Ocean users and marine scientists both have connections to the sea. This research explores how the nature of their connection to the sea leads to different perceptions of risk and comfort with uncertainty, and how these differences might be important to consider when one group has information another group needs. Publically available short-term forecasts of currents, wind, and waves are an important type of information that aids in decision-making and risk management for scientists, managers, and a diversity of ocean users and coastal residents. Despite this, there are unique challenges that have prevented ocean condition forecasts from being as user-friendly as weather forecasts. This research examines differences in perceptions of risk and comfort with uncertainty between two interdependent communities: the “information provider” and “information user,” and how these perceptions influence the accessibility and usefulness of data. Using open-ended, semi-structured interviews that focus on the concepts of risk exposure, effect, and mitigation, we explore the perceptions of both the academic and agency scientists that produce and disseminate the forecasts, and commercial fishermen that consume and interpret the forecasts. Commercial fishermen are selected as key information users due to their expertise at navigating the marine environment, using forecasts, and their important economic and cultural role at the Oregon coast. Documenting the “mental models” of these two
communities reveals insights into ways to leverage different kinds of expertise to improve the accessibility and usefulness of ocean condition forecasts, as well as improve the science of ocean condition forecasting. This holistic approach, that uses the nature of perception, reveals complexities about information exchange and how strengthening the relationships between information provider and user advances both science and application. Results also have implications for improving collaboration and communication in other areas of marine research that link natural science, short-term forecasts, and decision-making.
Ocean Views: Characterizing Risk Perception, Uncertainty, and Decision-making
Within the Ocean Condition Forecast System

by
Jessica A. Kuonen

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APPROVED:

Major Professor, representing Marine Resource Management

Dean of the College of Earth, Ocean, and Atmospheric Sciences

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Jessica A Kuonen, Author
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CONTRIBUTION OF AUTHORS

Matthew Mauch, Ashley Ellenson, and Jane Darbyshire contributed to the Introduction of Chapter 3: Second Manuscript in partial fulfilment of the NRT Interdisciplinary chapter.
# TABLE OF CONTENTS

**CHAPTER 1: INTRODUCTION, LITERATURE REVIEW, METHODS** .......... 1

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Usefulness of Ocean Condition Forecasts</td>
<td>2</td>
</tr>
<tr>
<td>Literature Review</td>
<td>6</td>
</tr>
<tr>
<td>Operational Oceanography: A Brief History</td>
<td>6</td>
</tr>
<tr>
<td>Usefulness of Short-term Ocean Condition Forecasts: A Case Study</td>
<td>8</td>
</tr>
<tr>
<td>Interdependent Communities: Data Providers and Commercial Fishermen</td>
<td>9</td>
</tr>
<tr>
<td>Ocean Forecast Data Providers in the United States</td>
<td>9</td>
</tr>
<tr>
<td>Commercial Fishing in Oregon</td>
<td>12</td>
</tr>
<tr>
<td>Theoretical Framework</td>
<td>14</td>
</tr>
<tr>
<td>Risk Perception</td>
<td>14</td>
</tr>
<tr>
<td>Managing and Coping Under Uncertainty</td>
<td>16</td>
</tr>
<tr>
<td>Mental Models</td>
<td>17</td>
</tr>
<tr>
<td>Research Methods</td>
<td>20</td>
</tr>
<tr>
<td>Mental Model Interviews</td>
<td>20</td>
</tr>
<tr>
<td>Participant Selection</td>
<td>21</td>
</tr>
<tr>
<td>Commercial Fishing Community</td>
<td>22</td>
</tr>
<tr>
<td>Data Provider Community</td>
<td>23</td>
</tr>
<tr>
<td>Observation</td>
<td>24</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>24</td>
</tr>
<tr>
<td>Validity</td>
<td>25</td>
</tr>
<tr>
<td>References</td>
<td>26</td>
</tr>
</tbody>
</table>

**CHAPTER TWO: FIRST MANUSCRIPT [Weather, Climate, and Society]** ........ 30

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>30</td>
</tr>
<tr>
<td>1. Introduction</td>
<td>31</td>
</tr>
<tr>
<td>2. Methods</td>
<td>34</td>
</tr>
<tr>
<td>Sample</td>
<td>34</td>
</tr>
<tr>
<td>Modified Mental Model Elicitation</td>
<td>37</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>37</td>
</tr>
<tr>
<td>3. Results</td>
<td>38</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS (Continued)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Commercial Fishing Community</td>
<td>38</td>
</tr>
<tr>
<td>3.1.1 Professional domain</td>
<td>38</td>
</tr>
<tr>
<td>3.1.2 Risk perception and Uncertainty</td>
<td>40</td>
</tr>
<tr>
<td>3.1.2.1 Physical risk</td>
<td>42</td>
</tr>
<tr>
<td>3.1.2.2 Monetary risk</td>
<td>43</td>
</tr>
<tr>
<td>3.1.2.3 Psychological risk</td>
<td>44</td>
</tr>
<tr>
<td>3.1.2.4 Intersecting and cumulative risk</td>
<td>45</td>
</tr>
<tr>
<td>3.1.3 Scale of decision-making and use of forecasts</td>
<td>46</td>
</tr>
<tr>
<td>3.1.3.1 Timing</td>
<td>47</td>
</tr>
<tr>
<td>3.1.3.2 Conditions and duration</td>
<td>48</td>
</tr>
<tr>
<td>3.1.3.3 Forecasts as imperfect</td>
<td>48</td>
</tr>
<tr>
<td>3.1.3.4 Confidence in the forecast</td>
<td>49</td>
</tr>
<tr>
<td>3.1.4 Managing and coping risk and uncertainty: Fishermen are resilient</td>
<td>50</td>
</tr>
<tr>
<td>3.2 Data Provider Community</td>
<td>53</td>
</tr>
<tr>
<td>3.2.1 Professional Domain</td>
<td>53</td>
</tr>
<tr>
<td>3.2.1.1 National Weather Service (NWS) Weather forecasting offices (WFOs)</td>
<td>55</td>
</tr>
<tr>
<td>3.2.1.2 Center for Operational Oceanographic products and services (CO-OPS)</td>
<td>56</td>
</tr>
<tr>
<td>3.2.1.3 U.S. Integrated Ocean Observing System (IOOS)</td>
<td>57</td>
</tr>
<tr>
<td>3.2.2 Risk and uncertainty: Within the data provider community</td>
<td>59</td>
</tr>
<tr>
<td>3.2.2.1 Conceptual and statistical uncertainty</td>
<td>59</td>
</tr>
<tr>
<td>3.2.2.2 Practical uncertainty: Operational</td>
<td>62</td>
</tr>
<tr>
<td>3.2.3 Application risk: Regarding users outside of the data provider community</td>
<td>63</td>
</tr>
<tr>
<td>3.2.3.1 Application risk: Regarding commercial fishing end users</td>
<td>66</td>
</tr>
<tr>
<td>3.2.4 Managing and coping risk and uncertainty: Formalized procedures</td>
<td>67</td>
</tr>
<tr>
<td>3.3 Differences and Similarities: Commercial fishing and Data Provider communities</td>
<td>69</td>
</tr>
<tr>
<td>4. Discussion and Conclusion</td>
<td>74</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>78</td>
</tr>
<tr>
<td>References</td>
<td>78</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS (Continued)

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>ABSTRACT</td>
<td>81</td>
</tr>
<tr>
<td>1.1</td>
<td>Approach</td>
<td>85</td>
</tr>
<tr>
<td>1.1.1</td>
<td>Transdisciplinary Process</td>
<td>85</td>
</tr>
<tr>
<td>1.1.2</td>
<td>Defining Uncertainty</td>
<td>86</td>
</tr>
<tr>
<td>1.1.3</td>
<td>Communicating Uncertainty in Ocean Forecasts</td>
<td>87</td>
</tr>
<tr>
<td>1.2</td>
<td>Interdisciplinary chapter</td>
<td>88</td>
</tr>
<tr>
<td>2</td>
<td>Methods</td>
<td>88</td>
</tr>
<tr>
<td>3.1</td>
<td>Mental models of risk and uncertainty</td>
<td>90</td>
</tr>
<tr>
<td>3.2</td>
<td>Scale of decision-making in time and space</td>
<td>92</td>
</tr>
<tr>
<td>3.2.1</td>
<td>Planning</td>
<td>92</td>
</tr>
<tr>
<td>3.2.2</td>
<td>Accessing forecasts</td>
<td>94</td>
</tr>
<tr>
<td>3.2.3</td>
<td>Ocean hazards</td>
<td>96</td>
</tr>
<tr>
<td>3.2.4</td>
<td>Contextual factors: Dungeness Crab Fishery</td>
<td>97</td>
</tr>
<tr>
<td>3.3</td>
<td>Uncertainty quantification</td>
<td>99</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>104</td>
<td></td>
</tr>
<tr>
<td>References</td>
<td>104</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>CONCLUSION</td>
<td>108</td>
</tr>
<tr>
<td>Additional Results and Discussion</td>
<td>108</td>
<td></td>
</tr>
<tr>
<td>Data Providers</td>
<td>108</td>
<td></td>
</tr>
<tr>
<td>Commercial fishermen</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>Recommendations for the Ocean Condition Forecast System</td>
<td>114</td>
<td></td>
</tr>
<tr>
<td>Where do we go from here?</td>
<td>116</td>
<td></td>
</tr>
<tr>
<td>Limitations and Recommendations for Future Work</td>
<td>119</td>
<td></td>
</tr>
<tr>
<td>References</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>APPENDICES</td>
<td>130</td>
<td></td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS (Continued)

| Appendix A. IRB Verbal Consent Card | ................................................................. | 131 |
| Appendix B. Interview Questions for Commercial Fishing Community | ................ | 132 |
| Appendix C. Interview Questions for Data Provider Community | ................ | 133 |
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1</td>
<td>5</td>
</tr>
<tr>
<td>Figure 1.2</td>
<td>11</td>
</tr>
<tr>
<td>Figure 1.3</td>
<td>23</td>
</tr>
<tr>
<td>Figure 1.4</td>
<td>23</td>
</tr>
<tr>
<td>Figure 2.1</td>
<td>36</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>36</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>53</td>
</tr>
<tr>
<td>Figure 3.1</td>
<td>94</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>116</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 1.1 NOAA founding agencies .................................................................9

Table 1.2 Data providers and number of participants interviewed .................24

Table 2.1 Data providers and number of participants interviewed .................37

Table 2.2 Comparison of mental models of risk and uncertainty between data user (DU) and data provider (DP) communities by organizing theme ..............70

Table 2.3 Key quotes representing similarities from data provider and fishing community participant interviews for the organizing theme: time and spatial scale ......................................................................................73

Table 3.1 Types of decisions informed by ocean condition forecasts that were described by research participants. List is not exhaustive ......................99

Table 3.2 List of potential benefits to data providers generated from mental model interviews ........................................................................103

Table 4.1 List of potential benefits to data providers created from results of mental model interviews .................................................................117

Table 4.2 Potential list of benefits to data users (fishermen) created from results of mental model interviews .........................................................118
CHAPTER 1: INTRODUCTION, LITERATURE REVIEW, METHODS

“All models are wrong, but some are useful.” (George Box, 1978)

Introduction

In the most general sense, a scientific model is a simplified representation of a complex process or a system that is difficult to observe directly. In the natural sciences, models of physical, chemical, and biological systems are mathematically based, are run on computers, and in some cases are used to try and predict the behavior of a system. Advances in information and communication technology have allowed scientists from many disciplines to transition predictive models from research mode to application for the purpose of aiding public decision-makers in a variety of contexts. Key to the success of this transition is whether the model is useful in the applied context.

Three elements have been identified over the course of this research that contribute to whether information, or “data,” from predictive models are useful. These elements of usefulness include the tool that is used for communicating the data, the accuracy of the data, and the nature of the decision. The tool is the infrastructure, usually a web interface, that delivers the data to end-users using simple or advanced scientific visualizations. The tool is an essential component for usefulness and is often the main focus of individuals and institutions that provide data; however, the tool alone cannot ensure that the data is useful. Accuracy is one kind of uncertainty metric that is commonly used in applied settings that describes how well predictions agree with reality. There is currently no way to quantify and communicate accuracy metrics for predictions due to the nature of not having a value to compare it to. Some weather forecasts have been able to provide probability estimates as a measure of uncertainty through ensemble models, but this capability is not available to most deterministic modelers. Furthermore, the level of accuracy in
one context may not be necessary in another; and some contexts may value a tradeoff for predictions further into the future that are less accurate. These considerations highlight the importance of the final element of usefulness: the nature of the decision. The nature of a decision depends on context and influences both the accuracy requirement and the tool. Understanding the nature of the decision also means understanding the needs of the decision-maker, which requires time, communication, and often means establishing a relationship between the scientists providing the model and the decision-maker.

This research explores the three elements that contribute to a model being useful within the context of ocean condition forecasting and with a focus to the latter two elements: the accuracy of the models and the nature of the decision. These elements are ideally suited for social science research because they largely depend on relationships and communication between different social groups. The National Oceanic and Atmospheric Administration (NOAA) is moving forward in their efforts to create a West Coast ocean forecast model. They are, however, less clear and experienced in crafting relationships with end users to improve the data in the models and in the process of collaboratively designing and implementing visualization systems.

Usefulness of Ocean Condition Forecasts

Each day a diverse group of ocean users make strategic safety decisions for themselves and sometimes others, based on the condition of the ocean and the atmosphere, when they decide to leave the mainland and take to the seas for personal and professional reasons. A core group of these users, commercial fishermen, regularly risk personal safety, property, and economic loss and are particularly adept at seeking out sources of ocean condition information that include surface temperatures, currents, waves, and wind to inform their decisions. Ocean forecasting,
like weather forecasting, has an ancient history but it has come with its own set of unique technical challenges. Inadequate computing capacity and a lack of political will due to the inability to demonstrate significant economic benefits that would justify such a large investment prevented nations from committing to the global effort that would be required (Flemming, 2002). This changed in the 1990’s through a global recognition that the ocean should be monitored and predicted like the atmosphere in order to study the impact of anthropogenic change on Earth’s ecosystems (Flemming, 2002). The Global Ocean Observing System (GOOS) was formed in 1995 and a new generation of ocean scientists have brought forth integrated coastal observing and modelling systems that have substantially advanced the quality of coastal forecasts along with the recognized need to integrate the information collected and transform it into products that could serve the ocean use community (Kourafalou et al., 2015).

In 2012, a master’s student from the Oregon State University Marine Resource Management (MRM) graduate program worked with members of the commercial fishing fleet from Newport, OR as part of an effort to document and understand how they make strategic decisions using ocean condition forecasts (Duncan, 2014). Findings revealed that the fishermen used a variety of data sources for a variety of reasons yet lacked a single trusted source (Duncan, 2014). This led to a cooperative product development effort that created seacast.org (Seacast), a web interface that presents ocean forecast data provided by marine scientists at Oregon State University (OSU) in a simple and intuitive format driven by the visualization needs of the fishermen. These needs, some of which were not able to be met given the constraints of the project, include the ability to overlay multiple layers at the same time, separating swell and wind waves, and forecasts that went as far into the future as possible.
Seacast demonstrated the meeting of a capability and a need around a tool that delivers information; however, there are limits to its usefulness largely due to the length of the forecast lead time and uncertainty around the accuracy of the models. The forecasts that are presented through the tool are considered to be the best in the region but when fishermen ask the question, “How accurate are they?” there is currently no way to convey an answer. Ocean condition forecasts only produce one predicted result for a given time and space and not a range of values like in weather forecasts, and therefore there is no way to express uncertainty. Modelers can understand a measure of the accuracy of the models for themselves by comparing them to observations, but this can only be done in near-real time or looking backward in time - not for predictions into the future. Furthermore, in addition to being limited by computational resources, modelers express discomfort at providing forecasts further than two days into the future for high stakes end-users like commercial fishermen due to the knowledge that the models underperform at certain times and at certain locations in space.

This research seeks to bridge the gap between the end-user and the data provider by framing the problem of how to provide useful ocean condition forecasts as a system, where data provider and end-users are interdependent, but the data provider has ultimate power over the tool. It assumes that the needs of the end-user are better served through understanding how they use the data to make decisions. However, it recognizes that even if the needs of the end-user could be understood, the modelers that provide the forecast information work within institutional settings that have their own standards of rigor and ultimately set priorities and make decisions about what information should be presented and how. Data providers and end users are interdependent (Figure 1.1) as humans carrying out marine operations in support of scientific inquiry and industry in the vast, and often harsh, marine environment.
Figure 5.1 An interdependent ocean forecast system of data providers and users

Data providers of ocean condition forecasts are dependent on end-users to demonstrate societal value for publically-funded scientific operations and are also motivated for altruistic reasons. Ocean end-users are dependent on accessible and useful ocean condition forecasts to assist with planning and decision-making to harvest seafood and remain safe at sea.

The method for understanding decision-making for these two groups is through understanding each groups’ perception of risk and comfort with uncertainty. Forecasts are a useful type of information to individuals that are managing risk and making decisions about the future. Commercial fishermen seek out weather and ocean condition forecasts to plan fishing trips, but little is known about the details of their decision-making process or the perceived risks that they are trying to manage beyond a general sense of safety and economic risk. Furthermore, little is known about how fishermen think about the uncertainty of the forecasts, and whether that plays a role in their decision-making. This is particularly important when we think about the risks faced by the data providers. Forecasts themselves can be a risk to those providing them due to the uncertainty attached with the nature of predictions. Ocean condition forecasting is a young field with diverse end users that is fragmented across different institutions and geographic regions. Little is known about how ocean forecast providers within these different settings perceive and manage the risk of forecasting and the uncertainties of the predictions, particularly when research-mode forecasts are utilized by high-stakes end users like commercial fishermen.
Ocean forecast data providers and end users are united by a capacity to produce and a need to consume ocean forecast data. This context provides a unique opportunity to learn about the ways that risk perception and uncertainty influence decisions about the production of ocean data by data providers, and how that data is consumed and interpreted for decision making by the end-user. This holistic approach frames the data provider and end user as a system that both have valid contributions to risk knowledge. The goal of this systems-based approach that frames the problem to include discipline- and practice-based knowledge and uncertainty is to bring awareness to the processes that govern decision-making and outcomes for the system as a whole (Bammer, 2008). A systems-approach also helps to bridge the gap between the lofty and vague goal of ‘societal benefits’ and how that plays out in a local context, where end-users are already navigating risks and uncertainties.

Literature Review

Operational Oceanography: A Brief History

Operational Oceanography is like weather observation and forecasting but for the ocean, where systematic and long-term routine measurements are collected and rapidly interpreted and disseminated to a diverse set of end-users (EuroGoos, 2018). Ocean observation and forecasting is a relatively young field compared to weather forecasting due to early technological constraints that required much greater computing capacity compared to global meteorology, and lack of a justifiable cost-benefit analysis for such an expensive initial investment (Flemming, 2002; Pollard, 1994). In contrast, public investment in dependable weather forecasting was aided by clear economic benefits to major industries like agriculture, shipping, and construction and even financial support from commercial aviation and the NAVY (Flemming, 2002).
The 1980’s and 90’s ushered in a revolution on computing power and numerical modeling, satellite remote sensing, and a recognition by all nations that the threat of global climate change and sea level rise would best be understood through a unified effort towards a global ocean observing system (Flemming, 2002). Strengthened by the 1992 Rio Convention, the Global Ocean Observing System (GOOS) was established by the United Nations (UN) agencies in late 1993 after sufficient economic justification was determined. A key component of implementing a worldwide system has been the ability of different countries and regions to determine their own needs on short and long-term timescales based on their local industries, services, societal needs, and environmental conditions (Flemming, 2002). GOOS and its associated regional operational systems have always emphasized the importance of proving benefits to a multitude of different customers even when there was uncertainty regarding who exactly, they were (Flemming, 2002). A key concept in the 2008 Framework for Ocean Observing that provides the foundation for the US regional ocean observing systems is that there is equal focus on scientific inquiry and societal issues. This dual focus is based on recognition that the funding base for the ocean research community cannot meet the growing requirements for ocean information without the support of national governments and the ability to demonstrate societal benefits (IFSOO, 2012).

Who the end-users are and what the societal benefits will be has been left for regional systems to determine. A recent NAS study on ocean observation cited the importance of serving the needs of “weather and seasonal-to-interannual forecasting, living marine resource management, and marine navigation” in addition to the primary goal of understanding climate variability and change (NAS, 2017, pg 6). The US Integrated Ocean Observing System (IOOS) recognizes five themes of end-uses for coastal and ocean information: marine operations, coastal
beach and nearshore hazards, water quality, ecosystem and fisheries, and long-term change and decadal variability (Price & Rosenfeld, 2012). Economic studies in the US have estimated that benefits from national investment will likely exceed cost, particularly with recreational activities due to the large number of people who use beaches and engage in recreational fishing (Kite-Powell, Colgan, & Weiher, 2008). This consistent need at the regional and national level to demonstrate the usefulness of operational oceanography to society provides the basis for framing ocean data providers and end-users as an interdependent system. National governments provide investment to ocean observation and forecast data providers on behalf of end-users, and ocean data providers provide useful information to those end-users.

