimum of 10 semi-structured interviews was set to gather a good foundation of knowledge from the ecologists. Using a random generator from the roster, I selected 20 names, knowing that most likely there would be rejections for the interviews. Using the twenty-two-day timeline for outreach described in Dillman (2014), I contacted to marine ecologists to conduct interviews.

There was an additional interview opportunity for those scientists who were too busy or were not able to participate in an online or phone interview. I provided the opportunity to fill out a semi-structured survey on Qualtrics with the same questions asked for the semi-structured interview. There were four interviews, and six online survey responses. The questions were focused on identifying the most informative OA indicator given the available data in the Salish Sea, identification of other OA indicators that may not have been already identified, and management and coordination information. Interviews were completed over an online video conference platform and phone. See Appendix D for questions asked during this stage.

### *3.1.1 Interview Results*

In stage one, using the semi-structured interviews over the phone or via skype, there were four participants, two from Canada, and two from the United States. Once implementing the use and flexibility of semi-structured questions online via Qualtrics, an additional six participants participated, two from Canada and four from the United States. In total, there were four Canadian scientists and six Americans. In this stage of the study, additional OA indicators were identified. Newly identified biological indicators for the Salish Sea included shellfish, zooplankton, and benthic forams. The top identified indicators when asked were pteropods (33.3%), followed by shellfish (16.7%), eelgrass (15%), pH (11.1%), and zooplankton (11.1%) (figure 4). The indicators of pH, alkalinity, pCO2, and aragonite saturation are chemical OA indicators identified, whereas pteropods, shellfish, zooplankton, benthic forams, and eelgrass are biological OA indicators.

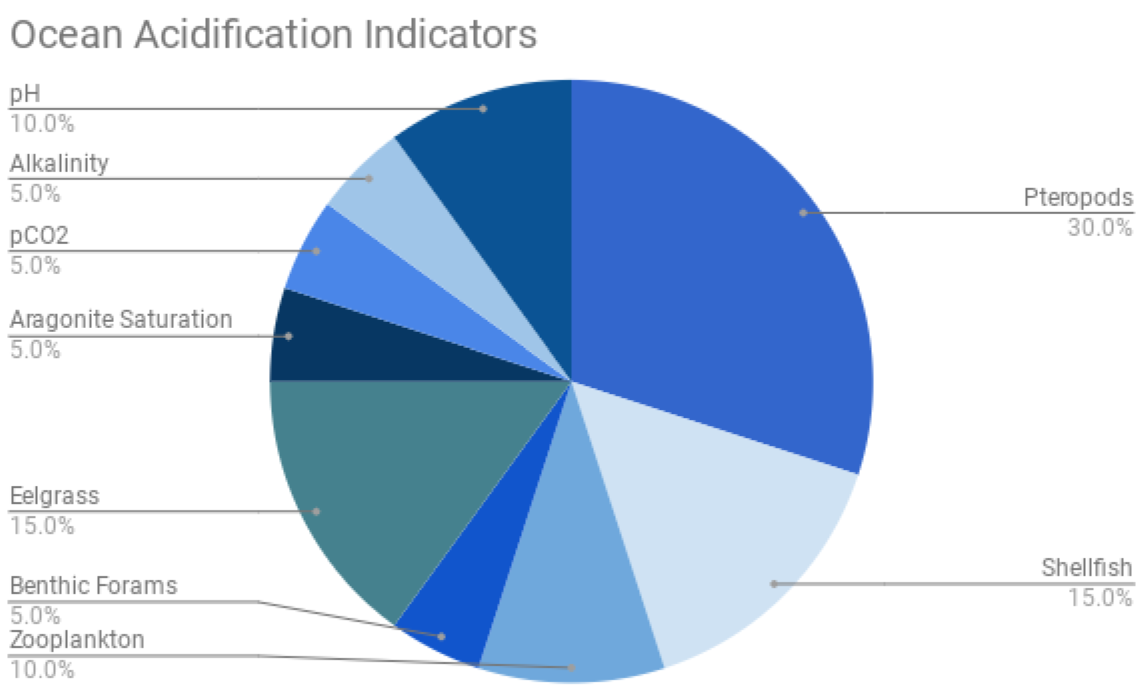


Figure 4: Chart of responses from the question of "What are the main OA indicators currently being researched in the Salish Sea?" Top 3 answers were pteropods, shellfish, and eelgrass.

When interviewees were asked to identify up to the top three problems facing the Salish Sea, the top answers were pollution (18.2%), development (13.6%), OA (13.6%), and habitat loss (13.6%) (figure 5). The "other" category also received a high percentage of responses. The ‘other’ category included responses such as ‘lack of data’ or ‘variability of understanding.’

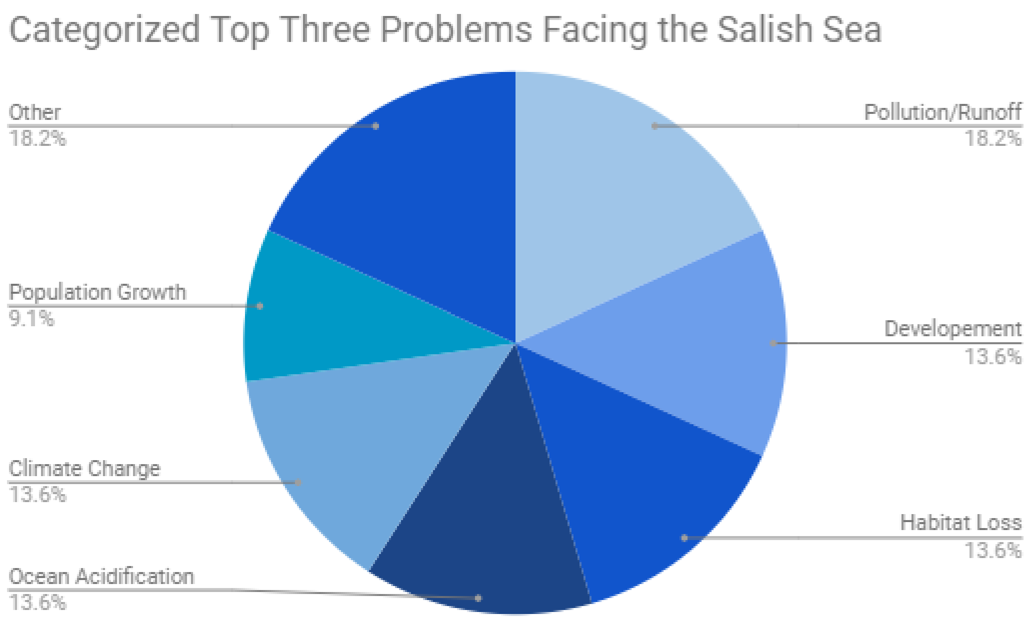


Figure 5: Chart of the responses from the questions of “What are the top three problems facing the Salish Sea?” Top answers are the words that are the largest: Ocean acidification, habitat loss, and development. This chart reflects answers that were then categorized into the categories as seen above.

When asked how they were seeing the effects of OA in the Salish Sea, while showing some variation, it could be concluded from the responses that OA is a challenging impact to show how it is impacting the waters, especially in the Salish Sea. However, failures in hatcheries and chemical indicators that are monitored are some ways that we can see such effects and impacts (4 responses).

> *“I know it is happening, but I can't see or detect the effects on the ecosystem. Hatchery and lab studies document impacts on individual species in containers...”*
> - Marine Scientist

Due to surveying/interviewing two different nations’ scientists, when asked if there were any local, state, or federal policies in place for their given countries, respondents struggled to coming up with a response. Three US scientists mentioned the Washington State Blue Ribbon Panel which is not technically a policy, but rather a coordination/panel group that provides policy recommendations on the topic of OA. As for the Canadian side, there was no identification of any policies.

OA management and coordination between government, the scientific community, and over the border perspectives had a wide variety of insights, but especially between Canadian and US scientists. Three of the four Canadian scientists interviewed reported that there was little to no coordination, especially in comparison to the US. The majority of the US scientists said there are coordination efforts, but there was a diversity of responses to the amount of coordination efforts actively occurring or in place.

> *"I would say there is a very large and prosperous amount of collaboration in the SS. Coordination with NOAA and academics has been strong. Extremely healthy. Collaborations with the shellfish industry, we have projects with them on developing better sensors, and monitoring, so that is happening."*
> - US Scientist

> *"I would say now seeing both sides of the border that the states are more collaborative or at least in BC. And I'm not sure why that is."*
> - Canadian Scientist

> *"Sometimes the coordination doesn't always happen..."*
> - Canadian Scientist

When asked coordinated management actions to reduce OA, the responses were a wide range of suggestions (figure 6). The most common answer that emerged was the reduction of global carbon dioxide. Canadian scientists identified reduction of carbon emissions, reducing runoff/nutrients, alternative energy, stopping industrialization, and nothing. The most frequently identified effort by Canadian scientists was carbon emissions reductions. US scientists identified reduction of carbon emissions, protection of eelgrass/seagrass, reduction of runoff/nutrients, adaption, nutrient management, reduction of atmospheric pollution, and nothing. The most frequently identified efforts by US scientists were to reduce runoff/nutrients, protect eelgrass/seagrass, and adapt to changing conditions.

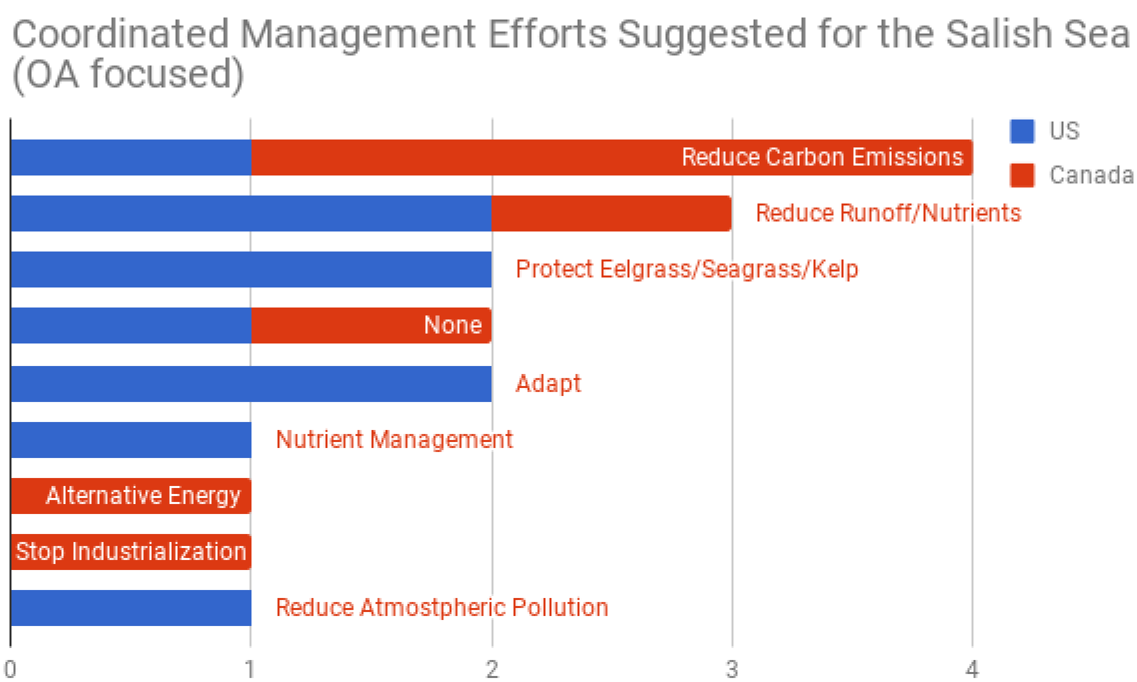


Figure 6: Results of "What are coordinated management efforts to reduce OA in the Salish Sea?" The y-axis were suggestions. The x-axis is the number of time the suggestion was mentioned. The responses in blue were identified efforts suggested by the US scientists and the red is efforts suggested by the Canadian scientists.

### *3.2 Survey Modifications*

Through the contextual analysis and discussions in the first stage, a difference between the classifications of OA indicators, biological vs. chemical, became clear. Biological indicators were the understanding that the indicator was a biological species, whereas the chemical indicators were the chemical properties such as aragonite saturation or pH. This distinction between types of indicators was a critical insight as I moved forward into the second stage survey. Adapting to this clarified insight, the online survey questions were altered so respondents would identify biological, chemical, or both indicators. Additionally, it became clear by one of the interviewees that when utilizing biological OA ecological indicators, the data must also provide chemical indicator supplement to prove that the changes that the biological indicators are changing to are indeed due to the chemical properties of the water.

> *"You have to have the timeline of chemistry with OA to actually say it is an OA indicator."*
> - Marine Scientist

### *3.3 Online Survey*

For the second stage, when the interviews were finished being analyzed, the subset of OA ecological indicator data and variables were updated on a questionnaire. The questionnaire was created using an online survey platform, Qualtrics. Ranking on the top three previously identified OA indicator was collected. Additional components such as OA policies, collaboration, and inputs from marine ecologists were also added to the online survey. The survey was distributed to the same Salish Sea Ecosystem Conference marine ecologists affiliated to the climate change and ocean acidification category. The roster has approximately 100 marine ecologists; however, due to changes in contact information and those who wished to be excluded from the outreach, the sample size decreased to 88. The survey response rate was 38 % (33 out of 88 individuals responded). By using the Dillman (2014) twenty-two-day timeline for implementing the online survey, I outreached to the marine ecologists for their participation. There was a three-day adjustment for the third contact due to a holiday. By having a pool of marine ecologists identify and rank OA indicators, the results of a completed survey provide a ranking priority for which

OA indicator to be mapped.

### *3.3.1 Results*

In stage two, using a structured online survey, I received 33 responses out of the 88 contacts. These survey questions were presented as optional, so there was not always 33 data points for each given question.

When asked to rank the most informative biological-ecological indicator, the top order was shellfish, followed by pteropods, eelgrass, and ‘other’ respectively (figure 7). The ‘other,’ category included responses for echinoderms, kelp beds/forests, coralline algae, zooplankton assemblage, and benthic foraminifera.

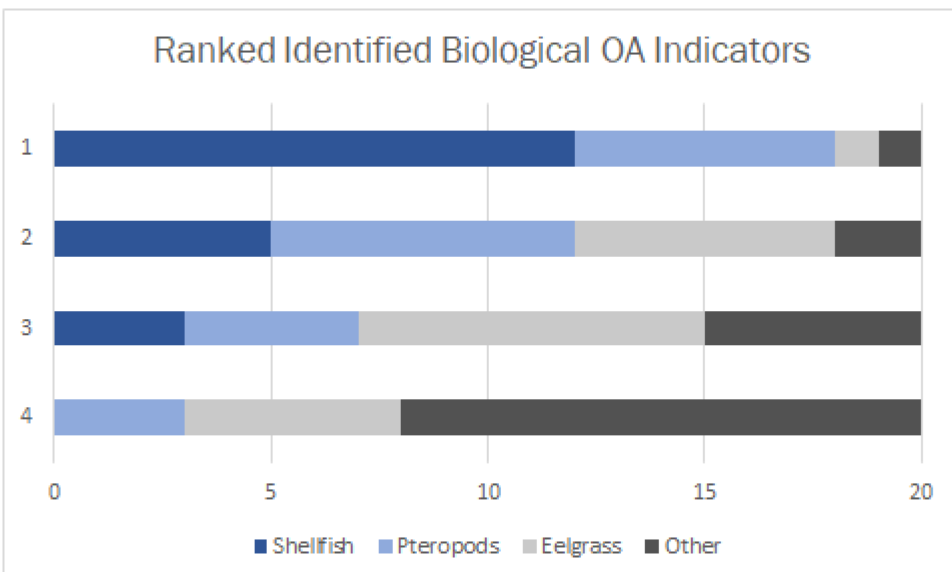


Figure 7: Rank is on the y-axis and number of scientists are on the x-axis. The figure shows the overall results of ranked identified biological OA indicators by marine scientists for the Salish Sea.

