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Jeremy L. Childress for the degree of Master of Science in Marine Resource Management presented on September 29, 2010.

Title: Evaluation of Dungeness Crab Pots as Platforms of Opportunity for Ocean-Observing Research

Abstract approved:

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Oregon Fishermen in Ocean Observing Research (OrFIOOR) is a cooperative research program between ocean scientists and fishermen in the Pacific Northwest. Dungeness crab fishermen attach sensor packages (temperature and dissolved oxygen) to crab pots. The pots serve as platforms of opportunity for ocean observing. This study examines three principle questions related to the OrFIOOR program: Are fishermen and scientists involved in ocean observing favorably disposed to the continued use of platforms of opportunity in ocean observing? Is the quality of data produced from instrumentation attached to platforms of opportunity similar to that produced from more traditional ocean observing platforms? Does the use of crab pots to deploy temperature and dissolved oxygen sensors off the Oregon Coast compare favorably to more traditional ocean observing platforms when assessed against important criteria for operational performance such as spatial and temporal coverage and cost? To answer these questions, interviews were conducted with fishermen engaged with the OrFIOOR program (n=9) and ocean observing scientists from the Pacific Northwest (n=11), a correlation analysis was conducted for OrFIOOR oxygen data and 2009 data from the Microbial Initiative in Low Oxygen Areas off Concepcion and Oregon (MILOCO), and a multiple criteria decision analysis (MCDA) framework was constructed to incorporate quantitative and qualitative elements of six ocean observing platforms into a measurement of user satisfaction. Results from this research indicate that the OrFIOOR program has the support of many fishermen and ocean-scientists, can provide data of comparable quality to existing ocean observing platforms, and compares favorably to more traditional methods for alongshore monitoring of temperature and dissolved oxygen variables.
Evaluation of Dungeness Crab Pots as Platforms of Opportunity for Ocean-Observing Research

by

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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.

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Jeremy L. Childress, Author
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1. Introduction

1.1 Ocean Observing

The world’s oceans are dynamic and highly variable systems experiencing wide-scale biological, physical and chemical changes over varying time scales. Information describing the temporal and spatial extent and nature of these changes is essential for informing natural resource decision making and is the “foundation upon which managers base their decisions about the marine environment” (Schiff et al. 2002). However, ocean-observing is an expensive endeavor and although much of the technology necessary for collecting and disseminating this information is already available, a need remains for innovative approaches to ocean monitoring which deliver greater spatial and temporal resolution at a reduced cost.

Since the early 2000s, the United States has been developing and implementing an Integrated Ocean Observing System (IOOS), a “network of observations and data transmission, data management and communications, and data analyses and modeling that systematically and efficiently acquires and disseminates data and information on past, present and future states of the oceans and U.S. coastal waters” (NOISOO 2006). At a national level, this system provides fundamental information required by most regions and links global and coastal ocean observations. This “National Backbone” (NOISOO 2006) also establishes a framework for the development of regional coastal ocean observing systems (RCOOSs), which serve to enhance the temporal and spatial resolution of measurements as well as develop strategic monitoring plans that serve the needs of each respective region.

The Northwest Association of Networked Ocean Observing Systems (NANOOS) serves as the regional ocean observing system of IOOS. Reflecting the high priority needs of citizens in Pacific Northwest, NANOOS specifically emphasizes research and applications which can improve maritime operations, ecosystem impacts, fisheries, and mitigation of coastal hazards (Newton 2007). With growing concern for water quality degradation and the impacts of climate change in this region, NANOOS will provide observations and predictions of ocean conditions and help fund products that serve these needs (Newton 2007).

Off the coasts of Oregon and Washington, research suggests that nearshore waters have experienced increased seasonal hypoxia and anoxia over the past 8 years (Grantham et al. 2004, Chan et al. 2008). The rise and expansion of these low-oxygen waters can significantly affect the structure and functioning of coastal marine ecosystems (Chan et al. 2008, Diaz et al. 2008). As a result, local efforts to describe the nature and extent of these affected areas have been expanded in recent years to now include a combination of ship sampling (Ott et al. 2004, Hooff & Peterson 2006), moorings (Barth et al. 2009), autonomous underwater gliders (Barth et al. 2009), remotely
operated vehicles (Grantham et al. 2004), and profilers (Devol et al. 2007, Rhoades et al. 2008) to measure dissolved oxygen as well as other ocean variables (Table 1).

1.2 Appropriate Sampling (Opportunities and Limitations)

There are, however, obstacles to the expansion and wider use of ocean observing technologies, including funding (Glenn et al 2000) and the “human resources needed for sustaining and improving the observational networks” (Roemmich et al. 2009). Ship time, for instance, is very expensive, but remains a limiting factor for the deployment, servicing, and retrieval of observation platforms (OSB 2009). These factors contribute to a fundamental under-sampling of coastal ocean conditions, both spatially and temporally in the Pacific Northwest (NOAA 2007, Newton 2007, Kite-Powell 2004).

To reverse this trend of under-sampling ocean conditions, a range of actions need to happen. Existing ocean-observing programs must receive sufficient funding to cover operational costs, and/or ocean researchers need to adopt innovative, lower cost technologies and methods that can help address the data gaps that currently exist (Alverson 2008). At the federal level, the National Oceanic and Atmospheric Administration (NOAA) plans to support, under the Integrated Coastal and Ocean Observation System Act of 2009 (Sec. 12302(3)), the development of existing and emerging technologies that address these fundamental gaps and transition proven technologies from research into the United States Integrated Ocean Observing System (NOAA 2007). The Coastal Jobs Creation Act of 2010, recently introduced in the House of Representatives, could also provide support and funding for projects that “develop, test, and deploy innovations and improvements in coastal and ocean observation technologies.”

At the state level, there are also initiatives to enhance coastal monitoring for ecological, social, and economic reasons. The West Coast Governors’ Agreement on Ocean Health (WCGA 2006), for example, promotes monitoring and increased predictive capabilities for hypoxia and harmful algal blooms (Action 1.3). The West Coast Sea Grant programs, in their West Coast Regional Marine Research and Information Needs report (Risien 2009), build on the Governors’ report and demonstrate the need to “understand the causes and dynamics of ocean stressors” through “coordinated investigation of physical processes […], biological processes […], and linkages between different locations” (pg 42). Further, “new research is needed to gain a better understanding of local and latitudinal variation in the dynamics of nearshore and offshore systems” (Risien 2009, pg 34).
1.3 Platforms of Opportunity

One demonstrated way to obtain oceanographic data in a cost-effective manner over a large area is through the use of platforms of opportunity (Roemmich et al. 2009). These platforms can be fixed or mobile, are already widely available, and in the case of mobile platforms, are presently traversing the ocean in some form. Examples include human-made structures (e.g. piers, pilings), ocean-going vessels, and marine wildlife. One important benefit of these platforms of opportunity is that once equipped with oceanographic sensors they can collect large amounts of data in a cost-effective manner and from areas that may otherwise be logistically difficult to sample (Lydersen et al. 2004). Boehlert et al. (2001), for example, were able to add nearly 76,000 temperature-depth profiles in the northeast Pacific using migrations from only nine elephant seals over a 3-year period. Other benefits include reduced boat time and associated costs as well as reduced numbers of at-sea research personnel.

To illustrate the widespread use of this research, many types of platforms of opportunity have been used to aid in the collection of environmental data. For instance, instrumented King Penguins have been used in the southern hemisphere as a cost-effective means of complementing data derived from conventional hydrographic surveys and sensing (Koudil et al. 2000, Charrassin et al. 2004, Sokolov et al. 2006). Other animal species that have been used as platforms of opportunity include Wandering Albatrosses in the Southern Ocean (Weimerskirch et al. 1995), Northern Elephant Seals in central California (Boehlert et al. 2001), Ringed Seals in Norwegian and Russian waters (Lydersen et al. 2004), Antarctic fur seals at Bird Island, South Georgia (McCafferty et al. 1999), and salmon and whales in the Gulf of Maine (Alverson 2008). Ships can also serve as platforms of opportunity, referred to as Vessels of Opportunity or Voluntary Observing Ships (http://www.vos.noaa.gov/), and have been used for measuring sea surface temperature (Emery et al. 1997), performing acoustic surveys (Potter et al. 2001), and for deploying floats and drifters (Roemmich et al. 2009).

It must be noted that although these applications may demonstrate types of lower cost ocean-monitoring, platforms of opportunity act as a compliment and not a replacement for traditional ocean observing platforms and programs. The collection of environmental data is a minor or nonexistent goal of the platforms: researchers can make a best guess about where the vessels or animals will move to, but have little control over the platforms. Marine mammals and seabirds, for example, are typically outfitted with sensors designed to collect data for ecological research describing their foraging behavior or migration patterns (Costa 1993). However, if the data can be geo-referenced and the time and depth of measurements is known, then it can be added to the “oceanographic data stream for parts of the ocean where data is sparse or lacking” (Boehlert et al. 2001, pg 1882). Other challenges when using biological platforms of opportunity include a lack
of acceptance with many scientists within the oceanographic community, the development of small but power efficient sensor packages, attachment of sensors, costs of development and deployment, and public opposition to using marine animals as sensor platforms (ACT 2007). A workshop on Integrated Sensor Systems for Vessels of Opportunity identified a number of major limitations for vessels of opportunity which include costs and difficulty of initial installation, system maintenance, biofouling, calibration frequencies, and quality assurance and quality control of data (ACT 2006).

1.4 Cooperative Science

Recent fisheries literature addresses cooperative fisheries research and describes a continuum from cooperative to fully collaborative interactions between fishermen and researchers (Conway & Pomeroy 2006, Hartley & Robertson 2009). Cooperative research projects generally include scientists chartering fishing vessels, fishermen participating aboard survey vessels, or fishermen conducting experiments in gear design and bycatch reduction (Hilborn et al. 2004). Collaborative projects, on the other hand, incorporate fishermen into all aspects of the research process including formulation of research questions and generating hypothesis (Hilborn et al. 2004, Hartley & Robertson 2009). For the purposes of this research, the type of interaction between fishermen and scientists is regarded as cooperative, though the broader research program of which this thesis forms part is open to exploring more collaborative relationships in the future.

Cooperative science can also provide a cost-effective means for collecting scientific data. Cooperative science engages both members of the public and professional scientists to undertake research projects (Raddick et al 2009). For example, in the United States, fishermen have been engaged in cooperative fisheries research with ocean scientists since the early 1900s. This practice can reduce the costs of research, increase data collection and encourage public engagement. Cooperative science has been described as a “critical component to legitimize bureaucratic decisions, improve and expand the information base for making decisions, and enhance accountability by opening up decision making to public scrutiny” (Herath and Prato 2006, 3). Read and Hartley (2006) summarize the practice of cooperative research in the context of fisheries research as “combining the scientific community’s methods and credibility with the fishing community’s knowledge of the marine ecosystem and marine operations” (xviii).

Other non-specialist researchers have also been used for scientific research projects. In the Pacific Northwest there are a number of ongoing citizen science programs: the Hood Canal Dissolved Oxygen Program: the Citizen’s Monitoring Program (HCDOP 2009); Oregon Beach Monitoring Program (OBMC 2009); and Washington Sea Grant Citizen Science Projects (WSGSP
Citizen scientists have also been trained in select Oregon fishing communities to help complete ethnographic community profiles to supplement NOAA efforts (Package 2009). These programs were each created with the goal of increasing sampling effort in space and time, and demonstrate that non-scientists can be trained to collect data that adheres to the highest scientific standards. Darwall & Dulvy (1995) describe some of the advantages that citizen science can provide to researchers which include:

… (a) the provision of manpower sufficient to conduct extensive surveys; (b) large financial savings through the provision of free labor; (c) an increase in the level of public awareness of ecological problems through active participation in ecological survey work; and (d) the provision of a survey program requiring simple and inexpensive techniques that can be continued in the long term using local expertise and financing (pg 223).

In the past 10 years, researchers have also begun looking to fishermen to assist with monitoring physical parameters of the sea. In the Gulf of Maine, for instance, NOAA researchers have worked with fishermen since 2001 to deploy environmental sensors attached to lobster traps (Manning & Pelletier 2009). In the Gulf of Mexico, fishermen have also been engaged to help collect water quality data to help link fishery effort data to hypoxic areas (MRGM 2004). Historical data collected by fishermen has also proven beneficial to ocean researchers; in Greenland, bottom temperature records associated with shrimp trawl surveys have been critical to explaining the melting of glaciers (Holland et al. 2008).

1.5 Oregon Fishermen in Ocean Observing Research

1.5.1 Background

The OrFIOOR program was created in 2005 in response to a need for greater spatial and temporal coverage to resolve the wide range of processes that occur in Oregon’s coastal ocean. Oregon’s commercial crab fishermen spend many days at sea each year from December through August. Oregon State University researchers saw an opportunity to engage these fishermen as “citizen scientists” to aid in the collection of ocean data. Incorporating ocean observations from sensors attached the fishermen’s crab pots has the potential to substantially increase the data available on a number of environmental variables including temperature, dissolved oxygen, and salinity. What began as a small-scale pilot project in 2005 with one fisherman assisting with data collection has since grown to include measurements collected by 10 fishermen from Port Orford Oregon, to Astoria, Oregon (Figure 1).
1.5.2 Goals and Findings

The OrFIOOR program was created to have two primary objectives: First, to determine whether or not there is the long-term potential to relate spatial and temporal variability in crab catches with observed variations in physical ocean conditions such as water temperature, stratification, salinity and dissolved oxygen using data from sensors attached to crab pots; and second, to determine whether or not sensors deployed on crab pots can provide fine scale oceanographic data that is sufficiently robust to be formally integrated into the regional ocean observing system.

OrFIOOR is focused on two near-shore ocean variables: temperature and dissolved oxygen. Temperature data are collected using ONSET Tidbit sensors (Figure 2) installed on approximately 40 crab pots over a North-South distance of 220 nautical miles and up to 4 nautical miles offshore. The dissolved oxygen (DO) component of the project, added in 2009, utilizes AANDERRAA Oxygen Optodes #3835 (Figure 2) also attached to crab pots and placed within a region of recurring hypoxic conditions measuring 10 nm North-South by 3 nm East-West along the central Oregon coast. The DO sensor housing units were designed and fabricated in consultation with Oregon State University researchers and fishermen.

Unpublished results from 2005-2008 suggest that temperature sensors attached to crab pots can resolve seasonal variability of nearshore coastal ocean conditions in response to atmospheric events such as changes in wind direction (data from 2005-2008). Data collected during 2009 marked OrFIOOR’s first attempts at collecting dissolved oxygen data from crab pots. Chapter 3 presents a comparison of OrFIOOR data with data collected by other ocean observing programs over the same period and general location.

1.5.3 Human Dimensions

A third goal of the OrFIOOR program has emerged in recent years emphasizing the human dimensions of the OrFIOOR program based on the question of how best to engage commercial fishermen in ocean observing research in a way that provides the greatest utility for both ocean researchers and fishing communities.

An overview of the participants involved in this project highlights the differences in geographic location and fishing technique. Fishermen come from almost all of the major port towns in Oregon (Port Orford, Charleston/Coos Bay, Florence/Newport, Depoe Bay, and Warrenton/Astoria), and the OrFIOOR program is looking to expand to include coverage out of Brookings/Gold Beach and Tillamook Bay as well.

The fishing technique of the participants varies as well. Some crab vessel operators work with a crew of one or more other individuals while others manage fishing activities alone.
Further, some operate larger vessels capable of longer voyages to more remote crab grounds while others work closer to port with smaller vessels. In Port Orford, for example, fishermen are limited to using vessels small enough to be lifted from the water onto hard standing using a dock crane, as the community port offers no protected harbor.

Other human dimensions issues or themes that tie into the notion of cooperative research include communication and trust concerns. These will be discussed further in Chapter 2.

1.6 Goals of this research

Cooperative research and ‘platform of opportunity’ programs appear to have considerable potential to complement more traditional ocean observing systems (Manning & Pelletier 2009). This research asks whether or not the use of platforms of opportunity for ocean-monitoring is likely to be technically feasible, supported by scientists and citizen participants, and affordable? An affirmative answer would suggest that platforms of opportunity could be implemented at wider scales and be integrated into regional and national ocean-observing initiatives.

To address this research question three hypotheses are explored using quantitative and qualitative data and research methods (Table 2).

The remainder of this thesis is broken into four distinct chapters:

- Chapter 2 presents the results of a series of interviews conducted with fishermen involved in the OrFIOOR program and with researchers in the field of ocean observing.
- Chapter 3 provides an analysis of the OrFIOOR data to demonstrate its scientific merit and the technical feasibility of adding scientific instruments to crab pots.
- Chapter 4 presents a framework for and the results of a multiple criteria decision analysis. The purpose of the analysis was to quantify the utility (to researchers) of crab pots as scientific research platforms compared to five other ocean-observing programs; these include: autonomous gliders, Ship-based CTDs, autonomous profilers, surface buoys, and bottom landers.
- An overview of the study is presented in Chapter 5, which also includes recommendations for the future of the OrFIOOR program.
<table>
<thead>
<tr>
<th>Ocean-Monitoring Platform</th>
<th>Description</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crab pots</td>
<td>Crab pots have recently been used for deploying temperature and oxygen sensors as part of the OrFIOOR program. Data can be collected from surface waters by sensors attached to the buoy and from bottom waters with sensors attached to the pot.</td>
<td><img src="photo1.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Autonomous gliders</td>
<td>Autonomous underwater vehicles that maintain a few hydrographic lines off the central Oregon coast. Platform operates by “flying” through the water column and collecting profile data through wide swaths of ocean.</td>
<td><img src="Oregonstate.edu" alt="Image" /></td>
</tr>
<tr>
<td>Bottom landers</td>
<td>Researcher designed and deployed platforms that sit on the ocean floor. Sensors can also be attached at various locations along a float line to provide coarse profile data. An example is the SH70 MILOCO site in Oregon’s coastal ocean.</td>
<td>![Image](Photo: Justin Brodersen)</td>
</tr>
<tr>
<td>Ship-based CTD</td>
<td>“Conductivity, Temperature, and Depth” profilers that are deployed from scientific vessels and used all over the world.</td>
<td><img src="Oregonstate.edu" alt="Image" /></td>
</tr>
<tr>
<td>Buoys</td>
<td>Floating scientific platforms that are moored at a precise location in the ocean. Can provide atmospheric and coarse ocean profile data. Example is the NANOOS NH10 mooring.</td>
<td><img src="Ocean.org" alt="Image" /></td>
</tr>
<tr>
<td>Autonomous profilers</td>
<td>Autonomous profilers can be bottom or surface-based and utilize a winch to move an instrument package up and down in the water column for high resolution profile data. Example is the CAPABLE system designed in partnership by Oregon State University researchers and WET Labs.</td>
<td><img src="http://www.oratiny.org/" alt="Image" /></td>
</tr>
</tbody>
</table>
Figure 1. OrFLOOR temperature sensor pair locations at the start of the 2008-2009 Dungeness crab season.
Figure 2. OrFIOOR temperature and dissolved oxygen sensors. Tidbit v2 temperature sensor and Oxygen Optode 3835 used by the OrFIOOR program (not shown to scale). Images courtesy of Onsetcomp and Aanderaa.
Table 2. Null and alternative hypotheses for the present study

<table>
<thead>
<tr>
<th>$H_0$</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_{01}$</td>
<td>Citizen participants and scientists involved in ocean observing are indifferent to the continued use of platforms of opportunity in ocean observing.</td>
</tr>
<tr>
<td>$H_{02}$</td>
<td>The quality of data produced from instrumentation attached to platforms of opportunity compares unfavorably to more traditional ocean observing platforms.</td>
</tr>
<tr>
<td>$H_{03}$</td>
<td>The use of crab pots to deploy temperature and dissolved oxygen sensors off the Oregon Coast performs similarly to more traditional ocean observing platforms when assessed against important criteria for operational performance including spatial and temporal coverage and cost.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$H_1$</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_{11}$</td>
<td>Citizen participants and scientists involved in ocean observing are favorably disposed to the continued use of platforms of opportunity in ocean observing research.</td>
</tr>
<tr>
<td>$H_{12}$</td>
<td>There is no significant difference in the quality of data produced from instrumentation attached to platforms of opportunity compared to more traditional ocean observing platforms.</td>
</tr>
<tr>
<td>$H_{13}$</td>
<td>The use of crab pots to deploy temperature and dissolved oxygen sensors off the Oregon Coast performs differently (more or less favorably) to more traditional ocean observing platforms when assessed against important criteria for operational performance including spatial and temporal coverage and cost.</td>
</tr>
</tbody>
</table>
2. Stakeholder’s Experience & Perceptions

2.1 Introduction

Assessing the human dimensions of a cooperative research project is an important and often overlooked component of evaluating the effectiveness of scientific research programs (Conway & Pomeroy 2006). Because OrFIOOR is centered on the concept of cooperative ocean monitoring and the mutual benefits that researchers and fishermen can derive from such cooperation, demonstrating the success of the program requires an examination of the attitudes of program participants and other affected parties to determine acceptance and buy-in of the program (Read & Hartley 2006) and incentives and disincentives for participation (Johnson 2010). This analysis will help to determine if fishermen and researchers are favorably disposed to the continued use of platforms of opportunity for ocean observing off the Oregon coast.