Usefulness of Short-term Ocean Condition Forecasts: A Case Study

Ocean condition forecasts include predictions of a wide array of parameters that include wind speed and direction, current speed and direction, wave height and periodicity, water temperature at various depths, chemical factors such as salinity, and biological composition such as chlorophyll-A (Kite-Powell et al., 2008). Ocean condition forecasts are available on a range of timescales, and short-term timescales with a lead time of 4 to 72 hours are of particular interest to marine operations for planning optimal routes to take advantage of preferred conditions or to avoid dangerous ones (Price & Rosenfeld, 2012).

In 2012, a research project began that tried to understand how one user-group, commercial fishermen, use ocean condition forecasts to make decisions (Duncan, 2014). The genesis of that research was that sport fishermen had discovered ocean forecast data from an academic website that was for scientists. When commercial fishermen were directed to the Northwest Association of Networked Ocean Observing Systems (NANOOS) Visualization System website for the same ocean data, they commented on how the forecasts were not
presented in a way that supported their needs for decision-making; it was overly complicated and cluttered, presenting data in metric units, etc. That research turned into cooperative product development between commercial fishermen and the modelers and represented the meeting of a capability and a need. One feature that the commercial fishermen requested were longer forecast lead times. The modelers are researchers, and felt discomfort providing model data to high stakes end-users since the research models are not fully operational forecasts to the level of the National Weather Service (NWS). This situation brings to light a unique situation where the ideals of GOOS and IOOS have been realized with innovation in a regional context, but the ocean modelers are put in a situation that is outside the normal bounds of their profession as research scientists.

Interdependent Communities: Data Providers and Commercial Fishermen

*Ocean Forecast Data Providers in the United States*

Ocean observation and forecasting falls under the purview of NOAA as the scientific agency within the US Department of Commerce whose mission is to “understand and predict changes in climate, weather, oceans, and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources (NOAA, 2018a).” When NOAA was formed in 1970, it brought together three ocean and coastal science agencies that were among the oldest in the Federal Government (NOAA, 2006).

**Table 2.1** NOAA founding agencies

<table>
<thead>
<tr>
<th>Agency</th>
<th>Year formed</th>
<th>Historical relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. Coast and Geodetic Survey</td>
<td>1807</td>
<td>1st physical science agency</td>
</tr>
<tr>
<td>Weather Bureau</td>
<td>1870</td>
<td>1st agency dedicated to atmospheric sciences</td>
</tr>
<tr>
<td>Bureau of Commercial Fisheries</td>
<td>1871</td>
<td>1st conservation agency</td>
</tr>
</tbody>
</table>
NOAA’s organizational structure has evolved over time and is currently guided by 9 key focus areas that benefit from and contribute to ocean observation and forecasting, with 6 line offices that represent the operating branches of NOAA that are responsible for managing the delivery of products and services. The remainder of this analysis will focus on three branches of NOAA whose missions include delivering ocean observation and forecasting data products to marine navigation end users.

The National Weather Service (NWS) is an entire line office of NOAA dedicated to “providing weather, water, and climate data, forecasts, and warnings for the protection of life, property, and enhancement of the national economy (NOAA NWS, 2016).” The NWS has consistently provided marine forecasts to mariners since its founding as the Weather Bureau in 1870. Today, ocean forecasts are created at the Ocean Prediction Center national office in Silver Springs, Maryland and then sent out to its 122 weather forecast offices (WFOs) for dissemination to their geographic areas of responsibility. Marine forecasts and data products include buoy reports, tides, and marine forecasts for offshore and high seas with a gridded marine forecast option for more localized forecasts. The NWS is fully operational, with staff working 24 hours a day, 7 days a week, and data products are available in many formats that can be used by 3rd party services, local news organizations, and the public through their website. WFOs also broadcast weather information through NOAA Weather Radio. The Oregon Marine WFOs are located in Portland and Medford.

The Center for Operational Oceanographic Products and Services (CO-OPS) is housed within the National Ocean Service (NOS) line office along with 7 other agencies and is descended from the U.S. Coast and Geodetic Survey, formed in 1807. The mission of CO-OPS is to serve as “the authoritative source for accurate, reliable, and timely tides, water levels,
currents and other oceanographic information (in support of) safe and efficient navigation, sound ecosystem stewardship, coastal hazards preparedness and response, and the understanding of climate change (NOAA, 2013).” Data products can be accessed through the “Tides and Currents” webpage. CO-OPS has a particular emphasis on assisting mariners through navigation services at major US ports and harbors through the Physical Oceanographic Real-Time System (PORTS®). All CO-OPS offices are located in Silver Springs, MD.

The U.S. Integrated Ocean Observing System (IOOS) national office is also housed in the NOS line office; however, it is much younger and is structured much differently than typical NOAA agencies and offices. IOOS was created as part of The Integrated Coastal and Ocean Observing System (ICOOS) Act of 2009, which established statutory authority for the development of the IOOS as the US national system that functions as the US regional alliance with GOOS. It is governed by the Interagency Ocean Observing Committee (IOOC) with a Director and staff at the national office to serve as coordinator of all U.S. IOOS activities. IOOS is a federal, regional, and private sector partnership among 17 federal agencies and 11 Regional Associations (RAs) that operate the regional coastal observing systems (Figure 1) (Price & Rosenfeld, 2012).

![Coastal U.S. IOOS: 17 Federal Agencies; 11 Regional Associations](image)

**Figure 1.6** IOOS 17 federal partners and 11 Regional Associations
The mission of IOOS includes integration of observing capabilities, collaboration with Federal and non-Federal partners, and maximizing access to data and generation of information products to inform decision making, and promote economic, environmental, and social benefits. Each of the 11 RAs are non-federal entities that receive federal funding from the national IOOS office. IOOS RAs are mostly seated in academic research institutes, with governing councils that include representation from government (e.g.: state, local, tribal, and federal) and non-government (e.g.: research institute, industry, and non-governmental organizations (NGOs)) entities. Governance for each RA is based on a Memorandum of Understanding (MOU), a Memorandum of Agreement (MOA), or a 501(c)(3) status.

The RAs function independently from one another to provide products and services that benefit their region; however the basic components of each RA include observing systems (platforms and sensors), models, data management, and product development and engagement with end-users (Price & Rosenfeld, 2012). Each RA has a website that provides access to data products; however, each website and data products are entirely unique.

Oregon falls within The Northwest Association of Networked Ocean Observing Systems (NANOOS) located at the Applied Physics Laboratory at the University of Washington in Seattle. Other West coast RAs include Central and Northern California Ocean Observing System (CENCOOS) located at the Monterey Bay Aquarium Research Institute (MBARI) in Moss Landing, CA; and the Southern California Coastal Ocean Observing System (SCCOOS) located at the Scripps Institution of Oceanography at University of California, in San Diego.

Commercial Fishing in Oregon

Oregon’s commercial fisheries have long been an integral part of the fabric of many coastal communities and are an economic driver for the coast and the state, annually contributing
over $500 million in personal income (ODFW, 2017). The commercial fishing industry extends beyond skipper and crew aboard commercial fishing vessels to fish processing plants, fishery supported-business, and port operations (Pomeroy & Dalton, 2003). Common commercial fisheries in Oregon include Dungeness Crab, pink shrimp, Albacore tuna, groundfish, Pacific whiting, Pacific sardines, salmon, and halibut. A variety of gear types are used across and within fisheries that include pots and traps, longline, trawl, troll, gillnet, and purse seine. Fisheries are connected to habitat and exist in different locations along the coastal and open ocean space. They are also managed in different ways that include stock assessments, limited entry systems, quotas, closures (through seasons, protected areas, and bycatch limits), and selective catch. Fishery, gear type, location in space and during the year, and management strategy all impact the way that commercial fishing operates as an industry and as a coastal community of interest. The Oregon Dungeness crab fishery, a limited entry fishery with over 400 permit holders, has been the most valuable single-species fishery in recent years and accounts for forty percent of all commercial landings (ODFW, 2017).

There are 13 ports located along the Pacific Coast of Oregon. The Port of Astoria, located at the mouth of the Columbia River, is a primary port for the region. Newport is the second largest port in Oregon and is located on the Yaquina River estuary. Charleston is the third largest port in Oregon and is located on the Coos Bay estuary; the rest of Oregon ports are smaller ports with working waterfronts.

Commercial fishing off the Oregon coast is physically risky and economically uncertain. Nation-wide, commercial fishing is ranked as the most dangerous occupation, with a death rate 31 times greater than the national workplace average, with weather factors and waves being the highest contributing factors (Lincoln, J & Lucas, D, 2010). Accessing the ocean is difficult in the
Pacific Northwest due to hazards of “crossing the bar,” where a flowing river enters the ocean. The “bar” refers to the accumulation of sediment often deposited at the mouth of a river which then amplifies incoming wave height and creates turbulence. Other factors, especially the tide, play a role in conditions at the bar.

Theoretical Framework

Risk Perception

Risk perception is the intuitive risk judgement that people rely on to evaluate the hazards that they encounter and is useful to understand how people make decisions with imperfect information in response to risk and uncertainty (Slovic, 1987). Psychological research has shown that humans use a suite of heuristics and biases as mental shortcuts to make sense of partial information in an uncertain world (Ropeik, 2012; Slovic, 1987). These mental shortcuts are neurologically hardwired to respond with instinct and emotion first and can lead to large, persistent biases or systematic errors in judgement that results in a mismatch between an objective risk assessment and risk perception (Ropeik, 2012; Slovic, 1987; Tversky & Kahneman, 1974).

A large body of risk perception research from the past 40 years has yielded insights into what factors underlie people’s perception of risk. Early economic and psychometric studies attempting to reveal patterns of “acceptable” risk-benefit trade-offs found that for any level of benefit, greater risk was tolerated if the risk was “voluntary, immediate, known precisely, controllable, and familiar;” with hazards judged as “voluntary” tending also to be judged as “controllable” (Fischhoff, Slovic, Lichtenstein, Read, & Combs, 1978; Slovic, 1987). These factors are useful for understanding what influences an individual’s risk tolerance and how it varies between activities and technologies (Slovic, 2016). For example, the voluntary nature of
commercial fishing may contribute to a higher risk tolerance, just as the involuntary nature of having to provide extended model forecasts to end users under the direction of an institution may contribute to a lower risk tolerance.

It is worth noting that the genesis for risk perception research has been driven by a desire to predict, encourage, and manage the public’s acceptance of hazards and risks associated with advances in science and technology, such as nuclear energy and chemical engineering (Short, 1984; Slovic, 1987), and thus has persistently framed the problem of risk management through an expert/non-expert hierarchy. This framing and earlier methods found that “risk” means different things to different people. Risk management experts hold a narrower view of risk that is grounded in statistical analysis, and the non-expert public holds a broader conception of risk that is qualitative, complex, and context-dependent (Slovic, 2016). Risk perception researchers have come to recognize that there are legitimate, value-laden issues underlying public risk perceptions that need to be considered in risk management decisions and social research has challenged the assumption that risk can be objectively quantified through risk assessment (Slovic, 2016). Risk perceptions have been found to be influenced by social and cultural factors; where social influences transmitted by friends, family, fellow workers, and respected public officials mediate perception (Short, 1984; Slovic, 2016).

Data providers that produce ocean condition forecasts are not experts in risk assessment. However, the nature of their work and social norms within their community of practice that use similar statistical methodologies may place them closer to the expert conception of risk, and thus at a disadvantage in understanding risk perceptions of commercial fishermen. At the same time, data providers are individuals working within an institution and may have personal or other social influences that place them at an advantage in understanding risk perceptions of
commercial fishermen. The concept of the “expert” is beneficial for many problem domains; however, there can be costs to expertise when applied to unfamiliar settings such as making “useful” forecasts for a community that may not share a similar conceptualization of risk perception.

**Managing and Coping Under Uncertainty**

Uncertainty is part of every decision we make as individuals, groups, or institutions and it is approached and communicated differently based on discipline, profession, or problem domain (Smithson, 2008). The way that different disciplines and professions orient towards uncertainty has implications for the way it is coped with and managed. Uncertainty can be framed positively, as a means of freedom, opportunity, and creativity; or negatively as a threat or risk, and there can be positive and negative connotations within a community of practice (Smithson & Bammer, 2008). Scientific research and exploration is driven by the unknown, and it seeks to objectively quantify and describe the uncertainty within its methodology. For commercial fishermen, there is freedom and opportunity in the unknown as they set out in search of catch; however, they are motivated to reduce the uncertainty of future weather and ocean conditions through checking forecasts.

The expression of uncertainty metrics is standard practice within scientific cultures that produce measurements of a physical quantity, so that those who use it can assess its reliability and compare it to other measurements (JCGM, 2010). Ocean forecasts are produced using deterministic ocean models, and therefore cannot provide the kinds of uncertainty metrics that the public is used to seeing with weather forecasts that use ensemble modeling. There has been a recent commitment by the weather enterprise regarding the characterization, communication, and perception of weather forecast uncertainty (NAS, 2017; NRC, 2006). While useful to draw upon
this work that relates to the general public, it is important to acknowledge that ocean users have their own expertise and unique understanding of forecast uncertainty and risk from ocean use.

*Mental Models*

The arc of risk perception research has led to the current recognition that all risk assessment, both formal and informal, is inherently subjective, value-laden, and contextual (Ropeik, 2012; Slovic, 2016). Recent methodologies aiming for a deeper understanding of specific issues have turned away from broad quantitative assessments to a deeper, more qualitative understanding of an individual’s mental model that recognizes that the actions of every individual are based on a legitimate bottom line.

Mental models are a way to represent the manner in which individuals organize their thoughts and beliefs about how something works or how something is, and influence the way that new information is interpreted (Cone & Winters, 2011). Individuals construct these ‘internal representations’ based on their personal life experiences and use them to reason, anticipate events, form explanations, and interact with the world (Craik, 1943; Jones, Ross, Lynam, Perez, & Leitch, 2011). They are also ‘working models’ that are dynamic and able to adapt to changing circumstances and evolve over time through learning (Craik, 1943; Johnson-Laird, 1983; Jones et al., 2011). An individual’s orientation towards uncertainty and risk perception is a function of their mental model, which is shaped by factors that include discipline, profession, life experience and social groups.

Mental models serve a functional role to structure and simplify the world and therefore are not complete or accurate representations of reality (Abel, Ross, & Walker, 1998; Jones et al., 2011). This simplification carries a cost when different people that are trying to communicate or solve a problem together have mental models that “differ in structure, content, focus, and range
of concerns” (Abel et al., 1998, pg 79). Mental models serve as the basis for the expert/non-
expert hierarchy in risk perception research; and the growing field of science communication is
another problem domain where scientists try to overcome communication barriers due to
differences in mental models. The cost of what scientific experts gain in efficiency and insight
through their own specialized mental models, is that they lose the ability to understand another’s
mental model outside of their discipline, thus inhibiting communication and collaboration
(Kaplan & Kaplan, 1982). Likewise, any non-scientist’s mental model that is constructed based
on their own motives, goals, background knowledge, or existing knowledge structures will filter
incoming information according to their own information needs and understanding of the world
(Jones et al., 2011; Klayman & Ha, 1989). From a psychology perspective, mental models are
structured like working memory that can simulate the future and evaluate alternative courses of
action, which makes them well suited to cause-and-effect dynamics and process-thinking (Abel
et al., 1998; Craik, 1943; Jones et al., 2011). In the ocean forecast system context, understanding
decision-making in terms of process-thinking for both groups can allow comparison of mental
models to better understand differences and similarities between them.

Mental models are not available for direct inspection or measurement and a variety of
elicitation tools and techniques have been developed for different fields of research, including
resource management, science communication, and risk communication (Jones et al., 2011). In
the domain of rangeland management research, Abel et al. (1998) elicited, compared, and
combined mental models from pastoralists, extension agents, and researchers about landscape
water processes to gain an enhanced understanding of the system through the combination of
scientific theory and local knowledge. This work highlighted how the expert/non-expert
hierarchy becomes blurred when the problem domain moves from theoretical knowledge meant
to generalize about the behavior of a system to the application for a specific purpose at a local scale. If we apply this framing to the ocean forecast system of data provider and end-user, the disciplinary expertise and technical capabilities of data providers can be combined with practical expertise and information needs from the commercial fishing to optimize the usefulness and societal benefits of the system.

A systems approach to combining the mental model of data providers and intermediate end-users was recently used in a study by Bostrom et al. (2015) with the goal of improving hurricane forecast and warning production, communication, and decision-making, by integrating the perceptions and needs of multiple users from different organizations along the process (Bostrom et al., 2015). This study frames data providers as its own system of connected end-users and highlights the usefulness of understanding the variation in perceptions and needs within the data provider community. Bostrom et al (2015) followed the Morgan et al (2002) mental models method for risk communication, whereby a mix of open-ended and semi-structured questions on the concepts of risk exposure, impact, and mitigation elicit causal thinking about the hazardous processes related to risk mitigation decisions (Bostrom et al., 2015). A companion study by Lazrus et al (2016) utilizes the Morgan method to elicit mental models from the broader public and professionals to identify critical gaps in knowledge, misunderstandings, and misconceptions about the rapid evolution of flash floods from the public (Lazrus, Morss, Demuth, Lazo, & Bostrom, 2016). This final example of comparison of the expert-non-expert mental model represents the original application of the Morgan method, which then goes on to addresses the gaps through improved risk communication.
Research Methods

Mental Model Interviews

Mental model interviews were conducted with individual participants from both communities following a modified protocol developed by Morgan et al. (2002). This approach is specific to risk communication and provides a systematic and repeatable interview procedure to elicit an individual’s mental model about risk. There are several procedures to elicit and interpret an individual’s mental model based on research ranging from cognitive psychology to natural resource management. The Morgan et al. (2002) line of inquiry begins with open-ended questions that allow participants to freely express their views about a risk, followed by more specific, semi-structured questions that target the typical risk assessment topics of exposure, effect, and mitigation of risk (Cone & Winters, 2011; Morgan, Atman, & Bostrom, 2002). The typical goal of the Morgan method is to use mental model interviews to build an understanding of how a target audience views a system and its risk, and then compare it to an expert mental model to identify gaps in understanding that then informs risk communications. The goal of this study is not to identify gaps in understanding between two groups about the same risk. Rather, it is to gain a more holistic understanding of risk knowledge from two communities facing separate but interrelated risks, and to understand the decision-making process of each community as a system united by ocean condition forecasts.

Contrary to the expert/non-expert hierarchy, this study assumes that each community has valid contributions to risk knowledge within the ocean condition forecast system, where data providers are experts in oceanographic data collection and modeling, and ocean harvesters as data users are experts in navigating the marine environment. Ocean condition forecasts are a form of knowledge that has value specifically due to the risk that arises from the interaction of
two systems: the physics of the coastal ocean and the human communities that are in relationship to it. The data provider and ocean harvester communities face separate but interrelated risks and uncertainties around ocean condition forecasting and ocean use. Data providers face risks from having an advanced theoretical, yet imperfect, understanding of the physics of the ocean which can result in providing inaccurate or incomplete data that people use to make decisions. Commercial fishermen face direct risks from the ocean itself to their lives, property, and ability to earn a living. Therefore, this study used two sets of interview questions that followed the mental models line of inquiry but were tailored to each community based on the unique risks they face. This non-hierarchical structure of expertise, with an emphasis on understanding perceptions of risk and comfort with uncertainty for both communities, is intended to inform a two-way flow of information, learning, and discovery.

Participant Selection

Participants from the commercial fishing and data provider communities were selected through a combination of purposeful selection to capture a range of variation within each community (Maxwell, 2013) and modified snowball sampling to gain access to a wider group of participants (Auerbach & Silverstein, 2003). Recruitment for both communities started with key contacts and contributors already engaged in the Seacast project and additional contacts were obtained at the suggestion of existing participants. Interviews for each community were conducted either in-person at a location chosen by the participant, or over the phone, until saturation was reached (Miles, Huberman, & Saldana, 2013). A total of 15 interviews were conducted with 17 members of the data provider community and 16 interviews with 16 members of the ocean harvester community. All interviews were recorded, except for one.
Commercial Fishing Community

For the purposes of this study, the commercial fishing community includes commercial fishermen and their onshore counterparts. Commercial fishermen are a core group of data users for ocean condition forecasts because the nature of their profession requires a great deal of time on the ocean and daily decision-making that is influenced by ocean conditions. Onshore counterparts of commercial fishermen include fishermen’s wives and representatives of the industry who have personal and economic interest in the success of the commercial fishing fleet. Participants in the latter group were selected in response to literature about fishermen and risk perception that suggests that fishermen may play down the presence of an actual risk situation as part of a coping strategy in high-risk work environments (Bye & Lamvik, 2007). The goal for interviewing onshore counterparts was to gain further insights into the risks and uncertainties faced by the fishermen from those that were removed from the immediate physical danger, but still able to make daily observations and interpretations of the behavior of members of the fishing fleet.

Recruitment of members from the commercial fishing community started with key contacts and contributors already engaged in the Seacast project and additional contacts were obtained at their suggestion. In total, 11 fishermen, 4 fishermen’s wives, and 1 industry representative were interviewed and were mostly based out of Newport, the second-largest port for commercial fishing landings located along the central Oregon coast. Participants represented the typical Oregon fisheries and a range of gear types (pot, trawl, troll, longline), fishing vessel lengths (Figure 1.2), and ages (Figure 1.3).
Figure 1.7 Range of vessel lengths from fishing community research participants (n=15), industry representative excluded.