When asked to rank the most informative chemical ecological indicator, the top order was aragonite saturation, followed by pH, the partial pressure of carbon dioxide (pCO2), alkalinity, and then ‘other’ (figure 8). When chosen ‘other,’ I got specified responses of dissolved inorganic carbon (DIC) and salinity.

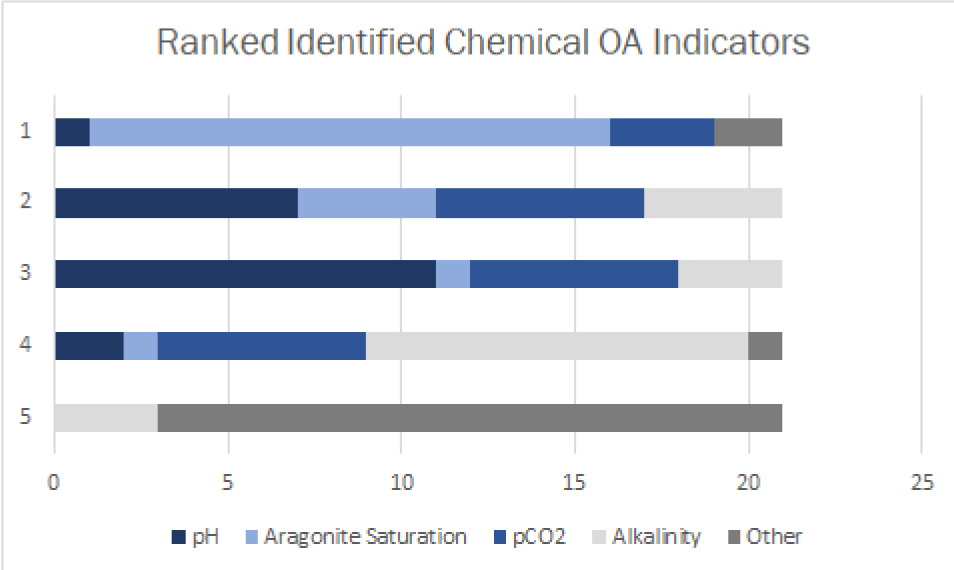


Figure 8: Rank is on the y-axis and number of scientists are on the x-axis. The figure shows the overall results of ranked identified chemical OA indicators by marine scientists for the Salish Sea.

While OA indicators can be insightful and informative individually, a combination of indicators can be just as insightful if not more so. When asked if there were informative combinations of OA indicators, the most popular results (60%) of the identified combination was aragonite saturation and pteropods or shellfish (figure 9). Since shellfish and pteropods are calcifiers and aragonite saturation is directly related to the process of calcification, thus this combination was expected.

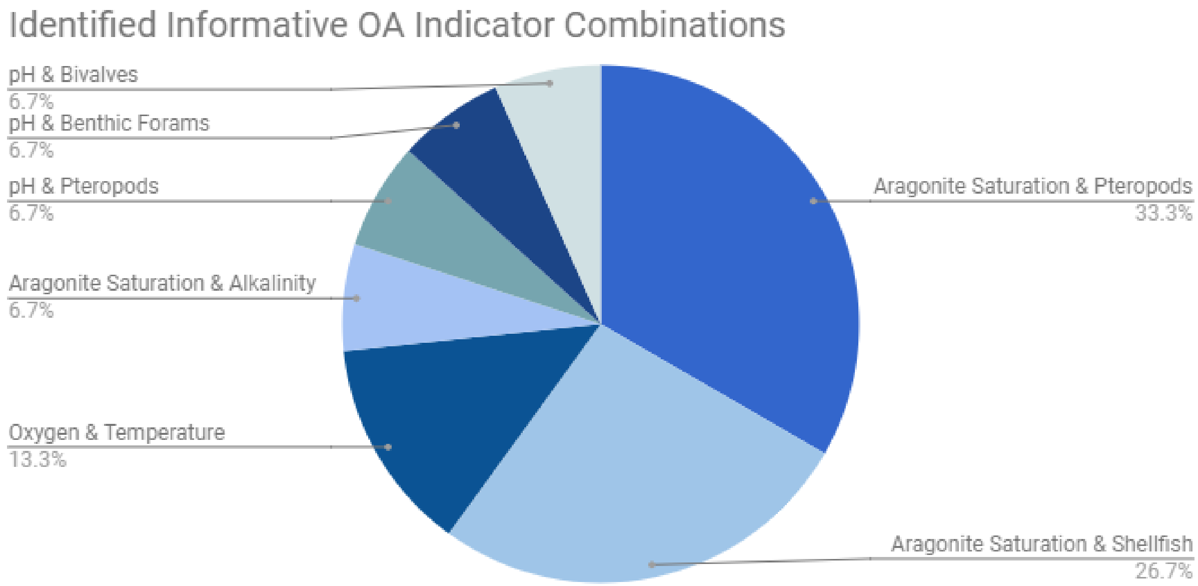


Figure 9: Chart of responses to the question asking if there is a combination of biological and chemical indicators that would be informative or beneficial.

For questions 5 and 6 in the survey regarding if an interactive map could have a potential outcome, responses were gleaned and summarized into three categories, Yes/Possibly, No, Depends/Unsure/Other. The categorized responses were what was graphed as seen in the next two figures.

When asked if an online interactive map, such as the one created for this project, could increase coordination between scientists, organizations, and communities, most respondents stated yes or possibly (70%). A quarter (25%) of the scientists answered they were unsure, it depended, or left a response that was unable to categorize. Only 5% of the scientists answered that it would not due to the lack of data and the complexity of the ecosystem (figure 10).

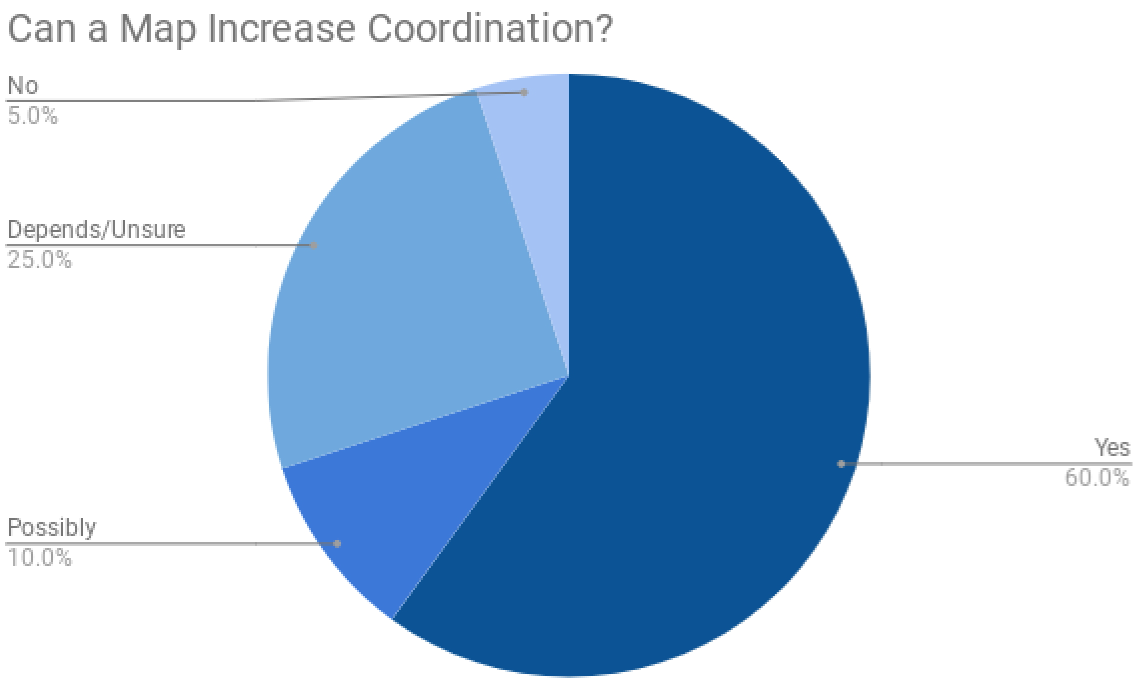


Figure 10: Chart of categorized responses to the question if an online interactive map could increase coordination between scientists, organizations, and communities.

When asked if an online interactive map, such as the one in the project, could potentially spur increased policy and management, the majority of scientists (72.7%) said yes or possibly. There was 27.3 % of scientists that stated they were unsure or it depends (figure 11). No respondent indicated that an interactive map would not potentially spur policy or management.

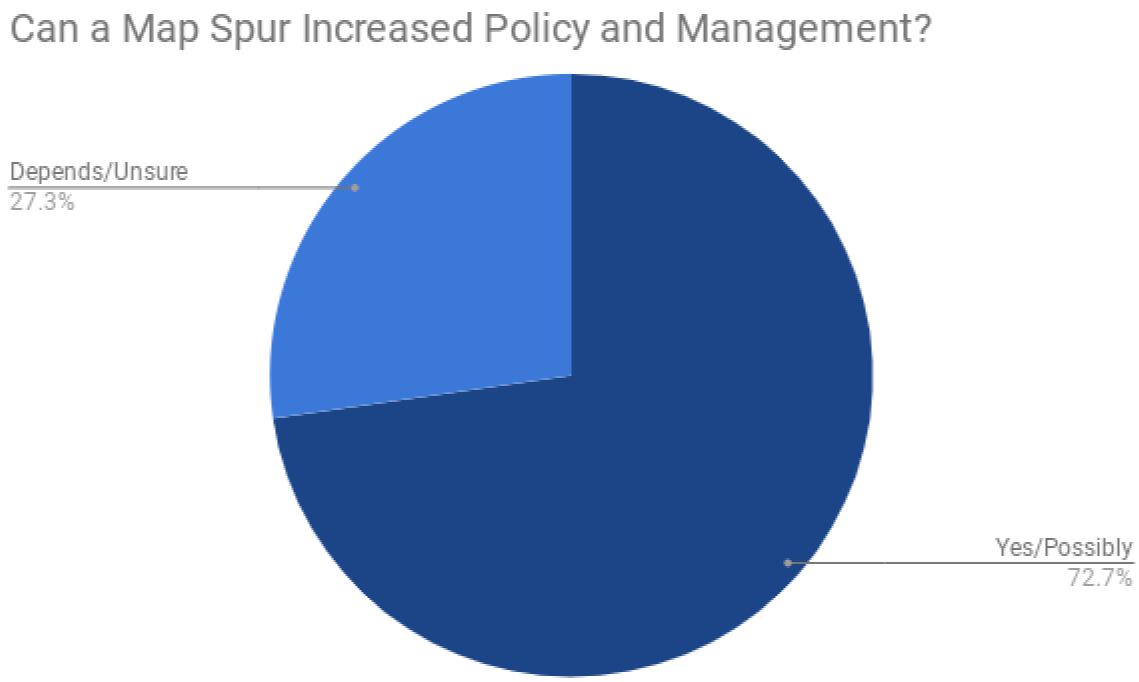


Figure 11: Chart of categorized responses to the question if an online interactive map could spur increased policy and management in the Salish Sea.

### *3.4 Map Development*

The OA indicators, pteropods, shellfish, and eelgrass, identified by the marine ecologists from the online survey results were mapped with MPA locations throughout the Salish Sea. Using the online mapping platform on ArcGIS, a story map format was used to display the maps. Pages and maps created in the story map included sections for shellfish, pteropod field data, pteropod experimental lab data, eelgrass, MPA locations, and a combination of indicators with MPA data. The process of making this map went through two major cycles of editing: a draft before the analytic deliberation input (figure 12), and then adjustments and edits from the analytic deliberation group. The goal for the first round of creating and editing the map was to create a map that contained all the MPAs and OA indicator data spots, and to be user-friendly for marine scientists, policy makers and the public. Data for the MPAs came from both National

Oceanic and Atmospheric Administration (NOAA) and Protected Planet World Database in the form of shapefiles. Data on the OA indicators was collected from several sources including NOAA, universities, open source databases such as PANGAEA, and private institutions. Due to the varying sources of data collection, data harmonization on the data was applied to unify the data structures and components (Hu et al. 2015; Janecka et al. 2013; Knox et al. 2015). The final online map produced from this project combined the efforts of data from MPA locations and OA ecological indicator data together.

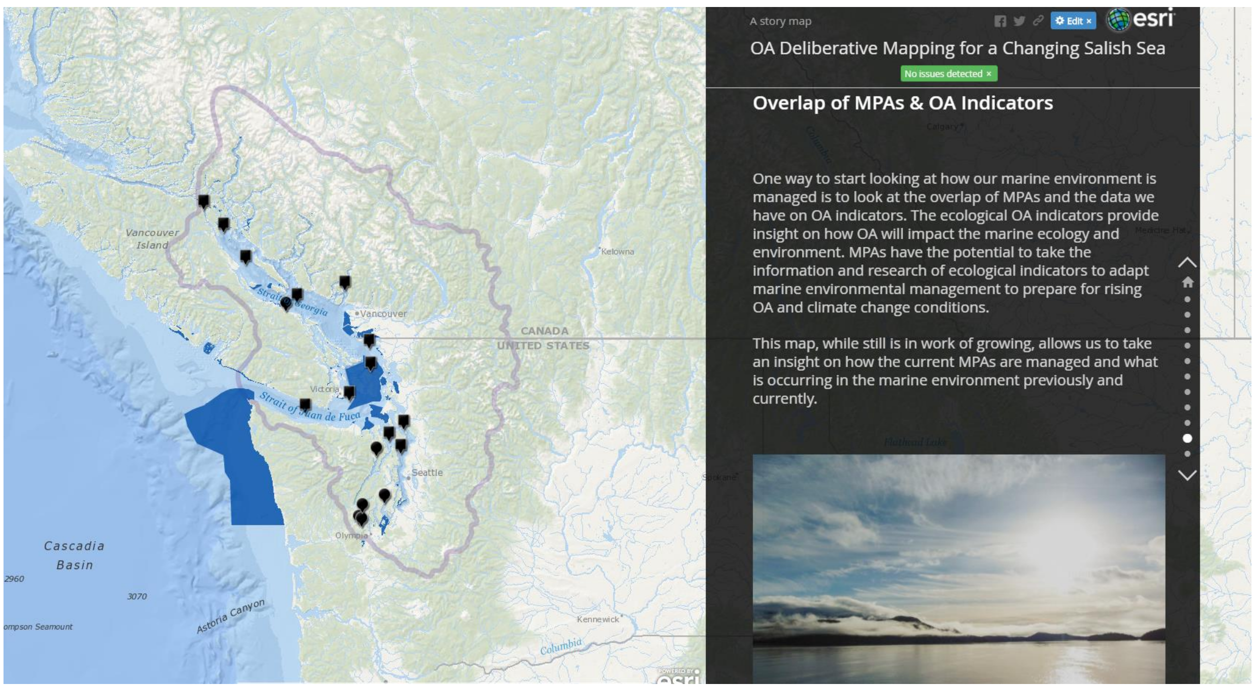

Figure 12: Screenshot of the online map draft shown during the analytic deliberation phase. This was an interactive map which allowed the users to click on the points or polygons to access the data and information. This screenshot shows the overall tab. This mapping format changed over time due to data limitations and feedback from the analytic deliberation groups.