To evaluate the attitudes of affected parties towards the OrFIOOR program, interviews were conducted with fishermen and researchers as part of a “Stage 1” program assessment, which follows the strategy described by Susan C. Weller (1998, pg 398) for developing: “a set of items relevant to the area of interest and to the people to be interviewed” as part of an Exploration of Specific Beliefs. The goal of these interviews was to not only learn about attitudes towards the program, but also to better understand how the data can be used to help both fishermen and researchers. Information garnered from the interview process was also used to inform the multiple criteria analysis in Chapter 5.

2.2 Methods

2.2.1 Fishermen Selection

Fishermen were chosen based on their involvement in the OrFIOOR program. Of the 11 persons who have participated in the project since its inception in 2005, all agreed to be interviewed. However, only seven interviews were completed due to time constraints and scheduling issues on the fishermen’s behalf, since the start of the crab season coincided with the time over which interviews were being conducted.

2.2.2 Researcher Selection

An initial pool of scientists was generated based on their involvement with ocean-observing in the Pacific-Northwest. This purposeful sampling technique, coupled with the social science techniques of referrals from key informants and snowball sampling (Bernard 1988, Robson 2002, Berg 2001), were used to select respondents from a broad range of institutions including academic departments and government and non-government research organizations in Oregon and
Washington. Of the 17 researchers contacted for participation in this project, interviews were conducted with 11. The other six were unavailable for interview due to scheduling conflicts or failure to return communications.

2.2.3 Data Collection

A qualitative method of data collection was chosen in order to collect the diversity of opinions and experiences rather than to generalize them (consistent with Fernandes et al. 1999). Data collection for this evaluation took place from December 2009 to February 2010 and consisted of questionnaires administered via phone interview by a single researcher (Robson 2002). For the purposes of this study, two separate but similar questionnaires were developed; one for fishermen and one for researchers. Questions for each were created to elicit specific information from each of these groups, but centered on the common themes of: A) Ocean Observing Involvement (with OrFIOOR or other research programs); B) Communication, Data-Gathering and Data-Use; and C) Future of the OrFIOOR project. The questions selected fell into the response categories of yes/no, multiple choice, ranked-multiple choice, and open-ended.

Potential participants were contacted by phone or e-mail and given information about the purpose of the questionnaire and how it fit into the larger program evaluation. After this initial contact, a mutually convenient time was set for a phone interview and participants were sent a packet (appendix A-2) including a cover letter, informed consent form and a copy of their respective questionnaire. Interviews were conducted over the phone (or in person at the interviewee’s request) and took between 0.5 and 0.75 hours to complete. The interviews were not tape-recorded (as per IRB requirements for exempt status) but detailed notes and quotations were taken in writing.

The questionnaires (including notes) were analyzed using descriptive statistics and a simple content analysis to identify common themes in responses.

2.3 Results

2.3.1 Fishermen - Project Involvement

Responses to the questionnaire show that the fishermen learned about the project from OrFIOOR researchers (graduate students), meetings (Scientist and Fisherman Exchange - SAFE), or third parties, such as port liaisons who relayed information from researchers to fishermen. Fishermen also joined the project because they were directly asked to participate (5 of 7) and/or volunteered (4 of 7).
When asked what their reasons were for becoming involved in the research, the most common responses included an interest in enhancing ocean observing data, science in general, and the OrFIOOR research project specifically (Table 3). Less mentioned reasons included increased income and opportunities to learn from or teach others. One respondent also mentioned that a reason for his involvement was to “set an example for my peers.” These results are fairly consistent with the interviewee’s perceptions on the reasons that other fishermen would become involved with one notable exception: six of the respondents thought that other fishermen would be motivated by additional income.

Table 4 shows how the fishermen responded when asked about their obstacles to involvement in the OrFIOOR project. The main obstacle to involvement cited by the fishermen was “time” (3 of 7). Other obstacles include the collection of sensitive information about fishing location and crab catch, and the need for consistent optimism about the project among crew members. Some (3 of 7) responded that there were no obstacles to participation for them. When asked what the main obstacles for other fishermen’s involvement in the project might be, the responses again were similar with one exception: four of seven respondents cited a “lack of trust with researchers and/or science” as an obstacle for participation. Trust does play a large role in cooperative research programs between researchers and members of the commercial fishing industry, especially when proprietary information about fishing grounds and their productivity are at stake.

### 2.3.2 Fishermen - Communication, Data Gathering, and Data Use

Communication with the participants is an important part of engaging non-scientists in cooperative science. This is the most effective way to audit the data-collection process to ensure that data quality remains high and to maintain consistency across individuals. It is also important that participants have an opportunity to communicate their needs, be it informational or equipment-related in nature. One fisherman also suggested that “reassurance [about how data will or will not be used] improves the communication.” Of the fishermen questioned, all said that communication between researchers and participants was “good” (6 of 7) or “okay” (1 of 7) (choices included good, okay, not good, don’t know/not sure, other).

Data use by fishermen and more specifically, trust in how the data will be used by others, is also an important consideration. Although many of the participants would like to see how crab catches relate to temperature and dissolved oxygen observations, they are more concerned about misuse of logbook information that reveals to other fishermen where they crab, when they crab, and how many crab they are landing. To gauge their level of comfort with data sharing, the fishermen participants were asked how comfortable they were having their name associated with various types of data. Their replies can be seen in Table 5.
All seven are comfortable being associated with the project in general, including having their name posted on the project website or in publications, and most (6 of 7) responded that “location”, “temperature”, and “location and temperature together,” would be acceptable; fewer were comfortable being associated with their “catch data” (5 of 7) and “location and catch data together” (4 of 7). It should also be mentioned that, while the majority of participants will allow their personal research-related information to be published, most would prefer that the information be kept “more general” when possible.

2.3.3 Fishermen - The Future of OrFIOOR

Of the seven fishermen respondents, all agreed to continue working on the project regardless of project funding. This signifies that they not only support the continuation of this program, but also are willing to volunteer their time and resources to participate. Further, six of the seven said that they would help to expand the project by encouraging other fishermen to participate. The seventh, though he wouldn’t actively encourage others’ participation, did say that he would “speak positively about the project.”

2.3.4 Researchers - General Ocean Observing Information

Among the researchers questioned for this study, the most frequently cited need for ocean-observations in the future is an increase in spatial and temporal coverage (8 of 11), followed by improvements in technology (5 of 11) and increases in funding (4 out of 11) (Table 6). The need to correlate biological and physical data was also mentioned (2 out of 11), but by fewer individuals than expected. Seven of the researchers interviewed are engaged in research areas that include these interactions.

2.3.5 Researchers - Communication, Data Gathering, and Data Use

Data gathering falls into three primary categories: (1) the equipment used; (2) proving that the collected data is of high quality; and (3) presentation of the data. When asked which factors determine confidence in equipment used for ocean observing (Table 7), the most important factor was the “Brand/Manufacturer” of the equipment (10 of 11) followed by “Third Party Testing” (8 of 11) and “Manufacturer Stated Operating Specifications” (7 of 11). Other factors cited for determining confidence included the condition or age of the equipment, the strategies for biofouling, the scheduled maintenance and calibration of sensors, and the past performance of researchers using the equipment. Because the OrFIOOR program is currently using the Aanderaa oxygen optode, a proven instrument in use by other ocean-observing programs (ACT 2004), the
researchers generally trust the program’s results so long as the sensors are well maintained and calibrated after each deployment.

Proving that the collected environmental data is of high quality is also an important part of the data gathering process and is aided by the presence of complete metadata. Metadata, or information describing the data collection process, for ocean-observing endeavors most generally consists of where and when the data was collected, who performed the data collection, how the data were handled and analyzed, what equipment was used, and information about equipment calibration. There was little consensus between researchers about the standards for ocean-observing metadata, though the need to package metadata with a dataset depends largely on where the data will be used or archived.

The same situation manifests itself with the presentation of data. Of the 11 researchers interviewed, five said that ocean-observing data must adhere to a particular format(s). Formatting also depends on where the data will be used or archived; inter-office exchange of data within an agency or organization is more concerned with consistency than particular formats because the data is often manually reorganized or reformatted to fit one’s needs. However, as data becomes incorporated into larger archived datasets, standardized formatting becomes more important to permit easier integration into searchable databases. Examples include the IOOS Data Integration Framework (DIF), and Network Common Data Form (NetCDF) used for array-oriented scientific data. Further, the Data Quality Act (DQA) requires that Federal agencies “issue guidelines that provide policy and procedural guidance to Federal agencies for ensuring and maximizing the quality, objectivity, utility, and integrity of information (including statistical information) disseminated by the agency” (Sec. 515 (b)(2)(A)). This suggests that as data are integrated at higher levels, formatting requirements will also become more stringent.

Data use is the final important step in defining the success of the OrFLOOR program as it demonstrates acceptance and utility. When asked if they would use data collected by this program, nine out of 11 researchers responded that “yes,” they would use it, though a number of them provided the caveat that the “quality still needs to be proven.” Of those that would use the data, its potential uses include providing greater temporal and spatial resolution of dissolved oxygen sampling and providing more information about physical and biological interactions in the coastal ocean. As one researcher put it, “[the project] is spatially more extensive than anything we could afford to do without the fishermen’s help.” The researchers also mentioned that the people who could most benefit from this data include shellfish researchers, crab scientists/biologists, fisheries stock assessors, Marine Protected Area planners, the Environmental Protection Agency, and physical oceanographers. Those that responded “no” said that the data is still of “scientific interest”, but they wouldn’t need it as part of their current research/jobs.
However, there are still some perceived obstacles for using data collected by OrFIOOR. These include biofouling of sensors, no coverage of depths greater than 50m, the inability to consistently measure in one location, and reticence on behalf of fishermen who may not want to disclose their prized locations. One researcher also mentioned that trust of logbook data collected by fishermen has been an issue in the past.

The majority (9 of 11) said that they would like to see the OrFIOOR program continue in the future, citing, for example, how the methodology could be expanded from nearshore locations into Oregon’s bays and estuaries, or be used to explore oxygen concentrations further offshore on Heceta Bank. This same majority also said that they would support additional funding for the program.

The two researcher respondents who did not answer “yes” to these questions also support the continuation of the project, but with the caveat that the methodology and data collected should first undergo further scientific scrutiny. Along these same lines, more information about the project’s overall costs, including equipment and fishermen compensation, needs to be known before they could agree to support additional funding for the program.

These concerns held by some of the researchers do bring up a valid point: at present, the quality of the final data is directly related to the quality of the work and record-keeping conducted by the participating fishermen. If the quality of the data suffers, then too will the marketability of the data and the ability to secure future funding. Likewise, if the overall program expenditures are perceived to be too high compared to the benefits garnered from the program, then the likelihood of funding support will diminish or disappear.

2.4 Key Findings of Fishermen

Upon reviewing the results of the fishermen interviews, three important points emerge:

1. The fishermen participants want the project to continue and want to continue being involved. Further, all stated that they would be willing to continue collecting data regardless of whether they receive compensation or not.

2. The fishermen participants have the perception that their peers are more interested in money and leery of researchers than themselves. These results are not surprising as the fishermen interviewed for this evaluation are already committed to working with researchers with little or no promise of compensation for their involvement. Further, those fishermen that may be less willing to work with researchers are not involved in the OrFIOOR program and therefore did not have the opportunity to be interviewed.
3. There is a trust concern with the fishermen participants about how data and personal information like crab catch and locations will be used. The knowledge and experience that fishermen have to offer is inherently valuable and researchers working cooperatively with these communities need to be sensitive to the fact that this information, in the wrong hands, could cause them financial damage. Trust will need to be explored more to expand the OrFIOOR program or to create a fully collaborative program.

2.5 Key Findings of Researchers

Interviews with ocean researchers also provided two key points:

1. Researchers also want the program to continue and support additional funding for the project pending continued satisfactory results. Some researchers are also personally interested in using the data that the OrFIOOR program can provide.

2. The researchers also have trust issues, though they are centered on the methodology, data quality, and equipment maintenance.

The interviews conducted as part of this program evaluation raise some important logistical and social concerns for cooperative research programs. First, regarding trust and data sharing, effective observation systems are supported by the “free and open exchange of data and data-products” (Roemmich et al. 2009, page 2). However, there still exists a concern for how data from cooperative fisheries research can be shared and exchanged without comprising a group’s livelihood or trust. In the OrFIOOR program, the catch data collected by fishermen could harbor great economic and conservation value, yet this data is also revealing. If the fishermen’s trust is (or is perceived to be) compromised or violated, that could lead to damaged relationships and financial losses for the fishermen.

Scientists also acknowledge that trust in the technology and methodology is an issue, yet they remain optimistic about the capabilities of the OrFIOOR program and are interested in both using the data and supporting future funding of the program. Given the fishermen’s interest in remaining engaged in the data collection process, it stands to reason that the OrFIOOR program withstands the acceptance portion of this evaluation.
Table 3. Fishermen reasons for involvement in the OrFIOOR project (n=7)

<table>
<thead>
<tr>
<th>Reason given for other Fishermen</th>
<th>Respondents</th>
<th>Reasons given for other Fishermen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest in science in general</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Interest in enhancing ocean observing data</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Interest in the research</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Motivated by additional income opportunities</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Opportunity to teach others what I know</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Opportunity for learning from others</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4. Fishermen obstacles to involvement in the OrFIOOR project (N=7)

<table>
<thead>
<tr>
<th>Reason given for other Fishermen</th>
<th>Respondents</th>
<th>Reasons given for other Fishermen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>None – there are no obstacles</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Money</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Lack of trust with researchers/science</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 5. What types of data are fishermen comfortable having their names associated with? (N=7)

<table>
<thead>
<tr>
<th>Data</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>The OrFIOOR project in general</td>
<td>7</td>
</tr>
<tr>
<td>Location data</td>
<td>6</td>
</tr>
<tr>
<td>Temperature data</td>
<td>6</td>
</tr>
<tr>
<td>Location and temperature together</td>
<td>6</td>
</tr>
<tr>
<td>Catch data</td>
<td>5</td>
</tr>
<tr>
<td>Location and catch data</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 6. What are the primary ocean-observing needs? (N=11)

<table>
<thead>
<tr>
<th>Need</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial coverage</td>
<td>8</td>
</tr>
<tr>
<td>Technology improvement</td>
<td>5</td>
</tr>
<tr>
<td>Funding/money</td>
<td>4</td>
</tr>
<tr>
<td>Physical/Biological Interactions</td>
<td>2</td>
</tr>
<tr>
<td>Public awareness</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 7. What factors determine confidence in equipment used for ocean observing? (N=11)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brand/Manufacturer</td>
<td>10</td>
</tr>
<tr>
<td>3rd party testing</td>
<td>8</td>
</tr>
<tr>
<td>Manufacturer stated operating specs</td>
<td>7</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
</tr>
</tbody>
</table>
3. **Data Quality**

3.1 **Introduction**

When evaluating the success of a new technology or methodology for use in ocean-observing research and long-term monitoring of climate change, the quality of the data (e.g. accuracy and precision) produced is an important concern. Further, demonstrating that an observing program can provide high quality data is an important step to implementation into larger regional and national ocean-observing systems.

For this study, temperature and dissolved oxygen data collected by the OrFIOOR program were analyzed to determine if attaching sensors to crab pots can provide data with no significant differences in quality from other platforms located in Oregon’s nearshore coastal ocean. To make this determination, that no significant difference in quality exists, data from OrFIOOR were compared to data from NH10 (National Data Buoy Center Station 46094), a buoy located on the Newport Hydrographic line. Data were also compared to the *Microbial Initiative in Low Oxygen Areas off Concepcion and Oregon* (MILOCO) project, which includes a bottom lander deployed at a similar depth range and location as the OrFIOOR instrumentation. These comparisons were conducted to find out if:

1. The range of values from OrFIOOR data is consistent with data from other sources;
2. The variability within the data is consistent with other sources;
3. The sensors used in the OrFIOOR program are capable of providing precise and accurate data during equipment deployments.

3.2 **Materials and Methods**

3.2.1 **Instrumentation**

The instrumentation used in the OrFIOOR program included temperature sensors (Tidbit v.2, Onset Comp, Pocasset, MA)\(^1\) and dissolved oxygen sensors (Aanderaa Data Instruments, Bergen, Norway)\(^2\) deployed on commercial crab pots between Newport, Oregon and Florence, Oregon. Crab pots containing only temperature sensors (6 pots; sensors located on both the pot and the surface buoy) were located at different depths and locations (Figure 3) throughout the season and recorded benthic and surface temperatures once every 10 minutes.

Dissolved oxygen sensors (also measuring temperature) were deployed on five crab pots at five locations along the central Oregon coast from May 28 to August 11, 2009 (Table 8, Figure 4). The sensors required the construction of custom pressure cases made of PVC, which housed serial

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\(^1\) See Appendix B-1 for datasheet
\(^2\) See Appendix B-2 for datasheet
dataloggers (SDR-2, Acumen Instruments, Iowa)\(^3\) and battery packs. Like the Tidbit temperature sensors, the sampling interval of each instrument was set to 10 minutes.

The dissolved oxygen instrument packages were designed with the specific goals of (1) making high quality measurements of benthic dissolved oxygen, and (2) having a low overall cost per unit so that an array of instruments can be deployed for concurrent monitoring of dissolved oxygen at higher spatial resolution than occurs at present. Aanderaa oxygen optodes were selected based on research demonstrating minimal drift over extended deployments in coastal nearshore environments (ACT 2004). Further, to reduce costs, the pressure case was constructed of standard plumbing PVC and assembled for deployments at depths up to 300m.\(^4\)

Locations for the dissolved oxygen instruments were chosen to capture cross-shelf and alongshore changes in dissolved oxygen concentrations in a region with consistently recurring hypoxic conditions. These locations were also consistent with the cooperating fisherman’s normal fishing grounds to minimize inconvenience to his fishing operation.

The instruments, measuring 13cm x 13cm x 53cm and shown below in Figure 5, were deployed inside the crab pots using stainless steel worm clamps to secure them firmly to the steel frames. Sampling commenced once the units were powered on using a magnetic reed switch operated by the vessel master or crew and ceased when the units were turned off or the batteries became depleted.

Although mounting the units inside the pots did offer protection to the instruments from damage caused by the fishing process (e.g. banging against the side or deck of the boat), the sensors (and their delicate sensing foils) were still subject to damage by the crabs. Of the five instruments deployed, three suffered mechanical damage to the sensing foils (Blue, Green, and Orange), but were still able to provide over 50 days of continuous measurements. The other two sensors (Red and Yellow) escaped unscathed, providing 76 and 61 days of measurements, respectively. Also, because their foils were still intact these two sensors were able to receive post-deployment calibrations.

### 3.2.2 Calibration

Maintaining a consistent calibration of ocean-observing equipment over time is essential for study of long-term environmental trends due to climate change or anthropogenic effects (Glenn et al 2000). For this study, temperature sensors were calibrated by immersing them in three increasingly warmer water baths (Table 9) while temperature readings were taken with a mercury

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\(^3\) See Appendix B-3 for datasheet

\(^4\) The pressure housings were pressure tested to 600m (approximately 866 psi). Factoring in a 2x safety margin, the housings are rated to a depth of 300m (approximately 433 psi) in seawater. Pressure test was conducted at the Oregon State University Oceanography Complex.
thermometer (0-200°C). The data collected by the sensors was compared to the thermometer data using a three-point linear regression to determine the calibration curve (slope and intercept) for each sensor. Calibration curves were then used to correct the experimental data collected during the previous season.