Figure 1.8 Fishing community research participant ages (n=16)

Data Provider Community

The data provider community includes academic researchers and agency scientists and managers that contribute to publically-available ocean condition forecast efforts through the NWS, CO-OPS, and U.S. IOOS. The goal of this sampling strategy was to gain insight into a range of perspectives across institutions that provide ocean data and how they might impact the data products. Local participants from the NWS were stationed at Oregon marine forecasting offices, and local participants from IOOS were associated with west coast Regional Associations with an emphasis on the Pacific Northwest. A total of 4 research participants from the national IOOS and CO-OPS offices in Washington, DC were also included. In total, 15 interviews were conducted with 17 members from the data provider community (Table 1.3).
**Table 1.3** Data providers and number of participants interviewed

<table>
<thead>
<tr>
<th>Data Provider</th>
<th>Number of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOOS</td>
<td>10</td>
</tr>
<tr>
<td>NWS</td>
<td>4</td>
</tr>
<tr>
<td>CO-OPS</td>
<td>2</td>
</tr>
</tbody>
</table>

Observation

Observations of both communities were collected from three annual meetings over the duration of the project, where ocean condition forecasting was the main topic. The Seacast project team facilitated two annual group meetings with a core group of commercial fishermen from Newport, OR to present updates to features on the Seacast website, and to collect feedback from the fishermen on what updates they would like to see in the future. Seacast meetings took place in a room at Englund Marine Supply in Newport, OR in November, before the start of crab season, and lasted approximately two hours. The group meetings fostered open discussion about the data needs and wants of the fishermen, and there were at least two representatives from the data modeling side to answer questions and discuss limitations. Additional meetings were attended by the Seacast project team with the data provider community but were not facilitated by the project team. Detailed notes and memos were kept by the researcher.

Data Analysis

All interviews were transcribed and coded for themes using a grounded theory approach and MAXQA software (Auerbach & Silverstein, 2003). The traditional data analysis method under Morgan et al (2002) is to create conceptual/influence diagrams that express causal connections between concepts, which are then compared (in order to distinguish) between both experts and non-experts. Because the purpose of this study is to build a holistic understanding of risk knowledge through a non-hierarchal structure, rather than creating risk communication by drawing distinctions, the grounded theory approach was deemed more appropriate. Initial open coding identified repeating ideas that were grouped into conceptual themes and then connected
back to the research questions in a stepwise process to create a theoretical narrative (Auerbach & Silverstein, 2003; Bernard & Ryan, 2010; Creswell & Creswell, 2017). The commercial fishing and data provider communities were coded separately and then four organizing themes were used to structure a comparison of similarities and differences between the communities.

Validity

Subjectivity, interpretation, and context are interwoven into every research project (Auerbach & Silverstein, 2003), and it is important for researchers consider to particular processes or events that could lead to invalid conclusions (Maxwell, 2013). Researcher bias refers to the selection of data that fits the researcher’s existing theory, goals, or preconceptions, or that “stands out” to the researcher (Miles et al., 2013). Researcher bias was addressed in several ways throughout the process of study design, data collection, and data analysis. My positionality as a researcher was continually reflected upon through memos that were recorded after interviews and while analyzing data to capture my feelings in response to interactions with research participants. My socioeconomic status, education (including recent graduate school coursework), and some aspects of my professional experience grants me insider status to the scientific data provider community; however, I have never studied the ocean. Other aspects of my professional experience – specifically working in industry and natural resources – grant me a level of comfort with the commercial fishing community.

The nature of the problem that this research seeks to address sets up a likely potential for critique of the data provider community. Research methods were selected to frame the data providers and end-users as an interdependent system to create a structure where both stories can be told to gain a fuller picture that alleviates some of the potential for critique. A diverse range
(and relatively large sample size) of research participants were selected from both communities to reduce the risk of systematic biases (a.k.a. triangulation (Maxwell, 2013)).

Reactivity refers to the influence of the researcher on the setting or individuals studied, particularly during interviews (Maxwell, 2013). While reactivity cannot be completely eliminated, efforts were made to minimize its effects by following the interview protocol consistently for each participant, by not asking leading questions, and by providing minimal verbal input. Interviews were conducted in a setting that was selected by the research participants so that they were comfortable. During data analysis, intercoder reliability -- the extent to which two or more independent coders agree on the coding of the content (Miles et al., 2013) -- was performed for transcripts from both communities with another researcher experienced with qualitative research methods.

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CHAPTER TWO: FIRST MANUSCRIPT [Weather, Climate, and Society]

Navigating mental models of risk and uncertainty within the ocean forecast system:
An Oregon case study

ABSTRACT

The case study examined here explores how to add value to regional ocean condition forecast information by bringing awareness to the processes that govern decision-making and outcomes within the system. A modified mental models research approach is applied to examine differences and similarities in perceptions of risk and comfort with uncertainty between two interdependent communities: the ocean “data provider” and “end user;” and how these perceptions impact accessibility and usefulness of data products. Data providers are academic and agency scientists from institutions that provide ocean condition forecasts to public end-users (n=17). End users are members of the Oregon commercial fishing community (n=16). Comparisons reveal key differences and similarities related to the nature of each profession that impact perceptions of scale in time and space; and the ways in which cumulative and intersecting risks and uncertainties act as key drivers in decision-making for both groups. Implications for expanding the current understanding of how ocean forecasts are produced and used include 1) highlighting the value of optimizing ocean forecast delivery tools based on end-user needs; 2) identifying structural and cultural barriers within the data provider network that prevent them from doing so, and 3) identifying ways to structure cooperation and strengthen relationships between data providers and end-users by recognizing differences and building on similarities in each groups’ mental models of risk perception and comfort with uncertainty.
1. Introduction

Integrated coastal observing and modeling systems have substantially advanced the quality of regional ocean forecasts in recent years and there is a recognized need to transform these activities into products that can serve end-users other than the scientific community; however, this class of end-users has not been well-defined (Flemming, 2002; IFSOO, 2012; Kourafalou et al., 2015; NAS, 2017). In the Pacific Northwest, commercial fishermen are recognized as important end-users that seek out ocean forecast information about currents, surface temperatures, waves, and wind for safety and efficiency (Duncan, 2014; Price & Rosenfeld, 2012), but little is known about why and how they use this information to make decisions. Furthermore, commercial fishing off the Oregon coast is physically risky and economically uncertain. Ocean forecast data providers and end-users are united by a capacity to produce and a need to consume ocean forecast data. This context provides a unique opportunity to learn about the ways that risk perception and comfort with uncertainty influence decisions about the production of ocean data by data providers, and how that data is consumed and interpreted for decision making by the end-users.

The ocean enterprise -- defined here as encompassing the academic, public, and private sectors that contribute to ocean observation and forecasting -- is a relatively young field compared to the weather enterprise. Ocean forecast data have the potential to serve a diverse set of advanced marine operations end-users that includes commercial shipping and fishing, recreational boating and fishing, bar pilots, the coast guard, and oil spill response (Price & Rosenfeld, 2012). Despite the differences between land and ocean end-users, there is much to be gained from the institutional knowledge and experience of the weather enterprise (Fischhoff, 1995). This includes a recent commitment to improving the scientific understanding of the
factors that affect decision-making and behavior among individual end-users and institutional actors for the purpose of strengthening overall performance of the forecast system (Bostrom et al., 2015; Lazrus, Morss, Demuth, Lazo, & Bostrom, 2016; NAS, 2017; NRC, 2006).

Uncertainty is part of every decision we make as individuals, groups, or institutions and it is approached and communicated differently based on discipline, profession, or problem domain (Smithson, 2008). Furthermore, the way that different disciplines and professions orient towards uncertainty has implications for the way it is coped with and managed (Smithson & Bammer, 2008). Risk perception is the intuitive risk judgement that people rely on to evaluate the hazards that they encounter and is a useful concept for understanding and describing how people make decisions with imperfect information in response to risk and uncertainty (Ropeik, 2012; Slovic, 1987).

Recent methodologies in the field of risk communication research that aim for a deeper understanding of the subjective nature of risk perception have turned toward a more qualitative understanding of an individual’s mental model of risk (Bostrom et al., 2015; Lazrus et al., 2016; Ropeik, 2012; Slovic, 2016). Mental models are a way to represent the manner in which individuals organize their thoughts and beliefs about how something works or how something is; they also influence the way that new information is interpreted by the individual (Cone & Winters, 2011). An individual’s orientation towards uncertainty and risk perception is a function of their mental model, which is shaped by factors that include discipline, profession, life experience and social groups (Short, 1984; Smithson, 2008). Mental models are well suited to cause-and-effect dynamics and process-thinking (Abel et al., 1998; Craik, 1943; Jones et al., 2011). In the ocean forecast system context, understanding decision-making in terms of process-
thinking for both groups can allow comparison of mental models to better understand differences and similarities between them.

Recent mental model studies regarding hurricane and flood risk communication and management use the Morgan et al (2002) method for mental model elicitation (Bostrom et al., 2015; Lazrus et al., 2016; Wagner, 2007; Wood, Kovacs, Bostrom, Bridges, & Linkov, 2012). These studies frame data providers as their own system of connected end-users for comparison within professional domains; or frame data providers and public end-users for comparison across an expert/non-expert domain. The typical goal of the Morgan method is to use mental model interviews to build an understanding of how a target audience views a system and its risk, and then compare it to an expert mental model to identify gaps in understanding that then informs risk communications (Morgan et al., 2002). The goal of the present study is not to identify gaps in understanding between two groups about the same risk. Rather, it is to gain a more holistic understanding of risk knowledge from two communities facing separate but interrelated risks, and to understand the decision-making process of each community as a system united by ocean condition forecasts.

Ocean condition forecasts are a form of knowledge that has value specifically due to the risk that arises from the interaction of two systems: the physics of the coastal ocean and the human communities that are in relationship to it. Contrary to the expert/non-expert hierarchy typically associated with risk communication research, this study assumes that each community has valid contributions to risk knowledge within the ocean condition forecast system, where data providers are experts in oceanographic data collection and modeling and commercial fishermen as end-users are experts in navigating the marine environment. The data provider and commercial fishing communities face separate but interrelated risks and uncertainties around
ocean condition forecasting and ocean use. Data providers face risks from having an advanced theoretical, yet imperfect, understanding of the physics of the ocean, which can result in providing inaccurate or incomplete data that people use to make decisions. Commercial fishermen face direct risks from the ocean itself to their lives, property, and ability to earn a living.

The goal of this systems-based approach is to bring awareness to the processes that govern decision-making and outcomes for the system as a whole (Bammer, 2008). This paper frames the problem to include discipline- and practice-based knowledge and uncertainty of ocean forecast data providers and commercial fishermen, respectively. It views these as an interdependent system and asks 1) What are the main similarities & differences in ocean users’ and data providers’ comfort with uncertainty and risk around the ocean and ocean condition forecasting? 2) How does data providers’ comfort with uncertainty and perception of risk impact the accessibility of ocean condition forecasts to ocean users? 3) How does the accessibility of ocean forecast data impact the ocean users’ comfort with uncertainty, perceived risks, and their ability to cope?

2. Methods

Sample

Participants from the commercial fishing and data provider communities were selected through a combination of purposeful selection to capture a range of variation within each community (Maxwell, 2013) and modified snowball sampling to gain access to a wider group of participants (Auerbach & Silverstein, 2003). Recruitment for both communities started with key contacts and contributors already engaged in previous work with each community related to this topic (Duncan, 2014); additional contacts were obtained at the suggestion of existing
participants. Interviews for each community were conducted either in-person at a location chosen by the participant, or over the phone until saturation was reached (Miles et al., 2013).

For the purposes of this study, the commercial fishing community includes commercial fishermen from the central Oregon coast and their onshore counterparts. Onshore counterparts of commercial fishermen include spouses and representatives of the industry who have personal and economic interest in the success of the commercial fishing fleet. Participants in the latter group were selected in response to literature about fishermen and risk perception that suggests that fishermen they may play down the presence of an actual risk situation as part of a coping strategy in high-risk work environments (Bye & Lamvik, 2007). The goal for interviewing onshore counterparts was to gain further insights into the risks and uncertainties faced by the fishermen, from those who were removed from the immediate physical danger but still able to make daily observations and interpretations of the behavior of members of the fishing fleet. In total, 16 interviews were conducted with 11 fishermen, 4 fishermen’s wives, and 1 industry representative. Most of these were based out of Newport, the second-largest port for commercial fishing landings located along the central Oregon coast. Participants represented the typical Oregon fisheries and a range of gear types (pot, trawl, troll, longline), fishing vessel lengths (Figure 1.2), and ages (Figure 2.2).
The data provider community includes academic researchers and agency scientists and managers that contribute to publically-available ocean condition forecast efforts through the National Weather Service (NWS), the Center for Operational Oceanographic Products and Services (CO-OPS), and the U.S. Integrated Ocean Observing System (IOOS). The goal of this sampling strategy was to gain insight into a range of perspectives across institutions that provide ocean data and how they might impact the data products. Local data provider participants included Oregon coastal weather forecasting offices (WFOs), and participants from IOOS west coast Regional Associations with an emphasis on the Pacific Northwest. A total of 4 research
participants from the national IOOS and CO-OPS offices in Washington, DC were also included. In total, 15 interviews were conducted with 17 members from the data provider community.

Table 2.1 Data providers and number of participants interviewed

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Modified Mental Model Elicitation

Mental model interviews were conducted with individual participants from both communities following a modified protocol developed by Morgan et al. (2002) specific to risk communication that provides a systematic and repeatable interview procedure to elicit an individual’s mental model about risk. The Morgan et al. (2002) line of inquiry begins with open-ended questions that allow participants to freely express their views about a risk followed by more specific, semi-structured questions that target the typical risk assessment topics of exposure, effect, and mitigation of risk (Cone & Winters, 2011; Morgan et al., 2002). Because data providers and commercial fishermen play functionally different roles in the data provider/end-user system, different interview questions were used for each group. Data provider interview questions elicited responses about the risks of providing ocean forecast data to end-users, and commercial fishermen questions elicited responses about ocean use and ocean forecast use. Interviews for each community were conducted either in-person at a location chosen by the participant.

Data Analysis

All interviews were transcribed and coded for themes using a grounded theory approach and MAXQA software (Auerbach & Silverstein, 2003). The traditional data analysis method under Morgan et al (2002) is to create conceptual/influence diagrams that express causal
connections between concepts, which are then compared (in order to distinguish) between both experts and non-experts. Because the purpose of this study is to build a holistic understanding of risk knowledge through a non-hierarchal structure, rather than creating risk communication by drawing distinctions, the grounded theory approach was deemed more appropriate. Initial open coding identified repeating ideas that were grouped into conceptual themes and then connected back to the research questions in a stepwise process to create a theoretical narrative (Auerbach & Silverstein, 2003; Bernard & Ryan, 2010; Creswell & Creswell, 2017). The data for each community was coded separately; however, four broad organizing themes were identified and used to structure a comparison between communities, presented in Section 3.3.

3. Results

3.1 Commercial Fishing Community

3.1.1 Professional domain

Oregon’s commercial fishing community is a network of captains, crew, fishing families, fish processors, fish buyers, and gear shops that work together to harvest ocean resources. Most full time, active commercial fishermen in the study region have at least two fisheries that they prosecute to make a living, one of which being the nearshore Dungeness Crab fishery that begins in December or January and lasts through winter and into spring depending on the year (and the fisherman’s plan of work). Other fisheries prosecuted at different times of year include shrimp, black cod, halibut, salmon, and Albacore tuna. One fishermen described what might be considered a typical year:
“We’ll crab until March or early May at the latest. Usually by May we’re Black Cod fishing. We fish Black Cod in May and June. Then, once we catch that quota we’ll do a couple of halibut openers in late June and early July. From then on; as long as the tuna are around, we’ll be offshore tuna fishing. We’ll be tuna fishing until September / end of September; something like that. We usually spend October and November working on the boat, getting crab gear ready to go for another go around.”

Time of year and fishery prosecuted determines where fishermen are in space. For example, the Dungeness crab fishery largely takes place 5-10 miles from the beach at less that 100 fathoms (180 m) depth; the Black cod fishery largely takes place along the edge of the continental shelf anywhere from 20-45 miles offshore between 100 and 300 fathoms (180 – 550 m) depth; and Albacore tuna is highly variable, ranging from 40 to 100 miles offshore. There are specific hazards associated with entering and leaving port, or “crossing the bar,” compared with hazards at sea. The “bar” refers to the accumulation of sediment often deposited at the mouth of a river which then amplifies incoming wave height and creates turbulence.

Vessel size and experience of the captain was the most important factor in a fishermen’s risk orientation and influenced all aspects of decision-making. A clear “big boat/small boat” division exists within the fleet with the dividing line somewhere around 60 feet (18.3 meters). Boats larger than 60 feet in length are generally able to fish more because they can withstand higher wind speeds and wave heights for longer periods of time at sea and can enter and leave port (cross the bar) more often because they have a higher tolerance for hazardous conditions. Smaller boats have much lower tolerances and rely more heavily on weather and ocean condition forecasts to move strategically in space. Beyond this general distinction; vessel shape, material (ex: steel or wood), and age also play a role:
“Every vessel operates differently. Every boat rides waves differently. Some boats fare better than others.”

There was overall agreement regarding risk perception and comfort with uncertainty among fishing community research participants; however, there was variation based on age, experience, and whether a fisherman had a family on-shore. Self-described “old-timers” that had been part of the fishing community for over 40 years could articulate the risks and uncertainties more concisely, whereas younger fishermen tended to describe specific scenarios and details. Fishermen’s wives tended to focus hazards related to the vessel (i.e. equipment failure) and the operators (i.e stress and exhaustion); whereas some fishermen focused more on hazards from ocean conditions.

3.1.2 Risk perception and Uncertainty

The work of commercial fishing largely takes place in the ocean environment and, as part of nature, is dynamic or ever-changing. The dynamic nature of the ocean and weather was described by the commercial fishing research participants over space and through time, looking towards the past, the present, and the future in relation to fish populations, sea surface temperatures, and storm intensity and frequency. They reported a sense of interconnectedness when describing the environment, with reference to how coastal Oregon is only a small piece of a global system and how winds create the weather and ocean conditions and influence the health of the ocean through the food web. Being a dynamic natural environment, there is inherent uncertainty and a belief that humans lack the capacity to study and understand the whole ocean because of the many forces at play. Uncertainty is part of life for a commercial fisherman, whether it be uncertainty about the weather and the catch, or uncertainty about when one can return home.
The inherent uncertainty and risk of commercial fishing is a large part of the appeal of the profession and the lifestyle. Research participants shared that commercial fishermen appreciate the challenge and the thrill of the catch and the chase, a love of the ocean, and the freedom it affords. For some, the ocean is a place to escape to and a place that operates outside the normal societal constructs of life on land. There is an acknowledgement that the profession is “not for everyone” and that commercial fishermen are “gamblers at heart.” As one participant declared:

“I don’t know if there’s any way to eliminate the risk and if there was I don’t think anyone would be really interested in doing it.”

Risk is accepted, and sometimes celebrated, as part of the job. Risk is also minimized at times by comparing the risk in commercial fishing to other situations that involve risk, such as working in construction or driving a car on the highway. Even fishermen that have experienced great losses and consequences from the inherent risk choose to continue. Some of the wives interviewed described times when their fisherman spouse tried to quit the profession but were unhappy and eventually rejoined the fleet, indicating that commercial fishing provides personal satisfaction beyond financial gain. For some, it’s the reason they live. In dealing with the risk, one wife participant summed it up as:

“For me it's no different than a police officer. It's a calculated risk. You do a job that you love. You do your best to be safe. You do everything you can to do it right, and then you go out there and work.”

While participants expressed the appeal of the challenges of commercial fishing, it was consistently emphasized that their main motivation was to achieve financial gain. The motivation to be profitable creates tension between the monetary risk from running a small business and the physical risk of operating in the ocean environment, or risk versus reward. This tolerance, or threshold, for physical risk is determined by each vessel operator and depends on
many contextual factors for any given scenario. The strategy is to fish right up to the threshold or “push the envelope,” without endangering the crew or the operation.

3.1.2.1 Physical risk

Participants reported that fishermen generally perceived themselves as always working to avoid physical risk. Physical risks include injury, death, and damage to the vessel. A common way to damage a vessel and risk injury is crossing the bar or being at sea during hazardous conditions that can result in lost windows and electronics. Mental and physical exhaustion from long hours and lack of sleep also contribute to physical risk. Navigating around structures such as shipping lanes, debris in the water, fishing gear, and scientific instruments in the marine space add another layer of things to consider. Strong currents that pull at gear hanging in the water can impact vessel stability, and gear that is not properly tied down can create a hazard to crew on deck. As vessels endure the rough ocean environment, weak points can develop in the hull that need repair but might not be attended to in a timely fashion due to the need to work and earn money at specific times.

Despite their best efforts to prepare and be safe, accidents do happen at sea. Many stories of boats going down were at times when someone made a poor judgement call to go out during extreme events when everyone else knew to stay home. However, it was also acknowledged and accepted that accidents sometimes just happen:

“When boats that are lost here and perish, there are some mistakes made and sometimes things just happen, and you can’t really blame anybody. It’s not really for me to say why things happen, they just do.”

