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Increasing Use and Growing Value of Ocean Observing Systems in Fisheries:

With Illustrations from the U.S. Mid-Atlantic (MARCOOS) Region

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Contents

Introduction

An Integrated Ocean Observing System (IOOS) was first conceived and implemented in the 1990s as a way to increase the value of physical and environmental observations about ocean conditions.[1] Continued IOOS funding has required demonstrating and, where possible, quantifying and monetizing these values. As a result, a small body of literature has emerged that deals with methods of estimating the value of IOOS in general and of various regional observing systems that are part of IOOS. In some cases these tools have been used to estimate the economic value of specific upgrades or expansions of those systems.

The value of information depends on how it is used to improve decisions in ways that reduce risks or costs or increase some measure of benefits. In general, studies of the value of ocean observing systems (OOS) first trace and measure how data they generate are used to provide information that improves two kinds of decisions: those made in economic sectors, such as commercial and recreational fishing, shipping, offshore energy, beach use, and tourism; and those made in the public sector, for example to improve the targeting of search-and-rescue operations or oil spill responses and to better identify sources and expected distributions of contaminant and harmful algal blooms. The value of the data is then measured by comparing how those improved decisions resulted in higher benefits or lower costs and/or risks.

Focus

This article describes applications of this basic approach to determine the fishery-related economic benefits of improved ocean observations in the region served by the Mid-Atlantic Regional Coastal and Ocean Observing System (MARCOOS) (www.marcoos.us). Interviews conducted to focus this work indicated that fisheries-related economic value of ocean data generated by MARCOOS is increasing rapidly for five reasons:

1. Interest is growing in "ecosystem-based fishery management" and "marine spatial planning " that require more information about variability in ocean conditions;
2. Expectations that changing ocean conditions associated with global warming will significantly affect fish population dynamics and the abundance, availability, catchability, and spatial distribution of fish stocks;
3. Improvements in computing capacity, data storage and retrieval systems, and web-based communication are dramatically reducing the cost of using ocean observations in fishery research and allowing it to be analyzed more effectively and incorporated more usefully in fishery science;
4. Increased focus on coupled physical-biological models that rely on ocean observations, and are evolving quickly and proving their value in many fishery applications that directly affect fishery values;
5. Increasing accessibility of online real-time observations about ocean conditions that help fishermen find targeted fish stocks more effectively, reduces search time and related costs and energy use, and also allows fishermen to minimize by-catches of at-risk fish stocks, marine mammals, and sea birds.

Format

This article will describe MARCOOS benefits associated with each of the specific benefit pathways listed above and, where possible, provide some baseline estimates of associated monetary values. The article has three parts:

Part 1 provides a brief review of the literature regarding the value of earth and ocean science information in general, from IOOS in United States coastal waters, and from IOOS as it relates to fisheries.

Part 2 describes the results of an online survey of U.S. fishery scientists conducted in 2008, which illustrates the potential value of IOOS in reducing uncertainty regarding fish population dynamics and improving fishery management; and identifies which types of observations fishery scientists believe are most and least important.

Part 3 shows how IOOS-based reductions in uncertainty about the level of harvest required to achieve legally-mandated stock-rebuilding goals result in direct economic gains to fishermen; and provides a preliminary estimate of those dollar gains in the MARCOOS region.