Oxygen calibration curves were determined for the Aanderaa Optodes using a de-ionized water bath. Samples for dissolved oxygen were analyzed using a Brinkman Dosimat titrator interfaced with a microcomputer. The chemistry is the same as that used in the classical iodometric titration (Grasshoff et al. 1983) except that the progress of the titration is monitored amperometrically using a platinum electrode (Knapp et al. 1990). Sodium Sulfite was then added until no more solute would dissolve in solution. This provided a theoretical anoxic condition that could be used as a zero point for the sensor calibrations – theoretical because the resulting water chemistry was too disturbed to permit further titration. The resultant linear regressions were used to correct the oxygen data based on a time-dependant function to accommodate sensor drift:

Equation 1. Calculation of time-dependant calibration slope
\[ m(t) = \frac{m_1 - m_0}{t_1 - t_0}(t - t_0) + m_0 \]

Equation 2. Calculation of time-dependant calibration y-intercept
\[ b(t) = \frac{b_1 - b_0}{t_1 - t_0}(t - t_0) + b_0 \]

Equation 3. Calculation of calibrated DO value based on time dependant slope and y-intercept
\[ DO^{Cal} = DO^{Raw}[m(t)] + b(t) \]

3.2.3 Data handling

On recovery of the temperature sensors, data were transferred to a computer using HOBOware Pro software (Onset Comp., Pocasset, MA) and converted to CSV (comma separated values) files. Dissolved oxygen data were transferred from the dataloggers as DAT files and converted to XLSX (Excel) spreadsheet files.

The handwritten logbook data (Figure 6) was digitized into a XLSX spreadsheet format that included all of the data relevant to the season’s deployment (sensor serial numbers, deploying fisherman, deployment number, latitude and longitude of deployments and recoveries, times of deployments and recoveries, water depths, and crab counts). These files were then used to clean the temperature and dissolved oxygen data files by identifying only those data corresponding to deployments (when the sensors were submerged).

Due to the response time of the sensors and to accommodate any logbook recording error, an additional 30 minutes were subtracted from the beginning and end of each deployment to
minimize the inclusion of erroneous data caused by the sensor being out of water or ascending or descending in the water column.

3.2.4 Data Analysis

Data collected by the OrFIOOR program was compared to and analyzed against a bottomlander deployed as part of the Microbial Initiative in Low Oxygen Areas off Concepcion and Oregon (MiLOCO). Located at approximately 44°15’0” N and 124°13’50” W at 70m depth, the MiLOCO platform represents the nearest continuous source of benthic temperature and dissolved oxygen data available for comparison. The MiLOCO research platform is comprised of a bottomlander with sensors for measuring temperature, dissolved oxygen, fluorometry, conductivity, pressure, nitrates, and PCO$_2$ at the ocean bottom. As MiLOCO data from 2009 had not yet been published at the time of this analysis, data was provided by MiLOCO researchers upon request.

Due to the differing locations of the OrFIOOR oxygen units and the MiLOCO bottom lander, the mean dissolved oxygen values were expected to vary based on the isobaths where they were sampled. Statistical analyses for this data included linear regression, to determine if there is coherent variability between the two platforms, and Pearson correlation analysis, to determine if variability between datasets was significantly correlated. All data manipulation was carried out using Matlab R2008b (The MathWorks, Inc., Natick, MA, USA) and Microsoft Excel.

Because the temperature data from each sensor pair was collected from a variety of locations and depths over the season, each time-series was dissected into many shorter duration deployments based on logbook data. This made statistical comparison to other data sources (using linear regression, Pearson’s correlation) impractical due to small sample sizes. Tidbit sensors, however, have a proven track record for collecting robust scientific data across multiple aquatic environments (Dunham et al 2005, Dunham et al 2007) and in platform of opportunity research (Manning & Pelletier 2009) so analysis of this data instead focuses on instrument calibrations and visual comparisons to the other available datasets (NH10 and MiLOCO).

3.3 Results

3.3.1 Temperature

Visual inspection of the bottom temperature data from the OrFIOOR and MiLOCO programs (Figure 7) suggest that values are more consistent between programs during spring months before winds become predominantly from the North (denoted as negative velocity), which occurred around Julian days 140 and 150 during the 2009 season. After this point, the shallower sites (closer to shore) occupied by OrFIOOR sensors experienced warmer spikes in temperature (approximate Julian days 160, 170, 190, 220, and 225) corresponding to relaxations or reversals of
upwelling favorable winds. Consistency of values was high between OrFIOOR and MiLOCO during upwelling events, when minimum values from both programs were almost identical (approximate Julian days 180, 200, and 210).

At the surface, temperature data is relatively consistent with NH10 data with a few exceptions (Figure 8). On approximate Julian days 170 and 190, during a period of upwelling favorable winds, surface temperatures offshore at the NH10 location stayed higher for longer following a relaxation event. Seasonal trends in surface data are also consistent with what researchers would expect to find. Prior to summer, winds are predominantly poleward resulting in uniform heating and cooling of the sea surface. As winds change direction in the summer, the nearshore environment experiences phases of upwelling and downwelling, leading to larger fluctuations in sea surface temperature. Further, solar irradiance intensifies at higher latitudes during that time of year, leading to higher surface temperatures and increased water column stratification (Figure 9) during downwelling and relaxation events.

3.3.2 Dissolved Oxygen

Figure 10 shows the range of dissolved oxygen values from the MiLOCO and OrFIOOR programs. Each of these time series shows the response of oxygen concentrations to the prevailing winds, though at different extents and time scales. The OrFIOOR 10m site (yellow) shows the greatest response to upwelling and downwelling favorable winds as well as higher mean temperature during sensor deployment. OrFIOOR 30m sites (blue, green, and orange) show a lower magnitude response to changes in wind stress as well as similar means and ranges of values. The data also show that dissolved oxygen concentrations at the MiLOCO 70m and OrFIOOR 50m (red) sites have the lowest magnitude response to changes in wind stress and their values are tightly coupled to each other (means: 0.9873 and 1.2112, and standard deviations: 0.4026 and 0.4969, respectively)(Figure 11). The dissolved oxygen concentration at the MiLOCO 70m site was consistently lower than the OrFIOOR 50m site (0.22 ml/L on average), but this difference is most likely explained by a combination of the differences in location and depth and dynamic nearshore processes operating on weekly, monthly and seasonal time scales.

3.3.3 Dissolved Oxygen Comparison to MILOCO

To determine if the variability of data from the OrFIOOR dissolved oxygen instruments was consistent with MiLOCO measurements a comparison of values was conducted using linear regression and Pearson’s correlation analysis. Results of the linear regression (Figure 12) show that the OrFIOOR 50m data can predict the DO concentration at MiLOCO 70m ($R^2=0.621$, p=000). Similarly, results of the correlation analysis (Table 10) show that the Red (50m) sensor
was highly correlated with the MiLOCO data from the same time period \((r = 0.7883, p=1.48\text{e}-15)\), meaning that the two variables tend to increase and decrease together. The Green (30m) was also significantly correlated to MiLOCO \((r = 0.3944, p=2.00\text{e}-03)\), but to a lesser degree than the 50m location.

3.3.4 Sensor Calibrations

To determine if the sensors used in the OrFIOOR program are capable of providing precise and accurate data during deployments, the Tidbit and Aanderaa Oxygen Optodes were calibrated to determine how far their measurements deviated from standard temperatures and dissolved oxygen concentrations. Results of 12 Tidbit temperature sensors calibrations showed that slopes ranged from 1.006 to 1.010 and intercepts ranged from -0.594 to -0.456. Of the five dissolved oxygen sensors used, two had enough sensing of their sensing foil remaining to permit calibration. Slopes from these two sensors were 1.037 and 1.092; intercepts were -0.054 and -0.040. Results of both temperature and dissolved oxygen sensor calibrations are shown in Table 11.

3.4 Discussion

The results of this analysis demonstrate that the temperature and dissolved oxygen measurements from sensors attached to crab pots produce results that compare favorably to measurements produced by other, more conventional, ocean observing platforms, specifically the MiLOCO 70m bottom lander located in Oregon’s coastal ocean. Comparisons did not yield perfect synchronicity, however, but that is to be expected as the temperature and dissolved oxygen measurements were recorded at different locations and at different depths.

3.4.1 Physical Factors that Contribute to Differences between Sites:

There are a variety of important processes that contribute to shelf-wide and localized changes in ocean temperatures and dissolved oxygen concentrations off the Oregon coast. Surface and bottom temperatures are influenced by interannual variability of offshore water and surface heating/cooling and seasonal forcing that includes the “air-sea heat flux…, advection of diluted Columbia River discharge…, and coastal runoff from small rivers and streams…” (Huyer et al. 2007, 129). Seasonal alongshore wind stress (predominately upwelling favorable in the summer) and weather band wind variations, with typical scales of 3-10 days and responsible for creating relaxation events, also contribute to changes in ocean temperature from seasonal to several-day time scales (Huyer 1983, Fernandes et al 1993, Hickey & Banas 2003).

Dissolved oxygen concentrations off the Oregon coast are also susceptible to change as a result of physical forcing through cross-shelf transport of source waters low in oxygen and
biological respiration (Grantham et al. 2004). During the summer months when winds are predominantly equatorward, nutrient-rich (but oxygen-poor) waters are pulled onshore where they fuel primary production. As the nutrients become diminished, phytoplankton die and sink to the benthos where they are consumed by bacteria which further reduce dissolved oxygen levels in the coastal ocean. Interannual variability of source-waters, significant annual and alongshore variations in the strength of coastal upwelling, and changes to the biological communities in the system all contribute to the dissolved oxygen concentrations found alongshore and across the shelf (Huyer 1983, Grantham et al. 2004).

Given the scales the variability and rapid pace at which conditions change, it stands to reason that time series recorded at any two sites will experience differences in their water properties (e.g. temperature, dissolved oxygen, etc.). In this case, because the OrFIOOR 50m site and MiLOCO 70m site were separated by a North-South distance of ~9.25 km, an East-West distance of ~5km, and 20m in depth, we wouldn’t expect the data recorded at both sites to be identical. Instead, we would expect to see lags between the datasets during high intensity upwelling and downwelling events, and completely different values when upwelling and downwelling intensities are low (because water masses with different properties may not travel far enough before a reversal in winds and currents occurred).

3.4.2 Other Factors that Influence Data Quality:

There are still biological concerns that can impact the effectiveness of the sensors. First, considering that three of the five instruments in the OrFIOOR array were damaged and therefore unable to accurately sample dissolved oxygen concentrations or undergo post-deployment calibration in the lab, a need remains to further protect the sensors from mechanical damage while simultaneously allowing adequate water flow to permit accurate measurements. Second, though of lesser concern, sensors located for any length of time in the photic zone will have significant algae and barnacle growth by the end of the deployment. While barnacles did not impact the DO monitoring on this deployment (a few individuals did need to be removed from the sensing foils once the instruments were retrieved), their continued growth in any number on the sensing foil could sufficiently restrict water movement and affect readings. To address both of these concerns, plans have been made to construct a new metal guard that would prohibit large crustaceans (Dungeness crabs) from scratching the foil, and to use copper tape in the vicinity of the sensing foil to deter the growth of smaller crustaceans, or biofouling.
3.4.3 Improving Accuracy of Data

In their 2009 paper, Manning and Pelletier recognize a “variety of limitations associated with collaborative research with fishermen,” which include uncertainty in the mooring location and depth of deployments. The OrFIOOR program suffers from similar limitations and, in addition to increasing the level of protection of the sensors to prevent mechanical damage and biofouling, there are other improvements that could be made to further enhance the effectiveness of these technologies. First, GPS data-logging devices could be added to the surface buoys to validate the sensor locations described in the logbooks. Second, additional sensors, such as pressure sensors, could be added to the instrument packages to validate depth recordings. While these improvements would not directly impact the effectiveness of the sensors themselves, the overall increase in data would be an improvement.

Another way to improve data accuracy, and more specifically the location and depth data, would be to work with the fishermen to improve their logbook keeping. Fishermen do have the ability to keep their gear in a relatively fixed location, and improvements could be made to make detailed log keeping easier, but the gear is still at the mercy of natural forces such as wave action that can (and do) move fishing gear around. For this reason, incremental improvements in technology that can accommodate these natural forces will probably be most successful for improving data accuracy.

3.4.4 Improving Timeliness of Data

While it isn’t necessarily a current goal of the OrFIOOR program, improvements could be made that would allow near real-time monitoring of dissolved oxygen concentrations along Oregon’s coastline. Improving the timeliness of the data would help the OrFIOOR researchers to recognize equipment problems and failures sooner so that steps could be made to ensure a high quality data stream for the entire duration of deployments. This is consistent with research (Glenn et al 2000, pg 26) which states that, “there is still a need for real-time data, but primarily for quality control purposes, so that sensor malfunctions can be repaired as quickly as possible to minimize gaps in the data time series.” Improved timeliness achieved through real-time communications can also help with now-casting and forecasting of local water quality and oceanic events of interest.

At present, the OrFIOOR program lacks real-time communications, instead relying on the physical retrieval and manual downloading of data from the devices. This is similar to marine mammal and bird programs that require the recapture of animals to download data (e.g. McCafferty et al. 1999; Boehlert et al. 2001). In recent years, advances with satellite data transmission have permitted use of real-time communications in animal observing programs.
(Lydersen et al. 2004). These technology improvements could conceivably be adapted for use on fishing gear, though similar results could be achieved through increased in-season retrieval and downloading of sensor data by fishermen, at a lower cost.

3.4.5 Implications of Technical Effectiveness and Improvements

The implications of successfully deploying oceanographic sensors on crabpots are significant for ocean observing research. First, success in this regard will help the OrFIOOR program to be recognized by other observing programs and NANOOS as a reliable source of benthic ocean variable measurements. This mode of data collection could also interest fisheries researchers who are interested in collecting physical data in conjunction with crab fishery data. Second, and perhaps just as important, this research provides an avenue for other researchers to engage fishermen in different types of ocean-observing projects, knowing that they will be able to collect data that is both scientifically robust and cost-efficient.
Figure 3. OrFIOOR 2008-2009 bottom temperature locations off the Central Oregon Coast
Table 8. Dissolved oxygen instrument locations in 2009

<table>
<thead>
<tr>
<th>Instrument ID</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Depth</th>
<th>Deployment Dates (Julian)</th>
<th>Usable Dates (Julian)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>44 20.10 N</td>
<td>124 10.05 W</td>
<td>50 m</td>
<td>148 - 224</td>
<td>149 - 224</td>
</tr>
<tr>
<td>Blue</td>
<td>44 20.04 N</td>
<td>124 07.74 W</td>
<td>30 m</td>
<td>148 - 224</td>
<td>149 - 210</td>
</tr>
<tr>
<td>Yellow</td>
<td>44 19.87 N</td>
<td>124 06.80 W</td>
<td>10 m</td>
<td>148 - 224</td>
<td>149 - 209</td>
</tr>
<tr>
<td>Orange</td>
<td>44 25.04 N</td>
<td>124 06.86 W</td>
<td>30 m</td>
<td>148 - 224</td>
<td>149 - 200</td>
</tr>
<tr>
<td>Green</td>
<td>44 30.02 N</td>
<td>124 06.76 W</td>
<td>30 m</td>
<td>148 - 224</td>
<td>149 - 210</td>
</tr>
</tbody>
</table>

Figure 4. Map of OrFOOR dissolved oxygen sensor locations in 2009
Figure 5. Schematic view of dissolved oxygen units used in the OrFIOOR program. Instrument is shown without pressure case.
Table 9. Description of water baths used for post-season Tidbit temperature sensor calibrations

<table>
<thead>
<tr>
<th>Water Bath</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice Bath:</td>
<td>Ice placed in large cooler. Sensors left in bath overnight prior to calibration to acclimate to temperature. Thermometer temperature recorded every 15 minutes using a mercury thermometer.</td>
</tr>
<tr>
<td>Room Temperature:</td>
<td>Tap water placed in bucket overnight with lid removed to achieve ambient room temperature. Thermometer temperature recorded every 15 minutes.</td>
</tr>
<tr>
<td>Warm Water:</td>
<td>Sensors placed into 15 gallon fish tank with an aquarium heater. Thermometer temperature recorded every 15 minutes.</td>
</tr>
</tbody>
</table>
**Figure 6.** Example logbook from 2009 dissolved oxygen instrument deployment
Figure 7. Bottom temperatures from sensors attached to 6 crab pots during 2008-2009 Dungeness crab fishing season. North-South wind stress shown above. Negative values depict winds to the South (upwelling favorable).
**Figure 8.** Surface temperatures from sensors attached to 6 crab pots during 2008-2009 Dungeness crab fishing season. North-South wind stress shown above. Negative values depict winds to the South (upwelling favorable).
Figure 9. Differences between surface and bottom water temperatures at different depths off the central Oregon coast during 2008-2009 Dungeness crab fishing season.
Figure 10. Day averaged dissolved oxygen concentrations from five sensors deployed by the OrFIOOR program during the summer of 2009. NS wind stress shown above. Negative values depict winds to the South (upwelling favorable).
Figure 11. Mean values (+- 0.5 STD) of DO time series data from MiLOCO and OrFIOOR ocean observing programs, summer 2009.
Figure 12. Results of the linear regression analysis between the OrFIOOR 50m and MiLOCO 70m 2009 data sets.

Table 10. 2009 Daily-averaged OrFIOOR bottom dissolved oxygen data comparison to MiLOCO 70m. Significant correlations are depicted in bold.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Pearson’s Correlation (r)</th>
<th>P-value</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red (50m) and MiLOCO</td>
<td>0.7883</td>
<td>1.48E-15</td>
<td>Reject Null (p &lt; 0.01)</td>
</tr>
<tr>
<td>Blue (30m) and MiLOCO</td>
<td>0.2789</td>
<td>3.24E-02</td>
<td>Accept Null (0.01 &lt; p &lt; 0.05)</td>
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<tr>
<td>Green (30m) and MiLOCO</td>
<td>0.3944</td>
<td>2.00E-03</td>
<td>Reject Null (p &lt; 0.01)</td>
</tr>
<tr>
<td>Orange (30m) and MiLOCO</td>
<td>0.0913</td>
<td>5.33E-01</td>
<td>Accept Null (0.01 &lt; p)</td>
</tr>
<tr>
<td>Yellow (10m) and MiLOCO</td>
<td>0.2908</td>
<td>2.68E-02</td>
<td>Accept Null (0.01 &lt; p &lt; 0.05)</td>
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</table>
Calibration Curve for Tidbit Temperature Sensors  
12-Nov-09

<table>
<thead>
<tr>
<th>Pair #</th>
<th>Serial #</th>
<th>Cold (°C)</th>
<th>Medium (°C)</th>
<th>Warm (°C)</th>
<th>Slope (b)</th>
<th>Intercept (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1306910</td>
<td>0.08</td>
<td>22.44</td>
<td>29.41</td>
<td>1.007</td>
<td>-0.565</td>
</tr>
<tr>
<td>21</td>
<td>1306946</td>
<td>0.11</td>
<td>22.45</td>
<td>29.40</td>
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<tr>
<td>34</td>
<td>1306936</td>
<td>0.10</td>
<td>22.39</td>
<td>29.34</td>
<td>1.010</td>
<td>-0.587</td>
</tr>
<tr>
<td>35</td>
<td>1306927</td>
<td>0.05</td>
<td>22.46</td>
<td>29.38</td>
<td>1.007</td>
<td>-0.542</td>
</tr>
<tr>
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<td>22.45</td>
<td>29.36</td>
<td>1.007</td>
<td>-0.542</td>
</tr>
<tr>
<td>55</td>
<td>1306929</td>
<td>0.08</td>
<td>22.50</td>
<td>29.44</td>
<td>1.006</td>
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</tr>
<tr>
<td>74</td>
<td>1306960</td>
<td>0.00</td>
<td>22.41</td>
<td>29.36</td>
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</tr>
<tr>
<td>75</td>
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<td>22.42</td>
<td>29.38</td>
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<td>22.39</td>
<td>29.35</td>
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</tr>
<tr>
<td>81</td>
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<td>22.46</td>
<td>29.41</td>
<td>1.006</td>
<td>-0.560</td>
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<tr>
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<td>22.44</td>
<td>29.40</td>
<td>1.006</td>
<td>-0.538</td>
</tr>
<tr>
<td>95</td>
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<td>-0.03</td>
<td>22.37</td>
<td>29.32</td>
<td>1.006</td>
<td>-0.456</td>
</tr>
</tbody>
</table>

Calibration Curve for Aanderaa DO Sensors  
28-Oct-09

<table>
<thead>
<tr>
<th>Saturation</th>
<th>0</th>
<th>100</th>
<th>Slope (b)</th>
<th>Intercept (c)</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DO True (ml/l)</td>
<td>0</td>
<td>6.061</td>
<td>-</td>
<td>-</td>
<td>y=1.037x -0.040</td>
</tr>
<tr>
<td>Sensors:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DO Red (ml/l)</td>
<td>0.039</td>
<td>5.885</td>
<td>1.037</td>
<td>-0.040</td>
<td>y=1.092x -0.054</td>
</tr>
<tr>
<td>DO Yellow (ml/l)</td>
<td>0.049</td>
<td>5.602</td>
<td>1.092</td>
<td>-0.054</td>
<td></td>
</tr>
</tbody>
</table>

**Table 11.** Post deployment equipment calibration data from 2009. Temperature and dissolved oxygen values are averages of replicate measurements from water baths. “True” values represent controls in the calibration process. In total, calibration data from 12 temperature sensors and 2 dissolved oxygen sensors were used in this analysis.
4. Multiple Criteria Decision Analysis

4.1 Introduction

An important element in determining the overall potential of a technology or program is analyzing how it compares to similar (or competing) activities. The OrFIOOR program may have demonstrated its capability to collect robust ocean data, and it may have support from the research and fishing communities, but does the methodology compare favorably or unfavorably to more traditional ocean observing platforms when assessed against important criteria for operational performance such as spatial and temporal coverage and cost? In an effort to quantify the strengths and limitations of the OrFIOOR program, and thereby answer this question, crab pot platforms of opportunity and traditional ocean observing platforms were assessed using a structured evaluation process known as Multiple Criteria Decision Analysis (MCDA) (Saaty and Kearns 1985), a decision analysis tool that was selected to provide a systematic and transparent means for comparing the different ocean-observing platforms.