One fishermen noted how inexperienced recreational boaters have been known to go onto the ocean without looking at forecasts and that don’t have an understanding of the way tides, the swell, and wind work together and bad things happen very quickly. This is in contrast to
commercial fishermen, who consider understanding the risks and planning for them to be part of the job.

3.1.2.2 Monetary risk

Participants shared that commercial fishermen are motivated to work as much as possible because operations have significant overhead costs that include vessel payments, vessel maintenance, insurance, fuel, and paying a living wage to crew members. This economic mental model guides fishermen in maximizing profit and minimizing loss. One of the primary risks to a commercial fishing operation is lost fishing time. Sea time is extremely valuable because there are not enough fair-weather days to maintain profitability, and operators must decide when they can “tough it out” through hazardous conditions. If a vessel is out at sea and a storm is coming, an operator will want to avoid ending (commonly referred to as “breaking”) the fishing trip, by either staying at sea and traveling around the weather to a different location or shutting down operations and drifting as the weather passes if the vessel can withstand it. If an operator does make a run to port, there is a risk that they might not have an opportunity to get back out across the bar to return to fishing at a later time. Multiple, consecutive lost fishing days quickly adds up to a major impact on profitability.

Decisions around the placement of gear and the need to track it over time add another layer of monetary risk to an operation that can have cumulative impacts. Because fishing time is valuable, commercial fishermen must choose where and how to set gear at sea so as not to lose time and effort. Furthermore, there are many thousands of dollars invested in gear that fishermen don’t want to lose. For example, when crab pots are set nearshore there is a risk that a large swell will wash the pots onto the beach, into the reefs, or into deeper water where they may not be able to retrieve them. Heavy rains can wash kelp patties and logs into the nearshore that
can catch crab pots and deposit them offshore. If pots are washed onto the beach and fill with sand, fishermen need to identify them, wait for a day of calm surf, and then pump the sand out of the pots before they can retrieve them.

“I don’t think of it as risk, as like “We’re going to die” risk, as much as it’s like, “I just lost my crab gear because we had a 28-foot sea that I didn’t foresee coming.” That’s risk. [It] washed all my gear on the beach. So, if I don’t get it back I lose thousands of dollars”

The cumulative effects from lost gear on top of lost fishing time compounds the monetary risk, and the effects of being unable to deliver product to buyers and processing plants onshore can ripple through the local economy.

3.1.2.3 Psychological risk

Working in a dynamic and competitive environment with the responsibility to financially support their operations while remaining safe means vessel operators risk their mental and emotional well-being from the stress of decision-making. As the operator of a smaller operation stated:

“[It’s] always in the back of your mind, “Should I have gone this morning, should I have gotten out and gotten some work done?” Stress is the biggest one [risk] for guys running boats. It’s huge. It sucks. That’ll kill you quicker than the ocean does.”

For many, the risk of not being able to cross the bar to get home to their families was a significant factor and added to their stress. Participants described emotional experiences of times when they were miserable sea, dealing with the consequences of bad decisions, and times when they felt great fear, anxiety, and frustration.

Weather and ocean forecasts play a critical role in decision-making and can contribute to stress when they are inaccurate. For example, if a weather forecast over-predicts hazardous conditions and the decision is made to stay at port, this leads to irritation from lost fishing time.
On the other hand, when weather forecasts under-predict hazardous conditions, there is lost fishing time at sea while also battling rough conditions. Participants reported that commercial fishermen have a dualistic relationship to weather and ocean forecasts expressed as both frustration and gratitude. Forecasts contribute to stress when different sources have conflicting information, particularly when conditions are marginal, and the decision is not clear. Regardless of accuracy, when a forecast is predicting unworkable conditions there is a tendency to check more frequently, or even “dwell” on them, in hope that it will change so that they can get to work, as expressed here:

“I think it keeps me up at night...you’re waiting for one [forecast] to tell you what you want it to tell you.”

The complexities of decision-making and high stakes, often related to weather, leads to a general background level of stress that is enhanced at times when an operator perceives greater monetary risk associated with their operation.

3.1.2.4 Intersecting and cumulative risk

Most participants describe their decision-making in terms of avoiding physical risk at all costs; however, the pressure to fish at certain times of year when the weather is the most hazardous makes defining the line between safe and unsafe difficult, and stressful, to discern. For example, commercial fishermen make a significant portion of their annual income in the first four weeks of Dungeness crab season when severe winter storms bring the most hazardous conditions. There is competition to set pots on opening day and deliver crab to market to satisfy the holiday demand when consumers are more likely to spend money on non-essentials. If an operator misses time during the opening weeks of crab season, they will not be able to catch up throughout the year. Many stories of close-calls and great loss coincided with the start of the Dungeness crab season in December or January.
Hazards from weather and ocean conditions can form from the cumulative effects of multiple forces acting together. Sometimes the forces of current, wind, and swell can come in opposing directions that makes being in the ocean feel “like a washing machine.” Depending on how long they’ve been working, vessel operators and crew may experience exhaustion or increased stress during rough conditions. Equipment failure, such as a broken pump or a weakness in the hull of the boat, is another hazard that can amplify risk. As one experienced fishermen put it:

“There have been a few calm sinkings but not very many. It always happens in weather, and it’s always a domino effect. Very seldom is it one specific issue that will sink a boat.”

This reported generalized typology of risk suggests that different types of risk, from acute to more abstract, intersect in complex, varying ways and over time for each individual. Participants reported that commercial fishermen generally take less risks over time as they gain experience on the ocean and in life. Several recounted their earlier days when they “pushed the envelope” more than they would now. Disaster experiences also seem to reconfigure the way commercial fishermen process their typology of risk. Many described close-calls and first-hand accounts of sunken vessel, rescues, and loss of loved ones. As one participant described:

“That sinking completely changed the way I behave on a boat. Everything is different now. I’m probably a little stressed out.”

3.1.3 Scale of decision-making and use of forecasts

Forecasts are used for planning when to go, where to go, and to get a sense of how long to go for, however the latter two may change once a fisherman is at sea and conditions change. Decisions vary by vessel operator, their risk tolerance, and the context of a scenario. The context of a decision scenario includes factors such as: time of year, fishery, gear type, vessel size, amount of catch on board, conditions, and whether the vessel is at sea or crossing the bar.
3.1.3.1 Timing

Much of the strategy for commercial fishing depends on the timing and duration of changing weather and ocean conditions and the tide. The tide is the most limiting factor for crossing the bar to enter or leave port and is the most precisely predicted as it is determined by astronomy; however, swell height, direction, period; current speed and direction; and wind are also important. The optimal time to cross the bar is on peak flood tide. Swell height limit is different for each vessel and vessel operator, and sometimes the difference of one foot of wave height can mean the difference between a safe and hazardous bar crossing. Different operators may have different thresholds for the same boat, which is largely based on experience. The following quote from a crewman-turned-skipper participant describes inheriting a boat from a fisherman with a higher risk tolerance for bar crossings:

“He was comfortable. He knew it, he fished here most of his life...Then when he said, ‘Okay it’s your boat,’ I looked at him ‘I will not cross half the bars that I crossed with you.’ And he said, ‘That’s fine I don’t expect you to.’”

Participants reported that fishermen have to plan their trips around the tide and commonly refer to windows of opportunity in between storms as “weather windows.” While the term can be used to reference multi-day trips during the summer, it is most commonly used during crab season when they are working nearshore and are aiming for a 12-hour tide cycle. Smaller vessels rely on weather windows more than larger vessel do:

“I might need to time a 12-hour window where I can run out, I can pull some pots, and I can be back in on the next tide and the weather is not going to affect me. That’s actually how a lot of these smaller boats who do fish real close to home operate during the bad wintertime storms.”

Current forecasts are especially helpful during weather windows for efficiency with laying gear. Working around the tides is also a strategy for smaller vessels when there is uncertainty in the forecast.
3.1.3.2 Conditions and duration

Participants reported that larger vessels have higher thresholds for wind speed and wave height while at sea than smaller vessels and can fish through all but the most extreme conditions.

“The only times we won’t fish because of weather is when it’s very severe. The big storm fronts and super high seas….and it’s going to be lasting for a long time.”

Duration of an event is an important factor and will influence whether a vessel will shut down operations and remain at sea so they can resume fishing when the storm passes, called “jogging,” or whether they will make a run for port. To maximize time at sea and the potential for profit, fishermen will remain at sea as long as possible until the weather comes up before making a run for home.

“It’s defining that line between what’s unsafe and what’s just uncomfortable. It can sometimes become blurry, and it can sometimes change unexpectedly, and you find yourself in those spots.”

The decision to stop fishing is not always an easy one.

3.1.3.3 Forecasts as imperfect

Participants related that fishermen perceive forecasts as imperfect, but still rely on them for planning and decision-making. Forecasts are inherently uncertain because nature is inherently uncertain. Fishermen understand that forecasting the weather and the ocean are difficult due to the complexity of the system. One fishermen described forecasters as:

“Sometimes they get in the rhythm of getting it right, and sometimes they get it in the rhythm of wrong.”

They recognize that forecast accuracy has improved over time, but they do not have an expectation that it will ever be perfect and consider weather and ocean conditions “beyond understanding.” Despite the inaccuracy for forecasts, fishermen perceive forecasters as “doing the best they can,” and providing the “best available science” in support of their decision-
making. Participants shared that while forecasts are useful for planning, the one place where their observations serve them better than any forecast is when crossing the bar. Fishermen sit at the bar and time the series. If there is a hazardous sea warning, fishermen will go to a place where they can watch the bar and time the wave series. The Coast Guard also produces bar reports for the fishermen and will shut the bar down at times of extreme danger.

3.1.3.4 Confidence in the forecast

Participants reported that fishermen determine their level of confidence in the forecast based on how well it aligns with real-time buoys and physical observations of the environment. While planning for trips they will not only be checking forecasts daily to get a sense of what lies ahead, they will also be checking the buoys to see how well the forecasts are aligning with real-time. This extra layer of interpretation into forecast accuracy by watching the trend was widely reported. Fishermen gain more confidence in forecasts the longer they have used them. They will combine forecasts from different sources based on the kind of information they are looking for, and they will compare multiple forecasts of the same variable to see how well they agree.

Participants shared that smaller vessels (especially) constantly monitor the NWS updates over the radio for upgrades that come sooner than the regular 12-hour update. Several fishermen expressed gratitude at times when there was a change to the forecast that they received that allowed them to react quickly and safely move offshore or into port at the right time. The fact that fishermen rely on these updates indicates that fishermen understand that weather changes quickly and unexpectedly. Fishermen experience small gales that are not captured in the resolution of weather forecasts, and times when the weather has come earlier or later than expected, or just “switches.” Fishermen also understand that the large NWS zones come with less accuracy. The NWS is the first source that fishermen check and is the most trusted.
The NWS forecast has been around the longest, since before smartphones or the Internet, and therefore it is the number one source every fisherman checks each day. There is also an understanding that other forecasting websites get all of their data from NOAA. Fishermen have mixed and differing feelings about NWS. Most had confidence with a 12-24 hours lead time, while others gave more a 50/50 confidence. Despite decreasing confidence in the forecast after 24 hours, fishermen still use longer range forecasts for planning and to get an “overall picture.” There was also a sense that NWS sometimes over predicts certain events with the intention of protecting the fleet, but when fishermen miss fishing time due to an incorrect forecast, they express frustration and a loss of trust. Participants also recounted times when NWS under-predicted large events and fishermen experienced a close call or were unable to work due to rough (and uncomfortable) conditions at sea. Experiencing over-prediction and under-prediction by the NWS contributes to the understanding that forecasts are not perfect and contain a “forecast-specific” risk. While fishermen like to complain about this, they still depend on them. Fishermen value objectivity in the forecasts. Fishermen cope with uncertainties in the forecast by remaining skeptical and evaluating their environment:

“Sometimes they’re spot on. And not to be critical of them, but I think it’s just hard. It’s a prediction, you know. It’s not “This is what we know,” it’s “This is what we’re looking at and this is what we’re predicting will happen.” And sometimes it just switches, you know? Or sometimes it comes just 12 hours later than what you thought. Or sometimes it comes 12 hours earlier than what you thought, or what the prediction was. So I think, all in all, most of the time, they get it close. But, it’s not always completely accurate. You’ve got to look at other things too, you can’t just go by that.”

3.1.4 Managing and coping risk and uncertainty: Fishermen are resilient

Participants reported that commercial fishermen are highly adaptive in order to survive in a constantly evolving world. Their lives revolve around the weather and so they, their families, and onshore counterparts must be flexible at all times. Despite weather playing a constant role in
planning, they considered having faith in their boats, experience, and composure under pressure as the main ways to mitigate risk. Being adaptive means that they are prepared for anything with back-up plans and redundancies built in, that their vessel and equipment are in the best operating condition, and they know the limitations of their vessels, the crew, and of themselves. Back-up plans include having the ability to cut a cable if it gets hung up on something, always having a destination in the back of their mind if they need to take shelter and being prepared to get stuck at sea if they can’t get home due to a hazardous bar. They are comfortable doing what they do, are confident in their decision-making, and take personal responsibility when they do misjudge something.

“I mean there’s times where there’s physical risk, you know, when you get in bad weather, you make bad choices, but you go in to be prepared for that. And you try not to put yourself in that position; I think that is the biggest deal.”

A large part of being adaptive means constantly monitoring the environment and evaluating their situation. Most participants described how they use their senses and watch their surroundings. They described paying attention to the clouds, seeing the way the buoys lie in the water, seeing the lines of current on the water, and watching the bar and the nearshore area “as far as the eye can see.” Some described being able to feel the electronics and speed of the boat change with the current or noticing when the fish stop biting. As one fisherman’s spouse who worked on the boat with him for several years described:

“In my mind, I can see everything that would make you terrified and it's hard to verbalize that.”

Most participants described ways that the fishermen communicate and cooperate with each other and with those on land for bar crossings and receiving weather updates. When at sea they “keep an eye on each other,” especially the younger and inexperienced fishermen, and call back and forth on the radio. For those that have satellite phones for offshore fisheries that are
out of cell phone range, such as Albacore tuna, fishermen will set up times to communicate with a spouse or business partner on land to get weather and ocean condition updates. One fishermen described asking his spouse to text him images of the forecast when he was close enough to cell service and that they pay more for a carrier that extends further offshore so that they can keep in communication more easily. Fishermen’s wives have a communication network on land as well, and they help each other track people down if something is suspected to be wrong. One operator of a smaller vessel described how he has several bigger boats he calls to see if the weather for an area is okay for his boat:

“I have a handful of other guys on bigger boats that I can call and be like ‘So what’s the weather like where you’re at?’ because we all kind of fish in the same areas and they’ll tell me ‘It’s not very nice, you don’t want to be here,’ or ‘Yeah you should be here, it’s pretty nice.’”

Fishermen sometimes communicate with the local NWS offices for advice on optimal routes to avoid weather when transiting large distances or to tell them their forecasts are wrong. The southern Oregon NWS office sends notices to the fleet when large swells are coming so that they can move their gear to safer locations to avoid being washed onto the beach. Communication is essential and expected during bar crossings:

“When the bar is dicey but there’s someone ahead we’ll ask, “How was that? What did you experience?” We always answer. Even though it’s a competitive business, there’s nothing but cooperation for safety in the bar crossings. And we share with each other; some people much more than others, what the current is doing so you don’t unnecessarily run for miles to pull crab gear and find that you should have started where you were.”

Fishermen are always watching, predicting, and trying to understand their environment.
3.2 Data Provider Community

3.2.1 Professional Domain

The Data Provider community is a network of scientists from different institutions (academic and agency) that carry out different roles to collect and aggregate data, distribute, and create and distribute data products for dissemination to a range of end-users. Risk perception and comfort with risk and uncertainty varies within this community depending on institution, role within an institution, and even between individuals with similar roles. Most of the “data” in the data provider system comes from observations as measurements of environmental variables that are collected from sensors placed in the ocean, on land, and in space. Figure 1 is a simplified schematic based on participant interviews that depicts how data moves between the functional roles of the data provider system. Leadership roles are not pictured.

![Diagram](image)

**Figure 2.3** Simplified schematic of the network of individuals and organizations within the data provider system and the potential pathways for data to flow and be interrupted.
Data enters the network through data collectors or external data providers and is centrally managed by data managers. Data undergoes quality assurance and quality control (QA/QC) and is stored at data centers. From there, it can leave the network through 3rd party data providers (private entities), external data providers, or move on to data services where it is disseminated into different levels of value-added products based on end-user requirements. Participants reported that while one goal of the data provider system is to provide data to end-users that are outside the network, another goal, which supports the first goal, is to share data openly between scientists within the data provider network. For example, modelers rely on observations from data collectors to create their models and validate the model output, and data collectors rely on other data collectors to validate their observations. Modelers access raw data to use as inputs to their models, and then provide model output back into the network via the data manager.

Risk and uncertainty take on different meanings depending on whether the end-user is within or outside the scientific community. There is comfort throughout the scientific data provider community with the methods, standards, protocols, and experience of data collectors that contribute to low perceived risk with observations. Several participants recounted stories of receiving “bad” data, but it was accepted within the scientific community as inevitable and could usually be identified and worked out quickly. The specialized positions within the community must work together to make the system work and each role has insights to the other roles within the system.

A key challenge reported by research participants across agencies and academia was that of resources to fund operations, largely due to the difficulty and cost of operating in the harsh marine environment. Collaboration with non-federal entities and between agencies in NOAA was cited by some research participants at all institutions as a means to leverage expertise and
use resources more efficiently; however, as one participant noted, collaboration is often voluntary and takes time resources.

“There are technical barriers that we can often overcome, but it’s more the programmatic and cultural barriers that are harder to overcome.”

The following sections present further insights into elements of the professional domain by research participants from those institutions in terms of mission, challenges, and relationships with perceived end-users.

3.2.1.1. National Weather Service (NWS) Weather forecasting offices (WFOs)

The NWS is an agency within NOAA whose primary mission is to produce timely weather forecasts and warnings that are distributed by local WFOs which consider the US public as “customers,” and work with targeted user groups to deliver specialized products. WFO research participants cited the Coast Guard, bar pilots, and other mariners such as commercial and recreational boaters and fishermen as examples of end-users for marine forecasts that are disseminated by coastal WFOs; however, end-users on land tended to be prioritized.

“We don’t have a lot of population at sea so it’s not the priority. The main priority is usually the inland stuff. And even then, it’s the stuff that happens where there’s the most people.”

The WFOs are focused on serving non-scientific customers and place a high value on establishing and maintaining relationships with end-users. The role of the Warning Coordination Meteorologist at each WFO is to act as a liaison with communities to find out what their needs and requirements are, to integrate those requirements into operations and procedures when possible, and to maintain relationships over time through communication and collaboration. This position holds community outreach activities, such as winter storm and tsunami preparedness, and integrates social science research to improve communication of warning information. Beyond this position, some WFO research participants were extremely knowledgeable about the
monetary and physical risks faced by commercial crabbers based on a personal a motivation to learn. They gained this knowledge through building personal relationships with members of the commercial fishing fleet by going down to the docks, attending meetings with the fishermen, and by taking a boater safety class to better understand the risks that they face:

“I attended a boating safety class for the fisherman and the recreational boaters and they all know [about the hazards], but we weren’t communicating that hazard well enough because we weren’t understanding the hazard that well ourselves. And so, to get that partnership where we are both on the same page we understand and find out what their concerns are.”

The importance of communicating wave steepness and separating out swell waves from wind waves in the forecast (rather than reporting combined seas) are examples of valuable changes that the WFOs have adopted to make the forecasts useful to mariners. This example highlights how the benefits of forming relationships with end-users has led to a better data product; however; it should be noted that this is a special case and likely doesn’t reflect the NWS forecasting community as whole. NWS research participants noted other challenges related to communicating the marine forecasts to mariners. These included their lack of presence on mobile-friendly sites, the inability to update the national forecast site to make it more user-friendly, the limited range of VHF radio, and use of consistent terminology across offices, agencies, and communities.

3.2.1.2. Center for Operational Oceanographic products and services (CO-OPS)

CO-OPS is an agency within NOAA that specializes in providing operational oceanographic products for a variety of coastal uses, primarily safe and efficient commercial navigation. Research participants held leadership positions and were not directly involved in the collection of observations or the creation of ocean forecasts. There was an emphasis on improving efficiency within CO-OPS and across NOAA so as not to duplicate efforts, and to
collaborate across agencies to make better forecast products. There was also an emphasis on forecast uncertainty quantification and communication that will be discussed in a later section.

3.2.1.3. U.S. Integrated Ocean Observing System (IOOS)

IOOS differs in institutional structure from NWS and CO-OPS in that it is not a federal agency. The 11 regional associations (RAs) are situated within academia and operate regional coastal observing systems as non-federal partners that serve multiple mission goals of integration, collaboration, and maximizing access of data to regional end-users. RAs are tasked with carrying out the seven societal goals related to the IOOS mission, and there is currently no national guidance on how to define who the regional end-users or stakeholders are or how to engage with them.

The primary means of communication with the range of end-users is through an annual meeting. When asked about end-users, research participants described relationships with shellfish growers and agency level users, like fisheries managers, while others deferred to members of the RA Advisory Board as being the “official” end-users, such as dischargers, sanitation districts, and federal and state agencies. Oil companies, shipping, and bar pilots were considered high risk users due to the potential for safety, environmental, and economic impacts, and those user groups tended to have an open line of communication with the data providers. Oil spill response and coast guard were frequently cited.