The final online map can be accessed at this the link (https://wwu.maps.arcgis.com/apps/Cascade/index.html?appid=6ecfbfc222ac4b1f9954aadcfbf4bc22). However, the final map has limited data due to a lack of public availability to raw data and a lack of collaboration due to government restrictions and/or individual desires. Due to these data restrictions, the online map refocused the primary goals of bridging the gaps of collaboration and data sharing, to focus more on the need for collaboration to occur. Due to the lack of collaboration, the map provides a sense of how limited data sharing is, and the consequences of lack of collaboration and communication for this region.

## *3.5 Analytic Mapping Deliberation*

In the third stage, I conducted an analytic deliberation session. Analytic deliberation, much like focus groups mixed with consensus workshop methods, had 5 participants. These participants were identified GIS professionals and academic faculty. I reached out to these individuals via email (see Appendix C). During the analytic deliberation sessions, I asked the group a series of questions (see Appendix F) described in a sequence of Objective, Reflective, Interpretive, and Decisional (ORID) prompts.

These sequences of questions can be described in four phases. The first phase or objective phase had questions aimed to engage the senses of the map users. The second or reflective phase asked questions that are designed to elicit and acknowledge the emotions, memories, and initial associations of participants. The third or interpretive phase asked questions that were designed to elicit the sharing of experiences and meanings, build shared awareness, and identify options and possibilities. The fourth or decisional phase had prompts that were designed to develop collective opinions and resolve that may lead to future action (ICA 2000). These questions were aimed to improve the map draft to make it more user-friendly and geographically correct. The analytic deliberation session was approximately two hours.

### *3.5.1 Objective Responses:*

There were 5 GIS professionals and academics who attended the analytic deliberation session. Over the timespan of 2 hours, there were 12 questions asked. For the first phase of

ORID, Objective, I asked the following questions: (1) What was your favorite/interesting online map(ping) experience recently? (2) What visual design elements impressed you the most? (3) What about the user-interface did you like the most?

Four different online maps were identified: pollution tracker, city zoning, river forecast, and a backcountry map (See appendix for links). When discussing the pollution tracker map, elements such as the colored trends, easy to read highlights of information, and easy to identify polygons for reach region, were all factors that allowed the map to have an easy to use and read user interface and visual elements. The backcountry, river forecast, and city zoning maps were more technical maps that required more work and understanding from the users but provided substantial information and data within the map. The difference between the pollution tracker map and the other three identified maps is the focus on what kind of users are using the map. For the pollution tracker, having an easy interface with easy to read data and information allows nearly any user to understand and navigate through the map. However, the data and information presented are somewhat limited. As for the other three identified maps, pollution tracker, zoning, and backcountry maps, these all had significantly large amounts of data and information available for the mapped area, but harder to navigate at first.

Input from the first ORID phase provided useful insights for user interface and visual elements for this project's map. Specifically, I made changes to the user interface such as creating colored symbology for trends and increasing the ease of data access for marine scientists.

#### *3.5.2 Reflective Responses:*

I asked the participants the following three reflective questions: (1) What Do you like/dislike about the map? (2) What does this map do? What could it do? and (3) What information do you find most clear? Most confusing?

Most participants (3/5) liked the Salish Sea border and the possibility of having access to OA datasets. Likewise, the majority (4/5) of participants appreciated seeing point locations but disliked the single color since there was no descriptive element to help their understanding if OA levels were 'bad' or 'good.' There was an agreement that this map has the potential to be helpful but found that it was not particularly helpful for either marine scientists or policy makers. Similarly, the participants found that while the information displayed on the Salish Sea, OA, and ecological indicators to be informative, the text-heavy descriptions made it easy to overlook the information. Bringing back the topic of point locations, having so much data information might be helpful to marine scientists, but the participants, who were not marine scientists, found that interpreting the data and understanding it was confusing.

From this phase, edits to the map include providing more obvious information on what the data means for the policy makers and public users, cleaning up the story map text to include only a few sentences on each page to highlight key information, and creating separate user interfaces: one for marine scientists and the other for policy-makers and the public.

### *3.5.3 Interpretive Responses:*

I asked the participants the following three interpretive questions: (1) Did the information help your understanding of OA? (2) What would you like to see or do in a web-based map of OA in the Salish Sea? (3) What benefit could it have for GIS? For marine scientists? For policy-makers? For the Public?

For the majority (4/5), they found that the text describing OA and the indicators was hindering to the point where they were not motivated to read the full description to understand

and learn about the topic. Although, once read through, they found that they did learn about OA and the indicators but felt that there was a lack of urgency and importance of the topic. Overall, they said the map has potential to be helpful for a diverse set of audiences but found that the current map was not displaying all the information to be informative to a particular subset of an audience.

Suggested edits  based on this phase was the creation of colored symbology to display if that data is showing negative and alarming results, creating more ‘map pages’ with fewer words, and adding more of a personal affect or story to the map to highlight the importance and personal connections to the issue.

### *3.5.4 Decisional Responses:*

I asked the following decisional questions: (1) What are the next steps for this map? (2) What needs to be added? (3) What needs to be deleted?

Similar critiques from the past three phases were brought up: colored symbology, fewer words, and easier or more direct access to data via a link at the beginning. Additional insights such as using less aesthetically pleasing pictures of the sea, were also mentioned. The version of the map had many clear blue skies and calm water pictures of the Salish Sea, which gave the impression of calm and lack of urgency around the OA topic. One participant suggested using videos or images that would be almost shocking or uncomfortable for the user to get the idea that OA is alarming and harmful. Another suggestion included the insight to use more keywords in the titles so that when the map is searched online, there is more likely ‘hits’ to draw users to the map.

## *3.6 Participant Observation*

Between April 4-6, 2018, the 3rd Salish Sea Ecosystem Conference was held in Seattle, Washington. The conference hosted hundreds of scientists, policy-makers, businesses, students, and professionals who are interested in the Salish Sea ecosystem. Participant observations include observation notes of presentations and abstract content analysis. For the content analysis, the categories of Ecosystem Management, Policy, and Protection, Climate Change: Impacts, Adaptation, and Research, and Policy, Management, and regulation were analyzed.

### *3.6.1 Content Analysis*

Content analysis of the track of ecosystem management, policy, and protection showed that the most common words used in abstracts and titles were United States, Canada, Washington, seagrass, and restoration respectively (figure 13). Similarly, for the track of Climate Change: Impacts, Adaptation, and Research, the most common words used in the abstracts and titles were United States, Sea, Salish, Canada, and NOAA respectively (figure 14). Varying between the two previous tracks, the track of Policy, Management, and Regulation showed that the most common words used in the abstracts and titles were Canada, Sea, Salish, United States, and Fisheries respectively (figure 15). Overall, United States and Canada were the most popular words for all three tracks. This result is partially due to the location of who submitted the abstracts since this content analysis included the entire page, including the authors and their locations. However, on the track of Policy, Management, and Regulations, the top word was not the United States like in the other two tracks, rather the most used word was Sea.

Conversely, collaboration(s), collaborative etc. were rarely used. In the Climate Change and Ecosystem Management tracks used the forms of collaboration(s)/collaborative(s) six times, and the Policy Management track used the words 11 times. The word transboundary was utilized even less with only occurring in the tracks at most five times. Transdisciplinary was never used in any track. Whereas, interdisciplinary occurred only in the Climate Change track three times.

At the Salish Sea Ecosystem Conference 2018 there were two panels I attended: Salish Sea Marine Ecosystem Data Collation and Management and Ocean Acidification Observations and Monitoring in Salish Sea Waters. My lead advisor Dr. Abel attended the "Thirty-Year History of the Salish Sea Ecosystem Conference- Where We Have Started, Where We Have Been, and Where We May Be Going" panel and shared his observations with me.

### *3.6.2 Data Collation and Management Panel*

During the Salish Sea Marine Ecosystem Data Collation and Management session, the first observation could be noted from the abstract. The first line of the abstract states that despite sharing a common sea, there is no sharing of common data. Furthermore, this abstract there is a gap of the collection of biological data.

> *"While we share a common sea, many times we do not share common data. Some of this is because of the international border, but many organizations are starting to address this in a cross-border manner. As well, some data systems focus on physical variables, yet not biological data, leaving ecosystem-scale data unattainable…"*
>
> -Abstract for Salish Sea Marine Ecosystem Data Collation and Management

During the panel session, there was five panelists, three of which worked in in British Columbia, and two who were from Washington State. One of panelist's presentation data showed only the Strait of Georgia with various gaps throughout the region. Another panelist had data located solely in the northern part of the Strait of Georgia, and the other Canadian panelist had data that focused primarily off Vancouver Island and the Canadian side of the Strait of Juan de Fuca. As for the other two panelists, they concentrated their data on the Puget Sound. As the panel discussed various data management efforts from local universities and organizations, the gap of data collection could be observed in the Southern Canadian Georgia Basin and a lack of complete Salish Sea data collation. Despite the various panelists from various locations throughout the Salish Sea, the discussion was primarily focused on data organization and management approaches from their respective organizations, rather than including any discussion around data collation in a transboundary perspective.

### *3.6.3 Ocean Acidification Monitoring Panel*

In the Ocean Acidification Observations and Monitoring in the Salish Sea panel, between the six papers presented for the session, each paper was focused on a subsection of the Salish Sea such as Bellingham Bay, the West Coast of Washington, the Puget Sound, the Strait of Juan de Fuca, or Baynes Sound. Despite labeling the panel session as the Salish Sea and one of the six papers including the term of Salish Sea, each of the papers focused on a sub-region of the Puget Sound or Northern Georgia Basin. Additionally, five of the six papers look at biological and chemical indicators. While this panel abstract describes goals and motivation to increase transboundary collaboration, none of the OA observations or monitoring panelists described a truly transboundary project.

> *"Sessions will be organized to progress from observations and monitoring through modeling, biological responses, and strategies for adaptation and mitigation. Participants and presentations will represent the breadth and diversity of OA research in the region. Anticipated outcomes of the session(s) include dissemination of new knowledge, strengthening of trans-boundary collaborations and partnerships, and emergence of new innovations for regional management, mitigation, and adaptation."*
> -Abstract for Salish Sea Ocean Acidification: Observations and Monitoring in Salish Sea Waters

### *3.6.4 Salish Sea Ecosystem Conference History Panel*

In the panel titled "Thirty-Year History of the Salish Sea Ecosystem Conference- Where We Have Started, Where We Have Been, and Where We May Be going," panelists described the initial progress the Salish Sea had overcome since 1988 when the first Salish Sea conference convened. With the support of the Puget Sound/Georgia Basin International Task Force (of the Environmental Cooperation Council (ECC)) and Environment Canada's Georgia Basin Action Plan, the transboundary progress seemed to increase until it peaked around 1992.

During the panel, one senior US participant noted that while the 1992 bi-national environmental cooperation agreement was a seminal moment, the overall transboundary collaboration in the Salish Sea declined slowly and eventually disappeared. Likewise, a senior Canadian scientist and official called for the reconstitution of a similar effort as the ECC that was established by the 1992 agreement. While the council is still technically in force, no true transboundary meeting for this council has taken place or at least been documented. According to multiple panelists, this council has diminished over time.

One of the sources frequently cited in this panel was the Encyclopedia of the Puget Sound. Yet, when analyzing their archived reports and proceedings, there is little focus or recommendations towards governance issues. While there is support on scientists' sense making of their science and venues to support the science efforts, there is no complementary collection of governance sense-makers. In the next section, I present a word cloud analysis of the panel descriptions from the SSEC 2018 conference website. The infrequency of the terms collaboration, collaborative, transboundary, and either trans- or inter-disciplinary also demonstrates how fragmented research can be around the Salish Sea.

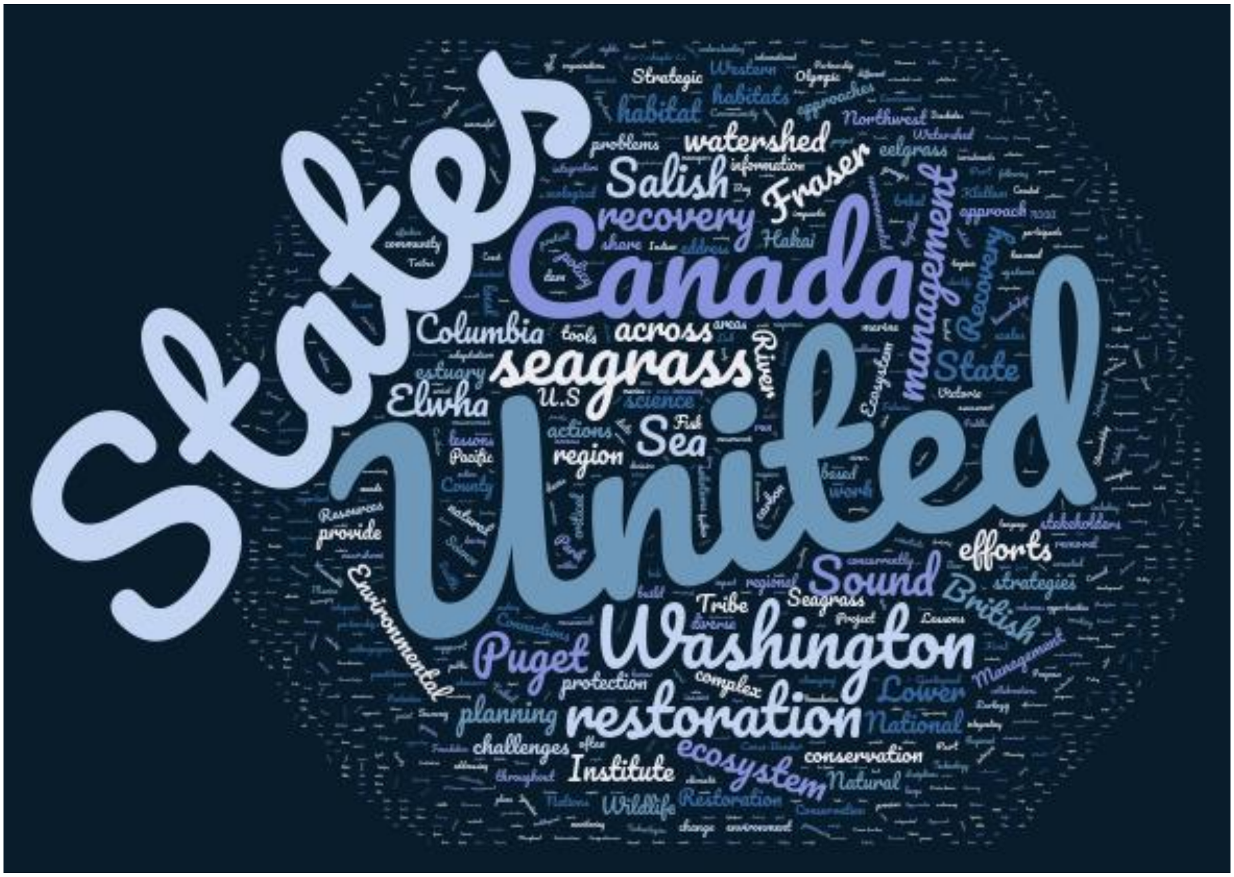


Figure 13: The word cloud of all session abstracts and titles of the Ecosystem Management, Policy and Protection Track at the Salish Sea Ecosystem. Below are the tables that identify the top words mentioned vs the number of times words related to collaboration or transboundary were used.