Tools that researchers and practitioners have traditionally used for evaluations to inform decision-making include ad-hoc (aka: informal, unstructured, or seat-of-pants (Forman & Selly 2001, pg 2)) methods, cost-effectiveness analysis (CEA), cost-benefit analysis (CBA), and multiple criteria decision analysis (MCDA). For everyday problems, ad-hoc decisions based on intuition can produce acceptable results when they involve few objectives and only one or two decision-makers (Baker et al 2001). However, as problems become more complex, ad-hoc methods are unable to provide the benefits of a robust decision-making process, namely:

- Structure to approach complex problems;
- Rationale for decisions;
- Consistency in the decision making process;
- Objectivity;
- Documented assumptions, criteria, and values used to make decisions; and
- Decisions that are repeatable, reviewable, revisable, and easy to understand.

In practice, CEA and CBA are capable of providing this structure and are commonly used in government and public works projects (DCLG 2009, Robson 2000). However, these methods fall short when dealing with complex decision problems that consist largely of qualitative elements or involve high levels of uncertainty (Keeney and Raiffa 1976, Kiker et al. 2005). Further, CBA is based on the idea that projects should only be undertaken when their benefits outweigh their costs (Bouyssou et al. 2000). While this may be useful and appropriate in some circumstances, many costs and benefits are difficult to quantify in monetary terms, especially for ocean-observing
systems where information needed to develop estimates of their economic benefits remains largely unavailable at this time (Kite-Powell et al. 2004, Kite-Powell 2009, Briscoe et al. 2008).

MCDA methods, on the other hand, are capable of handling complex problems with qualitative elements and high uncertainty by breaking problem-solving into its most simple components: desired outcomes, alternative choices, and criteria for scoring the alternatives. Major advantages of MCDA over other decision support methods are that MCDA recognizes the complexities of decision-making and provides a rational framework for integrating quantifiable information and qualitative data derived from intuition, experience, values, and judgments (Saaty and Kearns 1985). Examples of MCDA use, in its various forms, include spatial fisheries management (Pascoe et al. 2009), aquaculture site selection (Hossain et al. 2007), coral reef management (Fernandes et al. 1999), energy technology assessment (Burton et al. 2007, Noble 2006), and site selection for waste disposal (Merkhofer and Keeney 1987).

The three main families of MCDA methods are those based on the Multi-attribute Utility Theory (MAUT), Analytical Hierarchy Process (AHP) and Outranking methods (Fulop 2004, Kiker et al. 2005). Each method has strengths and limitations and choosing among MCDA methods is a complex task, meaning that decision-makers are often faced with choosing, on a case-by-case basis, the most appropriate decision-aiding tool for a given scenario.

For the present study, MCDA was implemented using a modified MAUT method that includes elements of Bayesian decision theory (Ullman 2004). By itself, MAUT provides a systematic framework for defining alternatives and attributes (criteria), evaluating each alternative on each attribute, weighting the attributes to reflect preference, combining the attribute weights and evaluations to yield an overall satisfaction score for each alternative, performing sensitivity analysis and making a decision (Ullman 2004). MAUT methods require information that is complete, consistent, certain, and quantitative (Watthayu and Peng 2004, Ullman 2004), and can be augmented with Bayesian probability theory to accommodate uncertainty and risk in the decision making process. This allows a “best choice” alternative (or alternatives) to emerge even with incomplete, uncertain, conflicting and/or evolving data (D’Ambrosio 1999, Ullman 2004).

4.2 Implementation

The multiple criteria decision analysis used for this study was carried out in three rounds, referred to hereafter as Scoping, Phase 1, and Phase 2. During the scoping round, information collected from the interviews (Chapter 4) was used to develop the context for the analysis, including which alternative ocean observing platforms to include (see Table 1), the differentiating criteria used to compare the alternatives, and the goals of ocean-observing which were used as

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5 Refer to Kiker et al. 2005 for a comprehensive review of MCDA methods.
problem statements within the analysis. Small focus groups of 2 or 3 people were then held to further refine the criteria following the reverse direction method described by Baker et al. (2001) whereby team members considered the available platform alternatives, identified differences among them, and developed criteria to reflect those differences. As much as possible, the guidance of Keeney and Raiffa (1976) was also followed to ensure the criteria set was complete, covering all important aspects of the problem; operational, lending itself to the understanding of the implications of the alternatives; decomposable, so that the evaluation process can be simplified by breaking it into smaller parts; non-redundant, to avoid double counting; and of minimal number, to keep the problem dimension manageable. The four MCDA goals and 13 criteria developed during the Scoping round for use in Phase 1 are presented in Table 12.

In Phase 1, 13 ocean-observing experts from the College of Oceanic and Atmospheric Sciences and Hatfield Marine Science Center were recruited as participants in the MCDA process. Each member was asked to individually rank the criteria from 1 to 13 based on a criterion’s perceived importance towards each of the four ocean observing goals. Weights were then derived from the ranked values using the Rank Order Centroid method, chosen because of its demonstrated efficaciousness and ease of implementation (Barron et al. 1996, Ullman 2006). Participants were next asked to score the six alternative platforms on each criterion. Qualitative criteria (A through H) were scored using belief maps to capture the level of criterion satisfaction and level of certainty of each team member. The alternative platforms were scored on a scale of ‘Not at All’ to ‘Fully’ meets the criteria statement (y-axis), and certainty was scored on a scale from ‘Not at All’ to ‘Very Sure.’ These scales are examples of Linguistic Variables, which are useful in studies of approximate reasoning (Zadeh 1975). Quantitative scores (I through K) were generated using ‘High’, ‘Most Likely,’ and ‘Low’ values given by researchers to accommodate uncertainty of these values over time. Finally, quantitative monetary values for ‘Fixed Costs’ and ‘Variable Costs’ (L and M) were created using most likely values for the initial purchase price of an instrument (fixed), expected equipment costs per year (fixed), research vessel costs per year (fixed), 20% depreciation (fixed), and personnel costs per year (variable). Once the scores and weights were acquired, the information was compiled using software (Accord), which mathematically generated satisfaction values (from 0.0 to 1.0, with 0.0 being completely dissatisfied and 1.0 representing complete satisfaction) for each individual team-member and graphically depicted the results of all team-members simultaneously.

Results from Phase 1 (Table 13) clearly show that Autonomous Gliders and Ship-based CTD consistently provide the greatest levels of satisfaction (plotted as the collective range of individual

\[ W_k = \frac{1}{K} \sum_{i=k}^{K} \frac{1}{i} \] where i goes from k (the number of the criterion with 1 being the highest weighted and K being the lowest) to K (the total number of criteria) (Ullman 2006).
values rather than as averages) given the original four ocean-observing goals, available alternatives, and criteria. Further, the satisfaction values for crab pots are highly variable and attained the lowest scores among the alternatives for three of the four stated goals. These findings have a number of assessments issues that include: (1) a need to improve the assumptions on which criteria scores for the alternatives are based; (2) too many decision-making criteria, resulting in fewer criteria that actually influence the performance of each criteria; and (3) a need to refine the ocean-observing goals to reflect specific needs (e.g. cross-shelf or alongshore monitoring) instead of general or vague requirements (e.g. cost-effective monitoring).

As the assumptions on which the Phase 1 results were based were ambiguous, for Phase 2 a more strict set of assumptions was adopted. First, costs for all financial criteria reflect the length of the Dungeness crab fishing season, or approximately 280 days of continuous monitoring. While each of the alternative platforms is not necessarily utilized in this manner, assuming that each program is in operation for that duration of time facilitates comparison between platforms. Second, because the OrFLOOR program is currently limited to monitoring only temperature and dissolved oxygen (and the possibility of conductivity), the costs for all platforms were updated to reflect just these parameters, thereby standardizing the sensor packages across all six alternatives to include just a CTD package. Other explicit assumptions include being able to deploy multiple platforms as part of a program (thereby taking advantage of economies of scale) and the cost of a 1.0 full-time equivalent (FTE) being equal to $64,260 per year.7

The criteria were also revised as they did not all assist in the differentiation of the alternative platforms in the analysis. To determine which criteria could be removed, the ranked values given by team-members were analyzed for frequency distribution to determine which criteria were consistently ranked as the least important by the team-members. These criteria were then removed as their final weighted value had little influence in the decision making process: Acceptance by scientists, Acceptance by non-scientists, Opportunity for engaging non-scientists in data collection, and Availability of relevant data in formats useful to the non-scientist. Also removed were criteria rendered obsolete when the assumptions were revised to improve consistency among alternatives (280 research days per year and only monitoring oxygen and temperature). These criteria were: Temporal coverage (days per year) and Number of variables measured. Finally, the Area of Coverage criterion was expanded into the three more specific criteria, North-South Coverage, East-West Coverage, and Water Column Coverage. The final set of revised criteria can be seen in Table 14 alongside the original criteria set.

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7 Assuming a monthly salary of $2500, an overhead rate of 26% and fringe benefits of 70%. Overhead and fringe benefit values taken from Oregon State University’s Office of Sponsored Programs.
Review of the MCDA results also revealed a need to improve the ocean-observing goals used in the analysis. For example, *Collecting data as cost-effectively as possible* essentially requires a single criterion: total cost. Further, this particular goal does little to set the context for the decision; that is, it provides no information about the effectiveness or acceptability required of a particular platform. Because the other three goals also provide limited information about the actual operational capabilities of a desired platform, all of the original goals have been revised to find the platform(s) that provide the greatest satisfaction for the following well-defined scenarios:

1. Making cross-shelf measurements
2. Making alongshore measurements
3. Making low-cost alongshore measurements

Based on the incorporated changes that were necessary to improve the MCDA, a *Phase 2* analysis was carried out in an effort to identify which ocean-observing platforms provide the greatest satisfaction for making cross-shelf and alongshore measurements of temperature, dissolved oxygen, and conductivity. During this final phase, only eight criteria were used so that each would be capable of influencing the decision and differentiating between the alternative platforms. Alternative scores on each criterion were reassessed based on the new assumptions and information derived from the *Phase 1* analysis. Criteria ranking was also reassessed given the three new ocean-observing goals and was reviewed by a smaller subset of the original 11 team-members such that a single set of ranks and scores were created for the group rather than individual scores. Table 15 provides the criteria ranks and weighted values derived from the Rank Order Centroid method that was used in the secondary data analysis.

### 4.3 Results and Discussion

Results from the second round of MCDA demonstrate how ocean-observing platforms can provide different levels of satisfaction based on how they are utilized (Table 16). Again, because the second phase of analysis was conducted using single values based on group consensus rather than individual scores, there is only one group satisfaction score instead of a range of scores. For making cross-shelf measurements, autonomous gliders provide the greatest satisfaction (0.66 out of 1.00), followed by ship-based CTD (0.56), autonomous profilers (0.47), bottom landers (0.41), buoys (0.35), and crab-pots (0.34). In this case, autonomous gliders and ship-based CTD scored highly on each of the three highest ranked criteria (east-west coverage, water column coverage, and historical value), therefore providing the highest level of satisfaction for platforms in this ocean-observing scenario. Because crab pot platforms of opportunity have little East-West or water column coverage, and are generally incapable of providing measurements in the exact same place year after year, they received the lowest satisfaction score towards cross-shelf monitoring.
For alongshore measurements, crab pots and ship-based CTD provide the greatest satisfaction (0.50), followed closely by autonomous profilers (0.47), autonomous gliders (0.44), bottom landers (0.39) and buoys (0.35). The scores for this scenario remain much closer, a result which can be attributed to the relatively higher North-South coverage afforded by the crab pot program as well as the high scores for ease of deployment and total year 1 costs (low costs provide a higher score), though these criteria carry a lower weight and therefore influence the decision less. However, when Total Year 1 Costs is moved to the top as the most important factor for alongshore monitoring, crab pots clearly provide the greatest level of satisfaction (0.55) compared to the other platforms.

In a decision-making context, the MCDA framework provides a list (or range) of satisfaction values, but doesn’t necessarily provide a user with the most cost-efficient or “bang for the buck” alternative. To accomplish this for the present study, the Total Year 1 Costs criterion was removed so that the resulting satisfaction values of each alternative observing platform could be plotted against their respective first year costs (Figure 13). While removing costs from the analysis does impact the scores (in particular, the satisfaction score of crab pots), the graph clearly shows that platforms of opportunity can provide perform similarly to more traditional ocean observing platforms for alongshore monitoring. Further, given the costs of purchasing an autonomous glider or running a ship-based CTD program for 280 days per year, utilizing platforms of opportunity is likely to provide much more utility per scientific dollar, when operating within the constraints of a particular platform of opportunity.

4.4 Limitations of Platforms of Opportunity

As the results of this study suggest, relative to other ocean-observing installations, platforms of opportunity, such as Dungeness crab pots, should be considered as a legitimate monitoring solution and in some cases provide satisfaction equal or greater than other more traditional platforms. However, platforms of opportunity are not without their weaknesses. Likewise, the use of MCDA in this context to compare ocean observing platforms and products presented some challenges of its own.

Platforms of opportunity are a niche ocean-observing product with special constraints. Because Dungeness crab fishermen place their pots largely within the Oregon’s territorial sea boundary (located 3 miles offshore) and move these pots as often as once a week during the fishing season, capturing high resolution time-series data from a specific location is difficult if not unfeasible. Further, fishing gear can be moved or lost by large seas, especially during the winter months. However, with as many as 150,000 pots deployed by fishermen during the season, there remains the potential to capture medium-resolution near-bottom temperature and dissolved oxygen
data along the entire Oregon coast. Although this data may not have a fine resolution historical component, some of the other platforms explored in this analysis have this capability though it comes at a cost. By creating a network that incorporates measurements from multiple observing platforms and technologies, researchers should be able to use platforms of opportunity to supplement these more expensive data sources with measurements from lower cost instruments.

Platforms of opportunity are also limited to carrying relatively few sensors and by extension, able to measure only a couple ocean variables at one time. While other platforms are capable of carrying upwards of five or more sensors, the base price of these platforms is more expensive than a platform of opportunity and only increases as the level of sophistication and autonomy increases. To combat this limitation, networks of crab pots could be instrumented with different types of sensors in an effort to capture more than just temperature and dissolved oxygen data. Further, temperature and dissolved oxygen are relatively cheap variables to measure. For more difficult water quality parameters, such as NO\textsubscript{3} and pCO\textsubscript{2}, which cost up to $30,000 per sensor to monitor, traditional platforms with increased capabilities such as profiling and satellite telemetry are more appropriate as they take fuller advantage of the expensive technology and are less susceptible to damage or loss.

The niche nature of the platforms of opportunity also makes them difficult to compare to traditional ocean observing platforms because they each are generally used for a very different and specific use. For this reason, MCDA can be used as an effective tool for comparison because, with an appropriate framework in place, MCDA gives researchers an opportunity to rapidly create different scenarios where ocean observing products may be used by re-ranking the criteria to reflect individual or group preferences. Some of these scenarios, such as cross-shelf monitoring, may ultimately favor traditional platforms. Others, such as alongshore monitoring within the territorial sea may favor platforms of opportunity.
Table 12. Phase 1 MCDA goals and criteria

<table>
<thead>
<tr>
<th>Goals of Ocean-Observing off the Oregon Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increasing temporal and spatial resolution of measurements.</td>
</tr>
<tr>
<td>2. Characterizing the entire water column from surface to benthos.</td>
</tr>
<tr>
<td>3. Collecting data as cost-effectively as possible.</td>
</tr>
<tr>
<td>4. Facilitating the comparison of physical and biological/fisheries ocean variables.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision-making Criteria</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Area of coverage</td>
<td>Effectiveness</td>
</tr>
<tr>
<td>B. Historical value (repeated measurements in the same place)</td>
<td>Effectiveness</td>
</tr>
<tr>
<td>C. Adaptability in terms of sampling protocol/mission</td>
<td>Effectiveness</td>
</tr>
<tr>
<td>D. Ease of deployment, retrieval, and servicing</td>
<td>Effectiveness</td>
</tr>
<tr>
<td>E. Acceptance by scientists</td>
<td>Acceptability</td>
</tr>
<tr>
<td>F. Acceptance by non-scientists</td>
<td>Acceptability</td>
</tr>
<tr>
<td>G. Availability of relevant data in formats useful to the non-scientist</td>
<td>Acceptability</td>
</tr>
<tr>
<td>H. Opportunity for engaging non-scientists in data collection</td>
<td>Acceptability</td>
</tr>
<tr>
<td>I. Temporal Coverage (days per year)</td>
<td>Effectiveness</td>
</tr>
<tr>
<td>J. Timeliness of data (numbers of days before data is cleaned and available)</td>
<td>Effectiveness</td>
</tr>
<tr>
<td>K. Number of variables measured</td>
<td>Effectiveness</td>
</tr>
<tr>
<td>L. Fixed costs per year (e.g. equipment, boat time)</td>
<td>Financial</td>
</tr>
<tr>
<td>M. Variable costs per year (e.g. personnel costs)</td>
<td>Financial</td>
</tr>
</tbody>
</table>
Table 13. Phase 1 MCDA results

<table>
<thead>
<tr>
<th>Goal 1. Increasing temporal and spatial resolution of measurements.</th>
<th>Satisfaction Range (0.0 - 1.0)</th>
<th></th>
<th></th>
<th>Plot of Satisfaction Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative</td>
<td>Low</td>
<td>High</td>
<td>Risk</td>
<td></td>
</tr>
<tr>
<td>Autonomous Gliders</td>
<td>0.77</td>
<td>0.88</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Autonomous Profilers</td>
<td>0.46</td>
<td>0.67</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Bottom Lansers</td>
<td>0.46</td>
<td>0.59</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Boogs</td>
<td>0.45</td>
<td>0.64</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Crab Pots</td>
<td>0.37</td>
<td>0.64</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Ship CTD</td>
<td>0.89</td>
<td>0.84</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Goal 2. Characterizing the entire water column from surface to benthos.</th>
<th>Satisfaction Range (0.0 - 1.0)</th>
<th></th>
<th></th>
<th>Plot of Satisfaction Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative</td>
<td>Low</td>
<td>High</td>
<td>Risk</td>
<td></td>
</tr>
<tr>
<td>Autonomous Gliders</td>
<td>0.71</td>
<td>0.87</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Autonomous Profilers</td>
<td>0.47</td>
<td>0.72</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Bottom Lansers</td>
<td>0.41</td>
<td>0.65</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Boogs</td>
<td>0.41</td>
<td>0.70</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Crab Pots</td>
<td>0.34</td>
<td>0.64</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Ship CTD</td>
<td>0.72</td>
<td>0.63</td>
<td>0.03</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Goal 3. Collecting data as cost-effectively as possible.</th>
<th>Satisfaction Range (0.0 - 1.0)</th>
<th></th>
<th></th>
<th>Plot of Satisfaction Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative</td>
<td>Low</td>
<td>High</td>
<td>Risk</td>
<td></td>
</tr>
<tr>
<td>Autonomous Gliders</td>
<td>0.68</td>
<td>0.89</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Autonomous Profilers</td>
<td>0.42</td>
<td>0.67</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Bottom Lansers</td>
<td>0.42</td>
<td>0.69</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Boogs</td>
<td>0.4</td>
<td>0.67</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Crab Pots</td>
<td>0.43</td>
<td>0.72</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Ship CTD</td>
<td>0.79</td>
<td>0.88</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Goal 4. Facilitating the comparison of physical and biological/fisheries ocean variables.</th>
<th>Satisfaction Range (0.0 - 1.0)</th>
<th></th>
<th></th>
<th>Plot of Satisfaction Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative</td>
<td>Low</td>
<td>High</td>
<td>Risk</td>
<td></td>
</tr>
<tr>
<td>Autonomous Gliders</td>
<td>0.75</td>
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<td>Autonomous Profilers</td>
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<td>0.72</td>
<td>0.03</td>
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<tr>
<td>Bottom Lansers</td>
<td>0.41</td>
<td>0.70</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Boogs</td>
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<td>0.82</td>
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<td>Crab Pots</td>
<td>0.35</td>
<td>0.66</td>
<td>0.04</td>
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<tr>
<td>Ship CTD</td>
<td>0.57</td>
<td>0.89</td>
<td>0.05</td>
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</table>
### Table 14. List of Phase 1 and Phase 2 criteria sets