“We like to think of decision-makers as a class of end users so, we kind of lump them all together.”

Fishermen and shellfish growers were emphasized as resonating with funders in Congress as justification for the program. The most excitement was in the areas of Harmful algal bloom (HAB) forecasting and ocean acidification (OA) research. HAB and OA research require integration and make IOOS an ideal platform for advancing scientific research in that area and
make shellfish growers ideal industry partners for collaboration. Most research participants from West Coast IOOS RAs did not consider working directly with fishermen to be a priority, however they did recognize that they use their data products:

“We have this funky history about how the tuna fishing community happened to find some of our products useful and then ever since then we've kind of maintained that relationship.”

One participant emphasized the importance of engaging the fishing community to get “buy in” when placing a buoy in marine space. Research participants considered feedback on data visualizations as the main type of feedback received from fishermen.

Despite the lack of clear guidance on engaging with end-users to create data products, most research participants were still motivated to make their data available to decision makers. Some provided their forecasts to the public as part of the terms of the grant that they received, while others saw a specific need and were motivated to help people, although they were not required to do so:

“There was no forecasting system for Oregon at all compared to what was present in California or some of the East Coast states.”

The transition from basic research to real world-application was also perceived by one ocean modeler as a logical next step in one’s career, and even a personal, moral obligation, despite the fact that the academic reward system does not support stepping outside the bounds of academic communication and peer-review.

“There is no real standard about how to do this, so we're trying to be as conservative as possible as we go. But yet, I think it is our duty as scientists to start to provide this stuff to the public even though it's not perfect...I feel like it's my duty to not just put stuff in academic journals for my whole career. If it's something that can be used, we should start to do that.”

This quote also conveys how the lack of set standards for communication of data outside of the scientific community impacts scientists’ comfort with uncertainty. There are ocean modelers
that have become experts in their field after many years of basic science research who have a
desire to contribute to society more directly than through academic knowledge production.
Despite some communication with targeted end-user groups, all modelers expressed some degree
of uncertainty about what the exact needs of the end-users are and how to best communicate.

3.2.2 Risk and uncertainty: Within the data provider community

3.2.2.1 Conceptual and statistical uncertainty

Participants expressed that the majority of data are brought into the data provider system
are observations from scientists as data collectors that manage and maintain sensors in the
environment that measure a range of variables. Observations carried much less uncertainty
compared to model output despite the acknowledgement that data from sensors is “never really
perfect either.” Sources of uncertainty for data collectors include things like calibration issues;
where sensors start to drift from reality, and interference from other environmental factors. For
example, cloud contamination makes satellite data unusable near coastal areas, and moisture in
the ground can interfere with HF radar readings. The sources of scientific uncertainty are
quantified as error and managed through protocols so that the user of the data understands the
limitations.

Buoys are considered the most reliable source for continuous offshore data from the data
provider research participants; however, representativeness -- the ability of sensors to accurately
depict the spatially dynamic coastal environment -- was a central concern. Placement of buoys at
optimal locations in space is another challenge for the community due to overlap with shipping
lanes, fishing grounds, hazardous material dumping locations, and NAVY test ranges. When
additional resources are available, buoys tended to be placed in high risk areas, like the entrances
of busy ports. Research participants shared that maintaining buoys and other sensors in the
environment is expensive due to the harsh marine environment where storms damage antennae or take out buoys. Equipment becomes old and requires repairs and is sometimes vandalized. These high costs provide a challenge to maintaining the data provider system.

Ocean modelers and marine forecasters who participated in the study described the nature of forecast model output as an imperfect representation of reality, conceptual rather than detailed, and idealized. Participants reported that NWS ensemble models are run on supercomputers at the NDIC and sent to local weather forecast offices (WFOs) for refinement based on local conditions and for dissemination in text format. One NWS forecaster noted that the increasing number of models to look at was becoming a challenge due to increased complexity and limited computing capacity.

Participants reported that IOOS modelers tend to be ocean scientists situated in academia that run deterministic models which produce only one prediction for a given space and time. They do not have the capability to run ensemble models or combine and modify forecasts (as the NWS does), but as one modeler noted - they are also not usually in the business of forecasting. IOOS modelers use weather forecasts data for 3 days into the future to initialize or “force” their ocean models; which limits their ocean models to forecast two days into the future. One ocean modeler described how uncertainty in the weather forecasts further into the future limits how much they are willing to input into their models:

“It’s pretty good for three days and when you get beyond that it's less good, so we don’t push it beyond that. We probably could go out a week if we really wanted to, but again, you don’t.”

Computing capacity is described as another reason that weather forecasts were limited to three days for forcing. Computing capacity – largely a function of adequate funding – also limited
better regional models at higher resolution. Ocean models were also described by participants as inherently uncertain because of the uncertainty built into the methods:

“I can very clearly define all of the sources of error that you're going to get. Both from the satellite data, the model data, merging the two, filling those in statistically when you do the interpolation, then forcing a statistical model that already has its own error characteristics. Then interpolating everything back onto a larger grid...you can imagine the error upon error that compounds.”

Despite these sources of compounding error, participants reported that predictive ocean models have improved greatly over time. Ocean modelers test the performance of their models through formal model skill evaluations and by daily visual checks where model output is compared to real-time observations. The ability to compare forecast model output to real-time observations is valuable to ocean modelers and gives them a sense for how well the model is doing on any given day and to make sure nothing has gone drastically wrong. Through this daily process, a modeler notices patterns of times or locations in space that the model underperforms.

When ocean forecast model output is wrong or the necessary data is not available, it is less a source of discomfort for scientists, than motivation for further research. For example, linking biology to physical ocean models is a major source of uncertainty in understanding OA and HAB forecasting, but it generates a sense of excitement and opportunity for data providers in that scientific community.

Other limitations, or known unknowns, in ocean model forecasts reported by participants included under-predicting extreme events due to the difficulty in collecting data from extreme events or not being able to adequately capture processes at locations that are spatially and temporally dynamic. Furthermore, the bathymetry of channels and estuaries of major river mouths are often modified by dredging or extreme events and the models might not reflect the most recent changes. Participants reported that model limitations become a source of discomfort
and a potential risk for scientific data providers when the model moves outside the bounds of academic communication and into real-world application. Marine forecasters in Oregon described how local data and models are used to better represent the Coastal jet feature that is not captured on the coarser resolution national model runs. Transitioning between model domains of regional WFOs is also a challenge.

3.2.2.2 Practical uncertainty: Operational

Data management was reported as an important role for IOOS RAs as a key part of their mission of regional integration. Data management was not referenced by NWS or CO-OPS, likely because their data management practices are part more specialized within NOAA as a federal agency, and more removed from data collection and modeling or forecasting. The role of data managers within IOOS as aggregators of data from multiple sources and distributors to a diverse set of end-users means they are charged with keeping the data moving, making sure it adheres to quality standards, and maintaining relationships with data collectors and other contributors to the system, as well as end-users. Disruptions to data streams that make data unavailable for end-users is a common uncertainty and risk reported by some research participants. Data streams can be disrupted if a sensor is damaged in the environment or if a server that contributes to the system gets a software upgrade that interferes with its ability to complete an automatic upload. Keeping the data accessible takes a lot of communication with data collectors, modelers, and external data providers, as well as communication with end-users who are often the first to notice when a dataset is offline. Furthermore, research participants had differing opinions about whether they were part of a fully operational system – supported 24/7, 365 days a year with people on call at all times -- or a research system that was more quasi-operational. IOOS is recognized by NWS and CO-OPS as an important regional data provider.
As integrators of regional datasets and funders for regional academic research, it was reported that IOOS faces unique challenges related to data sharing and data attribution. IOOS has no authority to make data providers share their data, even if they are funded directly through IOOS. One research participant described how some data providers can be protective of their data or unwilling to share, which results in a loss of impact:

“There is all sorts of data being collected and paid for by government or other state or local agencies, or private industry, or nonprofits. Data is being collected but it's just being used at such a small scale...The risk, or downfall, is that there is a loss of impact if we don't have people sharing their data.”

Data attribution -- giving proper thanks to everyone that funded or helped a dataset get created -- is a source of uncertainty reported by some members within the data provider community that can get “pretty endless pretty quickly” because there is no clear way to determine for what qualifies as appropriate attribution. The lack of clear guidance can be a source of discomfort and another reason that data providers might decide to not share their data.

3.2.3 Application risk: Regarding users outside of the data provider community

Just as winds, waves, and currents are not hazards until humans interact with them, ocean condition forecasts are not a source of risk until they are put into use for decision-making. For the purposes of this research, the term “application risk” will be used to refer to the perceived risk to the data provider when forecast data is used for decision-making by an end-user outside the scientific community. Not all end-users use ocean condition forecast data for decision-making. Scientific researchers and managers might use data for analysis, but the process of academic peer review was considered a way to mitigate risk of misuse by other scientists. Data providers perceive different levels of level application risk depending on the type of end-users. Research participants indicated a lack of comfort with end-users that are less familiar with
working with scientific data and perceived them as a higher risk due to the potential for misuse and misunderstanding of data.

Participants reported that application risk impacts both the data providers and the end-user simultaneously and in different ways depending on the context of the decision. High stakes decisions carry with them the risk of safety, economic, and environmental consequences to the decision-maker, and a loss of trust and credibility for the data provider with potential liability implications for modelers within IOOS. Lower stakes decisions can result in a sense of frustration by the decision-maker, and a loss of trust and credibility for the data provider. The potential genesis for application risk is perceived as due to either inaccurate or unavailable data on the part of the data provider, or misuse by the decision-maker who lacks understanding about the limitations, or known unknowns, of forecast data. These distinctions impact the process through which data providers manage and cope with application risk and can ultimately impact how and what data are made available. Many data providers were concerned with end-users making “bad” decisions, misusing data, or having a lack of understanding about the data.

“There’s always the risk that measurements are imperfect, and someone will act on them without having the same kind of filter in their mind like I do and not recognize if something is junk.”

Ocean modelers within IOOS referenced both positive and negative experiences with end-users that influenced their perceptions of risk in widely distributing their model data. Recalling a somewhat negative experience where an end-user from industry drew inferences that were not appropriate based on the spatial scale of a historical data set:
“What that story taught me is that once you put something out there it can be used for purposes that you and I both know it’s not supposed to be used for. But how do you anticipate what people could be using it for, and [how does one] prevent these mistakes from happening?”

Compared to the predictive nature of model output, real-time measurements from sensor observations with processes to ensure calibration generally carried less perceived risk; however, newer technologies paired with high public interest are a source of concern. Data providers recognize that it takes specialized technical knowledge to understand how to locate, retrieve, and manipulate the many datasets that are available. Data providers modify data products based on the scientific credentials of the end-user based on their understanding of whether the end-user would understand the limitations of the data. An example was shared for a dataset that was intended to give a sense of structure of a river plume for research purposes:

“I want(ed) to give (them) as much data as I possibly could. I'll turn off all the flags and make a product that I wouldn't necessarily distribute widely, but for certain applications and if somebody really understands what it is they're looking at, it's fine.”

However, for data that is more certain and carries less application risk, one participant expressed a sense of satisfaction from providing data in usable formats to non-scientific end-users who normally would not be able to access it:

“It's really cool to see that you build something with a particular audience in mind but then there's all these other users who utilize it.”

Participants reported that modelers generally take application risk more seriously, particularly for certain uses at certain time and spatial scales, because they feel a personal responsibility for the negative impacts to high-stakes end-users if the data are inaccurate or misapplied. For example, higher frequency forecasts at shorter (hourly) intervals is a common request from end users yet is a source of discomfort for modelers due to the uncertainty in the forecast. Liability was also mentioned as an obvious concern; however, the personal ethical
implications were more salient. There was a sense of ambiguity about liability protections through the institution and how that would play out in real life.

Communication risk that resulted in a loss of trust of credibility was particularly salient for WFO meteorologists that produce warnings in addition to forecasts, with the risk being that the warning or forecast would not be interpreted the way the forecaster intended.

“Communicating and maintaining trust. I'm always afraid that I'm not expressing it correctly, that my wording is not going to be right.”

All WFO forecasters made reference to the risk of “cry-wolf syndrome,” when a hazardous forecast or warning is issued but the hazards don’t materialize. The impact to end-users can range from minor inconveniences to major economic consequences, with the added risk that end-users are less likely to trust future forecasts or take action with future warnings.

3.2.3.1 Application risk: Regarding commercial fishing end users

Application risk specifically regarding commercial fishermen as end-users varied between research participants. Some participants considered them high-risk users, while others viewed them as savvy enough to understand that forecasts are just guidance to help save fuel or lead to better fishing.

“They said that they understand that it’s just a model but they still like it because it provides guidance to them.”

Research participants that had interacted with commercial fishermen over time felt more confident in them as trusted end-users. Marine forecasters at one Oregon WFO that are particularly well connected to the commercial fishing community described how fishermen determined the daily accuracy of the forecasts depending on how well they lined up with their physical observations:
“One big thing we heard is that if we are not right with what's currently going on, then their faith in our forecast is nil at that point. So, if we say that there are seas 8 - 10 ft and its 12 ft, they're just like, ‘No, they're not getting it today.’”

This observation about how fishermen determine forecast accuracy for themselves confirms the fishermen’s’ own accounts and demonstrates the value of forming relationships with the end-user to understand and how forecast limitations in accuracy are coped with.

3.2.4 Managing and coping risk and uncertainty: Formalized procedures

Data providers manage and communicate the uncertainty in their data through formalized processes. Standard operating procedures (SOPs) ensure that data quality is consistent and contains adequate metadata that represents and describes the data well enough so that it can be used by another data provider and is provided in standard formats. QA/QC is another type of procedure, often automated, that uses standardized checks performed on data that detect when values that are out of range or when sensors go offline. Challenges to integration arise when data providers have “different degrees of rigor and experience” or available resources to maintain their sensors, record proper metadata, and conduct QA/QC procedures. Furthermore, real time data from sensors like buoys and High frequency (HF) radar are an extremely valuable part of the data provider system; however, the nature of real-time data carries with it inherent risk and uncertainty because it cannot undergo QA/QC before delivery to an end-user. One research participant described this as a kind of “buyer-beware” for the end-user that is often communicated through use of disclaimers. System monitoring to maintain an operational system varied between IOOS RAs.

IOOS RA’s can go through a process of certification as a Regional Information Coordination Entity (RICE), which provides liability protection to three functional roles at each RA but excludes ocean modelers. The RICE certification process means that all data providers
to each RA system follows SOPs to ensure the data meets data quality standards set by NOAA. While helpful at reducing the likelihood for bad data, it was noted that it would not reduce the likelihood for end-users misusing data for purposes it was not intended and then complaining.

Ocean modelers manage application risk in various ways. These can include masking out data in regions where they are less confident, by withholding certain variables, or by making plots of data available as image instead of actual numbers in a downloadable format. Other modelers simply worry less:

“That level of comfort will vary between modelers in terms of how they feel about making certain parts of their model forecast available given the level of validation and calibration that they’ve done and their understanding of the model. PI’s can come to different decisions within similar settings.”

Research participants generally preferred to have an open line of communication with the end-users, and modelers that had worked closely and established relationships with certain end-user groups were more comfortable providing the data to them.

NWS WFOs also work with a noted class of “high-end” end-users on land that require extra information on the confidence of forecasts: emergency managers, those involved with monitoring and managing wildfires, and ODOT. These users require extra information about uncertainty due to the need for contingency plans. The NWS usually provides uncertainty information as confidence intervals. At CO-OPS, the most salient way to cope with uncertainty and risk was through uncertainty quantification and communication based on understanding end-user requirements for accuracy and precision. This philosophical shift away from withholding data and towards communicating uncertainty is due to the recognition that end-users have a wide variety of performance requirements.
“I think our goal is just to get the best information out there to the decision maker so that they can make the informed decision based on the information that we provide, but also on other sources of information that they have. And that ties into the uncertainty, right? How good is the forecast? How good is the observation? Then hopefully the decision-makers understand how good they need the observations and forecasts to be in order to make their decision effectively.”

The ability to quantify and communicate uncertainty within CO-OPS is largely possible due to a long history and emphasis on SOPs, QA/QC, documentation, evaluation, and monitoring.

3.3 Differences and Similarities: Commercial fishing and Data Provider communities

To structure the comparison of the mental models between the communities, the narrative analysis is summarized in Table 2.2 that presents key differences and similarities between data user (DU) and data provider (DP) communities. Differences and similarities are divided into four organizing themes: 1) Professional domain, 2) Risk perception, 3) Time and spatial scale, and 4)Managing risk and uncertainty. These organizing themes are a result of inductive codes that emerged from the data (i.e. Professional domain and Time and spatial scale), and deductive codes that were guided by the research questions (i.e. Risk perception and Managing risk and uncertainty) (Bernard & Ryan, 2010). The results of the table are presented as main themes as first line of each cell that either emphasize the differences or provide the basis for the similarities between each community. Bulleted sub-themes provide more detail that relates back to the narrative presented in Sections 3.1 and 3.2. The goal of the table is not to create rigid categories that are generalizable to all data users and providers, but instead organizes the results of this research to inform the discussion and conclusions.
<table>
<thead>
<tr>
<th>Organizing themes</th>
<th>Differences</th>
<th>Similarities (DU &amp; DP)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Professional domain</strong></td>
<td>Data user (DU)</td>
<td>Scientific institution</td>
</tr>
<tr>
<td></td>
<td>• Weather and ocean conditions</td>
<td>• Funding</td>
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<td></td>
<td>• Fish populations</td>
<td>• Organizational mission &amp; reward system</td>
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<td>• Regulations, management</td>
<td>• Specialized roles</td>
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<td>• Market forces</td>
<td>• Politics</td>
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<td>• Sustainability</td>
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<td>Data providers (DP)</td>
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<td>• Small business in natural resources</td>
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<td>• Weather and ocean conditions</td>
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<td>• Sustainability</td>
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<td></td>
<td><strong>Similarities (DU &amp; DP)</strong></td>
<td>Despite different motivations for work, both parties must acquire resources to sustain operations</td>
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<td></td>
<td>• Both value efficiency</td>
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<tr>
<td><strong>Risk perception</strong></td>
<td>Clear and individual</td>
<td>Abstract and public (application risk)</td>
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<td></td>
<td>• Risk acceptance</td>
<td>• Potential losses to DP: trust, credibility, reputation, liability</td>
</tr>
<tr>
<td></td>
<td>• Monetary: lost fishing time, gear</td>
<td>• Potential losses to DU: safety, economic, environmental</td>
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<tr>
<td></td>
<td>• Physical: ocean and weather hazards, equipment failure</td>
<td>• Ambiguous causes of loss: inaccurate data, miscommunication, misapplication, new technology</td>
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<td></td>
<td>• Psychological: stress, exhaustion, morale</td>
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<tr>
<td><strong>Time and spatial scale</strong></td>
<td>Practical and specific to decisions</td>
<td>Despite differences in risk, both parties face intersecting and cumulative risks and must strike the right balance between</td>
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<tr>
<td></td>
<td>• When to go, where, and for how long - related to professional domain: fish populations, regulations, market forces</td>
<td>• DU: risk and reward</td>
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<td></td>
<td>• Marginal events</td>
<td>• DP: asset and liability</td>
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<td></td>
<td>• Looking ahead in time</td>
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<td></td>
<td><strong>Conceptual and statistical</strong></td>
<td>Despite mismatches in spatial and temporal scales, both parties recognize</td>
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<td>• Representativeness of local physical processes</td>
<td>• Forecasts are imperfect</td>
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<td>• Extreme events</td>
<td>• The value of real-time data</td>
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<td>• Discomfort with high resolution space and time</td>
<td>• The dynamic nature of the ocean</td>
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<td>• Looking backward in time</td>
<td>• That most forcing is due to wind</td>
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<tr>
<td><strong>Managing risk and uncertainty</strong></td>
<td>Preparation and on-the-fly procedures</td>
<td>Due to the understanding of model limitations, both parties remain skeptical of model data and</td>
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<tr>
<td></td>
<td>• Combine forecasts with other information (physical observation, buoy data, communication with each other, Coast guard)</td>
<td>• Have processes in place to double check the data</td>
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<td>• Boat maintenance</td>
<td>• Value experience</td>
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<td>• Back-up plans</td>
<td>• Rely on communication within their networks</td>
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<td></td>
<td><strong>Formalized procedures</strong></td>
<td>• Provide feedback to data providers when they see something wrong</td>
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<td>• Documentation</td>
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<td>• Disclaimers</td>
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<td>• Withhold data</td>
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<td></td>
<td>• Uncertainty quantification</td>
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</tbody>
</table>
Professional domain refers to some of the main factors and challenges that play into decision-making based on the nature of the profession. Professional domain has the clearest differences between groups, with commercial fishermen operating as small businesses in natural resources and data providers operating as academic and agency scientists and managers in an institutional setting (Table 2.2). In addition to weather and ocean conditions, commercial fishermen must consider fish populations, management and regulations, and market demand in their decisions; creating an intersection of physical, biological, policy, and economic factors. These inherent challenges and uncertainties occur regardless of whether fishermen have access to forecast data and are part of the appeal of the profession. Data providers operating within an institutional setting must consider how to support operations under budget constraints; and unlike fishermen, are not compensated for working longer hours or taking more risks. Sometimes there is one clear mission goal or objective, and sometimes there are multiple mission goals or objectives that are prioritized in different ways and impact what end-users are prioritized. Data provider roles within the institutional setting tend to be highly specialized which can hinder the collaborative effort required to create useful forecasts. Despite these differences in professional domain, a key similarity is that both groups take on these professional roles to earn a living. Money plays a central role in the decision-making process for each group; however, it tended to serve as more of a barrier for data providers to creating useful ocean forecasts and a main motivation for commercial fishermen to go to sea.