Part 1: Review of IOOS Economic Benefits Literature

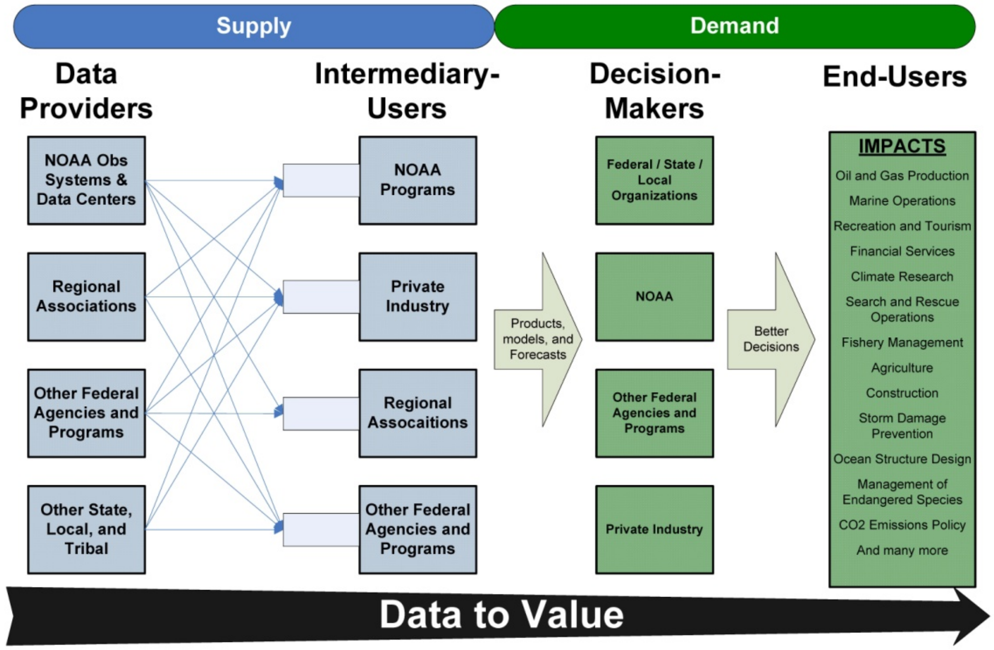
Assessing the value of any piece of information requires addressing four questions: how much better is it than the next best available information, how can it be used in decision making, what is at stake in those decisions, and what the information costs. Since the late 1970s several studies have attempted to answer these questions to assess the economic value of improved information generated about earth and ocean conditions.[2]

Specific attempts to assign economic value to information generated by OOS have been undertaken since the 1990s. These have included general studies that attempt to sum across various types of economic value pathways, and more narrowly focused studies that deal with particular benefit pathways associated with fisheries, shipping, search and rescue, oil spill response, or beach management, and so on. Appendix 1 provides references for most of these studies and gives an overview of the types of benefits that were measured, the general approach, and the results that were generated in each case.

In 2008, many of the most recent studies that were conducted to determine the value of U.S.-based OOS were summarized in a special issue of *Coastal Management Journal* that included case studies of the potential value of regional OOS for Florida, the Southeast, the Gulf of Maine, California, and Alaska.[3] Later in 2008, this work was used by NOAA to generate an overall assessment of IOOS benefits in the United States which was summarized in "The Business Case for Improving NOAA's Management and Integration of Ocean and Coastal Data."[4]

This 2008 NOAA report employs an "Ocean Data Value Chain" to describe how ocean observation data and communications capabilities generate value to intermediary users (e.g., fisheries scientists, meteorologists); and subsequently to decision-makers (e.g., fisheries managers, emergency and spill response managers); and eventually to end-users and other beneficiaries (e.g., fishermen, seafood consumers, the general public).[5] Figure 1 depicts this Ocean Data Value Chain which provides a useful framework for tracing and measuring the many different pathways of OOS values.

Figure 1. The Ocean Data Value Chain



Note: NOAA Obs Systems and Data Centers refers to providers of ocean data, data centers and centers of data, including National Data Buoy Center (NDBC), National Oceanographic Data Center (NODC), National Climatic Data Center (NCDC), National Geophysical Data Center (NGDC), CO-OPS, CoastWatch, and NOAA Fisheries Science Centers (NFSC).

Source: NOAA 2008a.

OOS Benefit Pathways

There are actually two discrete types of ocean-related information generated along an ocean data value chain that are used by two distinctly different types of decision-makers. ***Forecasts*** of ocean conditions provide data to be used in predictive models that generate results to help guide planning, investing, and strategic decision making. ***Nowcasts*** involve providing real-time or near real-time information to help guide operational decision-making, such as fishing, search and rescue operations, or responding to oil spills and contaminant plumes.[6]

The same ocean observations can be used to generate benefits through both forecasts and nowcasts, but they must be packaged and delivered to users in different ways. Historical data regarding sea surface temperature and currents, for example, may be useful to forecast fish larvae survival and establish allowable fish harvests that are sustainable; while real-time sea surface temperature and current data may help fishermen target their catch more effectively and reach the allowable harvest at lower costs and with fewer by-catch problems. In this instance, the values associated with these two pathways are additive. Improved surface temperature and current data reduce uncertainty regarding what the allowable level of harvest should be, and also make it less costly, in terms of dollars, energy and by-catch problems, for fishermen to take the allowable harvest.