<table>
<thead>
<tr>
<th>Phase 1 Criteria Set</th>
<th>Phase 2 Criteria Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Area of coverage</td>
<td>A. Good North-South Coverage</td>
</tr>
<tr>
<td>B. Historical value (repeated measurements in the same place)</td>
<td>B. Good East-West Coverage</td>
</tr>
<tr>
<td>C. Adaptability in terms of sampling protocol/mission</td>
<td>C. Good Water Column Coverage</td>
</tr>
<tr>
<td>D. Ease of deployment, retrieval, and servicing</td>
<td>D. High Historical Value</td>
</tr>
<tr>
<td>E. Acceptance by scientists</td>
<td>E. High Adaptability</td>
</tr>
<tr>
<td>F. Acceptance by non-scientists</td>
<td>F. Ease of Deployment</td>
</tr>
<tr>
<td>G. Availability of relevant data in formats useful to the non-scientist</td>
<td>G. Timeliness of Data</td>
</tr>
<tr>
<td>H. Opportunity for engaging non-scientists in data collection</td>
<td>H. Low Total Cost Year 1</td>
</tr>
<tr>
<td>I. Temporal Coverage (days per year)</td>
<td></td>
</tr>
<tr>
<td>J. Timeliness of data (numbers of days before data is cleaned and available)</td>
<td></td>
</tr>
<tr>
<td>K. Number of variables measured</td>
<td></td>
</tr>
<tr>
<td>L. Fixed costs per year (e.g. equipment, boat time)</td>
<td></td>
</tr>
<tr>
<td>M. Variable costs per year (e.g. personnel costs)</td>
<td></td>
</tr>
</tbody>
</table>
Table 15. Phase 2 MCDA criteria ranks and weights

<table>
<thead>
<tr>
<th>Rank</th>
<th>Weight (%)</th>
<th>MCDA Ocean-Observing Goals</th>
<th></th>
<th>Goal 2 - Alongshore</th>
<th>Goal 3 - Low Cost Alongshore</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Goal 1 - Cross Shelf</td>
<td>Goal 2</td>
<td>Goal 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>East-West Coverage</td>
<td>North-South Coverage</td>
<td>Total Cost Year 1</td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>34.0</td>
<td>Water Column</td>
<td>Historical Value</td>
<td>North-South Coverage</td>
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<td>2nd</td>
<td>21.5</td>
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<td>Historical Value</td>
<td>North-South Coverage</td>
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<tr>
<td>3rd</td>
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<td>Historical Value</td>
<td>Water Column</td>
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<td>11.1</td>
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<tr>
<td>5th</td>
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<td>6th</td>
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<tr>
<td>7th</td>
<td>3.3</td>
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<tr>
<td>8th</td>
<td>1.6</td>
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<td>Historical Value</td>
<td>Historical Value</td>
<td></td>
</tr>
</tbody>
</table>

East-West Coverage
North-South Coverage
Total Cost Year 1
Table 16. Phase 2 MCDA results

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Satisfaction (0.0 - 1.0)</th>
<th>Plot of Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomous Gliders</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>Autonomous Profilers</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Bottom Landers</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>Buoys</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>Crab Pots</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td>Ship CTD</td>
<td>0.56</td>
<td></td>
</tr>
</tbody>
</table>

Goal 1. Selecting an observing platform for making cross-shelf measurements

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Satisfaction (0.0 - 1.0)</th>
<th>Plot of Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomous Gliders</td>
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</tr>
<tr>
<td>Autonomous Profilers</td>
<td>0.47</td>
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</tr>
<tr>
<td>Bottom Landers</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>Buoys</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>Crab Pots</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Ship CTD</td>
<td>0.50</td>
<td></td>
</tr>
</tbody>
</table>

Goal 2. Selecting an observing platform for making alongshore measurements

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Satisfaction (0.0 - 1.0)</th>
<th>Plot of Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomous Gliders</td>
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<td></td>
</tr>
<tr>
<td>Autonomous Profilers</td>
<td>0.39</td>
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</tr>
<tr>
<td>Bottom Landers</td>
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<td></td>
</tr>
<tr>
<td>Buoys</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>Crab Pots</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Ship CTD</td>
<td>0.38</td>
<td></td>
</tr>
</tbody>
</table>

Goal 3. Selecting an observing program for making low-cost alongshore measurements
Figure 13. Comparison of ocean observing platforms and/or programs (networks of platforms) in Oregon on the basis of start-up and first year costs and the satisfaction they provide towards effective along-shore monitoring. Satisfaction values were derived from a multiple criteria decision analysis.
5. Conclusions

The purpose of this research was to explore the potential for incorporating crab pots as research platforms of opportunity to improve coastal monitoring in Oregon’s nearshore ocean. To accomplish this, interviews were conducted with stakeholders and OrFIOOR program participants to determine if stakeholders were favorably disposed to the research, data from OrFIOOR were examined against more traditional ocean observing platforms to assess data quality, and a multiple criteria decision analysis tool was employed to determine if, operationally, crab pots perform favorably compared to other ocean observing platforms for deploying temperature and dissolved oxygen sensors. The results of this study demonstrate that crab pot platforms of opportunity can provide data of similar quality to other programs such as MILOCO, and do so most cost-efficiently when used for alongshore monitoring within the territorial sea. The interview results also show that the OrFIOOR program is supported by members of both the fishing and scientific communities, further contributing to its potential for use supplementing other ocean observation efforts.

The acceptability of the OrFIOOR program by stakeholders was demonstrated in that the program is fully supported among those who were interviewed, leading to the acceptance of alternative hypothesis $H1$. In speaking with fishermen involved in the project, it is apparent that all of them see merit in this type of cooperative science and would like to continue working on the project, whether or not they receive financial compensation for their contributions. Similarly, researchers interviewed from Oregon State University, Hatfield Marine Science Center, University of Washington, and multiple government agencies in Oregon and Washington agreed that they would like to see this program receive more funding and continue into the future once the methodology and data have been thoroughly proven successful and accurate.

The data quality of the OrFIOOR program is demonstrated in three principal ways. First, the data show that fine-scale variation in oxygen concentrations can be seen and recorded by instruments attached to crab pots, and can be correlated to atmospheric conditions such as changes in wind direction. Second, the data are consistent with those acquired by other programs such as MILOCO and, while the comparison isn’t perfect, disparities can be explained by differences in depth, longitude, and latitude. Finally, sensor calibrations conducted at the end of the deployment showed that minimal corrections to the data were required, demonstrating that, technically, the sensors operated exactly as they were intended to. For these three reasons, alternative hypothesis $H2$, stating that there is no significant difference between data quality of the OrFIOOR program and that of other programs, is also accepted.
The last component to the evaluation was the development and execution of a multiple criteria framework for measuring the satisfaction of disparate ocean observing platforms against operational criteria. The framework and results demonstrate that comparing and selecting technologies for ocean-observing represent a complex problem that decision-making tools can help to solve. The research clearly demonstrates that different ocean-observing technologies will provide varying levels of satisfaction and utility based on the goals and needs of individual researchers. Crab pots as sensor platforms are able to provide some satisfaction for cross-shelf monitoring but provide the greatest benefit when used for the purposes of along-shore ocean observing. Based on these results, alternative hypothesis $H_3$ (that crab pots compare similarly to other platforms for measuring temperature and dissolved oxygen when assessed against operational criteria) is accepted with the caveats that they only compare favorably under certain circumstances and that the framework for comparison, while showing progress, is still under development.

5.1 Management Perspective

From a management perspective, platforms of opportunity can provide additional benefits as well. First, they can lower the cost of entry in ocean observing. For organizations that cannot afford the high costs of traditional observing technologies (gliders, moorings, landers, profilers, ship-based CTD), platforms of opportunity provide a means to collect robust nearshore data. Further, programs such as OrFIOOR benefit from economies of scale; that is, the cost of adding one more inexpensive instrument has little impact on a budget’s bottom line.

The lower costs of operating platforms of opportunity can also help ease the transition to fully operational status. Glenn et al. (2000) describe the difficulty for programs and technologies to move from the demonstration phase to fully operational because neither a parent agency nor long-term funding has been identified. Programs like OrFIOOR, however, have the potential to transcend this limitation because the costs of running the program are low, and the data have direct value to a large, interdisciplinary community comprised of fishermen, researchers, and managers.

Second, the OrFIOOR program has successfully involved important stakeholders (fishermen) in the collection of scientific data. This not only increases the credibility of ocean science in the eyes of fishermen, it also provides an avenue for sharing information between these two groups. Further, cooperative research allows researchers to tap into the local knowledge that fishermen have spent much of their lives collecting, which can result in improved equipment design for information about where to site instrumentation.

Next, collecting data from platforms of opportunity can facilitate the comparison of physical environmental data to other types of data such as biology, ecology, or behavior of important
marine organisms. Using Dungeness crab pots as research platforms has had the added benefit of allowing researchers to collect pot counts for legal and non-legal male and female crab. Although this growing data set is still relatively small, the potential remains to significantly improve researchers understanding of crab ecology and response to changes in the physical environment on the west coast.

A final consideration is that of the national and regional initiatives for ocean observing, which support the development and implementation of innovative and cost-effective ocean monitoring strategies. Further, the West Coast Governors’ Agreement on Ocean Health (WCGA 2006) and West Coast Regional Marine Research and Information Needs (Risien 2009) emphasize increased monitoring of hypoxia and other dynamic ocean stressors. Supplementing traditional ocean observing in these areas with measurements from platforms of opportunity is a step in the right direction for addressing these needs using innovative methodologies.

In summary, crab pots as platforms of opportunity for ocean-observing research:

1. Have the support of key stakeholders
2. Have demonstrated their ability to collect data that is accurate and consistent with other programs
3. Can provide a level of satisfaction equal to or greater than other platforms for alongshore monitoring of a few key ocean variables
4. Provide a low cost of entry in ocean observing
5. Involve and encourage stakeholders and citizens in the collection of scientific data
6. Facilitate the comparison of physical environmental data to ecological and fisheries data
7. Fit well with the national and regional initiatives for innovative and cost-effective ocean monitoring

OrFIOOR represents a low-cost, effective, and innovative way to collect information in Oregon’s nearshore coastal ocean that is congruent with the stated needs of national and regional ocean-observing administrations and helps advance the state of cooperative ocean science by providing an avenue in which researchers and commercial crab fishermen can work together. For these reasons, the use of platforms of opportunity should be considered as a necessary component to ocean observing and therefore become formally integrated into future networks of regional and national observing systems.
5.2 Recommendations for the Future

Recommendations for the future of crab pot platform of opportunity research fall into four major categories: technology improvements, social science, multiple criteria decision analysis, and integration into regional ocean observing systems. Research in these four areas has the potential to address some of the shortcomings of platform of opportunity research identified in this research, thereby improving the overall effectiveness of these sensor platforms and encouraging their more widespread use.

In terms of technology, improvements to the size, capabilities, and price of the instruments used in the OrFIOOR program will make them more useful to the ocean observing community. Efforts are already underway to reduce the power-consumption of the instruments. As a result, the units will require fewer batteries and smaller pressure cases to enclose the electronics inside. Revised electronics inside can also increase the number of variables that each unit is capable of monitoring and permit the use of wireless networking which, when coupled with communication relays onboard fishing vessels, will allow data to be harvested with delays of only a few days or weeks rather than months. Finally, lowering the cost per instrument will enable researchers to create a larger network of platforms which will be capable of resolving finer spatial variability in oceanic conditions in traditionally difficult areas to monitor (the ocean bottom).

Improvements in or a continuation of the social components of this research could help improve the “acceptability” idea of citizen science and cooperative ocean observing research. Revising the interviews so they could be administered as surveys to larger populations of fishermen and researchers would allow a more systematic or statistical evaluation of the attitudes towards the OrFIOOR program or other cooperative ocean observing endeavors. Further work in this area could also enable researchers to explore the limits of cooperative research and better understand the benefits of this research to participants. Questions could include:

- What is appropriate financial reward to compensate citizen scientists?
- How can we increase the non-financial benefit to fishermen?
- What payloads can they successfully and safely deploy using their crab pots or other platforms of opportunity?
- Are researchers comfortable with fishermen retrieving and deploying more expensive technologies and equipment?

Next, the MCDA framework used for analyzing ocean observing products could be enhanced through changes to the way the comparisons are structured and to the information used to inform the decision-making process. A major strength of MCDA is its ability to deal with complex problems and its adaptability to new or evolving information. This strength allows MCDA to be changed or modified to reflect the decision-space and the participants engaged in the decision-
making process and changes to the framework could include modifying or rearticulating the goals or “problem-statements” of the analysis, or adding to or removing criteria that are not germane to a particular scenario. Though generally unexplored for assessing ocean-observing research activities, MCDA stands as tool with a lot of potential for this converging area of technology and ocean science.

Finally, efforts to integrate the data from platform of opportunity research into regional ocean-observing systems should be maintained to take full advantage of the data that these opportunistic programs can provide. Further, as more people have access to and utilize this data, the value that this data can provide will be fully realized.
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APPENDIX A - INTERVIEWS
NOTIFICATION OF EXEMPTION

Date: November 23, 2009

To: Phazen Conway, Sociology
    Jeremy Chudowski (Student Researcher)

From: Institutional Review Board

Study number and Title: 4880 - Program Evaluation of Fishermen in Ocean Observing Research (FOCR)

Sponsor: None

The above referenced proposal was reviewed by the Oregon State University Institutional Review Board (IRB). The IRB has determined that your research project qualifies for an exemption under 45CFR46.111(b)(2).

(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior, UNLESS
(i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; AND
(ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

Further review of this research is not required and you may proceed with the research described in the protocol.

Please note that amendments to this protocol that impact the requirements for review must be reviewed prior to initiating the change. Please contact the IRB Office if you have questions about planned amendments.

To ensure that changes to this research project have not altered the review category, you will receive a brief annual inquiry regarding the status of this project.

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1 Review categories include exempt, expedited, and full board.
APPENDIX A-2
RESEARCH PROTOCOL

Project Title: Program evaluation of Fishermen in Ocean Observing Research (FLOOR)
Principal Investigator (PI): Flaxen Conway, Professor, Sociology
Co-Investigator(s): Jeremy Childress, MS Candidate, Marine Resource Management

1. Brief Description

A challenge facing ocean observing systems is the ability to achieve high spatial and temporal coverage at an affordable price. The Oregon Coastal Ocean Observing System (OrCOOS) relies on data from observational buoys, gliders, and towed arrays which, though proven technologies, are expensive to set up and maintain and only cover small areas of the ocean. As a result, there are limited year round oceanographic records at sufficient spatial scale off Oregon’s coast to fully describe the important physical processes that characterize this environment. To potentially supplement this limited data, an ongoing research program is underway to evaluate the affordability and feasibility of working with Oregon commercial crab fishermen to deploy scientific instrumentation. This evaluation aims to better understand fishermen’s attitudes towards the program, their perspectives on their current participation in the program, and their willingness to participate in the program in the future. We are also interested in the willingness of scientists to support the program, both monetarily and by using data collected by the program.

The results of this project will be used to meet requirements for a Master’s of Science in Marine Resource Management for one student researcher. In addition, it will be used in materials focusing on promotion of the project, participation in the project in the future, and future financial support for the project. It will also be submitted to several peer-reviewed scholarly journals.

2. Background and Significance

The world’s oceans are dynamic and highly variable systems experiencing wide-scale biological, physical and chemical changes over wide time periods. Information describing the extent and nature of these changes is essential for informing natural resource decision making at the user, manager, and policy-maker levels. Much of the technology necessary for collecting and disseminating this information is already available, yet a need remains for innovative approaches to ocean monitoring which deliver greater spatial and temporal resolution at reduced costs.

For several decades, U.S. Federal agencies have been working with local, regional, national and international partners to strengthen cooperation in Earth observations.\(^1\) The U.S. Integrated Ocean Observing System (IOOS) was established in 2002 and is the oceans and coasts component of the U.S. Integrated Earth Observation System (IEOS) and the U.S. contribution to two international programs: The Global Ocean Observing System (GOOS) and the Global Earth Observation System of Systems (GEOSS).\(^2\) The Northwest Association of Networked Ocean Observing Systems (NANOOS) is the regional association under IOOS in the Pacific Northwest, serving Washington, Oregon, and Northern California.

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1. EOC Strategic Plan.pdf
2. https://www.ocean Watch ea.tos
IOOS provides an end-to-end system of quality controlled data from satellites, aircraft, marine vessels, drifters and floats, autonomous underwater vehicles (AUVs) and fixed platforms. However, these programs still have limitations. In recent years, IOOS and NANOOS have both recognized a fundamental under-sampling of coastal ocean conditions in time and space. To improve the capabilities of these programs, NOAA plans to sponsor applied research and testing of emerging ocean observation technology as part of its IOOS Program Strategic Plan 2008-2014. To achieve this goal, NOAA will characterize requirements and gaps in observing technologies to guide NOAA’s investments in innovative research and technology; support verification and validation of existing and emerging technologies that address gaps, including those in information technology; and transition proven technologies from research into the U.S. IOOS operational system.

Proposed annual costs for implementation of the IOOS are projected to hit $500 million per year by 2010 with an estimated total cost of $2 billion over the first five years (2006-2010). However, in times of tight budgets, funding limitations can greatly affect monitoring efforts at local, regional, and national levels. For example, the NANOOS goal of "Strategically Maintaining Coverage and Range Observations in the PNW Shelf, in Coordination with Emerging National Programs" met with limited success in 2008 and 2009 due to lack of funding, resulting in fewer observations and less information on hypoxia/anoxia and harmful algal blooms (HABs), which are major regional concerns affecting ecosystem and human health, fisheries, and coastal economies.

One way to potentially overcome these funding limitations is to employ ocean users in the data-collecting process. For example, commercial crab fishermen spend many days at sea each year and their crab pots, each clearly positioned using GPS, cover much of Oregon’s coastal ocean from near shore to the shelf break. Incorporating ocean information gathered from instruments attached to these crab pots has the potential to substantially increase the data available to the NANOOS program and ocean researchers. However, the successful use of crab pots as sensor platforms, in terms of cost effectiveness, the quality of information gathered and support among scientists, has not been studied or determined yet on the west coast.

Research in the social sciences indicates that participation in the management process by those who are to be regulated should improve compliance to regulations (Kaplan & McCay 2004). Further, cooperative research programs that incorporate the expertise of stakeholders, scientists (including social scientists), and the government, can be key components to successful co-management of fisheries and marine resources when used properly with sound methodology and data collection and peer review. A critical component of this research, then, is to determine the satisfaction levels of fishermen engaged in the project and their willingness to participate in the future or to recruit others. Further, identifying whether or not the program and data meet the needs of ocean researchers is equally important as they are the primary consumer of the data or otherwise have the power to influence future funding procurements.

3. Methods and Procedures

Data collection for this evaluation will take place from late fall 2009 through early winter 2010, and will consist of phone questionnaires/semi-structured interviews (Robson 2002). Potential participants will be contacted either by phone or in person, and will be informed as to the purpose of the study, their role in the research process, and the means by which their confidentiality will remain secure. During this initial contact phase, each potential participant will be informed that they are in no way obligated to participate in this study and that their involvement is optional and voluntary. They will be informed that (prior to being

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2 NOAA Economics (http://www.economics.noaa.gov/?goal=ecosystems&file=obs/infabis)
4 Conceptual Design for NANOOS (2007)
6 IOOS Strategic Plan (2007) Page 4
9 Objective 3.3 IOOS Strategic Plan (2007) page 9

interviewed (asked to complete the questionnaire) by reading the cover letter (see Attachments) and agreeing to continue with the interview/questionnaire, that they are granting their informed consent.