Perceived risks for commercial fishermen tended to be clearer and impacted them as individuals, whereas, perceived risks for data providers tended to be more abstract and included perceived risks to and from the public in addition to themselves as data providers (Table 2.2). As businessmen operating in the ocean, commercial fishermen constantly navigate the line
between monetary and physical risk, or risk and reward. The stakes are high, but the risks are clear. Rather than risk and reward, data providers navigate the line between data as an asset or a liability – and there is ambiguity and a general sense of a lack of control over the data once it is placed in the public domain. When data products are useful for people outside of the scientific community in the public domain, it increases the value of the data and helps justify the cost of operations; however, it also increases the potential application risk to the data provider. If data is only utilized within the scientific community, there is less of a return on the investment of collecting or creating the data. Both fishermen and data providers struggle to find the balance between either risk and reward or liability and asset, and both groups face intersecting and cumulative risks that cannot be isolated and dealt with independently.

Commercial fishermen and scientific data providers often have a mismatch in their perceptions of spatial and temporal scale that is related to the nature of their professional domain. Commercial fishermen tend to operate on a practical scale that is specific to their decision-making; however, data providers tend to think on a more conceptual and statistical scale and are concerned with representing the local physical processes (Table 2.2). Timing plays a major role for practical decision in commercial fishing and examples include when they can cross the bar, where they can go, and for how long. Fishermen are concerned with what is happening right now or in the future; whereas, data providers are often concerned with what has happened in the past when they validate their models. Due to the perceived risks, fishermen tend to be more concerned with marginal conditions when the decision is less clear for actions such as crossing the bar; whereas data providers tend to focus on how well their models represent extreme events.
Despite these differences, there were some key similarities between fishermen and data providers when it came to time and spatial scale. Key quotes representing similarities in sub-themes are presented in Table 2.3.

**Table 2.3** Key quotes representing similarities from data provider and fishing community participant interviews for the organizing theme: Time and spatial scale.

<table>
<thead>
<tr>
<th>Sub-theme</th>
<th>Representative quotes from participant interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forecasts as imperfect</strong></td>
<td>“The risk to us is sort of the moral risk of making sure that people use these forecasts with an understanding that they are flawed. That they are just one piece of information to be used with everything else”</td>
</tr>
<tr>
<td><strong>The ocean as dynamic</strong></td>
<td>“You can't measure everything everywhere, so that's a problem. Especially in a very spatially dynamic area like our coast here off of the Pacific Northwest...It's very dynamic and very diverse, and so that makes any observation a challenge.”</td>
</tr>
<tr>
<td><strong>Trust and value real-time data</strong></td>
<td>“Largely the confidence is based on the validation we've done over the past, using observations...I check the model everyday by looking at a bunch of different buoys”</td>
</tr>
</tbody>
</table>

Both groups have a solid understanding that models are imperfect, and that accuracy varies in time and space. Data providers expressed that it was important for data users to know that models are flawed and that other forms of information need to be used, and commercial fishermen expressed this understanding of model limitations repeatedly and consistently because they experienced uncertainty in the forecasts so often. Research participants from both groups frequently used the word “dynamic” to describe the ocean and acknowledged the limited
capacity to be able to observe and predict it everywhere, and both groups emphasized the value of real-time observations as trusted source of data.

When it comes to managing risk and uncertainty, commercial fishermen focus on preparation and on-the-fly procedures; whereas, data providers rely more on formalized procedures and documentation (Table 2.2). Fishermen combine different forecasts with other types of information and focus on what they can control on board their vessels by having back-up plans and redundancies. Fishermen tend to focus on their tools (i.e. forecasts, vessel, equipment), whereas data providers tend to focus on processes (i.e. SOPs, QA/QC, documentation of metadata). Data providers might use disclaimers to communicate that the data are not perfect or may withhold data if it is considered high risk. Some data providers put more emphasis on uncertainty quantification, however it is not consistent throughout the community and is challenging with deterministic model output. Research participants from both communities expressed how they maintain a level of skepticism towards the data and have processes in place to double check it against other sources. Both communities value experience, rely on communication within their networks, and will provide feedback to the whomever they receive data from if they observe that something is in error.

4. Discussion and Conclusion

These results suggest several opportunities for improving the ocean condition forecast system. First, by expanding the current understanding of why and how forecasts are used for decision-making, these results highlight the value of ocean condition forecasts to the commercial fishing fleet in Oregon and suggest opportunities for improving the way forecasts are created and communicated. Second, expanding current understanding of why and how forecasts are created within the data provider community highlights the value of reaching end-users beyond the
scientific community and reveals some of the structural constraints that prevent data providers from doing so. Third, principle findings from both communities suggest potential ways to structure cooperation and strengthen relationships between scientific data providers and commercial fishermen as end-users by recognizing differences and building on similarities in each groups’ mental models of risk perception and comfort with uncertainty.

Characterizing the mental models of participants from the commercial fishing community conveyed the complexity of multiple risks and uncertainties that are constantly evolving, and intersecting based on situational context. Previous documentation of ocean forecast use by fishermen was limited to a general understanding of go/no-go decisions, were not regionally specific, and were for the purpose quantifying the economic benefits of regional ocean observing and forecast systems (Kite-Powell et al., 2008). This research expands that simplified understanding by highlighting the role of cumulative risks in decision-making and by documenting times and places of increased risk that reflect the physical, social, and economic environment of Oregon. Furthermore, this research reveals how fishermen interact with and interpret weather and ocean-related information (Morss et al., 2017). This new understanding suggests opportunities for improving the way ocean condition forecasts are communicated to the commercial fishermen community. For example, a fisherman and their gear experiences multiple interacting environmental forces while at sea (e.g. wind speed and direction; wave height, direction, and period; and current speed and direction). Thus, a simple interface that provides access to forecasts for multiple ocean variables for a location in space is useful for decision-making and planning because it aligns with their physical experience. These findings lay the groundwork for future studies to characterize the mental models for other potential user
groups other than the scientific community; and for other regions of the U.S. that have different physical, social, and economic contexts.

The fishermen’s need to integrate and combine forecasts and observations of different parameters for decision-making closely aligns with the mission and capabilities of data providers within NOAA; however, the majority of data produced within NOAA is for internal use. Characterizing the mental models of participants from the data provider community highlighted a network structure that allows data to flow between members within the scientific community with relative ease and low perceived risk compared to end-users outside the scientific community. Because specialized technical knowledge is often required to access much of the data available through agencies within NOAA, findings could indicate that there is less comfort with end-users that access data through web tools compared with end-users that download entire datasets in these formats (i.e. .csv, ASCII, NetCDF) or request them through personal contact with data managers. This interpretation is consistent with characterizations of the modern information environment, where the original creators of forecast information have limited control over how it is interpreted and used once it enters the public sphere (Morss et al., 2017). It also highlights the nature of the gap between research to operations and the important role of creating value-added products that are informed by end-user needs to bridge the gap.

Currently, there is little incentive to learn about the needs of the end-users beyond basic visualization preferences through formal feedback. These findings are consistent with research in weather forecast and warning systems that show a clear commitment by scientists to technical advances in modeling and less commitment to processes that ensure products are meaningful to users (Bostrom et al., 2015). However, in addition to incorporating feedback from users through formal processes (Bostrom et al., 2015), this research suggests that strengthening relationships
between data providers and end-users through face-to-face interactions over time results in more meaningful data products. The genesis for this type of engagement could be cooperative research, where fishermen collect observations from the ocean environment (described by data providers as costly and difficult to maintain) and provide feedback to help validate and improve the models, thus making it a truly interdependent and interacting system. While direct engagement may seem like a lofty task, it is important to remember that ocean forecast end-users are a much smaller portion of the population than weather forecast end-users and much less is known about how this data is used for decision-making. Investment in understanding the social and cultural contexts of decision-making in the modern information environment (Morss et al., 2017) could have potentially a high return in not only improvement of publicly available data, but for innovation into the private sector of ocean forecasting.

Finally, characterizing and comparing the mental models of data providers and end-users provides potential pathways forward to structure cooperation between the communities based on recognizing differences and building on similarities (Table 2.2). For example, if data providers were to learn about the professional domain and the perceived risks of the commercial fishermen, it could provide insights into relevant time and spatial scales to focus further research or communication. Likewise, if commercial fishermen were to learn about the formalized procedures, professional domain, and perceived risks of the data providers, it could help them structure processes to collect observations in support of the science. Future work can be aimed at validating the mental models of the data providers and end-users and structuring cooperation between groups. Optimizing ocean forecasts, framing the data providers and end-users as an interdependent system, and strengthening relationships between groups has the potential to
enhance the resilience of the overall ocean forecast system, and extends to both industry and the scientific enterprise along the nation’s coasts.

Acknowledgements

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References


CHAPTER THREE: SECOND MANUSCRIPT [Marine Technology Society]

Optimizing Ocean Condition Forecast Information Through Characterizing Mental Models of End-Users: A Case Study of the Oregon Commercial Fishing Community

(Interdisciplinary chapter in partial fulfillment of the National Science Foundation (NSF) National Research Traineeship (NRT) at Oregon State University)

ABSTRACT

This case study is in response to a recognized need to transform short-term regional ocean condition forecast information into useful data products for a range of end-users and for creation of uncertainty metrics for these forecasts. Commercial fishermen from Oregon are selected as key information users due to the physically risky and economically uncertain nature of their profession; their expertise at navigating the marine environment; and their important economic and cultural role at the Oregon coast. Semi-structured interviews that bring awareness to the processes that govern decision-making through risk perception and comfort with uncertainty were used to characterize the “mental model” of this community in regard to ocean use and ocean forecasts. Findings revealed how commercial fishermen consume and interpret forecast data in a non-linear fashion by combining multiple sources and data types, and with a heavy reliance on real-time data. Our assessment is that improving accuracy at temporal and spatial scales that are relevant to decision-making, improving the accessibility of forecasts, and increasing forecast lead time could potentially add more value to forecasts than quantifying and communicating uncertainty metrics to assist with decision-making.
1. Introduction

The Oregon Coast is located in the Pacific Northwest of the United States along the eastern boundary of the Pacific Ocean, where diverse marine resources support productive fisheries. Commercial fishing is culturally and economically important to coastal communities in Oregon, contributing more than $500 million annually in personal income (ODFW, 2017). However, commercial fishermen regularly risk personal safety, property, and economic loss due to the hazards that arise from navigating the marine environment in the Pacific Northwest. Ocean conditions can become hazardous due to dynamic weather patterns and large storms that travel across the Pacific Ocean. This is particularly dangerous in the winter months when fishermen are most likely to be at sea harvesting Dungeness crab, the most valuable fishery in Oregon (ODFW, 2017). The act of entering and leaving port, or “crossing the bar,” is especially hazardous due to the amplification of surface wave height over sandbars where coastal rivers meet the ocean. This complex interaction of the natural and human systems along the Oregon coast creates risks and uncertainties around the safety and economics of the commercial fishing fleet, as well as the motivation for forecasters to predict the conditions of the ocean.

To cope with these risks, commercial fishermen regularly seek out sources of ocean condition information about temperatures, currents, waves, and wind to inform their decisions. In recent years, on a national level, researchers have brought forth integrated coastal observing and modeling systems that have substantially advanced the quality of coastal forecasts with the recognized need to transform them into products that meet the data needs of the ocean use community (Kourafalou et al., 2015). To address these needs in Oregon, a research project was undertaken in the Marine Resource Management (MRM) graduate program at Oregon State University (OSU) to engage with members of the commercial fishing fleet in Newport, OR. The
goal of this project was to make an effort to document and understand how fishermen make strategic decisions about ocean use (Duncan, 2014). Findings revealed that the fishermen used a wide variety of data sources for multiple reasons and lacked a single trusted source of information. This led to a cooperative product development effort that created seacast.org (Seacast, 2018) a web interface that presents ocean forecast data provided by marine scientists at OSU in a simple and intuitive format driven by the needs of the fishermen. Today, Seacast (2018) continues to be used and improved based on feedback from local fishermen.

Forecasting tools and the models that inform them (such as Seacast) are subject to error due to the chaotic character of the atmosphere and the inevitable inadequacies in observations and computer models (AMS Council, 2008; NRC, 2003; NRC, 2006). Uncertainty, while a fundamental characteristic of any forecast, is rarely reported or visualized in ocean condition forecasts. In many cases, this is due to the nature of the ocean forecasting models being used, which differ from those used for weather forecasting. In typical weather forecasting methods, uncertainty is defined as a range of values wherein the “true” value exists. To derive this range of values, weather prediction often uses ensemble forecasting. This methodology produces a set of forecasts from slightly different initial conditions to result in a range of possible outcomes (NOAA, 2018). Ocean condition forecasts utilized by Seacast, on the other hand, use only one model forecast to produce one result for a given time and space, which is referred to as deterministic modeling. The OSU modeling groups involved in providing data for Seacast do not run ensembles due to limitations in their computational resources. In this type of modeling, there is no range of possible outcomes available for statistical analysis, and thus no readily available measure of uncertainty as it is defined in weather forecasting (for example, when predicting the probability of precipitation). However, if uncertainty metrics were made available, the ocean
condition forecasting model output could potentially become more useful to data users during their decision-making process.

Even if the uncertainties in predicted ocean conditions could be quantified, the different language and perceptions surrounding the definition of uncertainty complicate the communication of uncertainty between scientists and fishermen and can lead to confusion and a lack of trust between the two parties. One way to overcome these differences in communication and strengthen relationships is to work toward understanding the underlying perceptions of risk and uncertainty towards the ocean and ocean forecasting for both communities (Duncan, 2014). Web interfaces that deliver ocean condition forecast information, like Seacast, serve as boundary objects that bring together different groups of people and bridge perceptual and practical differences in understanding (Huvila et al., 2014; Karsten, Lyytinen, Hurskainen, & Koskelanien, 2001; Star & Griesemer, 1989). Implementing this understanding can bridge the gap in communication through the creation of uncertainty metrics that serve as boundary objects for both parties. For scientists, this would mean the creation of metrics that are mathematically rigorous; for data users, this would translate into uncertainty metrics that are consistent with their intuition and experience. These uncertainty metrics could therefore be comfortable for both parties. Communicating these metrics could ultimately serve to empower strategic decision-making based on each fisherman’s unique situation and provide more objective and transparent forecasts with respect to the perceptions of each party.

In this report, we build off of the knowledge and relationships created from the Seacast tool to explore the perceptions of uncertainty for both data providers and users. We then use the knowledge of these perceptions to derive metrics that address uncertainty which are acceptable to both parties. These metrics are then visualized using cartographic techniques related to
visualization methods that fishermen are already familiar with. We developed the following research question in order to guide our work on this topic: ‘How can ocean forecasts and their uncertainty be quantified and communicated to commercial fishermen?’ To address this question and achieve these goals, the Ocean Condition Forecast (OCF) Team was formed in September of 2016 as part of the National Science Foundation Research Trainee (NRT) Fellowship in Risk and Uncertainty Quantification and Communication in Marine Science at OSU. It is composed of four graduate students that represent different facets of the ocean condition forecast process. This process includes the generation of forecasted data and associated uncertainty metrics, integration of uncertainty metrics into map-based visualizations, and assimilation of divergent user and data provider perspectives into the entire process. The team members who are the respective counterparts to this process include two ocean modelers, one cartographer, and one social scientist. A transdisciplinary approach was used to generate the uncertainty metrics and communication design and is explained further in the following section.

1.1 Approach

1.1.1 Transdisciplinary Process

A transdisciplinary approach was used to guide OCF team members to inform and expand their disciplinary limitations and definitions of technical concepts, which ultimately resulted in a product that no one student could have achieved on their own. The societally-driven questions of how to create useful ocean condition forecasts and how to account for and represent the uncertainty of forecasts do not reside in a single disciplinary home, as the meaning of uncertainty transcends disciplinary boundaries, professions, and problem domains (Smithson 2008). Transdisciplinary research is well suited to this problem because it goes beyond disciplinary boundaries and brings together researchers with varied expertise to address a
problem they define under a joint conceptual framework (Ciannelli et al., 2014). This approach involved creating a clear framework for communication between the team members and cultivating strong relationships between them. Establishing this groundwork allowed team members to collaborate more effectively (Cheruvelil et al., 2014; Klein, 2013).

1.1.2 Defining Uncertainty

The team’s approach to defining uncertainty involved developing a quantification of ocean condition model uncertainty that was meaningful to both scientists and fishermen, given the constraints of ocean condition forecasting. Uncertainty may be broadly defined as a situation in which a given event may result in more than one expected outcome. People make decisions in an effort to manage this uncertainty (Pielke, 2007). Uncertainty associated with the creation, dissemination, and use of ocean condition forecasts has a strong influence on the decision-making process of fishermen, yet it is rarely expressed or reported as part of forecast products (AMS Council, 2008; NRC, 2003; NRC, 2006). The difficulty in expressing uncertainty in forecasts is due to the nature of uncertainty, which is such that there is no one universal definition. Some ways it can be expressed include: something that is known or known imprecisely, more than one possible outcome in a situation, or simply – doubt (JCGM, 2010; NRC, 2006; Pielke, 2007). Deriving one definition of uncertainty that satisfies data providers as well as data users poses challenges, in that each group defines uncertainty differently. This has resulted in a lack of current standards for representing the uncertainty contained within ocean condition model output.

Ocean condition forecast providers think of uncertainty as a quantifiable number, such as a bias or a measure of variance (Pielke, 2007). They derive this number from the uncertainty associated with deterministic ocean models. These uncertainties may consist of structural
uncertainty, which refers to the underlying physics which govern model behavior, or parametric uncertainty, which refers to numerical model inputs (Charles, 1998). This typically results in a metric of uncertainty that is quantified as a statistical distribution, or a range of values which can encompass the true value. In contrast, fishermen have a more tangible experience with uncertainty. For fishermen, uncertainty in the context of ocean conditions is strongly related to personal and financial risk. From their perspective, uncertainty is related to doubt. Doubt is associated with the accuracy of forecasts and weighing costs and benefits which, in turn, can complicate decision making. For fishermen, forecasts are predictions that they assign relative confidence to based on their intuition, which is derived from their experience with the ocean and using a variety of forecast tools.

1.1.3 Communicating Uncertainty in Ocean Forecasts

The team’s approach to communicating uncertainty related to ocean condition forecasts aims to use map-based visualization techniques that are closely related to those that fishermen are already familiar with. These techniques include contour lines, arrows, wind barbs, and color ramps (for example, a gradient from red to blue). The quantification of model uncertainty metrics must be paired with the communication of those metrics in a way that is clear and readily understood. Challenges arise when techniques for quantifying uncertainty are incompatible with the types of visualizations that fishermen are accustomed to. For example, offshore buoys are effective for validating wave models at a coarse spatial resolution at specific locations, but it could be more useful to fishermen if the model could be validated at a finer resolution over the entire area in which they work, or at a minimum, over the model grid. Ocean condition forecasts already serve as a platform for conveying information and should be used for integrating new uncertainty metrics. While perfecting the form of this communication is outside the scope of this
project, preliminary visualizations of the resulting uncertainty metrics were produced, and these are described in the NRT 2016-2017: Transdisciplinary Report, Ocean Condition Forecasting Team.

1.2 Interdisciplinary chapter

The remainder of this manuscript is written from the perspective of one of the Ocean Condition Forecasting Team members, focusing primarily on the human dimension perspective. This approach combines insights from my individual research (Chapter 1 and 2) and the transdisciplinary research efforts. The overarching question of the transdisciplinary team was: ‘How can ocean forecasts and their uncertainty be quantified and communicated to commercial fishermen?’ My research asks specifically: How can characterizing an end-user’s mental model of risk and uncertainty provide insights into how ocean condition forecasts are consumed and used in decision-making and direct uncertainty quantification methodologies for the data provider?

2. Methods

Mental model interviews were conducted with individual participants following a protocol developed by Morgan et al. (2002) that provides a systematic and repeatable interview procedure to elicit an individual’s mental model about risk. Mental models are a way to represent the manner in which individuals organize their thoughts and beliefs about how something works or how something is, and influence the way that new information is interpreted (Cone & Winters, 2011). There are several procedures to elicit and interpret an individual’s mental model based on research ranging from cognitive psychology to natural resource management. The Morgan et al. (2002) line of inquiry begins with open-ended questions that allow participants to freely express their views about a risk followed by more specific, semi-structured questions that target the
typical risk assessment topics of exposure, effect, and mitigation of risk (Cone & Winters, 2011; Morgan et al., 2002).

Interviews were conducted with 16 members of the commercial fishing community from the central portion of Oregon’s coast; included 11 vessel operators (skippers), and 5 onshore counterparts. Onshore counterparts of commercial fishermen include spouses and representatives of the industry who have personal and economic interest in the success of the commercial fishing fleet. Commercial fishing community members were mostly based out of Newport, the second-largest port for commercial fishing landings located along the central Oregon coast, while two participants were based out of Charleston-Coos Bay, a smaller port in southern Oregon. Participants represented the typical Oregon fisheries (ODFW, 2017) and a range of gear types, vessel sizes, and ages.