In strictly economic terms, the appropriate measure of the economic value of IOOS is the change in what economists call the "social surplus" expected to result from IOOS. Social surplus is the sum of the producer surplus (the difference between the value of output and the value of the inputs used to produce output) and the consumer surplus (the difference between what consumers would be willing to pay for output and what they actually pay). However, estimating producer and consumer surplus is extremely difficult and costly; and estimating them in industries that benefit from IOOS data and determining how they differ with and without IOOS data would be nearly impossible.

Therefore, following a convention initiated in a 1986 study of the value of weather forecasts in agriculture, energy, transportation and other industries, several studies of IOOS value simply assume that the social surplus benefit of IOOS information is about one percent of the total value of the output of the industries that use IOOS information.[7] Many of the IOOS valuation studies listed in Appendix 1 describe and sometimes provide limited illustrations of how more refined estimates of IOOS values could be generated for specific industries, but conclude that doing so would be prohibitively costly.[8] Studies that use the 1% rule usually include the caveat that results only provide a first approximation and suggest that more refined estimates should be undertaken at some time in the future when the costs can be justified. However, it seems clear from the IOOS valuation literature that while it may be possible to develop more refined value estimates for a few specific pathways of IOOS benefits in some regions, attempting to estimate the full range of IOOS values for a given region will require using some very general rules of thumb, like the 1% rule.

Setting up and operating ocean observing systems involves significant upfront and operational costs, estimated by NOAA at more than $20 million for FY2009 alone.[9] However, the development of these systems is taking place during a period when expanded use of the internet and other telecommunication technologies is driving the cost of information distribution toward zero, making it accessible nearly everywhere. While these new information delivery technologies greatly increase access to, and demand for, this information, they also complicate the links between the data producers (at one end of the ocean data value chain), the data and information consumers (the “end-users” at the other end of the chain), and those who ultimately benefit from the use of the information and may not even be aware of it.

For example, several studies have indicated that the main pathway of fishery-related economic benefits associated with improved ocean information is associated with higher short-term or long-term fish yields, which result when fishery scientists and regulators use better ocean information to reduce uncertainty about fish stocks and the sustainable allowable harvest. By reducing uncertainty about the causes of observed changes in fish stocks, fishery managers can more properly decide to reduce the allowable harvest - to keep the fishery sustainable - or increase the allowable harvest - to allow more short-term economic benefits. Either way, improved decisions by these "intermediate users" of ocean data ultimately benefit fishermen and seafood consumers, as well as the general public.[10] Analysis summarized in Section 3 of this report indicates that these fishery related OOS values have the potential to be worth $10 to $15 million per year in the MARCOOS region alone.

Uncertainty regarding the status of exploited marine populations leads to two types of fishery management problems. It results in fishery management decisions that may lead to allowable exploitation rates that either exceed threshold levels for a sustainable fishery, which reduces long-term economic returns from the fishery, or fall below sustainable levels, which limits the near-term economic value of the fishery.[11]

Recent research into the fishery-related benefits of better physical ocean data has been linked to how those data can be used to reduce uncertainty and associated errors in fishery management. A recent study by Jason Edwards and Thomas Miller reviewed research related to the use of ocean observations in fisheries science and management and described how coupled physical-biological models (CPBMs) are being used with increasing frequency to incorporate environmental factors into fisheries science and management. The authors suggest that advances since the late 1980s in the field of fish ecology and in hydrodynamic circulation modeling, and the subsequent development of CPBMs, present new opportunities for MARCOOS data to improve fisheries management. The authors note that over the past twenty years or so, CPBMs have evolved into an increasingly powerful tool for examining the relationships between fish and the physical environment, and with future improvements to both OOS technology and ocean circulation modeling, these models may become a valuable tool for incorporating realistic physical and biological variables into fish stock assessments over a range of temporal and spatial scales. They describe not only the overall potential and limitations of using ocean data and CPBMs in fisheries science and management, but also the frequency and resolution of ocean data that are required to make CPBMs useful for purposes of fishery management.[12]

Part 2: Use of Ocean Observations by Fishery Scientists and Fishery Managers

Survey Overview

Building on the research described above about the potential benefits of enhanced ocean-observation data and communications, we analyzed the potential economic benefits of ocean observations to fisheries and fisheries management in the MARCOOS region. As part of that work, we conducted an online survey of fisheries scientists and managers in the region to assess the benefits of MARCOOS data and communications to intermediary users (e.g., fishery scientists and managers) and ultimate beneficiaries (e.g., fishermen, seafood consumers, etc). We also sought to determine what types of MARCOOS data are, or could be, most useful to users in different stages of the "Ocean Data Value Chain."