Participants in the phone questionnaire/interviews will include two groups: Dungeness crab fishermen and ocean scientists involved in ocean-observing research. The fishermen asked to participate (no more than 20 individuals) are those who have been directly involved in the Oregon FLOOR cooperative research project.

Scientist participants (no more than 20 individuals) will be chosen at random from a pool of scientists involved in ocean-observing research along the west coast. The pool will include leading ocean academic scientists from institutions of higher education in California, Oregon, and Washington identified using referrals from key informants and snowball sampling (Robson 2002; Berg 2001).

The questionnaires/semi-structured interviews will consist of closed and open-ended questions (see Attachments) and will be administered over the phone. Data will be transcribed and stored electronically and coded such that participant identity will remain strictly confidential. It is estimated that each questionnaire/phone interview will take 30 minutes to complete. Participants are free to end their participation at any time.

4. Risks/Benefits Assessment

Risks
The risks associated with the project are minimal. The questions used for semi-structured interviews/questionnaire do not request any sensitive information. Rather, they refer primarily to participants’ experience, attitudes and perceptions of cooperative research and ocean-observing in Oregon. Participants will be interviewed individually and in private over the phone. Participants will be informed that their participation is completely voluntary and that they may choose not to answer any question or end their participation in the study at any time.

Benefits
There are no direct benefits for participants. The project provides participants an opportunity to express their opinions and views regarding cooperative ocean research in Oregon.

Conclusion
The risks involved in participating in this study are minimal, and participants will have the opportunity to contribute to the body of knowledge regarding the future cooperative ocean-observing research in Oregon.

5. Participant Population
We are interested in the knowledge and perceptions of fishermen directly involved with FLOOR, and of researchers engaged in ocean-observing projects. Semi-structured interviews/questionnaires will be conducted over the phone from November 2009 to January 2009. During that time, we will conduct no more than 40 interviews. Participants will not be excluded based on gender or ethnicity and no minors will be included in this study.

6. Subject Identification and Recruitment
Participants will be selected for this study through purposive sampling. This will begin with known group contacts (the fishermen that participated directly in FLOOR; and scientists known as leaders in ocean research). The scientist sample will be expanded by asking key informants to recommend other people from within their group whom they feel would also be beneficial to participate in this evaluation. When all is said and done, we will conduct a maximum of 40 interviews/questionnaires
7. **Compensation**

Individuals will not be compensated financially for their participation in this study.

8. **Informed Consent Process**

Potential participants will be contacted initially either in person or by telephone (see Attachments), and informed of the goals of this evaluation and the informed consent process. During this discussion we will identify or verify each person’s contact information and mailing address. Each person who agrees to participate in this research study will be required to read an explanation of the study (cover letter which explains the study and informed consent - see Attachments). Because this cover letter contains all the element of the consent and if the individual agrees to set up a phone questionnaire/interview, then it is assumed that they agreed. They may keep the hard copy of the cover letter. We believe, therefore that we do not need a signed letter of informed consent back from the participants.

9. **Anonymity and Confidentiality**

The semi-structured interview/questionnaire will be recorded on paper by the PI or graduate research assistant. The questionnaires will be stored in a secured system and only available to the PI or graduate research assistant. The interviews/questionnaires will be coded so that the individual’s identity will remain strictly confidential. Any statements or responses used in the evaluation will remain anonymous. The list of names and contact information will be kept in a separate secure location and available only to the PI and graduate research assistant. Once the project is completed, the data will be stored on compact discs and deleted from computer hard drives. Data discs will be stored in a locked cabinet for no more than five years prior to their physical destruction.
Script of Initial Phone Contact

- Hello, my name is Jeremy Childress. I’m a graduate student at Oregon State University in the Marine Resource Management program.

- I’m interested in learning more about your knowledge, perceptions, and attitudes regarding cooperative ocean-observing research between fishermen and researchers in Oregon. The results of the study will be used in a report and for a Master’s thesis.

- If you are willing, I’d like to set up a 20-30 minute semi-structured interview with you -at your convenience- to listen to your thoughts, ideas, and perspectives.

- Your participation is completely voluntary. You may refuse to answer any question or stop the interview at any time.

- What date and time would work best for me to visit over the phone with you?

- You will receive a letter explaining the project, the process of the interview, and a copy of the interview questions. Please look it over carefully. I’d be happy to answer any questions you might have when we talk on the phone.

- I can be contacted at Jeremy@childressonline.com with any further questions.

- Thank you for your willingness to participate. I’m looking forward our phone interview.
Sample Questionnaire Cover Letter

Date

Dear [Prospective Participant]:

I am a graduate student at Oregon State University in the Marine Resource Management program focusing my Master’s research on cooperative research between fishermen and scientists. Specifically, this research seeks to determine if cooperative research can serve as a robust, cost-effective, and community-supported tool for collecting physical oceanographic data. This project will form the basis of a Master’s of Science in Marine Resource Management.

You are being invited to take part in this study because:

A) As a participant in this study, you can provide valuable information about the successful qualities and limitations of the project.
B) As a researcher involved in ocean-observing research, you can provide valuable information about the scientific potential for this program and what you perceive to be its limitations.

I would appreciate it if you would be willing to visit with me for about 20-30 minutes over the phone to respond to the questionnaire. Only respondents 18 years of age or older are eligible to participate in this survey. Your responses will be added together with others and recorded as a group. If the results of this study are published, your identity will not be made public. Your participation in this study is voluntary and you may refuse to answer any question(s) for any reason. Participation in this study will not affect your participation in the Oregon FIGOR project.

The answers you provide will be kept confidential to the extent permitted by law. Special precautions have been established to protect the confidentiality of your responses. Your questionnaire will be destroyed once your responses have been tallied. We will take all precautions to keep all participants confidential. There are no expected direct benefits to you from your participation in this study, but your responses are extremely valued. If you do not want to participate and do not wish to be contacted further please let us know.

If you would like a copy of the survey results, just let me know at the time of the interview and I’ll add your name to the list of folks to receive them.

Thank you for your willingness and time to participate in this study. I may be contacted with questions at Jeremy@childressonline.com. You may also contact the principal investigator, Flaxen Conway, at 541-737-1418; flaxen.conway@oregonstate.edu.

If you have any questions about your rights as a research participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator at (541) 737-4933 or IRB@oregonstate.edu.

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Section A: Project Involvement

1. I learned about the project from:
   1. Fisherman
   2. Researcher
   3. Meeting/Discussion
   4. Other (please specify)

2. I became involved in this project because I:
   1. Was asked by a fellow fisherman
   2. Was asked by a researcher
   3. Volunteered
   4. Other (please specify)

3. What were your reasons for becoming involved in this research? (Circle all that apply)
   1. Interest in this research
   2. Interest in science in general
   3. Motivated by additional income opportunities
   4. Interest in enhancing ocean observing data
   5. Opportunity for learning from others
   6. Opportunity to teach others what I know
   7. Other (please specify)

4. What do you think are the reasons for other fishermen becoming involved in this research? (Circle all that apply)
   1. Interest in this research
   2. Interest in science in general
   3. Motivated by additional income opportunities
   4. Interest in enhancing ocean observing data
   5. Opportunity for learning from others
   6. Opportunity to teach others what I know
   7. Other (please specify)

5. What do you believe are the main obstacles for your involvement in this project? (Circle all that apply)
   1. Time
   2. Money
   3. Lack of trust with researchers and/or science
   4. Other (please specify)
   5. None -- there are no obstacles

6. What do you believe is the main obstacle for other fishermen's involvement in this project? (Choose 1)
   1. Time
   2. Money
   3. Lack of trust with researchers and/or science
   4. Other (please specify)
   5. None -- there are no obstacles
Section B: Communication, Data Gathering and Data Use
7. How would you characterize the communication between you and the researchers participating in the project?  
   1. Good  
   2. Okay  
   3. Not Good  
   4. Don't know/Not sure  
   5. Other  
8. How could communication with the researchers be improved? Explain:  
9. Are the logbooks easy to use?  
   1. Yes  
   2. No  
   3. Don't know/Not sure  
   4. Other  
10. Overall, how would you describe the use of logbooks in this project? Explain:  
11. Please share with me your thoughts on how the logbooks could be improved. Explain:  
12. Share with me how you would like to see data from this project used. Explain:  
13. Share with me any concerns you have with the data being used. Explain:  
14. Are you comfortable with your name being used in association with various types of data?  
   1. Yes  
   2. No  
   3. Don't know/Not sure  
   4. Other  
15. If yes, which types are you comfortable with?  
   1. Location data  
   2. Temperature data  
   3. Location and Temperature data  
   4. Catch data  
   5. Location and Catch data  
   6. The project in general (e.g. websites and publications)  
   7. Other  
   Explain:  

Section C: Future of the Project
16. Would you be willing to participate in this project as long as it has funding?  
   1. Yes  
   2. No  
   3. Don't know/Not sure  
   4. Yes, but with stipulations  
   Explain:
17. If funding were limited in the future, would you still be willing to participate in this project?
   1. Yes
   2. No
   3. Don't know/Not sure
   4. Yes, but with stipulations

   Explain:

18. Would you encourage or recommend other fishermen to participate in this project?
   1. Yes
   2. No
   3. Don't know/Not sure
   4. Yes, but with stipulations

   Explain:
Program Evaluation of Fishermen in Ocean Observing Research (FLOOR)  
RESEARCHER QUESTIONNAIRE

Section A: General Ocean Observing Information
1. A. What area of ocean-observing research are you currently involved in?
   Explain:
   B. In this area, what do you perceive as the greatest ocean observing needs?
   Explain:

Section B: Communication, Data Gathering and Data Use
2. A. Is there a particular format or standard that the data must adhere to?
   1. Yes
   2. No
   3. Don’t know/Not sure

   B. Please Explain:

3. How do you determine the quality of metadata?
   Explain:

4. A. What factors determine confidence in equipment used for ocean observing?
   1. Brand or Manufacturer
   2. Manufacturer stated operating specifications (accuracy, precision, reliability)
   3. Third-party testing
   4. Other

   B. Explain:

Section C: Future of the Project
Oregon Fishermen in Ocean Observing Research (OrFLOOR) is a cooperative program whereby Oregon State University researchers work with Dungeness crab fishermen to deploy environmental sensors attached to crab pots. The program began in 2005 as a pilot study and has since evolved to include approximately ten fishermen along the entire Oregon coast. Funding has been provided by Oregon Sea Grant.

5. Have you heard of this program before?
   1. Yes
   2. No
   3. Don’t know/Not sure

   Explain:

6. Would you use the data collected by this program?
   1. Yes
   2. No
   3. Don’t know/Not sure

   Explain:

7. A. Are there perceived obstacles for using data from this program?
   1. Yes
   2. No
   3. Don’t know/Not sure

   Explain:
B. If yes, what are they? (Choose all that apply)
   1. Time
   2. Money
   3. Lack of trust with fishers or the collection methods
   4. Lack of trust in the data or data quality
   5. Other (please specify)
   6. None - there are no obstacles

8. Describe how this program could be used to address your ocean observing needs.

   Explain:

9. Do you think scientists from other functional areas could benefit from data collected by this program?
   1. Yes
   2. No
   3. Don’t know / Not sure
   4. Other (please specify)

10. Based on what you know about the program, how do you think the temperature and dissolved oxygen data compares to data collected from:
    1. Gliders
       i. Favorably
       ii. Unfavorably
       iii. No opinion

   Explain:

    2. Moored Buoy
       i. Favorably
       ii. Unfavorably
       iii. No Opinion

   Explain:

    3. Towed Array
       i. Favorably
       ii. Unfavorably
       iii. No Opinion

   Explain:

    4. Are there other data sources to compare this program to?

   Explain:

11. Would you like to see this program continue in the future?
   1. Yes
   2. No
   3. Don’t know / Not sure
12. Would you support additional funding for this program?  
   1. Yes  
   2. No  
   3. Don't know/Not sure  
   4. Other (please specify)
APPENDIX B - PHYSICAL OCEANOGRAPHY
**APPENDIX B-1**

**EQUIPMENT DATASHEETS – TIDBIT V.2**

## Temperature (1,000 ft.) TidBit v2 Data Logger - UTBI-001

<table>
<thead>
<tr>
<th></th>
<th>Key</th>
<th>10</th>
<th>10-30</th>
<th>900+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>$10</td>
<td>$12</td>
<td>$23</td>
<td>$113</td>
</tr>
</tbody>
</table>

### Measures:
- Temperature

### Features:
- Onset’s smallest temperature data logger
- Waterproof to 300 meters (1,000 feet)
- Data readout in less than 30 seconds via fast Optic USB interface

### Description:
The tiny TidBit v2 has 12-bit resolution and a precision sensor for ±0.2 °C accuracy over a wide temperature range. The rugged TidBit is waterproof to 300m (1000 ft). Data readout is available in less than 30 seconds via the Optic USB interface. For accurate ambient air temperature measurements in sunlight, a solar radiation shield is required (UTBI-0200 Pyranometer Pod); assembly required. UTBI-055 pre-assembled Solar Protection Shield.

### Detailed Specifications:
- **Temperature Sensor**
  - Operation range: *0*-90 °C (32*-194 °F) in air; 0*-150 °C (32*-302 °F) in water
  - Accuracy: ±0.2 °C over 0*-50 °C (32*-122 °F)
  - Resolution: 0.01 °C at 25 °C (0.02 °F at 77 °E)
- **Response time:** 5 minutes in water; 10 minutes in air moving 2 m/sec; 20 minutes in air moving 1 m/sec (typical to 90%)
- **Stability drift:** ±0.05 °C (0.10 °F) per year

### Logger
- **Real-time clock:** ±1 minute per month 9*-50 °C (32*-122 °F)
- **Battery:** 3.7V Lithium, non-rechargeable
- **Battery life (typical use):** 5 years with 1 minute or greater logging interval
- **Memory (non- volatile):** 64K bytes memory (approx. 63,000 12-bit temperature measurements)
- **Weight:** 23 g (0.8 oz)
- **Dimensions:** 3.0 x 4.1 x 1.7 cm (1.2 x 1.6 x 0.65 in.); mounting bail 4.6 mm (3/32 in.) diameter
- **Wetted materials:** epoxy case
- **Wetproof:** To 305 m (1000 ft.)

### Logging Interval
- Fixed-rate or multiple logging intervals, with up to 8 user-defined logging intervals and durations; logging intervals may be delayed up to 30 days from the start date

### Accessories & Add-ons
- **Battery Indicator:** Battery level can be viewed in status screen and optionally logged in datafile. Low battery indication in datafile
- **NIST certificate:** Available for an additional charge

### CE Marking
- The CE Marking identifies this product as complying with the relevant directives in the European Union (EU).

---

*To guarantee accuracy, the TidBit v2 Temp must not be used in condensing environments and water temperatures higher than 30°C (86°F) for more than eight cumulative weeks over the life of the logger. Frequent or prolonged exposure will lead to measurement drift and eventual failure.*
Oxygen Optodes 3835/4130/4175

Since oxygen is involved in most of the biological and chemical processes in aquatic environments, it is the single most important parameter needing to be measured. Oxygen can also be used as a tracer in oceanographic studies. For environmental reasons it is critical to monitor oxygen in areas where the supply of oxygen is limited, e.g.,

- In shallow coastal areas with significant algal blooms
- In ponds or other areas with limited exchange of water
- Around fish farms
- In areas interesting for dumping of mine or dredging waste

The Aanderaa Oxygen Optodes are based on the ability of selected substances to act as dynamic fluorescence quenchers. The fluorescent indicator is a special platinum porphyrin complex embedded in a gas-permeable foil that is exposed to the surrounding water. A thick optical isolation coating protects the complex from sunlight and fluorescent particles in the water. This sensing foil is attached to a window providing optical access for the measuring system from inside a watertight titanium housing.

The foil is excited by modulated blue light, and the phase of a returned red light is measured (see illustration overleaf). By linearizing and temperature compensating, with an incorporated temperature sensor, the absolute O2 concentration can be determined.

The lifetime-based fluorescence quenching principle offers the following advantages over electrochemical sensors:

- Not affected by sensitivity (it contains no oxygen)
- Less affected by fouling
- Measures absolute oxygen concentrations without repeated calibrations
- Better long-term stability
- Less affected by pressure
- Pressure behavior is predictable
- Faster response time

The sensor is designed to operate down to 300 meters. It fits directly onto the top end-plate of Recording Current Meter RCMI, and other Aanderaa instruments.
## Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Oxygen Optode 3835</th>
<th>Oxygen/temperature Optode 4130</th>
<th>Oxygen Optode 4175</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oxygen</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measuring Range:</td>
<td>$O_2$ Concentration</td>
<td>$O_2$ Concentration</td>
<td>$O_2$ Concentration</td>
</tr>
<tr>
<td></td>
<td>0 - 5000 (M)</td>
<td>1 - 200 (M)</td>
<td>0 - 5000 (M)</td>
</tr>
<tr>
<td></td>
<td>0 - 120%</td>
<td>0 - 120%</td>
<td>0 - 120%</td>
</tr>
<tr>
<td>Resolution:</td>
<td>$&lt;1$ ppm</td>
<td>$&lt;1$ ppm</td>
<td>$&lt;1$ ppm</td>
</tr>
<tr>
<td></td>
<td>0.4%</td>
<td>0.4%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Accuracy:</td>
<td>$&lt;1$ ppm or 5%</td>
<td>$&lt;1$ ppm or 5%</td>
<td>$&lt;1$ ppm or 5%</td>
</tr>
<tr>
<td></td>
<td>relative to gravity</td>
<td>relative to gravity</td>
<td>relative to gravity</td>
</tr>
<tr>
<td>Settling Time (62%):</td>
<td>~20s</td>
<td>~20s</td>
<td>~20s</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range:</td>
<td>0°C to + 30°C</td>
<td>7.5°C to + 41°C</td>
<td>0°C to + 30°C</td>
</tr>
<tr>
<td>Resolution:</td>
<td>0.1°C</td>
<td>0.05°C</td>
<td>0.01°C to 0.05°C</td>
</tr>
<tr>
<td></td>
<td>0.01°C</td>
<td>0.005°C</td>
<td>0.006°C to 0.02°C</td>
</tr>
<tr>
<td>Accuracy:</td>
<td>1.0%</td>
<td>1.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Settling Time (62%):</td>
<td>~10s</td>
<td>10s</td>
<td>~10s</td>
</tr>
<tr>
<td><strong>Operating Temperature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 - 47°C (32 - 104°F)</td>
<td>0 - 47°C (32 - 104°F)</td>
<td>0 - 47°C (32 - 104°F)</td>
</tr>
<tr>
<td><strong>Operating Depth</strong></td>
<td>0 - 2000 (68 ft)</td>
<td>0 - 2000 (68 ft)</td>
<td>0 - 2000 (68 ft)</td>
</tr>
<tr>
<td><strong>Sampling Rate</strong></td>
<td>SR10: controlled by the data logger, RS-232: 1 to 2400 samples/hour</td>
<td>Controlled by the data logger</td>
<td>From 1 to 2400 samples/hour</td>
</tr>
<tr>
<td><strong>Output Formats</strong></td>
<td>Andressa SR10 (Oxygen) RS-232</td>
<td>Andressa SR10 (Oxygen) and WR22 (Temperature) RS-232</td>
<td>9-15V output: 0.01% of FSV 4-20mA output: 0.02% of FSV RS-232</td>
</tr>
<tr>
<td><strong>Current Consumption</strong></td>
<td>SR10: 10mA where the recording interval is 1 minute</td>
<td>Andressa SR10: 10mA (Oxygen) and 15mA (Temperature)</td>
<td>10mA where the recording interval is 1 minute</td>
</tr>
<tr>
<td></td>
<td>RS-232: 10mA/S to 0.01mA/S where S is recording interval in seconds</td>
<td>RS-232: 10mA/S to 0.01mA/S where S is recording interval in seconds</td>
<td>10mA where the recording interval is 1 minute</td>
</tr>
<tr>
<td><strong>Supply Voltage</strong></td>
<td>SR10: 6 to 14Vdc</td>
<td>Analog: 7 to 14Vdc</td>
<td>SR10: 5 to 14Vdc</td>
</tr>
<tr>
<td></td>
<td>RS-232: 5 to 14Vdc</td>
<td>RS-232: 5 to 14Vdc</td>
<td>RS-232: 5 to 14Vdc</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>38x5x5mm (SR10)</td>
<td>80x108x35mm (SR10)</td>
<td>80x108x35mm (SR10)</td>
</tr>
<tr>
<td></td>
<td>100x150mm (SR10)</td>
<td>100x150mm (SR10)</td>
<td>100x150mm (SR10)</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>170g (SR10)</td>
<td>350g (SR10)</td>
<td>350g (SR10)</td>
</tr>
<tr>
<td><strong>Materials</strong></td>
<td>Teflon, PTFE (SR10)</td>
<td>Teflon, PTFE (SR10)</td>
<td>Teflon, PTFE (SR10)</td>
</tr>
<tr>
<td><strong>Accessories included</strong></td>
<td>Sensor Cable 3835</td>
<td>Sensor Cable 3835</td>
<td>Sensor Cable 3835</td>
</tr>
<tr>
<td></td>
<td>to PC</td>
<td>to PC</td>
<td>to PC</td>
</tr>
<tr>
<td></td>
<td>Full Service Kit</td>
<td>Full Service Kit</td>
<td>Full Service Kit</td>
</tr>
<tr>
<td><strong>Accessories not included</strong></td>
<td>Sensor Cable 3835</td>
<td>Sensor Cable 3835</td>
<td>Sensor Cable 3835</td>
</tr>
<tr>
<td></td>
<td>to PC</td>
<td>to PC</td>
<td>to PC</td>
</tr>
<tr>
<td></td>
<td>Full Service Kit</td>
<td>Full Service Kit</td>
<td>Full Service Kit</td>
</tr>
<tr>
<td><strong>Warranty</strong></td>
<td>Two years against faultiness and manufacturing defects (3835, 3833, 4175)</td>
<td>Two years against faultiness and manufacturing defects (3835, 3833, 4175)</td>
<td>Two years against faultiness and manufacturing defects (3835, 3833, 4175)</td>
</tr>
</tbody>
</table>