Recruitment of members from the commercial fishing community started with key contacts and contributors already engaged in the Seacast project (a.k.a. convenience sampling) while additional contacts were obtained at the suggestion of current participants (a.k.a. snowball sampling) (Auerbach & Silverstein, 2003). Semi-structured interviews (Auerbach & Silverstein, 2003) were conducted either in-person at a location chosen by the participant, or over the phone until saturation was reached. All interviews were recorded, transcribed, and coded using a grounded theory approach and MAXQDA software. Initial open coding developed categories and then expanded to themes that connected back to the research questions in a stepwise process (Auerbach & Silverstein, 2003).
3. Results & Discussion

3.1 Mental models of risk and uncertainty

The inherent uncertainty and risk of commercial fishing is a large part of the appeal of the profession and the lifestyle. Participants expressed the enthusiasm for the challenges and freedom of working on the ocean; however, it was consistently emphasized that their main motivation was to achieve financial gain. The motivation to be profitable creates tension between the monetary risk from running a small business and the physical risk of operating in the ocean environment; risk versus reward. Risk tolerance is determined by each vessel operator and depends on several contextual factors for any given scenario; a finding that is consistent with other research into weather-related decision-making under risk and uncertainty (see Joslyn & LeClerc, 2013; Joslyn & Savelli, 2010; Savelli & Joslyn, 2012). The strategy is to maximize time at sea by fishing right up to the threshold or to “push the envelope,” without endangering the crew or the operation. Sea time is extremely valuable due to the significant overhead costs of running a commercial fishing operation that includes boat payments, boat maintenance, insurance, fuel, and paying a living wage to crew members; and the uncertainties related to fish populations, management decisions, and market forces. Maximizing time at sea also means fishing at certain important times; such as during the winter crab fishery and making optimal decisions about gear.

Physical risk is always present and there is always an attempt to avoided it; however, compounding hazards and the pressure to maximize profit does result in accidents. Accidents are a part of life in commercial fishing and are often attributed to bad weather, equipment failure, human error, or some combination of all three. The nature of decision-making in this high-risk environment often results in stress and frustration for vessel operators that takes a toll on their
psychological health, which in turn, can impact decision-making and the perceived risks surrounding profit and loss.

Participants reported that vessel size is an important factor in a fishermen’s risk orientation and influenced all aspects of decision-making. There is a clear “big boat/small boat” division within the Oregon commercial fishing fleet with the dividing line somewhere around 60 feet. Boats larger than 60 feet in length are generally able to withstand higher wind speeds and wave heights for longer periods of time and can cross the bars outside of harbors under more severe conditions. Smaller boats have lower thresholds and rely more heavily on weather and ocean condition forecasts to move strategically in space and for planning when to “cross the bar”. Beyond this general distinction; vessel shape, material (ex: steel or wood), and age, combine with the experience of the vessel operator to contribute individual risk tolerance. These results suggest that fishermen face intersecting and cumulative risks and that risk tolerance varies by operator and by context and are likely not well served by one-size-fits-all forecasts or verbally described risk categories (Joslyn & LeClerc, 2013). Furthermore, mental model interviews revealed that while there was overall agreement regarding risk perception and comfort with uncertainty among research participants, there was variation in decision making based on age, experience, and whether a fisherman had a family on-shore. Self-described “old-timers” that had been part of the fishing community for over 40 years could articulate the risks and uncertainties more concisely, where younger fishermen tended to describe specific scenarios and details. These results reflect the importance on understanding diverse perspectives within the community and how insights can vary.
3.2 Scale of decision-making in time and space

Commercial fishermen use forecasts for planning and informed decision-making to cope with the complex web of risks and uncertainties they face. The context of a decision scenario includes factors such as: time of year, fishery, gear type, vessel size, amount of catch on board, conditions, and whether the vessel is at sea or crossing the bar, and other socio-economic factors. Planning depends on the accessibility of forecasts before and during fishing trips and is largely driven by maximizing time at sea by avoiding hazards such as storms and high wind speeds and wave heights.

3.2.1 Planning

Research participants described planning for a range of time and spatial scales. Shorter-term decisions are considered within the length of a tidal cycle (looking 6-12 hours ahead) when deciding where to lay gear or when to cross the bar. When crossing the bar to enter or exit port, timing and magnitude of the tide, swell, wave period, and wave direction must all be considered together. Beyond these base factors is the consideration of how the channel has been dredged from year to year or how the current may be interacting with the waves, which can change from hour to hour. The most limiting factor for crossing the bar is the timing of the tide. One fishermen described the uncertainty in their decision-making process about when to cross the bar and how forecasts are used to manage that uncertainty:
“Is it going to be safer to cross the bar right now even though the swell is bigger, but the tide is in my favor? Or do I wait and watch it on the ebb for the smaller swell? Or do I wait until the next tide and see if this front that’s supposed to come in tonight is going to come before the tide changes? You’re looking at a lot of timing, and those are marginal conditions. It’s very marginal if everything has to happen right at the same time for it to be safe. That’s when you’re going to be paying the most attention to your forecasts. That’s when you get as much data as you can to try to predict.”

Research participants described how looking at forecasts 1 day (24 hours) ahead in time was helpful for making a plan of where to fish for the next day. Forecasts 2-4 days (48-96 hours) ahead were also helpful for planning and for practical considerations like knowing how much food to bring on a fishing trip. Different fishermen can come to different conclusions based on their own risk tolerance and the context that they are operating in, as seen in the following two quotes:

"We’re not going to stay in for two days if we can go fishing for a day or two and get some work done."

"No sense of going out today and having a couple hours of getting my butt kicked for no reason when in two days I’ll have 4 days of working weather. Good working weather."

The NWS marine forecasts are first source of weather and ocean conditions that are divided into coastal marine forecast zones for each Weather Forecasting Office (WFO), that is further divided into smaller geographic regions from north to south by points of interest on land, and from land to sea in increments of 0-10nm and 10-60 nm (Figure 1).
Figure 3.1 Marine zone forecast areas for the Portland, OR WFO

Marine point forecasts are also available for a smaller grid cell (1.6 km$^2$) within the larger marine zone forecast. Both marine zone and point forecasts are presented in text format and are generally considered a trusted and reliable source of forecast information, but at a very low resolution. Fishermen supplement this forecast using other sources available on-line.

Four days (96 hours) was cited by research participants as a typical trip length and planning timeframe, that partly reflects the maximum holding time for common fisheries and is within the length of the marine forecast. Though research participants typically have the most confidence in the 24-hour forecast with less confidence after that, four days (96-hours) may be an appropriate lead-time goal for regional ocean forecasters to invest in that could provide significant cost-benefits to the Oregon commercial fishing fleet.

3.2.2 Accessing forecasts

Active, full time commercial fishermen begin the process of planning for future trips by monitoring buoy data and the NWS weather forecasts that extend 5 days in advance using computers or smart phones to get a sense of what’s coming. During this on-shore planning phase they are comparing ocean and weather forecasts from a variety of sources, comparing them to
each other and to real-time information from buoys, and are watching the trends over time in a process that is typical of the modern, nonlinear and multimodal communication environment (Gladwin Hugh, Lazo Jeffrey K., Morrow Betty Hearn, Peacock Walter Gillis, & Willoughby Hugh E., 2007; Liz Neeley, 2014; Morss et al., 2017)

When at sea, research participants described how they make decisions about when to stop fishing or whether to move to different locations in space by accessing information about incoming weather. In the not so distant past, this information was accessed through the NWS VHF (very high frequency) weather radio station that plays on a continuous loop; however, the process has changed in recent years with advances in technology. The current process involves accessing weather and ocean forecast websites through smartphones or computers on board when working close to shore:

“Rather than having to sit and wait to hear it over the VHF, being able to go online and switch from one page to the next and look at everybody’s interpretation of what the ocean is doing is a lot easier. It’s a lot easier to process it that way.”

The VHF radio is still an important tool that the fishermen rely on, particularly when they are out of cellular range. One participant described getting cellular service out to Stonewall Banks, an important local feature and location of a NDBC buoy, located approximately 20 nautical miles from shore; while another participant described getting service 50 nautical miles offshore. When out of cellular and VHF radio range, some fishermen have satellite phones, but several research participants noted that it was prohibitively expensive for many. A common way to overcome this lack in data access is by fishing in groups, where some vessels do have access to data, and maintaining communication over the radio. Research participants described a process of continually checking the weather and adjusting the plan accordingly, as described in the following quote:
“The long-range forecast is always changing. It's more stable in the summer. You look at the daily and then you're looking at the next day because you've already set a plan for the day because yesterday's prediction for today is going to be pretty accurate. You're planning a day ahead if you're more than a day offshore. And then you're looking at the 3 to 5-day, and then you're looking at where you're at and where you going to go.”

3.2.3 Ocean hazards

Planning for and coping with the ocean hazards is an integral part of commercial fishing. Research participants tended to differentiate between hazards at the bar and at sea; and often described the cumulative impact of wind, waves, and current acting together or in opposition at different times and for different durations. Large swell waves alone may not be hazardous until a strong wind creates wind waves on top of the swell waves that have the potential to break at sea, sometimes referred to as “blowing the tops off.” Currents and random sea breaks were most often cited as individual hazards. Opposing forces happen at the bar with an outgoing tide running into incoming swell, or at sea with tidal and ocean currents running into the wind. Opposing forces create turbulence that was described as having a “vertical affect,” the ocean “getting confused” or feeling “like a washing machine.” Opposing forces can also happen on a large scale at certain times of year:

“A lot of times what will create a super hazardous condition is a northwest flow running into a strong front coming in from the south. That can be hideous for the first few hours. They’re just colliding into each other. The ocean gets really chaotic and a lot of times it’s pretty nasty until a storm front really takes control of the ocean and it gets the current and everything going in the same direction.”

Research participants described how weather and ocean hazards varied depending on the time of year. Winter hazards include large swell waves and storms from across the Pacific that contribute to dangerous bar crossings or hazardous nearshore conditions that coincides with downwelling season and the beginning of the nearshore Dungeness crab fishery. Summer hazards are due to a strong, continuous wind and current from the northwest that create
uncomfortable working conditions at sea during upwelling season, especially south of Cape Blanco. Wind was recognized the genesis for most weather and ocean conditions (with tides as an exception), and swell was often related to fetch-length, either from across the Pacific in the winter or from the north during the summer:

“Big, building seas, there’s a lot of fetch to it because it’s built over a long ocean. Understanding that it’s blowing in Northern Washington all the way down the coast of northern Oregon all coming from exactly the same direction. Its accelerating as it goes down the coast as the land lines up. It’s not a good ocean. Brings the current with it, lots of current.”

The nature of how cumulative and opposing forces change over time at sea and when crossing the bar that was described by research participants suggest the value of integrating multiple ocean condition forecast variables into one interface. This finding is consistent with results from the cooperative design of Seacast (Duncan, 2014).

3.2.4 Contextual factors: Dungeness Crab Fishery

The Dungeness crab fishery is an excellent example of how context impacts planning, decision-making, and access to forecasts. Participants described how most commercial fishermen in Oregon make a significant portion of their annual income in the first four weeks of Dungeness crab season when winter storms create hazardous nearshore conditions. If an operator misses time during the opening weeks of crab season, they will not be able to catch up throughout the year. It is a time when the most is at stake, financially and safety-wise. Many stories of close-calls and great loss coincided with the start of the Dungeness crab season in late December and January.

Large swell waves and high winds from winter storms create hazardous conditions at the bar and at sea. Research participants described times when they were stuck at sea due to bar closures and had to head offshore or to the north to avoid storms. Forecasted current speed and
direction are especially useful for knowing how to lay gear into the current rather than against it, to avoid wasting precious time:

"Sometimes you only have a 12-hour window. You want to be as efficient as you can be in that amount of time because there could be another storm behind you."

Commercial fishermen are typically within cellular range during the nearshore Dungeness crab fishery and check the forecasts often:

"I don’t even want to know how many times I look at the weather during the winter time, fishing crabs. It has me going, ‘Well, we can do this, and we can do that if the weather’s going to be like this.’ I watch it pretty often."

This example shows how fishery, socio-economic considerations, time of year and hazards all create the context in which decisions are made and how forecasts are accessed. In the summer, different fisheries moves fishermen offshore out of cellular range and utilizing different gear types and facing different physical hazards, reflecting how contextual factors influence access to information, interpretations of risk, and capacities to take action (Morss et al., 2017).

While context of decision-making is important to consider, Table 3.1 provides a summary of typical uses of ocean forecasts that were described by the Oregon commercial fishing community with an indication of when the forecast is accessed and the decision is made, and a reference to the scale of the decision in terms of space and time.
Table 3.1 Types of decisions informed by ocean condition forecasts that were described by research participants. List is not exhaustive.

<table>
<thead>
<tr>
<th>Planning</th>
<th>Type of decision</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-trip</td>
<td>When to depart (day)</td>
<td>Time</td>
</tr>
<tr>
<td></td>
<td>Duration of trip (hours to days)</td>
<td>Time</td>
</tr>
<tr>
<td>Directly before and during trip</td>
<td>When to cross the bar (hour)</td>
<td>Time</td>
</tr>
<tr>
<td></td>
<td>Where to fish</td>
<td>Space</td>
</tr>
<tr>
<td></td>
<td>How to lay gear – often based on current</td>
<td>Space</td>
</tr>
<tr>
<td></td>
<td>Choosing routes</td>
<td>Space and</td>
</tr>
<tr>
<td></td>
<td>• Whether to avoid or “jog” into storms</td>
<td>Time</td>
</tr>
<tr>
<td></td>
<td>• Angle of vessel relative to wave direction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Fuel savings based on current and wind</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Calculating travel time to bar crossing based on current and wind</td>
<td></td>
</tr>
<tr>
<td></td>
<td>When to stop fishing</td>
<td>Time</td>
</tr>
<tr>
<td>Longer-term</td>
<td>Planning the next trip</td>
<td>Time</td>
</tr>
</tbody>
</table>

The list is not exhaustive and is limited to use of forecasts in time and space. It is essential to understand that other drivers are considered by fishermen beyond ocean conditions. For example, the decision to stop fishing also depends on economic factors and how successful fishermen have been at meeting their catch goals; and the decision of whether to move offshore to avoid a storm or “jog” into a storm also depends on vessel size, risk tolerance of the vessel operator, and how much catch is on board. Specific ocean condition variables are not listed in Table 3.1; unless otherwise noted, because which variables are considered varies by individual over time or all may be considered, as is the case with bar crossings. The goal of Table 3.1 is to inform ocean forecast providers about some of the ways ocean condition forecasts are used by the Oregon commercial fishing community.

3.3 Uncertainty quantification

Commercial fishermen depend on weather and ocean condition forecasts for planning yet perceive the forecasts themselves to be another source of uncertainty in their decision-making process. The NWS marine forecasts of wind and wave conditions was consistently cited by all
participants as the first source that they check and is generally “pretty accurate” and has improved over time; however, there was overall agreement that they are imperfect and will never be perfect. Real-time information from the buoys is valued and trusted more than forecasts.

“The primary forecast is the NOAA websites and the buoys that are out there that give us wave height and update every hour. If we’re sitting here deciding whether to cross the bar, that’s going to be more important than anything the forecast says. It’s what it’s actually doing.”

Fishermen monitor buoys offshore, to the north, and to the south to get a sense of how weather and swell height will change in the coming hours. Real-time information is also used prior to fishing trips as a way for fishermen to assess the level of uncertainty of the forecasts for themselves by comparing forecasts with buoys to see how well they agree.

“So, in the next couple of weeks I’ll be looking at the forecast religiously. I’ll look at the forecast and then I’ll look at the Stonewall bank buoy and see how the swell height, the wind, and the forecast actually matches up with what’s happening out there. Then I can kind of get a picture as to how accurate it is, and then when it comes time to go I feel I have better information to make my decision on.”

Combining forecasts and real-time information to assess the trend in forecast accuracy was widely reported. Physical observances of the environment are another type of real-time information that was commonly valued over models. Deciding when to cross the bar is the one of the most important decisions made by a commercial fisherman in Oregon due to the number of conditions that they have to consider and how the ocean conditions have to align. The following passage from a fisherman describes how information is combined from multiple sources and is evaluated against what they are seeing with their own eyes and with help from the Coast Guard:
“And one variable is the [wave] series. It can be very different than the average swell height sometimes. A lot of times if we’re concerned about that then we’ll, well there’s really no substitute for sitting there watching...And the Coast Guard’s good about helping us with that too.”

Research participants reported having more confidence in forecasts the longer they have used them, and that they combine forecasts from different sources based on the kind of information they are looking for. Participants also reported a process of comparing multiple forecasts of the same variable together to see how well they agree and observed increased or decreased forecast accuracy under certain conditions. These findings are consistent with previous research (Savelli & Joslyn, 2012), suggesting that commercial fishermen are likely able to correctly identify overforecasting bias.

All participants recounted experiences when forecasts did not align with what they were experiencing that included both higher and lower wind speeds, currents moving in the opposite direction, and unforecasted gales or southerlies. Under-prediction of wind speeds and wave heights result in increased hazards to a vessel, where over-predicted wind speeds and wave heights result in missed opportunities to fish and frustration for the operator and crew. Despite frustration with inaccurate forecasts, most participants expressed gratitude for all sources of information and recognized that the nature of prediction is challenging:

“Those guys are doing the best they can but it’s difficult to predict everything in the environment. There’s so many forces at play that it’s hard to understand it all completely. Especially the ocean part. There’s something going on out there that we don’t understand completely. There are things that are really a mystery to all of us, I think. I don’t think we can understand every single thing.”

A common perception within the fleet is that NWS forecasters over-predict hazardous conditions at times as a means of discouraging the decision to go to sea, which adds another layer of uncertainty for the fishermen about the objectivity of the forecasts. Fishermen cope with sudden and unexpected changes in weather in real-time and also by monitoring updates to NWS marine
forecasts while at sea to revise their plans accordingly. These findings agree with a 2012 survey of Pacific Northwest boaters that found respondents anticipate the inherent uncertainty in deterministic forecasts which factors into their decision-making process (Savelli & Joslyn, 2012).

The commercial fishing community’s mental model of risk has demonstrated that they are comfortable with and expect uncertainty in the forecasts. They have their own processes in place to manage the uncertainty of the ocean and weather conditions and forecasts. These processes closely align with accuracy metrics or model skill assessments. Because fishermen analyze the trend of forecast accuracy over time, root-mean-square-error (RMSE) methods over the course of the past week or month could be a useful way to quantify and visually represent uncertainty metrics (Mauch, 2017).

These findings make clear that fishermen use complex processes to make decisions that are influenced by many interconnected factors rather than the solely on scientific and technical information (Morss et al., 2017). There are times when the uncertainty of forecasted conditions becomes irrelevant to decision-making, particularly when fishermen cannot afford to lose time at sea. The evidence presented here make the case that real-time data, in the form of buoys, physical observations, and communication between vessels over the radio will always supplant information from forecasts and any associated uncertainty metrics.

Considering the current challenges with communicating uncertainty in weather forecasts (Sivle, Kolstø, Kirkeby Hansen, & Kristiansen, 2014), it is unclear whether uncertainty quantification and communication of ocean condition forecasts would aid commercial fishermen in their decision-making since they already have their own processes in place to assess model uncertainty. Rather, based on the findings that fishermen gain more confidence in forecasts the
longer they have used them, expanding efforts towards making the forecasts more useful and accessible through direct community engagement is a worthwhile investment. Usefulness of forecasts could be improved through efforts at creating better interfaces that align with decision-making (i.e. integrating multiple ocean variable forecasts and real-time data), investing in mobile apps to enhance accessibility through smartphones, and increasing ocean forecast lead times to 96 hours (4 days) despite the known uncertainties.

Furthermore, this research suggests that continuing to improve model accuracy; particularly at locations and times that are of interest to the fishermen would be valuable to the commercial fishing fleet. Models are often improved through adding sensors to the environment (i.e. buoys or High Frequency (HF) radar) that provide more observations; however, sensors are costly to deploy and maintain. Another way to improve model accuracy at time and spatial scales relevant to the fishermen that is potentially much more cost-effective is to recruit fishermen to collect observations as they traverse the marine environment. This form of cooperative research could expand the role the commercial fishing community from ocean data users to ocean data providers and strengthen relationships between the commercial fishing and data provider communities. Potential benefits to data providers working directly with fishermen could go beyond supporting mission goals and objectives to building long-term economic, social, and human capital, in the region (Table 3.2).

**Table 3.2** List of potential benefits to data providers generated from mental model interviews

<table>
<thead>
<tr>
<th>Potential Benefits to Data Providers in Working Directly with Data Users (fishermen)</th>
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</thead>
<tbody>
<tr>
<td>1. Better understand users</td>
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<td>2. Cost-savings in observations</td>
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<tr>
<td>4. Positive impact to local communities</td>
</tr>
<tr>
<td>5. Learn from local and experiential knowledge</td>
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</table>
In addition to cost-savings in observations, working directly with fishermen could help data providers better understand their needs, thus creating more useful data products with less perceived risk regarding the product and the user. Furthermore, commercial fishermen are adaptive, observant, and technologically savvy. These traits make them valuable partners in marine space and for carrying out any type of marine operations. Partnering with fishermen to alleviate some of the economic and safety risks that they face could also provide direct benefits the onshore industry and families that depend on them. Finally, fishermen have extensive local experiential and ecological knowledge and are constantly discussing weather and ocean conditions. Fishermen regularly observe and try to make sense of patterns in nature, and data providers could potentially learn a great deal from their observations that could drive future research. Future work should be aimed at developing these relationships and processes through pilot studies.