We developed, pre-tested, and posted a survey questionnaire on the commercial Survey Monkey website (www.surveymonkey.com) in September 2008. We then emailed numerous fishery scientists, requesting their participation in our survey and providing them the web-link to the survey site. We also enlisted several well-known fishery scientists to contact their peers and request that they participate in our survey. By January, 5, 2009 forty-four fishery scientists had completed the online questionnaire. Results are summarized and discussed in the following sections.

In general, survey responses suggest that more frequent, accurate, and timely ocean-observation data, combined with an enhanced data management and communications capability resulting from MARCOOS implementation, would be of direct benefit to fishery scientists who would incorporate this information into their analyses. However, respondents were less certain that this information would then be incorporated into decisions by fishery managers.

Survey respondents generally agreed that providing commercial and recreational fishermen with reliable real-time, location-specific surface and subsurface water current and temperature data, would reduce search time and energy costs, would allow fishermen to be more selective in targeting particular fish, and would help them avoid some by-catch problems. These potential efficiencies could provide economic benefits to end-users, as discussed in Part 3 of this paper.

Survey Results

Importance of ocean observations in general

Survey respondents indicated that better information about physical ocean and environmental factors would help them in their work, supporting the conclusion described by Edwards and Miller (2009) in their review of coupled biological-physical models. All survey respondents said that in the fisheries where they work, the overall effect of physical ocean and environmental factors on the dynamics of fish populations was important, highly important or extremely important, with 80% responding in the "highly important" or "extremely important" categories. Similarly, 81% of survey respondents said that in assessing fish population dynamics, ocean-related physical and environmental factors are important, highly important, or extremely important. However, only 43% rated this in the "highly important" or extremely important" category and 19% said it was "not important" or "barely important."

Eighty-four percent of survey respondents agreed or strongly agreed that if more reliable physical and environmental data were available, more fishery scientists would incorporate changes in ocean conditions into their fishery analysis. Six percent disagreed or strongly disagreed with this statement, and 10% didn't know. By contrast, when asked the same question, but with reference to fishery managers, only 52% of survey respondents agreed or strongly agreed with the statement. Nineteen percent disagreed or strongly disagreed, and 29% didn't know.

Eighty-eight percent of survey respondents agreed or strongly agreed that changes in ocean conditions associated with global warming will make it difficult to manage fisheries in the future without a better understanding of ocean/fish interactions (forty-three percent strongly agreed with this statement). Two percent disagreed with this statement (no respondents strongly disagreed), and 10% didn't know.

Eighty-four percent of survey respondents agreed or strongly agreed that the difficulties fishery scientists have in predicting and explaining fish population dynamics in some fisheries are a result of ocean/fish interactions that are not understood. Eight percent disagreed or strongly disagreed with this statement, and 8% said they didn't know.

Sixty-five percent of survey respondents agreed or strongly agreed that uncertainty regarding the effects of ocean conditions on fish population dynamics is a significant source of conflict and distrust among fishing industry representatives, fishery scientists, and fishery managers. Sixteen percent disagreed or strongly disagreed with this statement, and 19% didn't know. However, when asked whether research to better understand the relationships between fish populations and physical and environmental factors should be given a higher priority in the field of fisheries, the vast majority (86%) agreed or strongly agreed with this statement.

Importance of reliable data on specific ocean factors

Survey respondents were asked, if reliable data related to a list of ocean factors were available, would they be important in improving the assessment of fish abundance and fish population dynamics, and would they enhance sustainable fishery management.

For most of the seven data categories on the list, the vast majority (≥75%) of survey respondents either agreed or strongly agreed (see Table 1). An exception was wave height, where just 16% agreed or strongly agreed, 29% disagreed or strongly disagreed, and more than half (55%) didn't know.