| # of Times Used | Word |
|---|---|
| 101 | United States |
| 52 | Canada |
| 29 | Washington |

| # of Times Used | Word |
|---|---|
| 6 | Collaboration(s)/ Collaborative |
| 1 | transboundary |

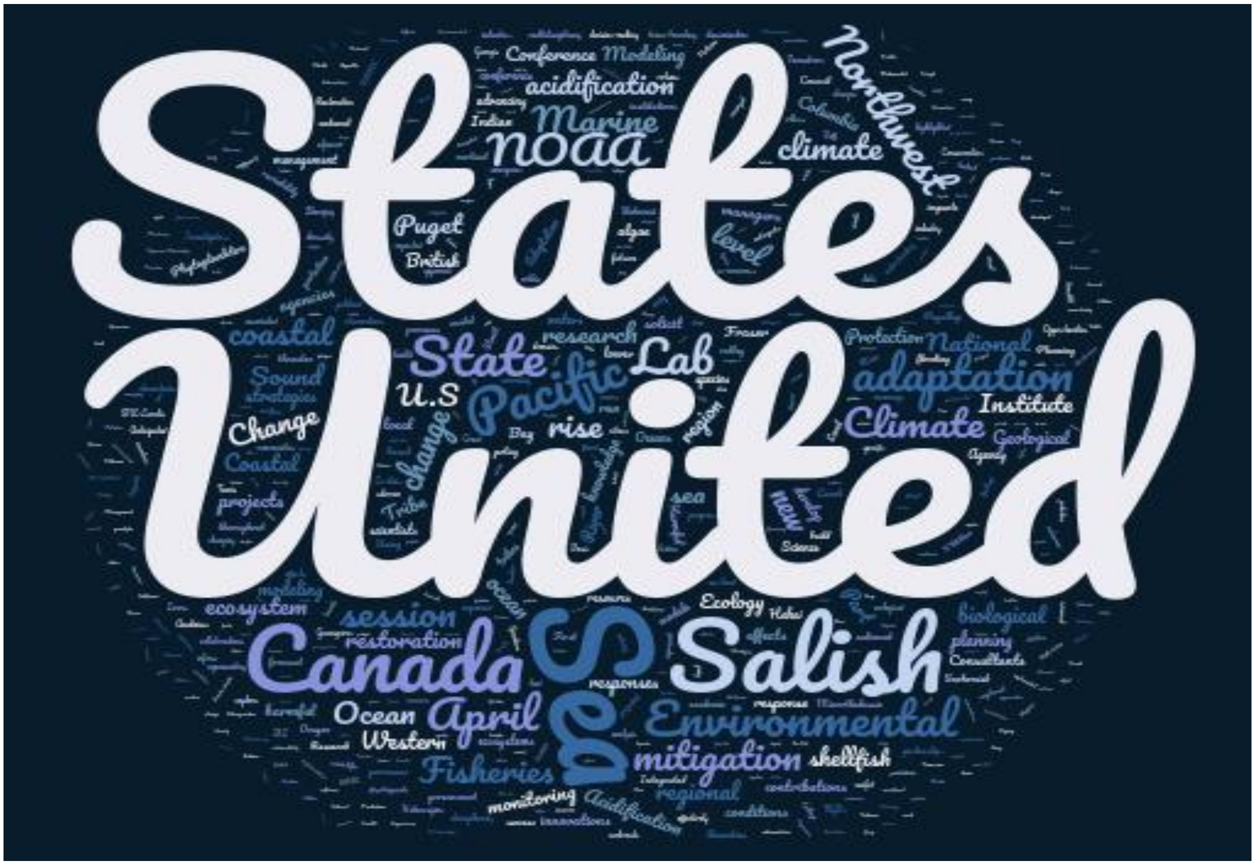


Figure 14: The word cloud of all session abstracts and titles of the Climate Change: Impacts, Adaptation, and Research Track at the Salish Sea Ecosystem. Below are the tables that identify the top words mentioned vs the number of times words related to collaboration or transboundary were used.

| # of Times Used | Word |
|---|---|
| 144 | United States |
| 56 | Sea |
| 41 | Salish |

| # of Times Used | Word |
|---|---|
| 6 | Collaboration(s)/ Collaborative |
| 3 | transboundary |

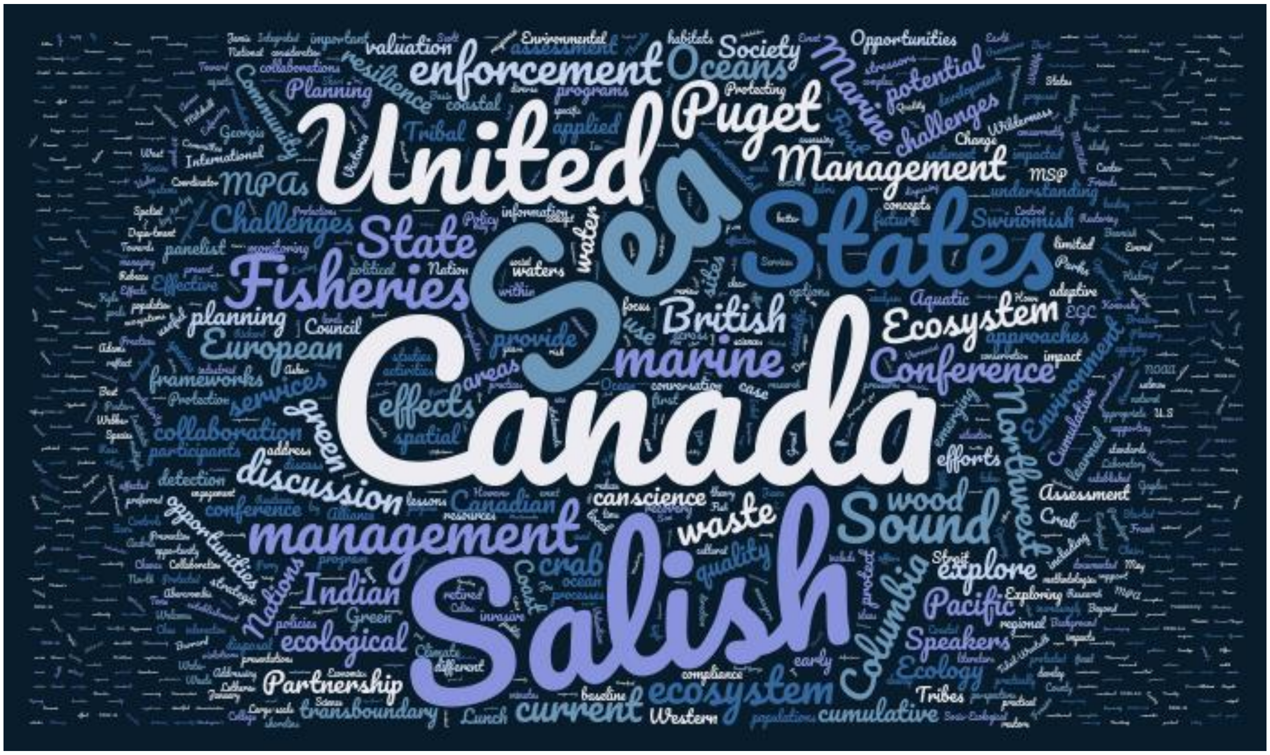


Figure 15: The word cloud of all session abstracts and titles of the Policy, Management, and Regulation Track at the Salish Sea Ecosystem. Below are the tables that identify the top words mentioned vs the number of times words related to collaboration or transboundary were used.

| # of Times Used | Word |
|---|---|
| 43 | Canada |
| 41 | Sea |
| 37 | Salish |

| # of Times Used | Word |
|---|---|
| 11 | Collaboration(s)/ Collaborative |
| 5 | transboundary |

# Chapter 4. But, Where's the Collaboration?

## *4.1 Ocean Acidification Indicators*

While extensive OA research occurs throughout the Salish Sea, there is a lack of focus and data collection on priority OA indicators. Yet, significant literature supports how ecological indicators can provide key insight on mitigation and adaptation efforts to emerging ecosystem issues such as OA (Turnhout 2009). Traditionally, oceanography related research gathers chemical indicators and data with buoys and cruises, however, when it comes to biological species, there is less uniform collection. Part of this project was to identify what the top indicators for OA were in the Salish Sea region to help inform scientists, policy-makers, and the public. These indicators could potentially provide insight on how the Salish Sea ecosystem will change and be impacted as OA rises in the region.

The preliminary background search on OA indicators: pteropods, coral, crab larvae, and seagrass, proved to be partially successful and informative (Bednaršek et al. 2012a; Gibson et al. 2011; Hoegh-Guldberg et al. 2007; Koch et al. 2013). Pteropods and seagrass, more specifically eelgrass, were identified multiple times through both interview and survey stages. While coral and crab larvae were not identified during the interview and survey stages, it does not mean that these are not informative OA indicators, but rather, these are not the top OA indicators perceived by the marine scientists that responded to the interviews and online survey. During the first stage, semi-structured interviews, there were additional OA indicators identified: shellfish, zooplankton, phytoplankton, and benthic forams. These results expanded the OA indicators in the Salish Sea list (Appendix K for the list of all indicators).

The EPA and Environment and Climate Change Canada created a joint effort on monitoring Salish Sea Ecosystem indicators (SSER 2014). Yet, no indicators on that list address OA conditions. With a list of ten indicators, not even one mentions impacts from OA. Comparing the list of OA indicators identified in this project, only one of the indicators, shellfish (harvesting), could be considered an overlap between the two lists of indicators. However, based on the description of monitoring efforts and reasons of concerns for shellfish harvesting, there is no language or content that mentions OA or climate change. This lack of acknowledgement of OA on a Salish Sea Ecosystem health indicator list suggests a lack of understanding of the importance and support for the OA efforts in this transboundary region.

One of largest challenges, which will be discussed in the next section in more detail, was the lack of availability of this data to the public from private and government entities. Based on interview and survey results, it was evident that scientists saw a need and want for the OA indicator data, however, individual and institutional restrictions prevented me from accessing OA data for my map. Another OA indicator challenge is the fact that OA indicators are still an emerging field of study. While there is data previously collected, only a small group of marine scientists' study OA indicators. As more studies occur over time, more data would be available to map.

### *4.2 Transdisciplinary Barriers*

A common discussion between academics and researchers are the arguments around whether research should be disciplinary or interdisciplinary, seldom do they discuss the possibility of it being transdisciplinary (Kanazawa 2017; Lang et al. 2012). Transdisciplinary research requires a knowledge production and sharing in new methods (Lang et al. 2012). One of the largest challenges facing transdisciplinary research is the lack of tools and ability to share knowledge. An online mapping tool such as what this project created, can be one such method to support and promote transdisciplinary efforts.

For complex issues that the Salish Sea faces, like OA, the idea of governance is one that can support and guide coordination. Transdisciplinary is a reflexive, integrative, method driven scientific principle concurrently aimed at solving societal and scientific problems by differentiating and integrating knowledge from various scientific and societal bodies of knowledge according to Lang et al. (2012, 26-27).

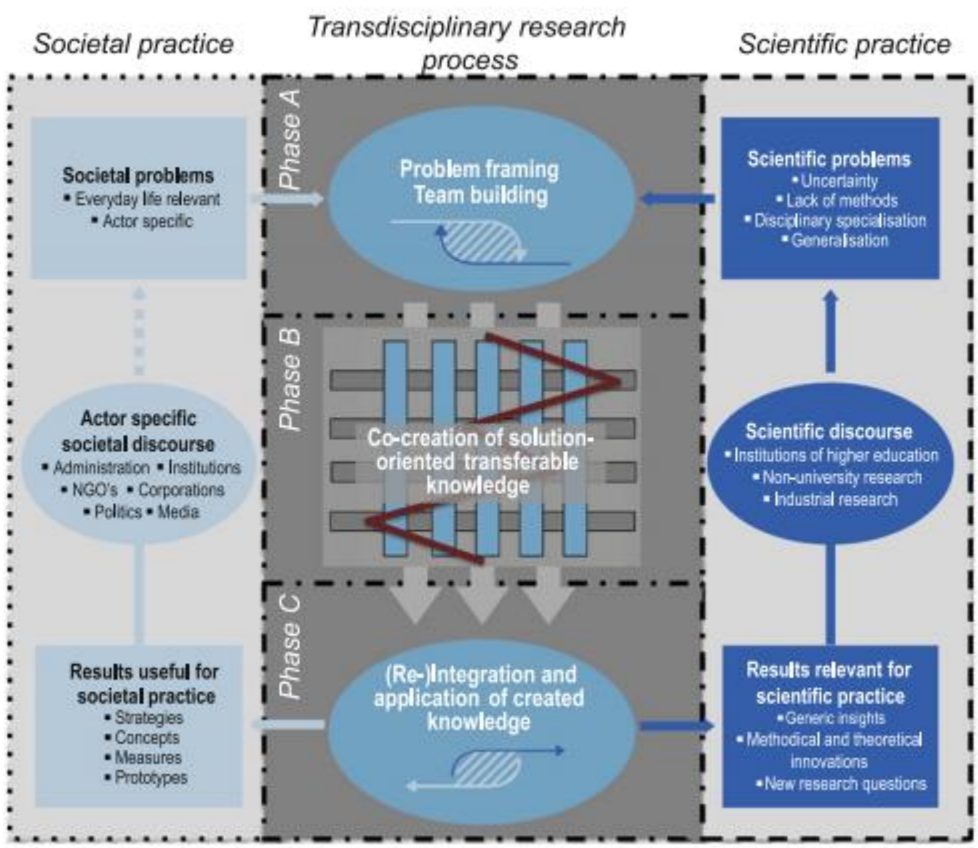


Figure 16: Adapted from Lang et al. 2012 on Transdisciplinary Research Process.

One example that has brought transdisciplinary actions to the Salish Sea is the Puget Sound State of the Sound. The report incorporates various tools such as the Salish Sea Ecosystem health indicators and the Puget Sound scorecard; it also supports annual reviews of the action agenda goals and the current status with those efforts. Through the incorporation of tools and providing policy recommendation for Washington State's legislature, the report includes all three transdisciplinary phases, and provides support for societal and scientific practice (see figure 16) (Lang et al. 2012).

Reviewing the current efforts of a transdisciplinary effort, the Salish Sea Ecosystem Conference is one forum that can bring together multiple stakeholders and disciplines to address the Salish Sea's challenges (SSEC 2018). However, upon analyzing the abstracts from three different policy and science tracks, the key terms of collaboration(s)/collaboratives, transboundary, and interdisciplinary/transdisciplinary were barely mentioned. This is even more observable when looking at the word clouds (figure 13, 14, and 15). It is barely, if at all, visible to find these key terms in the word clouds.