---

**Notes:**
- $O_2$ Concentration in air = 20.9% + 1%. To obtain the actual reading, divide by 20.95.
- The saturation range covered by SR10 is 0 to 150%, the temperature range covered by SR10 is 0°C to 95°C.
- The saturation range covered by analog (0-20mA) is 0 to 100%, the temperature range covered by SR10 is 0°C to 95°C.
- Andressa SR10/WR22 are signal protocols that are used with Andressa equipment only.
- SVS: 3000 baud, 8 data bits, 1 stop bit, no parity, non-habilitated.
- The accuracy of the Analog Adapter is 0.01% of FSV. Note however that the end of the scale (1,000 ppm) and +1300 ppm) is outside the range of the instrument.
- In order to change settings or calibrate the Optode to the Sensor, the Optode has to be connected to PC. To gain access to the Optode, the RS-232 signal is multiplied by an analog signal, which can be used to control the Optode.
- Specification 3033 is subject to the same conditions as the Optode 3833.
<table>
<thead>
<tr>
<th>Optode Model</th>
<th>3835</th>
<th>4130</th>
<th>4175</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>Integrated Panel Mounted</td>
<td>Integrated Body Terminable from Cassette String</td>
<td>Integrated Body with Analog and Serial Outputs</td>
</tr>
<tr>
<td><strong>Output</strong></td>
<td>Dual Channel: RS-232 data string (Oxygen, Temp.) or single 5810 (Oxygen) channel to ROMs or ROCPs</td>
<td>Dual Channel: 5810 (Oxygen) and 5120 (Temp.)</td>
<td>Dual Channel: 0-5V (Oxygen, Temp.) or 4-20mA (Oxygen, Temp.) and/or RS-232 (Oxygen, Temp.)</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Add sensor(s) to Top End plate of our ROM, ROC-400, or for OEM/3rd party user</td>
<td>For use with Aanderaa DL series dataloggers; added sensors to Weather Stations AWS 2700, Data Logger DL 4020 or our self-contained recording instruments</td>
<td>General Purpose use with third party dataloggers, e.g. CTDs, ADCPs, floats, ROV, ROIs, process industry controllers, recorders, data acquisition and control systems</td>
</tr>
<tr>
<td><strong>Sample Rate</strong></td>
<td>Set by host; 5kHz, continuously - 120 minutes</td>
<td>Set by host; 5kHz, continuously - 100 minutes</td>
<td>Set by host; 5kHz, continuously - 100 minutes</td>
</tr>
<tr>
<td><strong>Multi-sensor Configuration</strong></td>
<td>ROM: Yes, 2nd Channel via Cable 3256 and Receptacle 3222; LED: YES, 50m version; as for ROM 6</td>
<td>DL-1000 Max 15 sensors, depending on configuration</td>
<td>DL-1000 Max 15 sensors, depending on configuration</td>
</tr>
<tr>
<td><strong>Stand-alone Sensor (0-300m)</strong></td>
<td>Use Cable 3495; Output: RS-232 (Oxygen, Temp.) Sampling Rate: 1 Hz to 255 minutes</td>
<td>Use furnished datalogger or controller, Cable 3495; Output: 0-5V or 0-10V, or 4-20mA, or RS-232 (Oxygen, Temperature) Sampling Rate: 1 Hz to 255 min</td>
<td></td>
</tr>
</tbody>
</table>

(*) Note that when the Optode is connected to an instrument like the ROM, CMS, AWS or a datalogger, the sampling rate in a continuous recording mode depends on the number of channels for storage etc.

**Oxyview® Program**

Oxyview®, has been designed for use with Oxygen Optode/ Temperature Sensor 3830/3835. The program allows display of Oxygen Concentration, Oxygen Saturation and Temperature both in tables and graphical forms.

A Calibration Wizard is included in the program. This Wizard helps calibrate the Optode.

Oxyview® can also be used to configuring the Oxygen Optode.

**The Optical System**

The principle of measurement is based on the effect of dynamic luminescence quenching (lifetime based) by molecular oxygen.
EXAMPLES OF APPLICATIONS

To the right: The Oxygen Optode 3636 used with a Recording Current Meter to measure dissolved oxygen and temperature as part of environmental monitoring.

Below: The Oxygen/Temperature Sensor 4130 used with Display Unit 3395 to measure dissolved oxygen and temperature in a fish farm.
Acumen Instruments Corporation's DataBridge SDR-CF is another way Acumen Instruments makes it easy to add data storage to any device or system.

The SDR-CF is a compact, rugged device that captures data from any device equipped with a serial port and stores it in a PC-compatible file on a CompactFlash card.

No programming required.
The SDR-CF is a hardware solution that is ready to deploy. Unlike embedded computers, no programming is required, and you don't need to install special application software. Configuration can be changed using any computer's serial port.

Because the SDR-CF records data to PC-compatible files, your files appear on a standard drive letter and can be read with any common CompactFlash card reader.

If you already use a computer or laptop for data collection, the SDR-CF is a convenient drop-in replacement.

Low power consumption.
The SDR-CF consumes less than 1 Watt, offering significant power savings over PCs, laptops, and embedded PCs, so batteries last 10 to 100 times longer and no heat is generated. The SDR-CF operates from a 7-30 VDC power supply, simplifying system integration.

The flexibility you need.
At Acumen, we know every application has unique requirements. For devices that require it, the SDR-CF can send commands to the attached device on initialization, shutdown, or at specific intervals. You also control when files are opened and closed, how files are named, and date/time stamping.

Using the SDR-CF's configuration port, you can connect to a computer to control and monitor your recording, download files, change recording settings, or communicate with your device using serial passthrough mode.

Industry-standard storage technology.
The SDR-CF gives you access to industry-standard CompactFlash solid-state storage media. You benefit from competitive pricing as well as assured compatibility with your PC.

Options for OEMs.
A board only version of the SDR-CF, the SDR-OEM-CF, is available for integration with your product. Other OEM features include a remote panel interface connection. Customizations and quantity discounts are also available.

See it for yourself.
The DataBridge SDR-CF starter kit includes everything needed to get started. See our web site or contact Acumen Instruments Corporation for details.
**Specifications**

**Data rates**
2400 bps to 2304 kbps

**Handshaking modes**
RTS/CTS (hardware handshaking)

**File format**
PC-compatible (DOS/FAT16 file system)

**Storage device compatibility**
Devices conforming to the CompactFlash specification

**Electrical interface**
ATAATAPI (True IDE Mode)

**Storage capacity**
Limited only by storage device and FAT16 file system

**Power requirements**
7.35 VDC unregulated (under 1 W)

**Operating Temperature**
-40° to +85° Celsius (industrial temperature range)

---

**Physical Characteristics**

**Dimensions**
4.075" L x 3.375" W x 1.250" H
(10.3 cm x 8.6 cm x 3.1 cm)

**Weight**
8.3 oz (241 grams) without CF card

**Enclosure**
Extruded aluminum

**Serial connectors**
DB9 male (DTE data port)
DB9 female (DCE configuration port)

**Drive connectors**
Type I/II CompactFlash connector with ejector

---

**Media Options**

**Solid-state media**
CompactFlash media: 8 MB to 2 GB (limited only by FAT16 file system)

---

**Notable Features**

**Serial download protocols**
Ymodem batch, ASCII text

**Power-up modes**
Resume recording when file is open, append to file

**Real-time clock functions**
Scheduled file closing every 1 second or 194 days
Optional date/time stamping of recorded data

**Output messages**
8.256 byte strings
1 second or 194 days output interval
Messages can be sent at initialization or shutdown

**Device control**
Serial passthrough mode
(communications between hardware if needed)
MATLAB CODE – Read/Clean/Plot/Save Temperature Data from Tidbits

% Matlab script to read in Logbook and Tidbit Data
%-------------------------------
% 1. Read in Raw Data and Logbook Records
% 2. Input Calibration Coeff. (Slope and Y-Intercept Offset)
% 3. Plot Data based on Depth
% 4. Save Cleaned Data to CSV

clear all
close all

%... Read in any file in directly that begins with 'Logbook'
filenames = dir;
dir_list = strcat('Logbook*');

f=dir(dir_list);
[num1,txt1,raw1]=xlsread(f(1,1).name);

% Read Tidbit Pair Numbers from Logbook and create Name String
tidbit_pair_number_1=num1(1,3);
tidbit_pair_number_2=num1(2,3);
tidbit_pair_number_1=num2str(tidbit_pair_number_1);
tidbit_pair_number_2=int2str(tidbit_pair_number_2);

%... Find XLSX TIDBIT files that match Name String from Above
filenames = dir;
dir_list = strcat(tidbit_pair_number_1,'_*');

f=dir(dir_list);
[num2,txt2,raw2]=xlsread(f(1,1).name);

filenames = dir;
dir_list = strcat(tidbit_pair_number_2,'_*');
f=dir(dir_list);
[num3,txt3,raw3]=xlsread(f(1,1).name);

%..Read in Tidbit Serial Numbers
tidbit_serial_number_1=raw1(1,5);
tidbit_serial_number_2=raw1(2,5);

% Define Calibration Parameters
%-----------------------------------
Enter the Calibration value of b for Tidbit serial # above: '

Enter the calibration value of c for Tidbit serial # above: '

Enter the Calibration value of b for Tidbit serial # above: '

Enter the calibration value of c for Tidbit serial # above: '

%. skip first 2 lines to avoid headers
   dtmp=raw2(3:end,2);
   dtmp2=raw3(3:end,2);
   ttmp1=raw2(3:end,3);
   ttmp2=raw3(3:end,3);

%. get rid of records with now time: time string is short only
   mm/dd/yyyy
%. instead of mm/dd/yyyy HH:MM:SS PM
   l=0;
   for k=1:length(dtmp);
      if length(dtmp{k})<15;l=l+1;q(l)=k;end;
   end
   dtmp(q)=[ ];
   ttmp1(q)=[ ];

   l=0;
   for k=1:length(dtmp2);
      if length(dtmp2{k})<15;l=l+1;q(l)=k;end;
   end
   dtmp2(q)=[ ];
   ttmp2(q)=[ ];

%. convert date strings to matlab date numbers
   dn_tmp=datenum(dtmp,'mm/dd/yyyy HH:MM:SS PM');
   dn_tmp2=datenum(dtmp2,'mm/dd/yyyy HH:MM:SS PM');

%. convert temperature cells to numbers
   T1_tmp=cell2mat(ttmp1);
   T2_tmp=cell2mat(ttmp2);

%.Correct temperature using Calibration Equation
   T1_tmp=T1_tmp*b1+c1;
   T2_tmp=T2_tmp*b2+c2;

%. Assign final variables
   date_1=dn_tmp-datum(2009,01,01,00,00,00)+1;
   date_2=dn_tmp2-datum(2009,01,01,00,00,00)+1;
   temp_1=T1_tmp;
temp_2=T2_tmp;

%. Ensure that Bottom Temperature is Temp #1

if (mean(temp_1)>mean(temp_2))
    temp_temp=temp_1;
    temp_1=temp_2;
    temp_2=temp_temp;
end

%=============================================%.. Read rest of data from Excel logbook into matlab%=============================================
tidbit_vessel_master=raw1(1,13);

%. deployment number
deployment_number=cell2mat(raw1(5:end,1));

for k=1:length(deployment_number);
datenumber_deployed(k)=datenum([raw1(4+k,2)],'mm/dd/yyyy')+raw1{4+k,3};
datenumber_recovered(k)=datenum([raw1(4+k,8)],'mm/dd/yyyy')+raw1{4+k,9};
end
date_deployed=(datenumber_deployed-
datenum(2009,01,01,00,00,00)+1);
date_recovered=(datenumber_recovered-
datenum(2009,01,01,00,00,00)+1);

%. latitude and longitude
for k=1:length(deployment_number);
    latitude_deployed(k)=str2double(raw1{4+k,4}(1:2))+str2double(raw1{4+k,4}(4:8))/60;
    latitude_recovered(k)=str2double(raw1{4+k,10}(1:2))+str2double(raw1{4+k,10}(4:8))/60;
    longitude_deployed(k)=-(str2double(raw1{4+k,5}(1:3))+str2double(raw1{4+k,5}(5:9))/60);
    longitude_recovered(k)=-(str2double(raw1{4+k,11}(1:3))+str2double(raw1{4+k,11}(5:9))/60);
end

%. water depth in meters - cause we're scientists
water_depth_deployed_meters=cell2mat(raw1(5:end,7));
water_depth_recovered_meters=cell2mat(raw1(5:end,13));

%. catch data
catch_male_legal=cell2mat(raw1(5:end,14));
catch_male_small=cell2mat(raw1(5:end,15));
catch_female_legal = cell2mat(raw1(5:end,16));
catch_female_small = cell2mat(raw1(5:end,17));

% ...Loop to create NAN values for when the sensors weren't in the water
clean_temp_1 = repmat(nan,[length(temp_1) 1]);
clean_temp_2 = repmat(nan,[length(temp_2) 1]);
clean_lat = repmat(nan,[length(temp_1) 1]);
clean_long = repmat(nan,[length(temp_1) 1]);
clean_depth = repmat(nan,[length(temp_1) 1]);

for i = 1:length(deployment_number)
    xx=find(dn_tmp>datenumber_deployed(i));
    yy=find(dn_tmp>datenumber_recovered(i));
    clean_temp_1(xx(1)+10:yy(1)-10)=temp_1(xx(1)+10:yy(1)-10);
    %the adding and subtracting of 10 data points to remove potential error. Could adjust to 1 or 2
    clean_temp_2(xx(1)+10:yy(1)-10)=temp_2(xx(1)+10:yy(1)-10);
    clean_lat(xx(1)+10:yy(1)-10)=latitude_recovered(i);
    clean_long(xx(1)+10:yy(1)-10)=longitude_recovered(i);
    clean_depth(xx(1)+10:yy(1)-10)=water_depth_recovered_meters(i);
end

%================================
%Plot Data based on depth by changing colors
%==================================================================
% 0-9 meters = Magenta
% 10-19 meters = Blue
% 20-29 meters = Green
% 30-39 meters = Yellow
% 40-49 meters = Orange
% 50- meters = Red

xx=find(clean_depth<10);
depth_5=[date_1(xx),clean_temp_1(xx)];
plot(date_1(xx),clean_temp_1(xx),'m');
hold on

xx=find(clean_depth<20 & clean_depth>=10);
depth_10=[date_1(xx),clean_temp_1(xx)];
plot(date_1(xx),clean_temp_1(xx),'b');
hold on

xx=find(clean_depth<30 & clean_depth>=20);
depth_20=[date_1(xx),clean_temp_1(xx)];
plot(date_1(xx),clean_temp_1(xx),'g');
hold on
xx = find(clean_depth < 40 & clean_depth >= 30);
depth_30 = [date_1(xx), clean_temp_1(xx)];
plot(date_1(xx), clean_temp_1(xx), 'y');
hold on

xx = find(clean_depth < 50 & clean_depth >= 40);
depth_40 = [date_1(xx), clean_temp_1(xx)];
plot(date_1(xx), clean_temp_1(xx), 'c');
hold on

xx = find(clean_depth > 50);
depth_50 = [date_1(xx), clean_temp_1(xx)];
plot(date_1(xx), clean_temp_1(xx), 'r');
hold on

%...Plot the Data
%...Save the Data
%...This section will save the data into five columns of Date, Bottom Temp,
%Surface Temp, Latitude, and Longitude

dumb = repmat(nan, [length(date_1) 5]);
dumb(:, 1) = date_1';
dumb(:, 2) = clean_temp_1';
dumb(:, 3) = clean_temp_2';
dumb(:, 4) = clean_lat';
dumb(:, 5) = clean_long';
dumb(:, 6) = clean_depth';
dumb = dumb';

filename = strcat('2008_2009_', tidbit_pair_number_1, '_', tidbit_pair_number_2);

fid2 = fopen(filename, 'w');
fprintf(fid2, '%s', '#Time, Bottom Temp, Surface Temp, Latitude, Longitude, Depth');
fprintf(fid2, '
%s', '#Days since Jan 01 2009, Degrees C, Degrees C, Degrees North, Degrees West, Meters');
fprintf(fid2, '
%s', '');
fprintf(fid2, '%f %.3f %.3f %f %f %.1f
', dumb);
fclose(fid2);
APPENDIX B-5
MATLAB CODE – READ/CLEAN/ PLOT/SAVE DISSOLVED OXYGEN DATA

%========================================================================
% Matlab script to read in Logbook and DO files
%========================================================================
%.. 1. Read in Raw Data and Logbook Records
%.. 2. Input Calibration Coeffs. (Slope and Y-Intercept Offset)
%.. 3. Plot Data
%.. 4. Save Cleaned Data to CSV

clear all
close all

%... Read in any file that begins with 'Logbook'
filenames = dir;
dir_list = strcat('Logbook*');

f=dir(dir_list);
[num1,txt1,raw1]=xlsread(f(1,1).name);

%.. Read DO Color from Logbook and create Name String
do_color=txt1(1,3);

%.. Read in DO Serial Number
do_serial=num1(1,5);
do_serial=num2str(do_serial);

%... Find XLSX DO files that match Serial Number from Above
filenames = dir;
dir_list = strcat(do_serial,'*');

f=dir(dir_list);
[num2,txt2,raw2]=xlsread(f(1,1).name);

%========================================================================
% User input of Salinity and Calibration Numbers
%========================================================================
do_serial
depth=input('Enter the depth (meters) of deployment: ');
salinity=input('Enter the Salinity value (psu) for the deployment: ');
cal_slope=input('Enter the calibration value of b (slope) for DO Unit above: ');
cal_intercept=input('Enter the calibration value of c (y-intercept) for DO Unit above: ');
% Convert timestamp to matlab time
ydate_raw = raw2(1:end,1);
for k=1:length(ydate_raw);
    a=ydate_raw(k)(1:19);
b(k)=a;
end
ydate_fix = (b)';
ydate_num = datenum(ydate_fix,'mm/dd/yyyy HH:MM:SS');
ydate = ydate_num - datenum(2009,01,01,00,00,00)+1;
date = ydate;

% Create variables from source (after visually inspecting file at
% beginning and end
do_raw = raw2(1:end,5);
sat_raw = raw2(1:end,7);
temp_raw = raw2(1:end,9);

% Convert variables to numbers
oxygen = cell2mat(do_raw);
saturation = cell2mat(sat_raw);
temp = cell2mat(temp_raw);

% Convert Oxygen data from engineering units. =
% Variable "Oxygen" is output from Aanderaa =
oxygen = oxygen/44.62; % <mmol/l> to <ml/l>
oxygen(logical(oxygen<=0)) = NaN;

% Calculate Pressure compensation for Oxygen sensor
P_comp = (0.032*depth)/(1000*0.4)+1;

% Salinity Compensation coefficients for Oxygen
b0 = -6.24097e-3;
b1 = -6.93498e-3;
b2 = -6.90358e-3;
b3 = -4.29155e-3;
c0 = -3.11680e-7;