Survey respondents were then asked, if reliable data related to the same list of factors were available to fishery scientists in fisheries where they work, would it help strengthen confidence in and reliance on the recommendations they make to fishery managers.

For most of the seven data categories on the list, the majority of survey respondents either agreed or strongly agreed (≥55%), although not to the extent the respondents agreed with the previous statement. Again, wave height was an exception, with most respondents (48%) answering that they didn't know. In fact, in each of the other six categories, the difference in aggregate response between this and the previous iteration of the question was more the result of respondents saying they didn't know (between 16 and 37 percent, depending on the question), than disagreement with the statement (although, for each factor, the percentage of respondents disagreeing increased slightly).

Table 1. Survey responses regarding the importance of data on ocean factors

	% respondents who agreed or strongly agreed	
Data Category	**If reliable data were available, it would be important in assessment of fish abundance and population dynamics**	**If reliable data were available to fishery scientists, it would strengthen confidence in recommendations to fishery managers**
Surface Currents	92%	71%
Subsurface Currents	90%	68%
Wave Height	16%	22%
Water Temperature	98%	80%
Salinity (Density)	86%	78%
Dissolved Oxygen	84%	76%
Chlorophyll a	75%	55%

Usefulness of real-time, location-specific data for commercial and recreational fishers

Survey respondents were then asked if providing commercial and recreational fishers with reliable real time location-specific surface and subsurface water current and temperature data would allow them to…(accomplish a series of desirable objectives).

While the responses were typically more in agreement than not, in most cases a large percentage of respondents replied that they didn't know (see Table 2).

Table 2. Survey responses on usefulness of data for commercial and recreational fishers

Would real time location-specific surface and subsurface data allow fishers to...	Agreed or Strongly Agreed	Disagreed or Strongly Disagreed	Don't Know
reduce search time and related energy costs?	70%	4%	26%
be more selective in targeting particular fish?	66%	10%	24%
avoid some by-catch problems?	45%	16%	39%
avoid some encounters with endangered species?	34%	18%	48%
avoid some gear losses?	38%	16%	46%

Significance of ocean variables to fish populations, fishery science, and fishery management

Respondents were asked to rank physical ocean and environmental variables on a scale from 0-10 in terms of a) their impact on fish population dynamics, b) their use in fishery science, and c) their utility in fishery management. The ranking scale was as follows: Zero="Don't Know;" 1 & 2="Not Significant;" 3 & 4="Barely Significant;" 5 & 6="Significant;" 7 & 8="Highly Significant;" 9 & 10="Extremely Significant."

With few exceptions, each factor was scored highest in terms of its impacts on fish population dynamics, next highest in its use in fishery science and lowest in its utility in fishery management (see Table 3). The only exceptions to this were surface current maps and digital images of beach and near-shore oceans which are not environmental factors but products of research and therefore do not apply to fish population dynamics. Generally speaking, the ranking of factors was similar between importance to fish population dynamics and fishery science research, confirming that fishery scientists find the environmental factors most important to fish dynamics equally important in their own work. The lower scores for each variable for utility in fishery management suggests that respondents (i.e., fishery scientists) believe these factors will help them make better recommendations to fishery managers, but are less likely to be used directly by fishery managers.

The relative rankings (0-10, with zero for “don't know” and 10 for “extremely significant”) of the importance of physical ocean and environmental factors to fish populations, averaged from all survey participants, are found below.

Table 3. Survey responses on the significance of ocean variables to different users

Factor	Fishery science research		Fishery management	
	Rank	Average score	Rank	Average score
Surface and Bottom Salinity	1	7.27	6	5.18
Dissolved Oxygen Concentration	2	7.21	5	5.46
Surface Water Temperature	3	7.15	4	5.51
Surface Current Maps	4	7.07	2	5.71
Bottom Water Temperature	5	7.05	6	5.18
Chlorophyll	6	6.8	12	4.77
Dissolved Oxygen Saturation	7	6.7	3	5.53
Digital Images of Beach and Near-shore Oceans	8	6.64	1	6.25
Turbidity	9	6.51	9	4.94
Precipitation	10	6.47	16	4.58
Near-surface Current Direction	11	6.44	8	5.03
Wind Direction	12	6.42	13	4.76
Near-bottom Current Direction	13	6.26	10	4.86
Near-surface Current Speed	14	6.19	11	4.78
Wind Speed	15	5.94	17	4.45
Near-bottom Current Speed	16	5.91	15	4.7
Water Level	17	5.76	14	4.73
pH	18	5.7	19	4.2
CDOM (Chromophoric Dissolved Organic Matter)	19	5.44	18	4.22
Conductivity	20	5.31	20	4.16
Average score range	5.31-7.27		4.16-6.25	