There is another transdisciplinary effort called the Puget Sound scorecard. The Puget Sound scorecard is a tool that evaluates the progress of Near Term Actions (NTAs) and their progress. This tool utilizes one of Ostrom's design principles in which it develops a system carried out by community members, for monitoring members' behavior and their progress throughout the Puget Sound (Ostrom 2015). The Puget Sound State of the Sound report also integrates the element of analytic deliberation which was identified by Dietz, Ostrom, and Stern (2003) to be of help when incorporating perspectives of multiple stakeholders analyzing environmental and human system impacts on the Puget Sound. Furthermore, the report bridges collaboration efforts between communities, environmental stakeholders, and policy-makers by creating a report and tools to better inform everyone, which ultimately addresses the Fraser's et al.'s (2006) call to enhance collaborative knowledge management. Yet, in terms of OA, there is no such bridging collaboration effort encompassing the entire Salish Sea region.

When I had begun this project, I was inspired to work at the marine science and policy interface. As an undergraduate and oceanography researcher, there was an obvious gap in this kind of work which combines the two different disciplines. However, through experience, it was obvious to me that we needed more work and advancement in this transdisciplinary interface for marine science. Little did I know when I had started out how little collaboration, transdisciplinary efforts, and significantly large amount of fragmentation was occurring in our region. There is significant collaborative work that needs to occur in order to address OA.

Currently, in both the US and Canada, there is no official panel or council addressing OA for the region. Creating a panel for the entire Salish Sea similar to the Washington State Blue Ribbon Panel on OA, or recognized organization such as the Commission for Environmental Cooperation (CEC), to focus on the entire Salish Sea and the climate risks such as OA that threaten the region is needed. Based on the dissonance of perceptions of collaboration between nations, a panel or organization that provides a space in which the scientists, policy-makers, and/or stakeholders can communicate, would significantly improve collaboration for the region. This style of organization or panel should follow the transdisciplinary research process phases of problem framing and coordinating as a team, create a co-creation of solution oriented transferable knowledge, and then integrate and apply the co-created knowledge back into the societal and scientific disciplines as seen in figure 16. This kind of process is where scientists, policy-makers, and/or stakeholders could participate and build up knowledge and action between the different disciplines.

### *4.3 Transboundary Barriers*

OA issues in the Salish Sea are a unique and challenging problem for multiple reasons. For change or action to occur, there must be understanding from policy-makers and the public on

OA. Yet, communicating complex scientific data and discussion on OA to these audiences is another challenge. Furthermore, due to the transboundary region, there needs to be coordination, communication and collaboration between scientists, policy-makers, and the public on Canadian, First Nations, and US sides. While this project looked to bridge the gap of collaboration and communication between these audiences, the major challenge faced during this research was the differences in perception between marine scientists in Canada and the US.

As stated multiple times throughout this paper, the transboundary nature of the Salish Sea is a barrier towards collaboration efforts. This barrier can be reflected in the difference of US and Canadian perceptions of how to address OA, the amount of perceived collaboration, and the current amount of collaboration in the region. These differences in perception of collaboration is clearly illustrated by the Canadians scientists believe more collaboration should be occurring between scientists and governments, whereas many of the US scientists perceive that collaboration efforts are occurring.

Perceptions of collaboration between American and Canadian scientists are significantly different. Four of the ten interviewees were Canadian scientists, the remaining six were American. The sample population was intentionally recruited to get a near 50/50 split to give fair representation. Most of the Canadian scientists stated that there was little to no collaboration, whereas the American scientists mostly stated that there were coordination efforts, but that they could be improved. The US scientists mostly perceived collaborations between NOAA, universities, and private organizations, whereas not specifically identifying collaborations between the US and Canada. These perceptions could also be observed at the SSEC (2018), where many of the collaboration efforts were focused within the US region. This significant difference in perception on collaboration could be one of the hindering collaboration efforts between the two nations. This is reflected in efforts to collect data for this project as well. Many Canadian scientists were unaware of biological OA indicator data and its availability, whereas many Americans were aware of data, but were unwilling to provide data for this project.

A lack of collaboration and coordination efforts over the entire Salish Sea can be seen from the policy and management efforts. When the marine scientists were interviewed about policies and management efforts to address OA for the region, there was significant lack for both the US and Canada. However, some scientists did note the Washington State Blue Ribbon Panel on OA (state level), which while it is not a policy or regulation, it is a government endorsed effort to addressing OA for Washington State. The Washington Blue Ribbon Panel on OA is a unique panel of marine scientists in which they inform the government and public on OA policy recommendations. This style of panel was one of the first efforts in the US to start addressing OA outside of research (Washington State Blue Ribbon Panel on OA 2012). A lack of policies and management for the entire region is a transboundary issue and was one of the major focus points for this project and creating a tool to help increase this collaboration movement.

The difference between US and Canadian scientists arose again when discussing insight on possible coordination and management efforts that could reduce OA. Canadian scientists mostly focused on the efforts to reduce carbon dioxide or greenhouse gases, whereas the US scientists provided more diverse smaller, adaptive management effort suggestions in addition to reduction in greenhouse gases. Such management efforts include improved management of kelp beds and eelgrass and reduced nutrient loads. These management differences between the two nations could be an issue for present and future collaboration efforts. Canadian scientists were focused on the larger problem of OA, which is reduction of greenhouse gases. The American scientists were focused on smaller changes that could be taken to address OA issues. The difference in issue focus and management scale is a challenge for the Salish Sea since it means that the management focus switches at the border. The current state of dissonance between the two major governments follows the same fragmented governance and policies throughout the Salish Sea found by Alper (2004) and Clauson & Trautman (2015).

Aside from perceptions, there is also a lack of comprehensive data spanning the Canadian-US border. In marine science research, the US agency NOAA is a large contributor to oceanic research (NOAA 2018). However, due to the Canadian-US border, there is a distinctive line in which NOAA and other US data collectors do not sample or collect data (as seen in map 1). This transboundary region becomes a distinctive challenge for scientists who study and research the Salish Sea, and for policy makers in both countries. By only focusing research efforts in one nation, data gaps emerge. This lack of research for the Salish Sea as a whole becomes a problem for policy-makers to address the entire Salish Sea because there is limited data to support transboundary policies.

### *4.4 Policy Recommendations*

My case study research leads me to the following four prescriptions for overcoming the transboundary and transdisciplinary barriers facing OA in the Salish Sea.

**First, the newly established Salish Sea Institute at Western Washington University (WWU) should consider developing a proposal for the National Science Foundation's Research Coordination Network (RCN) program (NSF 2017).** This program provides support for RCNs. But, there are no programs supported for the Salish Sea. RCNs are primarily designed to bridge coordination and communication efforts across disciplines, organizational, geographic and international boundaries (NSF n.d.). According to the National Science Foundation (NSF)

RCNs:

> *"...do not support primary research. Rather, the RCN program supports how investigators can share information and ideas, coordinate ongoing or planned research activities, foster synthesis and new collaborations, develop community standards, and in other ways advance science and education through communication and sharing of ideas" (NSF 2017).*

By not funding the primary research and focusing on funding the efforts of collaboration and communication, RCNs create and incentivize data sharing between researchers. Moreover, the Salish Sea ecosystem and its OA challenges are also a good fit for the NSF program on the Dynamics of Coupled Human and Natural Systems (CHNs).

**Second, WWU's Salish Sea Institute should consider developing an RCN proposal for the NSF's** Coupled Human and Natural systems (CHNs). This is a framework and research program that describes the dynamics society or humans have with the natural system (see figure 17). Alberti et al. (2011) recommended that Coupled Natural and Human systems (CNHs) research projects: (1) identify and articulate analytical boundaries and scales of interest and (2) start with a common conceptual model. While there is a clear boundary and scale for the Salish Sea, the existing framework is mostly a biophysical perspective. As discussed, the current Drivers, States, Pressures, Impacts, Responses (DPSIR) framework used by Environment and Climate Change Canada (ECCC) covers little of the social, policy, and governance aspects of the Salish Sea ecosystem. However, NSF's CHNs program "supports interdisciplinary research that examines human and natural system processes and the complex interactions among human and natural systems at diverse scales" (NSF 2017).

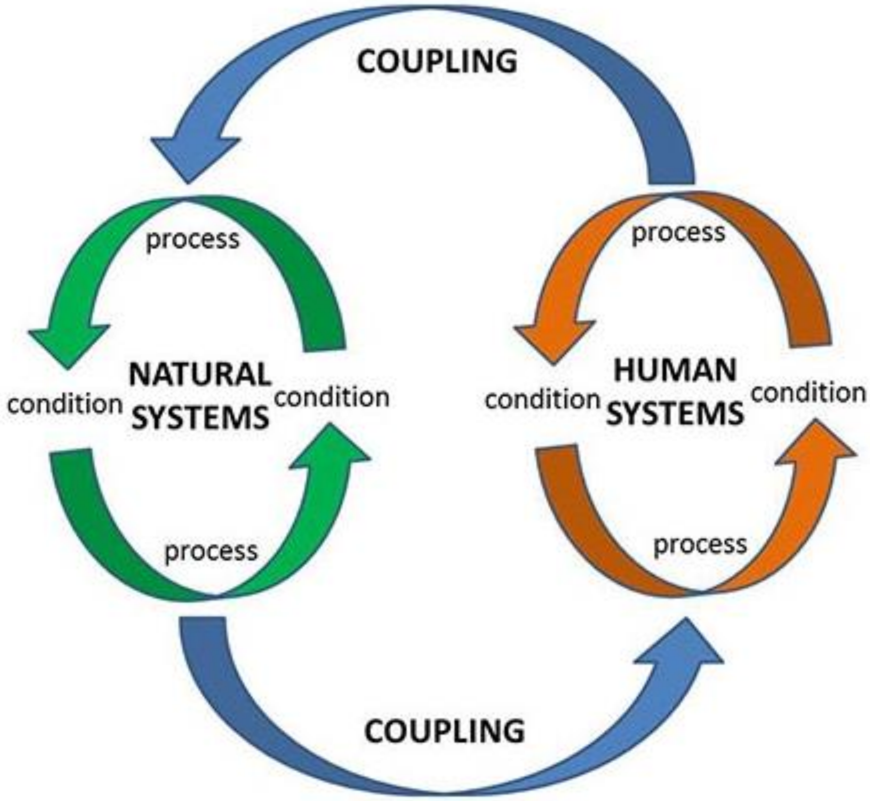


Figure 17: Figure from NSF's description of a Coupled Human and Natural Systems. This figure illustrates the dynamics of which the natural and human systems have to each other.
https://www.nsf.gov/pubs/2018/nsf18503/nsf18503.htm

The CHN perspective epitomizes a transdisciplinary framework that can address another barrier identified in my research.

**Third, WWU's Salish Sea Institute should consider supporting research that adopts a Transdisciplinary framework for OA challenges.** OA is a complex problem with multiple stakeholders and disciplines working on the problem. Yet, many of these stakeholders and disciplines are not communicating or collaborating, causing a gap in progressing forward in the

OA management and research. A transdisciplinary framework, as described by Lang et al. (2012), should bridge different disciplines, especially the societal/human and nature, together to solve the complex problem. While a transdisciplinary framework can be integrated into various forms, at the minimum, the research done in the Salish Sea should reflect this framework. This includes research inclusion of societal indicators like those found in the Puget Sound Partnership's vital society and governance indicators.

Governance and societal indicators can provide insights to governance and how to better adapt/manage. Fragmentation of nations and their policies leave a lack of uniformity and focus on the resource at hand in the Salish Sea. To progress away from fragmentation, the Salish Sea region should reflect on the current governance and indicators to utilize a stronger coordination approach like the International Joint Commission in Canada and the US around the Great Lake region. The International Joint commission coordinates in a transboundary manner and provides policy and environmental governance for the shared region. Their efforts also include the support of transboundary research, policy making, strategic planning, and settling freshwater disputes.

**Fourth, WWU's Salish Sea Institute should consider supporting the continued development of an online OA indicators and trends map.** Scientists have identified a need and want for such a tool as noted from the results of the online survey. With only 5% of surveyed scientists saying no that a map could increase coordination, and the majority of interviewed scientists noting that an online data sharing map could be informative, a mapping tool could be extremely beneficial, especially bridging coordination and policy efforts. Due to the current lack of collaboration and data sharing, this tool is very limited in powers. But as the data and research grows in the region, information and data should be made available. Furthermore, this type of tool could provide support and networking for the recommended RCN.

In sum, these four prescriptions could improve our region's governance of the Salish Sea and its resources. While the Salish Sea Ecosystem Conference is an effort to enhance cooperation and coordination, it is still extremely fragmented (figure 18). An RCN with a transdisciplinary framework that informs an online OA conditions and trends map offers a promising path forward that could enhance both the cooperation and coordination needed for more effective stewardship of a changing Salish Sea ecosystem (See Figure 18).

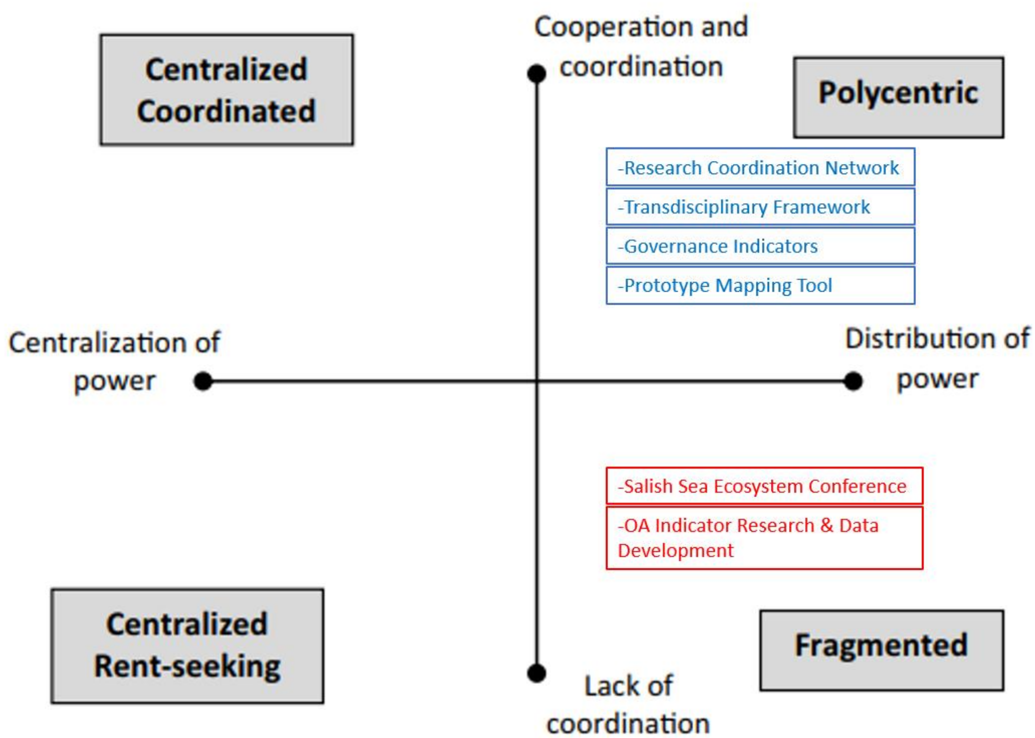


Figure 18: Adapted figure from Pahl-Wostl and Knieper 2014 article. In the grey boxes are the idealized governance regimes in which are described into two dimensions of degree of coordination and distribution of power. Added to the figure is the policy recommendations (blue) from this project and the current Salish Sea efforts of coordination, the Salish Sea Ecosystem Conference & current OA research (red).