% Calculate Salinity compensation for Oxygen sensor
a1 = (298.15-temp);
a2 = (273.15+temp);
Ts = log(a1./a2);
S_comp = exp(salinity.*(b0+b1*Ts+b2*Ts.^2+b3*Ts.^3) + c0*salinity.^2);

%..Apply Salinity and Pressure Compensation
oxygen=oxygen.*S_comp; % apply salinity compensation
oxygen=oxygen.*P_comp; % apply pressure compensation

%=============================================%..Calibration Calculations
%=============================================
oxygen_cal=cal_slope.*oxygen+cal_intercept;

%=============================================%.. Read rest of data from Excel logbook into matlab
%=============================================
vessel_master=raw1(1,13);

%.. deployment number
deployment_number=cell2mat(raw1(5:end,1));

for k=1:length(deployment_number);
datenumber_deployed(k)=datenum([raw1(4+k,2)],'mm/dd/yyyy')-raw1{4+k,3};
datenumber_recovered(k)=datenum([raw1(4+k,8)],'mm/dd/yyyy')-raw1{4+k,9};
end
date_deployed=(datenumber_deployed-
datenum(2009,01,01,00,00,00)+1);
date_recovered=(datenumber_recovered-
datenum(2009,01,01,00,00,00)+1);

%.. latitude and longitude
for k=1:length(deployment_number);
latitude_deployed(k)=str2double(raw1{4+k,4}(1:2))+str2double(raw1{4+k,4}(4:8))/60;
latitude_recovered(k)=str2double(raw1{4+k,10}(1:2))+str2double(raw1{4+k,10}(4:8))/60;
longitude_deployed(k)=-(str2double(raw1{4+k,5}(1:3))+str2double(raw1{4+k,5}(5:9))/60);
longitude_recovered(k)=-(str2double(raw1{4+k,11}(1:3))+str2double(raw1{4+k,11}(5:9))/60);
end
%.. water depth in meters - cause we're scientists
water_depth_deployed_meters=cell2mat(raw1(5:end,7));
water_depthRecovered_meters=cell2mat(raw1(5:end,13));

%.. catch data
catch_male_legal=cell2mat(raw1(5:end,14));
catch_male_small=cell2mat(raw1(5:end,15));
catch_female_legal=cell2mat(raw1(5:end,16));
catch_female_small=cell2mat(raw1(5:end,17));

%...Loop to create NAN values for when the sensors weren't in the water
clean_oxygen_cal = repmat(nan,[length(temp) 1]);
clean_temp = repmat(nan,[length(temp) 1]);
clean_lat = repmat(nan,[length(temp) 1]);
clean_long = repmat(nan,[length(temp) 1]);
clean_depth = repmat(nan,[length(temp) 1]);

for i = 1:length(deployment_number)
    if date_recovered(i) > date(end);
        date_recovered(i) = date(end);
    end

    if date_deployed(i) > date(end);
        date_deployed(i) = date(end);
    end

    xx=find(date>=date_deployed(i));
    yy=find(date>=date_recovered(i));
    clean_oxygen_cal(xx(1)+5:yy(1)-5)=oxygen_cal(xx(1)+5:yy(1)-5);
    clean_temp(xx(1)+5:yy(1)-5)=temp(xx(1)+5:yy(1)-5);  %the adding and subtracting of 10 data points to remove potential error. Could adjust to 1 or 2
    clean_lat(xx(1)+5:yy(1)-5)=latitude_recovered(i);
    clean_long(xx(1)+5:yy(1)-5)=longitude_recovered(i);
    clean_depth(xx(1)+5:yy(1)-5)=water_depth_recovered_meters(i);
end

%======================================
%...Plot the Data
%======================================
plot(date,clean_oxygen_cal,'b')
hold on
plot(date,oxygen,'r')
ylabel('Dissolved Oxygen (ml/l)')
legend('Calibrated O2','Uncalibrated O2')
grid
t_axis(date,2009)
saveas(gcf,[strcat('2008_2009_',do_serial),'_plot.jpg'])
clf

%==========================================
%...Create Map showing single sensor locations over a season
%==========================================
m_proj('mercator','lon',[-128 -120],'lat',[40 48]);
m_coast('patch',[.9 .9 .9],'edgecolor','none');
m_grid('tickdir','out','yaxislocation','right','xaxislocation','
bottom','xlabeldir','end','ticklen'.02);
m_line(clean_long,clean_lat,'marker','square','markersize',4,'color','r');
saveas(gcf,[strcat('2008_2009_',tidbit_pair_number_1,'_
',tidbit_pair_number_2),'_locations.jpg'])

%==========================================
%...Save the Data
%==========================================
%...This section will save the data into five columns of Date,
Dissolved O2,
%Bottom Temp, Latitude, and Longitude
dumb=repmat(nan,[length(date) 6]);
dumb(:,1)=date';
dumb(:,2)=clean_oxygen_cal';
dumb(:,3)=clean_temp';
dumb(:,4)=clean_lat';
dumb(:,5)=clean_long';
dumb(:,6)=clean_depth';
dumb=dumb';

filename=[strcat('2008_2009_',do_serial),'.csv'];
 fid2 = fopen(filename,'w');
 fprintf(fid2,'%s', '#Time,Dissolved Oxygen,Bottom
Temp,Latitude,Longitude,Depth');
 fprintf(fid2,'\n%s', '#Days since Jan 01 2009,ml/l,Degrees
C,Degrees North,Degrees West,Meters');
 fprintf(fid2,'\n%s', '');
 fprintf(fid2,'%f,%.3f,%.3f,%f,%f,%.1f\n',dumb);
 fclose(fid2);
%==========================================
%...Save Workspace
save([strcat('2008_2009_', do_serial), '.mat'])
APPENDIX B-6
MATLAB CODE – CREATE BATHYMETRIC MAP OF SENSOR LOCATIONS

%%=============================================================
%%.. Plot Sensor Locations in Bathymetric Map
%%=============================================================
%%..1. Set Projection
%%..2. Plot Bathymetry
%%..3. Plot Sensor Locations
%%..4. Save to Illustrator EPS file

clear all
close all

load USWC_ETOPO1.mat

USWC = USWC.*-1;

clf
m_proj('Miller Cylindrical','lon',[-124.5 -123.8],'lat',[44 44.8]);
m_gshhs_h('patch',[.5 .5 .5],'edgecolor','k');
hold on

%Plot Bathy
[cs,h]=m_contour(lon,lat,USWC,[100 70 50 30 10],'k');
set(h,'linewidth',.2)
clabel(cs,h,[100 70 50 30 10],'color','k','rotation',0,'FontSize',8);

%Plot OrFLOOR 50m (Red - 9300536) Location
m_line(-124.17,44.333,'marker','.','markersize',15,'linewidth',.8,'color','r')
m_text(-124.17+.01,44.333+.01,'Red (50m)','FontSize',8);

%Plot OrFLOOR 10m (Yellow - 9300535) Location
m_line(-124.11,44.333,'marker','.','markersize',15,'linewidth',.8,'color','y')
m_text(-124.11+.01,44.333+.01,'Yellow (10m)','FontSize',8);

%Plot OrFLOOR 30m (Green - 9300533) Location
m_line(-124.11,44.5,'marker','.','markersize',15,'linewidth',.8,'color','g')
m_text(-124.11+.01,44.5+.01,'Green (30m)','FontSize',8);

%Plot OrFLOOR 30m (Orange - 9300467) Location
m_line(-124.12,44.417,'marker','.','markersize',15,'linewidth',.8,'color','k')
m_text(-124.12+.01,44.417+.01,'Orange (30m)', 'FontSize', 8);

%Plot OrFLOOR 30m (Blue - 9300534) Location
m_line(-124.13,44.333,'marker','.','.markersize',15,'linewidth',.8,'color','k')
m_text(-124.13+.01,44.333+.01,'Blue (30m)', 'FontSize', 8);

m_grid('xtick',[-124.5:.5:-123.8],'ytick',[44:.5:44.8], 'tickdir','out','colour','k','FontSize',8);
orient tall
print -depsc -r300 test_bathy
APPENDIX B-7
MATLAB CODE – FIND TIME-SERIES DAILY AVERAGES

%%=======================================================
%%..Find Daily Averages
%%=======================================================
%%..1. Load All Time Series
%%..2. Find Start and End dates that encompass all time series
%%..3. "Find" data from midnight to midnight for each day
%%..4. Use NaNmean to calculate daily averages

%Find the Start and End times
time_start=floor(min(min([date_1;date_2;date_3;date_4;date_5])));
time_end=ceil(max(max([date_1;date_2;date_3;date_4;date_5])));
%Create Date String of Whole numbers
date_single=time_start:1:time_end;
%Create empty variables for Daily Averages
daily_avg_1=nan(length(date_single),1);
daily_avg_2=nan(length(date_single),1);
daily_avg_3=nan(length(date_single),1);
daily_avg_4=nan(length(date_single),1);
daily_avg_5=nan(length(date_single),1);

for k= 1:length(date_single);
    I= find(date_1>=date_single(k)-.5 &
    date_1<(date_single(k)+.5));
    daily_avg_1(k)=nanmean(oxygen_1(I));
end

for k= 1:length(date_single);
    I= find(date_2>=date_single(k)-.5 &
    date_2<(date_single(k)+.5));
    daily_avg_2(k)=nanmean(oxygen_2(I));
end

for k= 1:length(date_single);
    I= find(date_3>=date_single(k)-.5 &
    date_3<(date_single(k)+.5));
    daily_avg_3(k)=nanmean(oxygen_3(I));
end

for k= 1:length(date_single);
    I= find(date_4>=date_single(k)-.5 &
    date_4<(date_single(k)+.5));
    daily_avg_4(k)=nanmean(oxygen_4(I));
end

for k= 1:length(date_single);
    I= find(date_5>=date_single(k)-.5 &
    date_5<(date_single(k)+.5));
    daily_avg_5(k)=nanmean(oxygen_5(I));
end
APPENDIX C - MULTIPLE CRITERIA DECISION ANALYSIS
APPENDIX C-1
MULTIPLE CRITERIA ANALYSIS PARTICIPANT INSTRUCTIONS

Multi-Criteria Analysis – Ocean Observing Platforms

INSTRUCTIONS

1. Review the example on pages 2 and 3 for directions on completing this packet.

2. Fill out the Criteria Ranking Worksheet:
   - Please rank the criteria from 1 to 13 with 1 being the most important and 13 being the least important.
   - Three complete sets of weights should be generated to reflect the three specified ocean-observing goals.

3. Assign criteria scores for each of the platform alternatives:
   - Qualitative Scoring
     i. In response to the criteria statements, create a dark circle that corresponds to the criteria satisfaction and your certainty about the score on the Belief Maps.
     ii. Write the number (A through H) next to the identifying mark, indicating which criteria the score is associated with.
     iii. If appropriate, please provide a rationale for your decision. Space has been provided on the back of each score sheet.
   - Quantitative Scoring
     i. For criteria I through M you are asked to input the potential High and Low values as well as the Most Likely value into the provided table. Some values are in monetary terms, while others are in days per year, etc...
     ii. If you are unsure of the values for a platform that you are unfamiliar or not associated with, you may leave those spaces blank. However, even if you only have a rough estimate, please make an effort to input data.
     iii. If appropriate, please provide a rationale for the values that you input. Space has been provided on the back of each score sheet.

4. Questions/Comments
   - Please don’t hesitate to contact me (Jeremy Childress) if you have any questions related to this study.

5. When you are finished
   - Please send the finished materials to my campus address (provided below) or I can stop by and pick it up.
   - Thanks for your help!

Contact Info:
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Oregon State University
Corvallis, OR 97331
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(717) 779-8515
Example

Criteria Ranking

Part I: Car-buying Goal
In this example, we have two different goals in mind for purchasing a car. The first is to buy a fast car while the second is to buy a fuel efficient and affordable car.

<table>
<thead>
<tr>
<th>Goal 1</th>
<th>Goal 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buy a fast car</td>
<td>Buy a fuel efficient and affordable car</td>
</tr>
</tbody>
</table>

Part II: Criteria Ranking

In each of the columns in the table below, the 6 different criteria (A through F) have been ranked depending on their importance for meeting the stated goals. For Goal 1, horsepower is more important. In Goal 2, miles per gallon and price are most important. For this exercise, a ranking of "1" denotes most importance, while a ranking of "6" represents the criteria of least importance.

<table>
<thead>
<tr>
<th></th>
<th>Goal 1</th>
<th>Goal 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Torque</td>
<td></td>
</tr>
<tr>
<td>B.</td>
<td>Miles per gallon</td>
<td>5</td>
</tr>
<tr>
<td>C.</td>
<td>Car Color</td>
<td>3</td>
</tr>
<tr>
<td>D.</td>
<td>Stereo System</td>
<td>4</td>
</tr>
<tr>
<td>E.</td>
<td>Horsepower</td>
<td>1</td>
</tr>
<tr>
<td>F.</td>
<td>Price</td>
<td>6</td>
</tr>
</tbody>
</table>

Different priorities reflect the different car buying goals.
Example

Part I: Qualitative Criteria
For each of the statements below, please generate a "Criteria Satisfaction" score and "Certainty" score and then place the corresponding letter (e.g., "A", "B", etc.) on the belief map below. To demonstrate, we will use the criterion:
A) The car is easy to drive.

<table>
<thead>
<tr>
<th>Criteria Satisfaction</th>
<th>Certainty of Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully</td>
<td>Fully</td>
</tr>
<tr>
<td>Mostly</td>
<td>Mostly</td>
</tr>
<tr>
<td>Partially</td>
<td>Partially</td>
</tr>
<tr>
<td>Slightly</td>
<td>Slightly</td>
</tr>
<tr>
<td>Not at all</td>
<td>Not at all</td>
</tr>
</tbody>
</table>

A score in this corner says, "I know nothing but the car is very easy to drive."

"I'm an expert and the car is very easy to drive."

"I know nothing and I am neutral."

"I'm an expert and the car is not at all easy to drive."

Part II: Quantitative Criteria
For each section, you are asked to generate high, most likely, and low values for each of the quantitative criterion. These values can be taken from past experience, grant proposals, manufacturer stated operating specifications, or other reputable sources of information.

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Most Likely</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Torque (ft-lb)</td>
<td>150</td>
<td>135</td>
<td>100</td>
</tr>
<tr>
<td>B. Miles per gallon</td>
<td>50</td>
<td>28</td>
<td>18</td>
</tr>
<tr>
<td>C. Horsepower</td>
<td>205</td>
<td>180</td>
<td>150</td>
</tr>
<tr>
<td>D. Price ($)</td>
<td>28,000</td>
<td>27,500</td>
<td>25,000</td>
</tr>
</tbody>
</table>

These values are all examples of what you might find in a specifications booklet or a vehicle invoice.
Criteria Ranking Worksheet

Part I: Ocean-observing goals
In order to compare the alternative ocean-observing platforms, the following three goals were established so that the strengths and weaknesses of each platform could be meaningfully and fairly evaluated.

<table>
<thead>
<tr>
<th>Goal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal 1</td>
<td>Increasing temporal and spatial resolution of measurements.</td>
</tr>
<tr>
<td>Goal 2</td>
<td>Characterising the entire water column from surface to benthos.</td>
</tr>
<tr>
<td>Goal 3</td>
<td>Accessibility to interest groups and other organizations with limited budgets.</td>
</tr>
</tbody>
</table>

Part II: Criteria Ranking
In each of the columns in the table below, please rank the evaluation criteria from 1 to 13 based on their importance for satisfying the corresponding goal (with 1 being the highest and 13 the lowest). Once complete, each column should have one “1”, one “2”, etc... A space has been provided on the back of this sheet for notes.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Goal 1</th>
<th>Goal 2</th>
<th>Goal 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Area of coverage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Historical value (repeated measurements in the same place)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Adaptability in terms of sampling protocol/mission</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. Ease of deployment, retrieval, and servicing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. Acceptance by scientists</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F. Acceptance by non-scientists</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G. Availability of relevant data in formats useful to the non-scientist</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H. Opportunity for engaging non-scientists in data-collection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I. Temporal Coverage (days per year)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J. Timeliness of data (number of days before data is cleaned and available)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K. Number of variables measured</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L. Fixed costs per year (e.g. equipment, boat time)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. Variable costs per year (e.g. personnel costs)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX C-3
EXAMPLE – CRITERIA SCORING WORKSHEET BY PLATFORM

Platform: Ship-Based CTD
Name __________________________

Part I: Qualitative Criteria
For each of the statements A through H please generate a “Criteria Satisfaction” score and “Certainty” score and then place the corresponding letter (e.g. “A”, “B”, etc...) on the belief map below.

A. This platform has expansive, high-resolution N-S, E-W, and water column coverage.
B. This platform has historical value (repeated measurements in the same locations).
C. This platform is acceptable in terms of remotely changing sampling protocol and/or mission.
D. This platform is easy to deploy, retrieve, and service.
E. This platform is accepted by scientists.
F. This platform is accepted by non-scientists.
G. This platform produces relevant data in formats useful to the non-scientist.
H. This platform provides an opportunity for engaging non-scientists in data-collection.

Part II: Quantitative Criteria
For each of the criteria below indicate a high, most likely, and low value for the platform. If you are unsure of the values for a platform that you are unfamiliar or not associated with, you may leave those spaces blank.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>High</th>
<th>Most Likely</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>L. Temporal coverage (days per year)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J. Timeliness of data (number of days before data is cleaned and available)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K. Number of variables measured</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L. Fixed costs per individual platform (e.g. equipment, boat time)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. Variable costs per individual platform (e.g. personnel costs)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Part III: Criteria Scoring Rationale

If any of the qualitative or quantitative scores that you generated require justification or a rationale, please use the form below to capture that information.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX C-4
COST CRITERIA WORKSHEET AND ASSUMPTIONS

<table>
<thead>
<tr>
<th>FIXED COSTS</th>
<th>Variable Costs</th>
<th>Total Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Platform Purchase</td>
<td>Depreciation (20% of initial cost)</td>
<td>Expected Equipment Costs/year</td>
</tr>
<tr>
<td>Autonomous Gliders</td>
<td>$150,000</td>
<td>$30,000</td>
</tr>
<tr>
<td>Autonomous Profilers</td>
<td>$200,000</td>
<td>$40,000</td>
</tr>
<tr>
<td>Bottom Landers</td>
<td>$80,000</td>
<td>$16,000</td>
</tr>
<tr>
<td>Bottom Landers</td>
<td>$250,000</td>
<td>$50,000</td>
</tr>
<tr>
<td>Ship-based CTD</td>
<td>$20,000</td>
<td>$4,000</td>
</tr>
<tr>
<td>Crab Pots</td>
<td>$66,000</td>
<td>$13,200</td>
</tr>
</tbody>
</table>

Assumptions:
1. 280 days of operation
2. Running as a program (multiple platforms)
3. Three parameters (DO, Temp, Conductivity)
4. 1.0 FTE = $64,260k/year (Based on 260 working days = $246.5 per day)

<table>
<thead>
<tr>
<th>Initial Platform Purchase</th>
<th>Depreciation (20% of initial cost)</th>
<th>Expected Equipment Costs/year</th>
<th>Research Vessel Costs/year</th>
<th>Personnel Costs/year</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomous Gliders</td>
<td>1 Glider @ $150,000</td>
<td>--</td>
<td>6.6 Elakha days @ $3,000</td>
<td>2 x 0.5 FTE</td>
<td>--</td>
</tr>
<tr>
<td>Autonomous Profilers</td>
<td>1 unit @ $200,000</td>
<td>--</td>
<td>2 Wecoma days @ $30,000</td>
<td>0.5 FTE</td>
<td>--</td>
</tr>
<tr>
<td>Bottom Landers</td>
<td>4 units @ $20,000</td>
<td>--</td>
<td>6 Elakha days @ $3,000</td>
<td>2 x 0.5 FTE</td>
<td>--</td>
</tr>
<tr>
<td>Buoys</td>
<td>1 Buoy @ $250,000</td>
<td>--</td>
<td>2 Wecoma days @ $30,000</td>
<td>2 x 0.5 FTE</td>
<td>--</td>
</tr>
<tr>
<td>Ship-based CTD</td>
<td>1 unit @ $20,000</td>
<td>--</td>
<td>280 Elakha Days @ $3000</td>
<td>1.0 FTE</td>
<td>--</td>
</tr>
<tr>
<td>Crab Pots</td>
<td>15 DO Units @ $4,000 60 Temp Sensors @ $100</td>
<td>--</td>
<td>Cal = $1000 2 New Sensors @ $2,500 6 New Foils @ $200</td>
<td>.5 FTE &amp; 10 participants @ $1000</td>
<td>--</td>
</tr>
</tbody>
</table>