Acknowledgements

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CHAPTER FOUR: CONCLUSION

Additional Results and Discussion

Data Providers

This research originated from an observed gap in the usefulness of the Northwest Association of Networked Ocean Observing Systems (NANOOS) Data Explorer for use by a group of commercial fishermen. Findings from this research regarding risk perception in the data provider community highlighted what I refer to as perceived application risk -- when the decision-maker is outside of the scientific community. There is a lot of ambiguity around application risk. There are a range of potential causes that include inaccurate data, miscommunication, misapplication, or bad decisions by end-users; and the losses can range from safety, economic, and environmental consequences to a less tangible loss of trust or credibility.

It is interesting to observe where different data providers operating under different mission goals with different priorities land on the spectrum of perceived application risk in terms of causes and losses. For example, miscommunication resulting in a loss of trust was a central concern of application risk for data providers within the National Weather Service (NWS) Weather Forecasting Offices (WFOs). The NWS is responsible for weather warnings in addition to forecasts, and the central mission is to protect life, property, and enhancement of the economy. Data providers from within the Integrated Ocean Observing System (IOOS) never mentioned miscommunication as a cause of application risk, but rather focused on inaccurate data, misapplication, and bad decisions by users. Safety, economic, and environmental consequences were commonly cited impacts of application risk by research participants that were modelers and data collectors within IOOS; whereas, research participants that were data managers or in leadership roles were more likely to reference to loss of trust as an impact.
IOOS serves multiple competing mission goals with limited funding and non-federal status. While part of IOOS’s mission is to benefit public safety; integration and research are prioritized over providing data products to diverse stakeholders outside of the scientific community. Furthermore, each IOOS RA is responsible for interpreting how to carry out the seven societal missions that relate to end-users. The tradeoff from the benefits of non-federal status and a focus on integration and research that allows for innovation is that there is a lack of incentive to build relationships with regional end-users if they are outside the scientific community. Particularly missing are end-users that lack resources, political will, and visibility on the IOOS RA Advisory Boards, as our group of commercial fishermen from Oregon do. While the mission of the NWS WFOs provides incentive to build relationships with and understand the needs of regional end-users, the tradeoff is that they lack the flexibility and innovation of the IOOS RA.

Beyond ambiguity regarding mission goals, the academic reward system was cited by modelers from IOOS RAs as a barrier to science communication, as one modeler described:

“And part of the reason we’re not good at this as scientists is because we live in a value system, and an academic system that really does not reward any work that goes toward better communicating our science. Even though we say we do when it comes to the promotion and tenure process, which is how we get rewarded. All that stuff is like “Oh great, but do you have enough papers and enough dollars?” I argue that we need to look at our antiquated reward system that is hundreds of years old, and that we pride ourselves that it’s hundreds of years old, but you know, maybe it doesn’t serve us anymore. But that’s a bigger philosophical question.”

Academia is where the best research in basic science is taking place. Some IOOS modelers had clearly spent time thinking about how their science could be applied to benefit society; however, since there is no incentive or reward system in place - the full potential of innovation in applied settings may not be realized. Innovation does happen when there is political will or funding, as
in the case with Pacific Northwest shellfish growers or Columbia River bar pilots, however the potential to reach other groups with less time, money, and political sway still remains. While great progress has been made in efforts to build capacity in regional ocean observing systems, create best practices, and integrate regional datasets (IFSOO Task Team, 2012), these findings indicate that more of a focus on transitioning research systems to operational systems would better serve societal needs. One way to build capacity in this area is by creating best practices and ways to measure progress in this area.

In light of the differences in mental models between scientific data providers and end-users outlined through this research and the inherent resulting biases, IOOS RAs (and all data providers) could potentially improve data products and strengthen relationships with regional end-users through a dedicated position for end-user engagement. Currently, IOOS RAs have a dedicated position for outreach and education; however, engagement is different in that it is characterized by more of a two-way, coproduced flow of information. This position could be responsible for coordinating and facilitating exchanges between scientists and end-users, while also systematically identifying and documenting regional end-user needs over time. It would require resources and support from the IOOS national office and would be able to function best by holding a level of autonomy at each IOOS RA and support from IOOS leadership.

Translational ecology literature has coined the term “boundary spanner” to refer to institutions, groups, or individuals that straddle the divide between information producers and users, produce boundary products that enable communication between these two groups, and are accountable in some fashion to both groups (Guston, 2001; Parker & Crona, 2012; Safford, Sawyer, Kocher, Hiers, & Cross, 2017; Tushman, 1997).
Further evidence for the need of this type of role comes from a misperception from scientific data providers about commercial fishermen regarding the way that fishermen benefit from ocean condition forecasts. Several data provider research participants associated commercial fishermen with the National Marine Fisheries Service (NMFS), a regulatory agency, rather than the National Weather Service (NWS), who’s forecasts are used daily by commercial fishermen. Framing commercial fishermen as benefiting from NMFS data could be interpreted as a bias of data providers towards regulatory agencies within NOAA based on their mental models that have been influenced by working within scientific institutions. This interpretation is supported from research participants from NWS WFOs that detailed how the politics of NOAA as a regulatory agency can be perceived as a barrier to collaboration and trust [specifically, when discussing a partnership with fishermen to provide observations when at sea]:

“Yeah, we have a problem with that, and it’s not just that they don’t want to give us observations. I’m not talking about that, because it gives away where they are. But being in the weather service we have NOAA connected to us and the fisherman do not like NOAA...Once I stress that to them that I don’t have any connection with those people, usually they’re more open. But it takes that one-on-one. You’ve got guys that have never met us that still think we’re NOAA, and they don’t want to deal with us. It’s been tough trying to bridge that gap.”

Negative perceptions of NOAA as an agency did not come up in any interviews with commercial fishermen; however, it is likely that fishermen do harbor feelings of mistrust. The fact that NOAA was excluded from fishermen interviews might support ocean condition forecasts as opportunity for collaboration between scientists and fishermen that is not political (Duncan, 2014). Finally, a connection was consistently made by data provider research participants with leadership positions at west coast IOOS RAs that commercial fishermen, as constituents, resonated with Congress for keeping IOOS programs funded. If this is true, then
efforts should be made to honor that interdependency by optimizing ocean condition forecasts for their use.

Commercial fishermen

I learned a great deal about the commercial fishing community throughout the interview process. Risk can be a touchy subject when it comes to a hazardous occupation that often has the most annual fatalities in the United States (Lincoln, J & Lucas, D, 2010), but most participants were open about their experiences and many shared stories of great tragedy and loss. Beyond ocean hazards and how they make use of weather and ocean forecasts, I was able to learn about the profession, their family life, and their connection to the broader coastal community. Conversations with fishermen’s wives revealed some of the difficulties of living a life ruled by the weather, how little time they get to spend with the fishermen (often functioning as single-parents), and the stress and exhaustion that they observe on the fishermen between fishing trips. Of the wives that I spoke with, some played an active role in relaying ocean condition information to their husbands when they are offshore, and some knew very little about accessing and interpreting ocean condition information. Most operate under a “don’t ask, don’t tell” policy when it comes to the hazards their husbands face at sea because it only adds more stress. All of the fishermen’s wives were very supportive of this research because; to them, safety is number one. One fishermen’s wife with children and whose husband owns a smaller boat described the privilege afforded to pay-for ocean forecasting sites which brings up the issue of forecasts as a public resource:
“This information shouldn't be a privilege. It just shouldn't. I mean we're all doing the same thing - some people have big boats and some people have little boats.”

During interviews, several fishermen perceived the accuracy of forecasts for the 2016-2017 crab season as more inaccurate than usual:

“This is the craziest winter that people have known in apparently 50 years. Not just the precipitation but the storms. There's no real pattern, they keep spinning off.”

It would be interesting to follow up with data providers to understand if there is any explanation for the perceived inaccuracy.

It is my hope that the themes from the analysis captured risk perception, comfort with uncertainty, and allowed insights into the decision-making processes of the commercial fishing community. Due to the richness of the data, I’ll list the following quotes from research participants that give further insights. It should be noted that these quotes are from individuals and are not meant to be generalizable:

On confidence in forecasts:

“Well, it’s like the best available science. It’s the best available forecast. NOAA Weather puts their best foot forward. They have a model that they follow, and I think it’s pretty close actually, within reason. In the fishing industry you kind of know when something [weather] is coming. And I think they do a very good job of predicting and it can only get better from here.”

On accessibility to forecasts:

“So even though we’ve already established that its imperfect, we miss it when its gone. Because you want as much information as possible to make decisions, at least I do.”
On forecast lead time:

“‘I like as many days as possible. And like I said, it’s stupid because it changes so drastically, so rapidly. But I don’t know, I like it. It makes me feel better for some reason.’”

On the uncertainty of the ocean and forecasts:

“I get the uncertainty because I’ve experienced so much of that. You have to be able to. I experience it as you need to adapt to it. And make decisions that help me be as effective as possible as a marine harvester and as safe as possible as a fragile human being.”

On using their senses in combination with forecasts:

“We’re responsible for our own observations. And even good in this age of abundant information but imperfect forecasting, there’s a place for our own intuitive interpretation for what’s going on around us. So, we’ve got to keep using our senses, regardless of how good modeling is.”

“I’m open to reinterpreting what they’re saying a lot of the time based on the ground observations.”

On commercial fishing as a business connected to nature and the community:

“As an ocean producer, your opportunities to produce are limited. Like any harvest, our seasons depend primarily on how much we can work it. Our good weather years are the most productive and our tough ones are less productive. It affects the community and then that chain reaction goes from there.”

On commercial fishing as an identity:

“And even when I’m not finding the product, there’s a time where it’s just very easy for me to feel like I fit into this planet, you know? When you go into this relatively unknown space and we bring back terrific food to a larger community. It’s an archetypal experience and that’s how I experience it. It’s really valuable. I’m really lucky to be able to work with the natural world and feel a part of it.”

**Recommendations for the Ocean Condition Forecast System**

Results from this research suggest that it is an exciting, yet critical, time in ocean condition forecasting. Framing the ocean forecast system as interdependent data providers and
end-users shifts the focus from the data itself to the networks of people that produce it and use it. This framing, and through the lens of risk perception and comfort with uncertainty, allows us to gain a more complete story of the priorities, challenges, and barriers for both groups. A more complete story has the potential to provide more realistic pathways forward for more creating and communicating more useful forecasts. This research also redefines the concept of “useful” for forecasts that moves beyond visualization to addressing accuracy and uncertainty quantification and a more complete understanding of end-user decision-making. Relating to accuracy of forecasts, findings revealed that fishermen have always, and continue to, expect and experience forecast uncertainty due to the dynamic and variable nature of the ocean and atmosphere. Their lives depend on acknowledging this uncertainty and they have adapted processes to cope (Savelli & Joslyn, 2012). Understanding how best to communicate probabilistic forecast uncertainty in support of decision-making has become a priority within the weather enterprise (Dieckmann, Peters, & Gregory, 2015; Joslyn & LeClerc, 2013; NRC, 2006; Sivle, Kolstø, Kirkeby Hansen, & Kristiansen, 2014; Zabini, 2016). Deterministic ocean models do not produce probabilistic forecasts, but that may be okay for now because it is unclear whether the decision-making of commercial fishermen would be improved. This research suggests that continuing to improve model accuracy; particularly at locations and times that are of interest to the fishermen; and improving accessibility of forecasts through useful interfaces and access offshore would benefit the fishing community the most. It should be noted that models are often improved through the addition of observations to use as inputs. Thus, observations from buoys and High Frequency (HF) radar close to bar crossings could be of great value to the commercial fleet.
Another way to improve model accuracy at time and spatial scales relevant to the fishermen that is potentially much more cost-effective than deploying and maintaining additional sensors is to recruit fishermen to collect observations as they traverse the marine environment. This form of cooperative research could expand the role the commercial fishing community from ocean data users to ocean data providers, thus benefiting the entire ocean forecast system. This new role could expand the current meaning of interdependence through having ocean data flow in both directions, thus strengthening the relationship between the communities (Figure 4.1).

![Figure 4.1](Image)

*Figure 4.1* A fully interdependent ocean forecast system of data providers and users. The star represents where future cooperative efforts could focus through ocean data users (fishermen) providing ocean data back into the system.

**Where do we go from here?**

The goal of this study was to learn about risk perception and comfort with uncertainty for both groups. While the results point to some recommendations, the future of enhancing the usefulness of ocean condition forecasts ultimately lies with the data provider and end-user communities and their willingness to cooperate. Cooperative environmental monitoring has many potential benefits for both groups, as well as the potential to improve resilience of the system through social and adaptive learning between the communities, which can lead to shorter feedback loops between data providers and end-users (Cigliano et al., 2015). Potential benefits from cooperation to both communities are presented in Tables 4.1 and 4.2 based on each community’s mental model of risk and uncertainty.
The potential benefits to data providers in working directly with fishermen could go beyond supporting mission goals and objectives to building long-term economic, social, and human capital, in the region (Table 4.1).

**Table 4.1** List of potential benefits to data providers created from results of mental model interviews

<table>
<thead>
<tr>
<th>Potential Benefits to Data Providers in Working Directly with Data Users (fishermen)</th>
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<td>5. Learn from local and experiential knowledge</td>
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</table>

Working directly with fishermen could help data providers better understand their needs, thus creating more useful data products with less perceived risk regarding the product and user. Working directly with fishermen to collect observations in the marine environment can provide a cost-effective source of data to test model skill and drive future research. Fishermen are adaptive, observant, and technologically savvy. These traits make them valuable partners in marine space and for carrying out any type of marine operations. Furthermore, partnering with fishermen to alleviate some of the monetary and physical risks that they face could also provide direct benefits the onshore industry and families that depend on them. Finally, fishermen have extensive local experiential and ecological knowledge that data providers often lack and are constantly discussing weather and ocean conditions. Fishermen regularly observe and try to make sense of patterns in nature, and data providers could potentially learn a great deal from their observations.

The benefits to fishermen in working directly with data providers go beyond supporting personal financial goals to investing and contributing to resilience of the coastal economy and body knowledge about the ocean (Table 4.2).
Table 4.2 Potential list of benefits to data users (fishermen) created from results of mental model interviews

<table>
<thead>
<tr>
<th>Potential Benefits to Data Users (fishermen) in Working Directly with Data Providers</th>
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<tbody>
<tr>
<td>1. Additional income</td>
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<tr>
<td>2. Diversify skillset</td>
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<tr>
<td>3. Access to more data</td>
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<tr>
<td>4. More useful data products</td>
</tr>
<tr>
<td>5. Contribute to body of knowledge</td>
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</tbody>
</table>

Cooperative research in which fishermen are compensated for their time can provide an additional source of income that is not subject to the uncertainty of fish populations, management decisions, and market forces. Furthermore, taking part in scientific data collection and working with a new or different sensor can help fishermen expand and diversify their skillsets useful for fishing or other types of employment. New or different sensors on board fishing vessels could potentially benefit fishermen while at sea as an additional source of real-time data that could be used in ways that have not yet been conceived. Working directly with data providers can lead to more useful data products because the data providers are able to better understand their needs. Finally, many of the fishermen I spoke with were naturally curious about science and are invested in sustainable fisheries. Working directly with data providers could provide a way for fishermen to contribute more directly to the body of knowledge that is being generated as the presence of scientific operations continues to grow at the Oregon coast.

This research has identified an issue of supply (ocean forecast data) and demand (commercial fisherman, that can likely be extended to other mariners). My hope is that by framing the data provider and commercial fishing community as experts in different kinds of knowledge about the ocean, it can pave the way for future cooperation and collaboration. This research offers no secret formula or set of questions that can make each group better understand each other. Tacit knowledge is the personal skill and intuition that we use but find hard to
describe or formalize (Bammer, Smithson, & The Goolabri Group, 2008; Roux, Rogers, Biggs, Ashton, & Sergeant, 2006). Sharing tacit knowledge between groups through face-to-face interactions over time can bridge cultural barriers and lead to knowledge transfer in both directions (Roux et al., 2006). This depends on a willingness to cooperate from both sides.

Limitations and Recommendations for Future Work

As with any research project, there were limitations to the study design and execution. While I was able to interview participants from a range of fisheries and vessel sizes from the central Oregon commercial fishing community, some were missing – such as Pacific whiting. Furthermore, this study could have gained a fuller picture of the risks and uncertainties from speaking with other members of the commercial fishing community (ex: crew members, fish processors, and fish buyers). This sampling strategy might have allowed a better comparison of the “network” configuration that was observed within the data provider community, with the “data” replaced with the “product.” Future studies aimed at quantifying the economic benefits of ocean forecasts to the commercial fishing fleet might benefit from this approach. This study would have benefited from speaking to equal numbers of participants from the different agencies (IOOS, NWS, CO-OPS) and data provider positions within agencies (ex: data collectors, modelers, forecasters, data managers, leadership roles); however, it was not realistic based on time.

Knowing what I know now, I would have modified the interview questions for both communities. For example, I asked questions to the commercial fishing community about what they knew about how forecasts were created, which now feels unfair and seemed to make a few research participants uncomfortable. For the data provider community, there was a lack of open-ended interview questions at the beginning of the interview, they did not always apply to every
data provider position equally well, and some were repetitive. I might have begun with an open-ended question along the lines of, “Talk to be about the risks/uncertainties that you experience with your profession.” I also used the term “ocean-user,” which is vague and open to interpretation. Instead, I could have used a more specific term, such as “decision-maker” or “mariner.” It should be noted that this research was intended to be exploratory and not exhaustive. The findings of this study should be validated and extended by both communities through future research.
References


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APPENDICES
Appendix A. IRB Verbal Consent Card

Thank you for meeting with me today.

**Purpose:** We are studying the perceptions of risk and comfort with uncertainty faced by ocean users and ocean forecast data providers in the context of ocean condition forecasting. We reached out to you because of your experience in either ocean use or ocean condition forecasting, and we would like to include your perspective in our research.

**Activities:** This interview is focused on understanding how you experience and cope with uncertainty and risk in the work that you do. The length of the interview is up to you; they generally last anywhere from 30-90 minutes.

**Voluntary and Confidential:** Your participation in this interview is voluntary and you may refuse to answer any question for any reason. In order to accurately reflect what you share with me, I will be audio recording this interview. You have the option to decline recording at any point in the interview. If the results of this study are published, your identity will not be made public.

**Risk / Benefit:** There are no possible risks and no direct benefits for participation.

**Sponsor:** This research is funded by Oregon Sea Grant.

**Contact information.** If you have any questions about your rights as an interview subject, you may ask now or email me at kuonenj@oregonstate.edu, or contact Flaxen Conway (as the leader; 541-737-1339; fconway@coas.oregonstate.edu), or contact the OSU IRB office at at (541) 737-8008 or by email at IRB@oregonstate.edu.

With that said, do you provide your consent to be interviewed for this research?
Appendix B. Interview Questions for Commercial Fishing Community

OPENING QUESTIONS

1) Before we begin, talk to me about your background as a fisherman (or: as a member of the commercial fishing community).

In this project, we’re trying to find out what’s on ocean users’ minds relating to uncertainty & risk in the context of ocean condition forecasting. There are no right or wrong answers, we’re just really interested in what you think. So, to get us started…

2) Talk to me about the ocean as an uncertain place.

3) Talk to me about the ocean as a risky place.

I’m going to ask you some more specific questions. Some of them may seem to repeat things that you’ve already said. Please just bear with me, I need to ask all of the questions to make sure I have covered everything. If you feel you have already answered a question and you have nothing more to say on the topic, feel free to refer to the previous answer.

EXPOSURE

4) Tell me what creates hazardous ocean conditions.

5) Tell me what you know about how ocean condition forecasts are created.

EFFECT

6) How do hazardous ocean conditions impact you?

7) How does the availability of information/forecast data impact you?

MITIGATION

8) How do you cope with the risks & uncertainties of ocean conditions before, during, and after your trips?
Appendix C. Interview Questions for Data Provider Community

OPENING QUESTIONS

In this project, we’re trying to find out what’s on data provers’ minds relating to uncertainty & risk they face in the context of ocean condition forecasting. I thought you would be a good person to talk to because ____________. There are no right or wrong answers, we’re just really interested in how you think about it. So, to get us started…

1) Talk to me about your background and experience in creating/disseminating observations/ocean forecast data.

EXPOSURE

2) What are some of the main barriers to producing accurate and complete ocean observations/forecasts?

3) What kinds of uncertainty to you deal with when creating and/or disseminating forecasts.

4) Tell me about the risks you think about in providing that data to ocean users.

EFFECT

5) How do these uncertainties and risks impact what forecast data is made available to ocean users?

6) How do these uncertainties and risks impact your work as a professional or personally?

MITIGATION

7) What makes you have confidence in the observations/forecasts that you help create and disseminate?

Lastly, switching gears…

8) What do you know about the uncertainties and risks that ocean users, like commercial fishermen, face while on the ocean?