# Chapter 5. Conclusion

Through an iterative process, this project answered three questions: (1) what are the most informative ecological indicators to discern critical climate risk trends from OA; (2) how can OA ecological indicators be effectively mapped throughout the Salish Sea; and (3) what are the barriers of collaboration that the Salish Sea faces regarding OA? My field project resulted in both an online prototype map and recommendations for collaborative actions to confront the OA threats to a changing Salish Sea.

The first question was answered through a multi-step process of semi-structured interviews and surveys to marine scientists in the Salish Sea region. The top identified ecological indicators for OA were shellfish, pteropods, and eelgrass (figure 19). While the preliminary research found that the potential OA indicators for this region were pteropods, seagrass, coral, and crab larvae, only pteropods and seagrass (eelgrass is a subcategory of seagrass) were identified by scientists. Shellfish as a top-ranked OA indicator is due to the economic value and sensitivity, and pteropods were second-ranked due to their sensitivity as well (a list of all identified OA indicators can be found in the Appendix K).

| **Top Three Identified and Ranked OA Indicators** | | | |
|---|---|---|---|
| **Rank** | **Biological** | **Chemical** | **Combination** |
| 1. | Shellfish | Aragonite Saturation | Aragonite Saturation & Pteropods |
| 2. | Pteropods | pH | Aragonite Saturation & Shellfish |
| 3. | Eelgrass/Seagrass | pCO2 | Oxygen & Temperature |

Figure 19: This table shows the top identified OA indicators for three categories: biological, chemical, and a combination. The ranks and identification of these OA indicators are from the online survey responses.

The second question, “How to efficiently map OA indicators throughout the Salish Sea?” was only partially answered with this project. While I had created an online interactive story map, I was unable to develop a spatial tool to its fullest potential. OA indicators are a newer field of study in environmental science, and the topic has not been thoroughly researched. Data availability has been hindered by limited research, but also due to institutional and individual reasons for not sharing collected data. Development of the informative map was supported with semi-structured interviews, surveys, and an analytic deliberation workshop with GIS professionals. This process can help inform future studies and mapping efforts to help expand this project as data becomes available and to help create mapping projects that bridge multiple stakeholders’ ideas.

The third question, “What are the barriers to collaboration that the Salish Sea faces regarding OA?” was answered through a process of semi-structured interviews, online survey, and participant observations. While not originally part of the research project, this question was added as the process of researching OA and creating an online interactive map progressed. The dissonance of perceptions between US and Canadian scientists, lack of overall governance in the Salish Sea region, and continuation of fragmented communication and collaboration efforts as observed from the Salish Sea Ecosystem 2018 conference provided insights into this question. As a result, I found that the barriers could be summarized as that lack of both transdisciplinary research and transboundary governance for a changing Salish Sea.

However, my project did have its limitations and I’ve categorized them in three categories: collaboration, data, and time. The Salish Sea requires more communication and coordination efforts. Yet, as noted from the participant observations of the Salish Sea, there is a lack of shared coordination efforts throughout the entire Salish Sea region. Currently, fragmented efforts are inefficient and ineffective to address large and complex conditions like OA. Additionally, while I reached out to key scientists who study OA in the Salish Sea, far fewer scientists responded and provided their insights than I expected. This lack of willingness to share data and openness to providing insights on OA to various stakeholders and the public in the region was another barrier faced throughout this project. But, my project's two most substantial limitations to this project were the availability of data and time.

Through interviews with marine scientists, I was informed that there was OA indicator data being collected in the Salish Sea, however due to institutions and individuals, researchers would not share their data. This lack of availability of data was a significant challenge for the online map because, with such few data points, the map is less effective in illustrating the current OA conditions and impacts throughout the Salish Sea. This map data may expand as new studies, and OA efforts increase in the next decade. However, at the current stage, the data and timeframe prevented the furthering efforts of this online prototype map. Additionally, due to the timescale, the ability to collect more data on collaborative data and information was limited.

Future progress for the online mapping tool could include the expansion of data as it becomes available, additional OA indicators data, and other climate change indicators. This project map serves as a first-step or prototype map for this region but would become a more powerful tool if data would be continuously added. While the purpose of this map is focused on OA issues, the map and data could be expanded to other ecological data to help provide more insight on local ecosystem stressors or problems such as pollution, climate change, and nutrient runoff.

Another next step should also include policy management and coordination analysis. In regions where there are MPA’s and ecological indicator data, it is possible now to reanalyze the management and coordination efforts in those regions to identify if the current management or practice is effective or appropriate for the current level of ecosystem health in the area. As MPAs are sites of growing conservation efforts, they are also areas that provide ecological data and monitoring on the changing marine conditions. The sensitivity to changing conditions and the political foundation for MPAs provides opportunities to gather better understanding of future marine conditions, political impact, and an increase in climate change research. They are a key site where human and natural systems are coupled. Nonetheless, my prototype map has the potential to be a tool to inform and bridge the gap between various audiences.

My project focused on a unique transboundary region which requires multiple nations collaborating and communicating findings to solve or address problems facing the ecosystem. Creating an online map could allow easier collaboration and communication of results and could potentially be replicated for other regions or locations in which collaboration and communication are lacking. Suggestions based on efforts in this project support building more relationships with and between the scientists that were interviewed. A significant challenge for this project was communication between scientists. Many individuals had busy schedules or would be unresponsive to initial email contact. This challenge could have been reduced if there was more relationship between the researcher and the individuals being interviewed or surveyed.

In sum, my project ultimately leaves us with similar questions that I began with. Where is the OA science and governance collaboration within the Salish Sea, and when we will begin to fill in the policy and science gaps in our changing and shared waters? As the Salish Sea continues to change, and as we continue to emit greenhouse gases, OA problems will rise. So how will our Salish Sea communities react to such changing conditions? These are the questions that as scientists, researchers, various stakeholders, and policy-makers need to take strides to address.

***"While we share a common sea, many times we do not share common data. Some of this is because of the international border, but many organizations are starting to address this in a cross-border manner. As well, some data systems focus on physical variables, yet not biological data, leaving ecosystem-scale data unattainable."***

**-Lisa Wilcox Squamish Nation (Coast Salish Gathering n.d.)**

# Appendix A: Letter & Consent forms for Semi-Structured Interviews

## *A.1 Letter Invite for Semi-Structured Interviews*

Greetings,

You have been identified as someone with valuable insight and expertise on the issue of ocean acidification in the Salish Sea region. Drs. Troy Abel, Tammi Laninga and I seek expert input to inform our development of an online mapping tool that will inform the public, marine scientists, and policy makers about ocean acidification impacts on the Salish Sea and adaptive management options for the region. Our research will benefit from your insights. There are no anticipated risks associated with responding to our questions and you may benefit from learning and thinking about the online mapping of ecological trends. Your participation is voluntary and should not take more than 1 hour. You may stop the interview and withdraw your participation at any time without penalty.

If you agree to participate in an interview, I would like to record our conversation to accurately document the information you provide. Though you have the right to decline being recorded, I should note that the recording will be used for transcription purposes only and your identity will not be recorded or transcribed. The recording will be erased as soon as it has been transcribed. A random numerical code will be assigned to your transcript to protect your identity and any documentation linking your name to the code will be stored separately from the transcriptions by our lead investigator Dr. Troy Abel. That list of codes and identifying information will be destroyed as soon as we complete our interviews at the end of October.

You can stop participating at any time. All your answers will remain confidential and your responses will be aggregated for analysis. Small quotes and portions of the interview will be de-identified and maybe quoted in my final project manuscript. Your input will provide insights and prioritize the data that will be identified and mapped. Thank you in advance for your consideration, your insights and opinions are truly valuable to this research. To schedule an interview time, please contact Katrina Radach at radachk3@wwu.edu or by phone at (509) 952-3756.

If you have questions about this study or the information in this form, please contact the lead researcher, Dr. Troy D. Abel at (360) 739-6596 or Katrina Radach at radachk3@wwu.edu or by phone at (509) 952-3756. If you have questions about your rights as a research participant or would like to report a concern or complaint about this study, please contact the Western Washington University Human Protections Administrator (HPA) Janai Symons at janai.symons@wwu.edu or by telephone at (360) 650-3082.

Best Regards,

Katrina Radach

### *A.2 Consent Form Semi-Structured Interviews Participant/Researcher Copy*

Purpose: This research step is seeking stakeholders input to create an online mapping tool that will inform the public, marine scientists, and policy makers on the ocean acidification impacts and adaptive management for the Salish Sea region through combining data on ocean acidification indicators and marine protected areas. This research is for Katrina Radach's Western Washington University Graduate Thesis Project.

I UNDERSTAND THAT: 1) This an interview of approximately 1 hour. 2) During this I will be asked question regarding my connections, experiences, and perceptions of ocean acidification indicators. 3) I may refuse to answer particular questions during the interview. 4) I may stop and withdraw from the interview at any time. 5) I agree to an audio recording of my voice and answers during this interview (Initials: ______). 6) That portions and quotes taken from this interview may be used in the final research product (thesis). Additionally, portions and quotes from the interview may also be used in conference presentations and journal articles. 7) All transcripts and recording will be stored in a secure place and destroyed after the completion of the study. 8) No identifying information (name, address, title, etc.) will be asked of me. 9) My signature on this form does not waive my legal rights of protection. 10) This interview is conducted by Katrina Radach and Dr. Troy Abel. Any questions that you have about the research or your participation may be directed to them at radachk3@wwu.edu or (509) 952-3756. If you have any questions about your participation or your rights as a research participant, you can contact the WWU Human Protections Administrator (HPA), (360) 650-3082 or janai.symons@wwu.edu.

I have read the above description and agree to participate in this study and are 18 years or older.

________________________________________ Participant's Signature

________________________________________ Participant's PRINTED NAME

________ ______________Date

NOTE: Please sign both copies of the form and retain the copy marked “Participant.”

# Appendix B: Letter for Online Survey

Greetings,

You have been identified as someone with valuable insight and expertise on the issue of ocean acidification in the Salish Sea region. Dr. Troy Abel and I seek expert input to inform our development of an online mapping tool which is a Western Washington University Graduate Thesis Project that will inform the public, marine scientists, and policy makers about ocean acidification impacts on the Salish Sea and adaptive management opportunities for the region. Our research will benefit from your insights. There are no anticipated risks or discomfort associated with responding to our questions and you may benefit from learning and thinking about the online mapping of ecological trends. Your participation is voluntary and should not take more than 15 minutes. You may stop the online survey and withdraw your participation at any time without penalty.

By responding to the survey, you acknowledge your consent, agreement to participate, and that you are 18 years or older. This consent will be noted on the first page of the Qualtric’s survey, and you will not be able to go onto the survey until you have submitted accept. Your input will provide insights and prioritize the data that will be identified and mapped. All of your answers will remain confidential and your responses will be aggregated for analysis.

Thank you in advance for your consideration, your insights and opinions are truly valuable to this research. To schedule an interview time, please contact Katrina Radach at radachk3@wwu.edu or by phone at (509) 952-3756.

If you have questions about this study or the information in this form, please contact the lead researcher, Dr. Troy D. Abel at (360) 739-6596 or Katrina Radach at radachk3@wwu.edu or by phone at (509) 952-3756. If you have questions about your rights as a research participant, or would like to report a concern or complaint about this study, please contact the Western Washington University Human Protections Administrator (HPA) Janai Symons at janai.symons@wwu.edu or by telephone at (360) 650-3082.

{LINK}

Best regards,

# Appendix C: Letter for Analytic Deliberation

Greetings,

You have been identified as someone with valuable insight and expertise on the issue of ocean acidification in the Salish Sea region. Dr. Troy Abel, Dr. Tammi Laninga, and I seek expert input to inform our development of an online mapping tool that will inform the public, marine scientists, and policy makers about ocean acidification impacts on the Salish Sea and adaptive management opportunities for the region. Our research will benefit from your insights.

We are inviting you to participate via a workshop with approximately 6-10 GIS professionals and other relevant individuals. The goal of workshop is to critique and provide feedback on the user experience of the online mapping tool.

There are no anticipated risks or discomfort associated with responding to our questions during the workshop and you may benefit from learning and thinking about the online mapping of ecological trends and user experience. Your participation is voluntary and should not take more than 2 hours. We will be providing lunch and mileage reimbursement for your time and efforts. You may withdraw your participation at any time without penalty.

We are currently looking for a date that would work best for our participants for either February 2nd or 9th between 12 PM and 2PM. We will be providing lunch as well, so please let us know if you have any dietary restrictions. If you have a preference of a date or cannot make a specific date, please let us know. We will send a confirmation email on the date once we hear back from our participants.

I would like to record our conversation to accurately document the information you and the group will provide. Though you have the right to decline being recorded, I should note that the recording will be used for notes and references to make adequate adjustments to the online mapping tool. The recording will be erased as soon as the map has been finalized.

All your answers will remain confidential within the group and your responses will be aggregated for analysis. Small quotes will be de-identified and maybe quoted in my final project manuscript. Your input will provide insights and prioritize the data that will be identified and mapped. Thank you in advance for your consideration. your insights and opinions are truly valuable to this research.

If you have questions about this study or the information in this form, please contact the lead researcher, Dr. Troy D. Abel at (360) 739-6596 or Katrina Radach at radachk3@wwu.edu or by phone at (509) 952-3756. If you have questions about your rights as a research participant, or would like to report a concern or complaint about this study, please contact the Western Washington University Human Protections Administrator (HPA) Janai Symons at janai.symons@wwu.edu or by telephone at (360) 650-3220. Please contact us confirming your participation and if you have a preference on a date. Thank you.

Sincerely,

Katrina Radach
MA Candidate
Environmental Studies Department
Western Washington University

## Appendix D: Semi-Structured Interview Questions

Responses: 4 phone, 6 online

1. What is your research focus in the Salish Sea?
2. What are the top 3 issues facing the Salish Sea ecosystem?
3. How are you seeing the effects of OA in the Salish Sea?
4. What are the main OA indicators currently being researched in the Salish Sea region? a. How do these OA indicators inform our understanding of OA in the region? b. Who is collecting the indicator data? Could it be mapped?
5. (US scientists). Are there Washington state or US federal policies that address ocean acidification in the Salish Sea? If so, can you give me some examples?
   (BC scientists). Are there British Columbia provincial or Canadian federal policies that address ocean acidification in the Salish Sea? If so, can you give me examples?
6. How much OA indicator research coordination is occurring between marine scientists? Governments?
7. Can you name some examples of coordinated management actions that could reduce OA?
8. How effective could an interactive online mapping tool showing OA indicators be in increasing research or management collaboration, and/or increasing education about OA?

## Appendix E: Online Survey Questions

1. What are the most informative biological indicators, in your opinion, to be mapped (we are aware some options are already mapped from various other projects currently going on)? Please move with your mouse or finger the most informative to the top and least informative to the bottom:
   -Pteropods
   -Shellfish
   -Eel Grass
   -Other- Please Specify

2. What are the most informative chemical indicators, in your opinion, to be mapped (we

are aware some options are already mapped from various other projects currently going on)? Please move with your mouse or finger the most informative to the top and least informative to the bottom:
-pH
-Alkalinity
-Aragonite Saturation
-pCO2 (partial pressure of Carbon Dioxide)
-Other- Please Specify

3. Is there a combination of biological and chemical indicators about OA in the Salish Sea that together are more informative, e.g., the sum is greater than the parts?

4. Is there any other data that when mapped, it would be highly informative to your research and the organizations or communities you work in and with?

5. Do you think that an online interactive map would improve policy coordination among marine scientists, organizations, and communities? Please explain.

6. In your opinion, could an online interactive map spur more policy and management around OA in particular? Please explain.

7. Have you seen or developed good examples of online maps that have helped in your line of work or have helped communicate important ideas or research? If yes, please provide URLs or descriptions in the text box.

## Appendix F: Analytic Deliberation Questions

O -What was your favorite/interesting online map(ping) experience recently?

-What visual design elements impressed you the most? (sight question)

-What about the user-interface did you like the most? (touch/user question)

R -What Do you like/dislike about the map?

-What does this map do? What could it do?

-What information do you find most clear? Most confusing?

I -Did the information help your understanding of OA?

-What would you like to see or do in a web-based map of OA in the Salish Sea?

-What benefit could it have for GIS? For marine scientists? For policy-makers? For the Public?

D -What are the next steps for this map?

-What needs to be added?

-What needs to be deleted?

## Appendix G: Analytic Deliberation Map Identification Results & Links

These were the top identified maps by analytic deliberation GIS professionals of maps that they considered were good online maps.

City of Bellingham Zoning & Property Map: https://www.cob.org/services/maps/online-mapping

Backcountry Map: https://caltopo.com/map.html#ll=47.75353,-122.03708&z=10&b=mbt

Northwest River Forecast: https://www.nwrfc.noaa.gov/rfc/

Pollution Tracker: http://pollutiontracker.org/#

## Appendix H: Results of Stage One (Semi-Structured Interviews/Survey)

| Q1. What are the top three issues facing the Salish Sea Ecosystem? |
| --- |
| • Population growth, development, stormwater<br>• Pollution, habitat loss, multiple stressors<br>• OA, hypoxia, pollution<br>• temp, development, OA<br>• variability of understanding, lack of data<br>• runoff, development, global change<br>• OA, habitat loss<br>• Climate change, growing human population, habitat loss |
| Q2. How are you seeing the effects of OA in the Salish Sea? |
| • “I know it is happening but I can't see or detect the effects on the ecosystem.”<br>• reduced aragonite saturation states in regions with high concentration of shellfish aquaculture<br>• “... unclear if "effects" are identifiable yet…”<br>• already having detectable and concerning effects |

| |
|---|
| ● "... the term of OA is challenging. It implies that the chemistry is changing... in the summertime the anthropogenic signal is high. Higher saturation state and lower pco2 than it usually would be naturally. "<br>● "...In plankton data, we haven't seen any effects. We have studied pteropods and have seen dissolution and we are still working on linking if the dissolution is due to OA."<br>● In situ environment when it is low corrosiveness vs high corrosiveness leading to evolution<br>● "..there's failures in hatcheries. Everything else is harder to pin on OA, but could have been affected by OA." |
| Q3. What are the main OA indicators currently being researched in the Salish Sea? |
| ● Pteropods<br>● Pteropods and shellfish<br>● Various Zooplankton<br>● pH, alkalinity, and potentially looking at zooplankton.<br>● "pteropods, benthic forams (work by the burke museum)... Eelgrass and other species would be beneficial…"<br>● "Pteropods…" "shellfish…" "eelgrass…"<br>● pteropods, pH (water quality), shellfish bioassay<br>● "...aragonite saturation is a measure of OA, but OA changes can be indicated by pteropod dissolution and is estimated through changes in alkalinity and pCO"<br>● Eelgrass |
| Q4. If you are from the US/ studying in US waters: Are there Washington State or US federal policies or regulations that address OA in the Salish Sea? If so, can you give me examples? |
| ● "... Blue Ribbon Report and Refresh"<br>● "...the clean water act, but that was never really considered OA. It has pH, but the criteria is not responsive to OA…"<br>● "WA blue ribbon panel…"<br>● None<br>● Blue Ribbon Panel |
| Q5. The next two questions are around management and coordination with OA and OA indicator research. How much OA indicator research coordination is occurring between marine scientists? Between the governments? |
| ● I would hope a lot<br>● Should be improved. Not a lot of coordination right now<br>● "There are some cross-border panels (OA and Hypoxia) that have been successful at exchanging information..."<br>● Not much at all<br>● "At the federal level there are meetings between scientists and governments. Washington State has the blue ribbon panel... There is also the OA center which helps with the symposiums they hold and the panels of scientists to converse around their research and findings" |

| |
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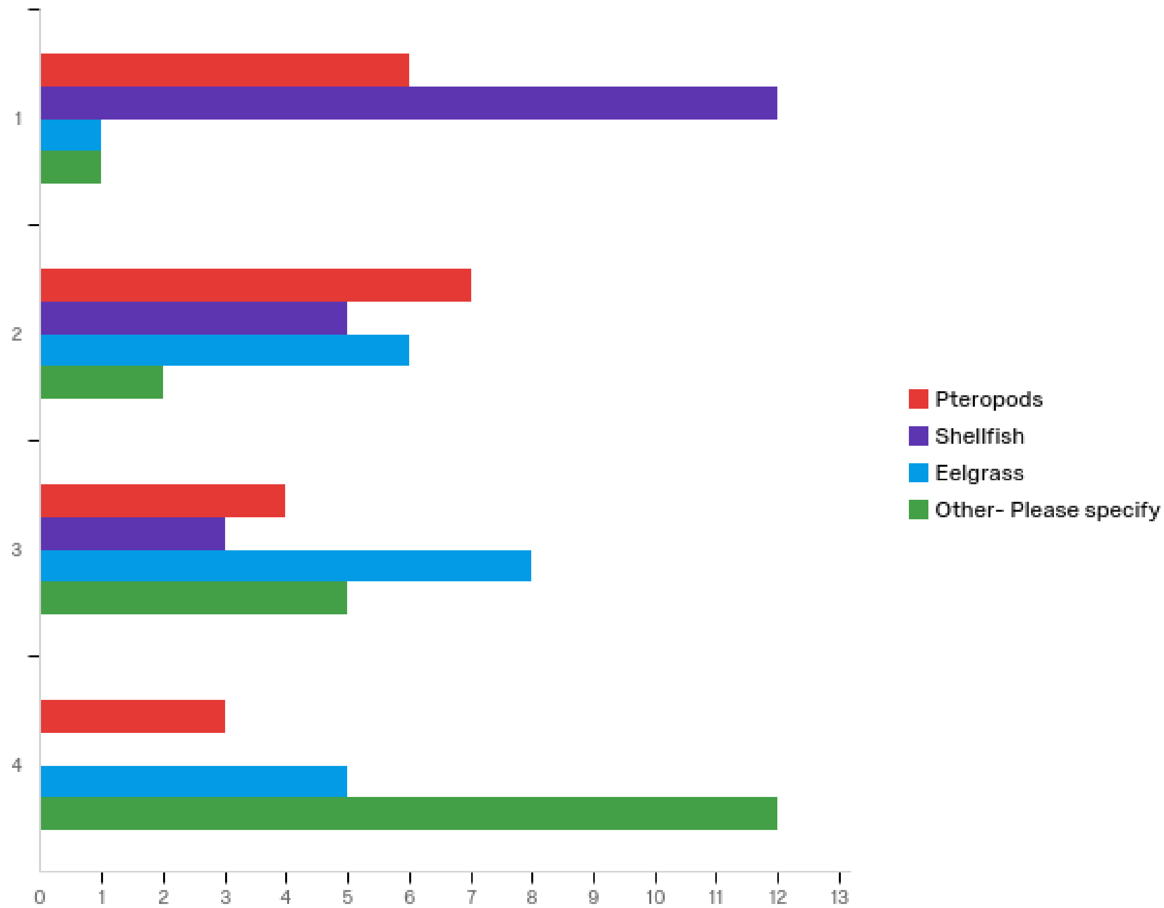
| ● Sometimes the coordination doesn’t always happen<br>● No, I would say there is a very large and prosperous amount of collaboration in the SS. Coordination with NOAA and academics has been strong. Extremely healthy. Collaborations with the shellfish industry, we have projects with them on developing better sensors, and monitoring, so that is happening . the WA OA symposium. The SS ecosystem conference, so that's a good way of bringing people together. We have been working with the state agencies, and creating a time series on data and chemistry on plankton. The blue ribbon panel is fantastic. The process we went through and MRAC has been going smoothly.<br>● “OAH group report....MEOPAR….They try to bring people together and collaboration between academics, government, and scientist...The states is more collaborative or at least in BC…”<br>● None |
| Q6. Can you name some examples of coordinated management actions that could reduce OA? |
| ● OA will increase for decades but if we cut carbon emissions dramatically through a carbon tax and investment in alternative energy, OA may start to decline in the next century.<br>● Protect eelgrass and kelp, nutrient management<br>● “... reduction of nutrient loads in runoff might be the most direct way to reduce OA...there is global mitigation of CO2 emissions which would reduce the air-sea exchange”<br>● reduction of nutrient outputs, reduce local atmospheric pollution, kelp-sea grass cultivation<br>● “...stop industrialization”<br>● No, but maybe we can adapt.<br>● Not at the moment<br>● Reduce CO2 emissions<br>● Reduce Runoff<br>● Reduce Carbon Emissions Globally |
| Q7. How effective could an interactive online mapping tool showing OA indicators be in increasing research or management collaboration, and/or increasing education about OA? |
| ● Very effective if you find enough indicators. NANOOS already displays oceanography data on a map.<br>● Depends on the spatial and temporal resolution of the indicator. To make management decisions, need highly<br>● resolved information<br>● If by 'OA indicator' you mean chemical measurements, I always think that having quality-controlled measurements<br>● of aragonite saturation useful. One point such a map might reveal is how little data are available in areas with high<br>● concentrations of shellfish aquaculture.<br>● Great, would be increasingly helpful! |

- That's difficult to say. It seems like what you'll most likely find is limited or in spots data for the map, which for scientists would not be that useful. But, it has the potential to educate communities. By seeing the data from their local neighborhood or water, they might be more interested in the topic.
- Quality assurance. Be aware of the different responses throughout the region with same species.
- I think it would be very beneficial and it sounds very similar to the PCC goals. It isn't just OAH data, but they are also having cataloging efforts. So the map you are talking about is very similar just on a more sub scale.

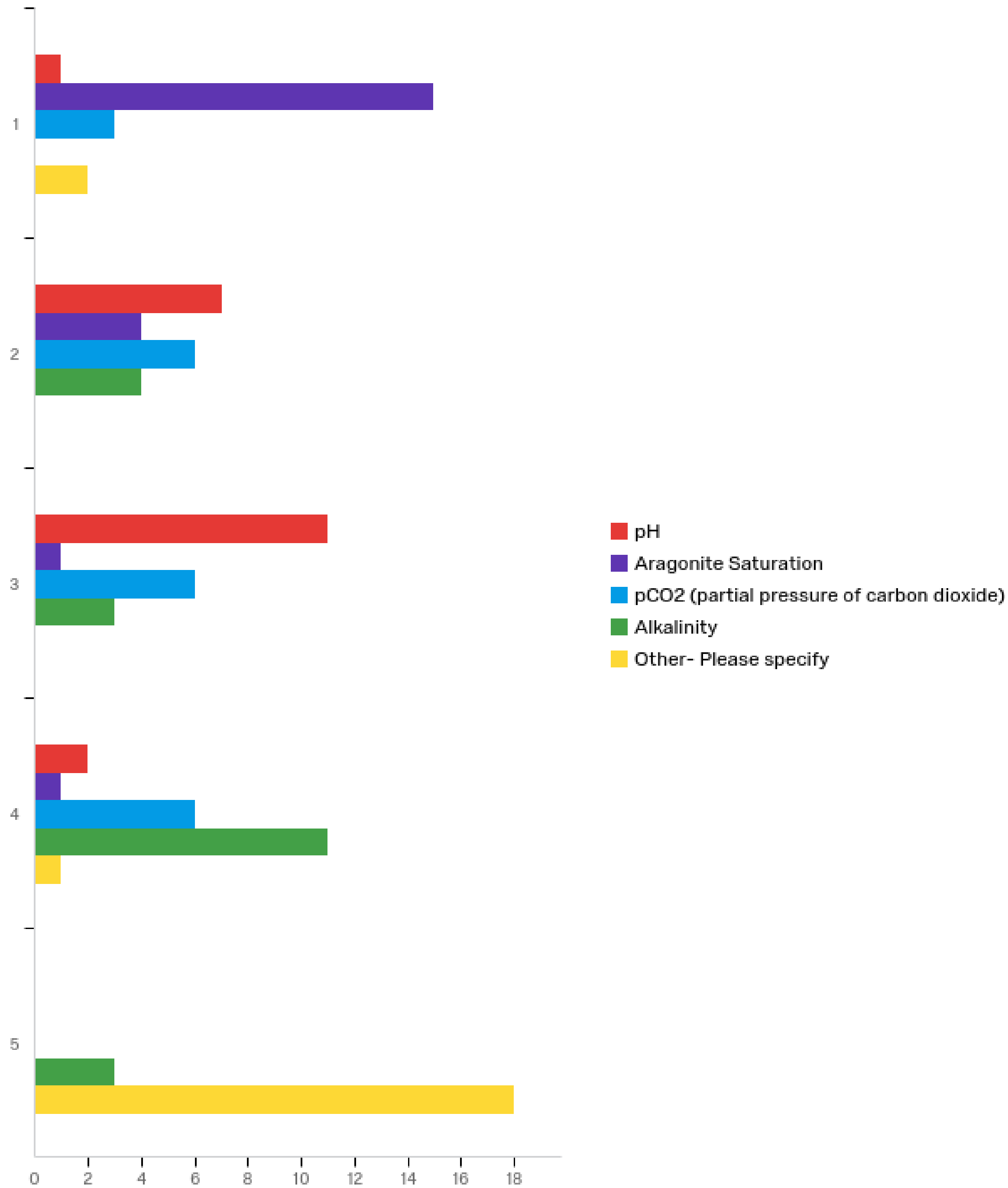
# Appendix I: Results of Stage Two (Structured Online Survey)

Q1. What are the most informative biological indicators, in your opinion, to be mapped (we are aware some options are already mapped from various other projects currently going on) ? Please Rank:




Other Responses:
- Echinoderms
- Kelp beds/forests
- Coralline Algae
- Benthic Forams

Q2. What are the most informative chemical indicators, in your opinion, to be mapped (we are aware some options are already mapped from various other projects currently going on)? Please Rank:




Other Responses:
- Dissolved Inorganic Carbon (DIC)
- Salinity

Q3. Is there a combination of biological and chemical indicators about OA in the Salish Sea that together are more informative, e.g. the sum is greater than the parts?

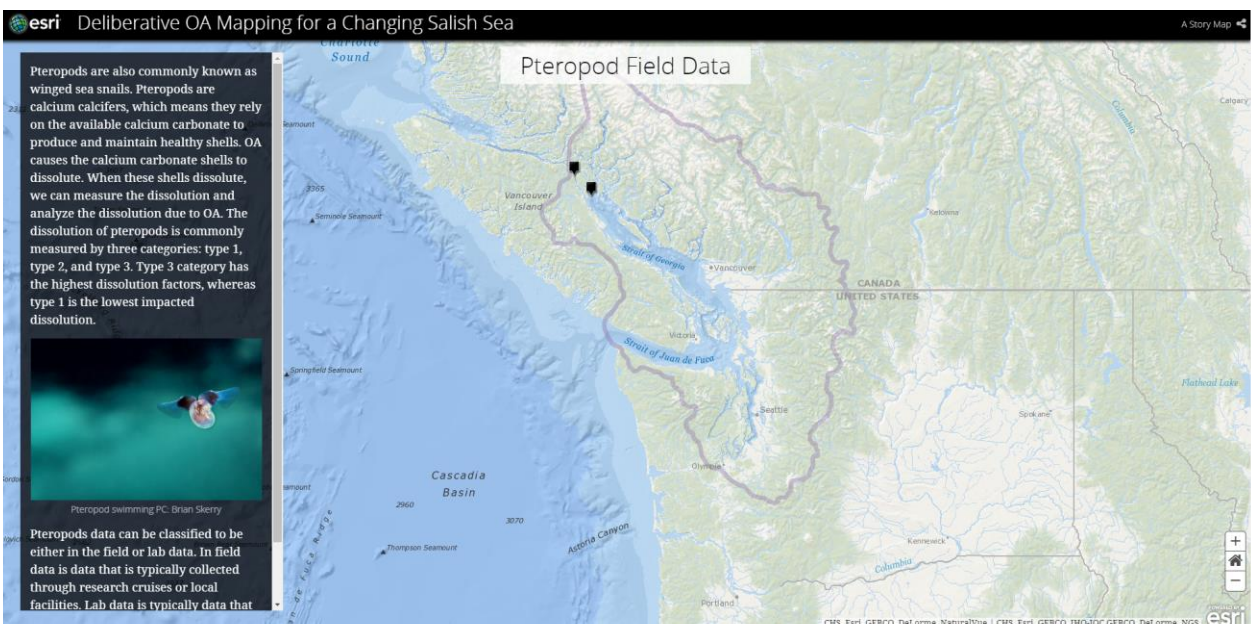
| |
|---|
| ● "...Aragonite saturation with bivalves or with pteropods, or with both?"<br>● "Aragonite/pteropod shell dissolution…"<br>● Not sure…<br>● Aragonite saturation and shellfish mortality<br>● Oxygen and temperature<br>● Very likely<br>● Aragonite and shellfish<br>● "Yes, but those combinations may not be so simple as say for example pH and reproductive success for oysters in the wild. Weather and surface water temperature may have an equal or greater effect on the sum than pH."<br>● "...not sure…"<br>● Pteropod and omega; I would also say that temp would need to be included since the impacts are greater under combined effect of OA and temp<br>● Not sure<br>● N/A<br>● Information on when threshold for marine resource species have been crossed (a la sutton et al. 2016)<br>● Aragonite + alkalinity<br>● We don't know this yet<br>● Aragonite saturation state + observations of biological responses (eg. pteropods)<br>● "pH and saturation state with calcifying bio indicators (pteropods, shellfish)..." |
| Q4. Is there any other data that when mapped, it would be highly informative to your research and the organizations or communities you work with? |
| ● Temperature, Salinity, Chl-a, Change indicators (Ban et al 2016), Vulnerability, e.g. Okey et al (2015), but a higher resolution analysis for the SS, fish and other less obvious taxa that might be sensitive to acidification<br>● Oxygen, temperature, salinity, nutrients, chlorophyll all aid in interpreting the marine pelagic ecosystem.<br>● Really depends on the objectives of the project<br>● Mapping it with and without anthropogenic inputs, seasonality effects, the location of most severe effects<br>● Should included dissolved oxygen, temp, salinity<br>● Water residence times in as high a resolution as possible for Puget Sound is critical<br>● Upwelling influence<br>● Temperature, DO, and primary production will all likely interact with OA and ecological interactions in unexpected ways<br>● Information on the distribution and abundance of holo zooplankton and shellfish larvae<br>● Kelp<br>● Adjacent land use patterns<br>● Temperature, salinity, dissolved oxygen, and possibly nutrients would also be important<br>● Temperature, salinity, primary productivity, DO<br>● If we could have good maps estimating residence time, that would be useful<br>● Temperature and dissolved oxygen profiles at-depth |

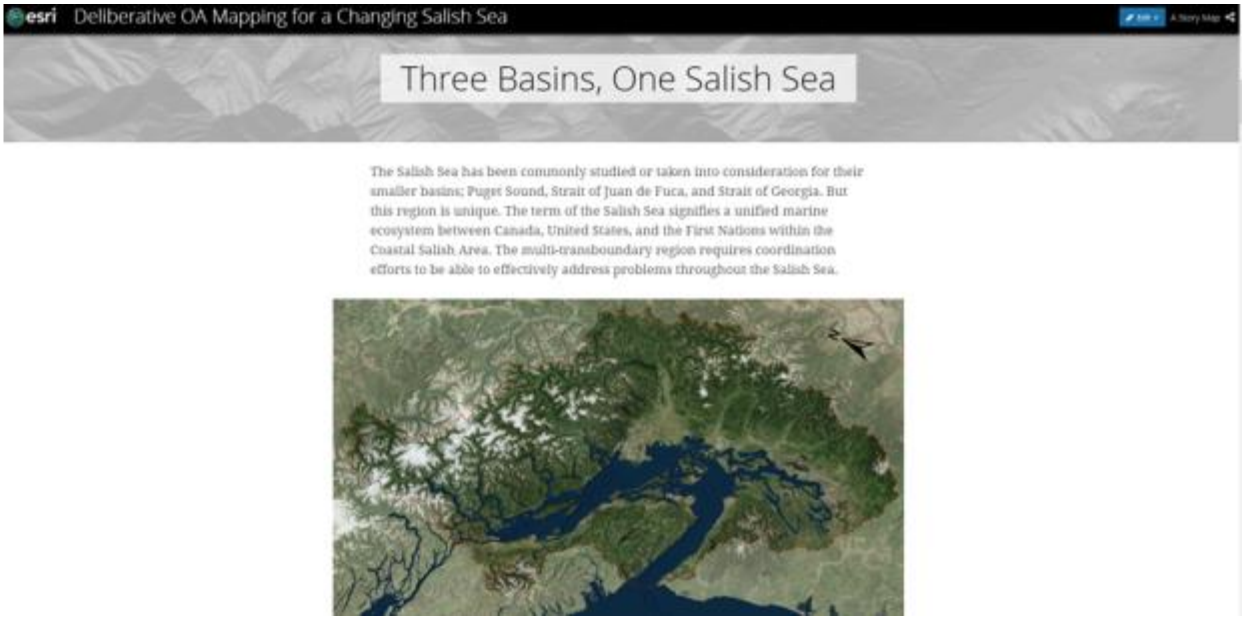
| |
|---|
| ● bottom water pH is missing data for so many places |
| Q5. Do you think that an online interactive map would improve policy coordination among marine scientists, organizations, and communities? Please explain. |
| ● Absolutely, and I think that observations from Citizen Science focusing on change would also be very useful, especially for certain indicators (eg. leonetwork.org)<br>● No, I think there are too many complexities and lack of data at present, but also, some entities already doing this now for the data we do have<br>● Really depends on the purpose. Online tools, including maps, can be a great resource<br>● I do. The map would require input from non-scientists to inform research, and then make the results of that research more accessible to non-scientists.<br>● yes, having a clear visualization interactive map would be of great importance to communicate the natural vs. anthropogenic effects<br>● This could help organization and communities have easier access to information being collected and disseminated via different scientists.<br>● Yes by providing a common information base<br>● Yes, If adequate data exists, data analysis including mapping can inform modeling and future monitoring.<br>● Yes! For example an online interactive map of water residence times would greatly advance native oyster restoration decision-making and planning<br>● If curated it would be a great scientific tool and help shellfish aquaculture. It needs to keep up with new findings though, and involve some sort of peer review<br>● Probably<br>● Possibly, but efficacy would really depend on uptake by resource managers, industry, and other stakeholders<br>● I'd be interested in discussion of this as I'm not sure how much impact this type of map would have. I'm thinking about a map of economic impacts of OA that might have stronger impact and wider utility to communities. Though maybe the 2 go hand-in-hand.<br>● Yes. We need to have an understanding of where resources and OA monitoring efforts are occurring.<br>● Maybe. It would be a useful tool for a researcher or policy maker who was attempting to undertake such an effort, but the map by itself would not accomplish this goal.<br>● Possibly. It will depend on how user-friendly the map is, how it is promoted, and where it is stored, as well as who links to it. Accessibility of concepts and language will be key - avoid scientific jargon and/or provide interpretations for non-science audiences.<br>● yes--a common information resource would streamline collaboration and concordant understanding<br>● It depends on how user friendly it is and what its goals are. It is hard to envision one tool that would be useful to all of those groups, or really bring about coordination. If there are coordination efforts already underway though, it could be an effective tool for scientists to share data, or for organizations to communicate with communities.<br>● Any tool that allows the display and analysis of interannual and seasonal patterns of physical and biological characteristics would assist conservation planning<br>● yes - graphics are always much easier to comprehend and assess |

| Q6. In your opinion, could an online interactive map spur more policy and management around OA in particular? Please explain. |
|---|
| <ul><li>I think so, especially considering that the SS is highly vulnerable to OA (Okey et al 2015).</li><li>In future. We are working hard on models and data sets based on work to date; some are already on-line at NANOOS (LiveOcean and Salish Cruises), but also Ecology's PNNL model too has been published. I'm not sure the interactive improvement over these that would be useful for management and policy.</li><li>Yes. Again, the map would make scientific results more accessible to managers and policy makers, and they would be more likely to use those results having been included in the research design process.</li><li>Not Sure</li><li>I think so, especially for the nutrient management</li><li>I believe maps are very powerful tools to share information with the local community and policy makers.</li><li>Not Sure</li><li>yes but it should include the shellfish farm operators</li><li>Maybe. OA is a result of human behaviors. Mapping it is a start, but mapping its causes would be needed to address it.</li><li>Yes it would. For native oyster restoration it would provide guidance on potential areas to avoid investments in restoration until the OA condition was addressed</li><li>Maps are easy to understand, though I am not sure what management options there are</li><li>I think it could spur more local (e.g., town, neighborhood, small NGO) engagement, especially when people can visualize how their local conditions and/or effects of OA</li><li>I think it would need to be a companion document to something else - see previous comment.</li><li>An OA map would be helpful when used in combination with other stressors that might produce problems</li><li>Yes. It would allow us to test hypotheses related to management and use science to make informed decisions.</li><li>When used properly as a tool for understanding pattern and process, yes.</li><li>Maybe--it depends on what trends are and the balance of OA and biogenic drivers</li><li>Not sure</li><li>I would want to be careful with this. Data will be spotty, and hard to interpret. People might see a spot that has a lot of variability and pick it out as having low problem pH when it is really diurnal variability there with little management implication. On the other had, if long term trends were evident it might bring more attention to the problem. So, I think it could, but that there are other less desirable potential outcomes as well.</li><li>I think the will is already there, but the ability to manage it or knowledge of what to do about it is the problem. Mapping OA data would probably go a long way towards providing a path for management action.</li><li>it shoudl do because you will be able to see the 'hot spots' readily</li></ul> |
| Q7. Have you seen or developed good examples of online maps that have helped in your line |

| of work or have helped communicate important ideas or research? If yes, please provide examples. |
|---|
| ● www.bcmca.ca<br>● http://data.piscoweb.org/marine1/seastardisease.html<br>● https://salishsea.eos.ubc.ca/nemo/<br>● http://www.nwstraits.org/our-work/soundiq/<br>● Yes - one of the best I've seen is on the history of the slave trade - http://www.slate.com/articles/life/the_history_of_american_slavery/2015/06/animated_interactive_of_the_history_of_the_atlantic_slave_trade.html<br>● http://portal.goa-on.org/Explorer - in development.<br>● The Community Mapping Network is a stakeholder in my research. http://www.cmnbc.ca/<br>● Department of Ecology<br>● SeaSketch, but the maps have been private rather than public because of data sharing issues<br>● www.nanoos.org and see NVS links to model output, Salish cruise sections, etc. Also, GOA-ON (www.goa-on.org) working on data synthesis products too<br>● leonetwork.org, Community Mapping Network, Okey et al. 2015, Ban et al 2016, iNaturalist, eBird |

## Appendix J: Online Map Screenshots & Link






Link:
https://wwu.maps.arcgis.com/apps/Cascade/index.html?appid=6ecfbfc222ac4b1f9954aadcfbf4bc22

## Appendix K: Salish Sea OA Indicator List

| | Ocean Acidification Indicator | Biological or Chemical Indicator? |
|---|---|---|
| 1. | Pteropods | Biological |
| 2. | Shellfish | Biological |
| 3. | Eelgrass | Biological |
| 4. | Zooplankton | Biological |
| 5. | pH | Chemical |
| 6. | Benthic Forams | Biological |
| 7. | pCO2 | Chemical |
| 8. | Alkalinity | Chemical |
| 9. | Aragonite Saturation | Chemical |
| 10. | Echinoderms | Biological |
| 11. | Kelp beds/forests | Biological |

| | | |
|---|---|---|
| 12. | Coralline Algae | Biological |
| 13. | Dissolved Inorganic Carbon (DIC) | Chemical |
| 14. | Salinity | Chemical |

# Appendix L: Glossary of Used Terms

**Alkalinity:** The measure of how much acidity the water can neutralize or the buffer capacity of water and acid.

**Aragonite Saturation:** the product of the concentrations of dissolved calcium and carbonate ions in seawater divided by their product at equilibrium:
$( [Ca2+] \times [CO3\ 2-] ) / [CaCO3] = \Omega$ .
When acidity in water increases, the saturation state of aragonite (Ω) decreases.

**Calcifers:** Marine organisms that calcify. Commonly these are organisms with calcium shells like pteropods.

**Dissolved Inorganic Carbon (DIC):** The total amount of carbon (dissolved) in water soluble substances.

**Hypoxia:** Oxygen deficiency in an aquatic environment.

**Ocean Acidification:** When carbon dioxide from the atmosphere gets absorbed by seawater and reacts to produces hydrogen ions. This ultimately causes the decrease of pH, which can then be described as becoming more acidic.

**Partial Pressure of Carbon Dioxide (pCO2):** Is the carbon dioxide's gas phase pressure in which would be in equilibrium with the dissolved carbon dioxide.

**pH:** Potential of Hydrogen. It is the measure of alkalinity or acidity of water soluble substances.

**Pteropods:** Are small mollusks and are snail like with wing like extensions.

**Salinity:** Concentration of dissolved salt in water.

**Sea Grass:** Is any of various submerged monocotyledonous plants like eelgrass.

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