The responses by fisheries scientists to the questions we posed in our online survey indicate that the physical ocean observations being collected by MARCOOS are valuable to intermediate users such as the scientists themselves. However, survey responses from fisheries scientists suggest that users further along the "Ocean Data Value Chain," such as fisheries managers and ultimately commercial fishers, are less likely to use this information. Recent changes to fisheries management regulations outlined in the next section suggest, though, that these data will become more valuable to both managers and fishers.

Part 3: Economic Benefits from Reduced Uncertainty in Fisheries Management Decisions in the MARCOOS Region

Our review of the relevant literature indicates that measuring the value of new information, such as improved observations about physical ocean conditions, is always difficult because it depends on how the information is used to improve decisions and how those improved decisions generate benefits or reduce costs or risks. It is also very difficult to distinguish the value of improved information (content) from the value of improvements in systems for conveying information to decision makers (delivery). The value of all information increases when it is made more accessible, understandable, and more likely to be useful in decision-making. For this reason, the value of all information has increased in recent years as a result of advances in telecommunications, computing capacity, data management, and protocol-sharing, making information more useful at lower cost to more people. As the survey results presented in the previous section indicate, this is especially true in the case of information generated by ocean observing systems.

Recent changes in how U.S. fisheries will be managed will have a direct and meaningful impact on the fishery-related value of ocean observing systems. The 2007 reauthorization of the Magnuson-Stevens Act (MSA), the U.S. law that governs fishery management, mandates science-based definitions of "overfishing" for all fisheries and requires regional fishery management councils to set clear targets and timetables for "preventing and ending overfishing and rebuilding U.S. fisheries."[13] Importantly, it also mandates a "precautionary" approach which requires fishery managers to consider scientific uncertainty and err on the side of fish stocks when imposing fishing restrictions to prevent overfishing and meet fish stock rebuilding targets.

This important shift in how fishery managers must deal with uncertainty about whether a fish stock is overfished or experiencing overfishing is important for two reasons. First, the level of uncertainty about the condition of fish stocks, under these new mandates, has a clear economic cost in terms of reducing the allowable harvest. Reducing uncertainty, therefore, has a direct economic value associated with increasing the allowable harvest.[14] Second, as the survey results presented in Part 2 demonstrate, misunderstanding ocean/fish interactions due to inadequate information about ocean dynamics causes a significant source of uncertainty about fish population dynamics. The availability of better ocean data to improve understanding of ocean/fish interactions, therefore, can be expected to reduce errors in fishery management and result in more stable and sustainable conditions in fisheries.

To appreciate how improvements in ocean observations will generate fishery-related economic benefits along this particular pathway, it is necessary to understand what this new fishery policy means in terms of how fisheries will be managed. A fish stock is classified as ***being overfished*** if fish abundance is below an established reference point; the stock is ***experiencing overfishing*** if the level of exploitation is above a particular reference point beyond which it will become overfished.[15] Establishing whether a fish stock is overfished or experiencing overfishing is the first step in determining the allowable harvest and what types of catch or effort restrictions are needed to assure that catches do not exceed the allowable harvest.

The significant new change in fishery management, however, involves how scientific uncertainty about fish abundance, levels of exploitation, and stock rebuilding potential will influence fishery management. Figure 2 depicts the general framework that is used in the U.S. to assess and classify fish stocks based on their abundance and level of exploitation, and to establish allowable harvest levels. The figure illustrates the various measures of the annual catch that are used to determine what catch limits are needed to prevent overfishing and rebuild overfished fish stocks. These include four carefully defined reference points:

- "Overfishing limit" (OFL)
- Acceptable Biological Catch (ABC)
- Annual Catch Limit (ACL)

- Annual Catch Target (ACT)

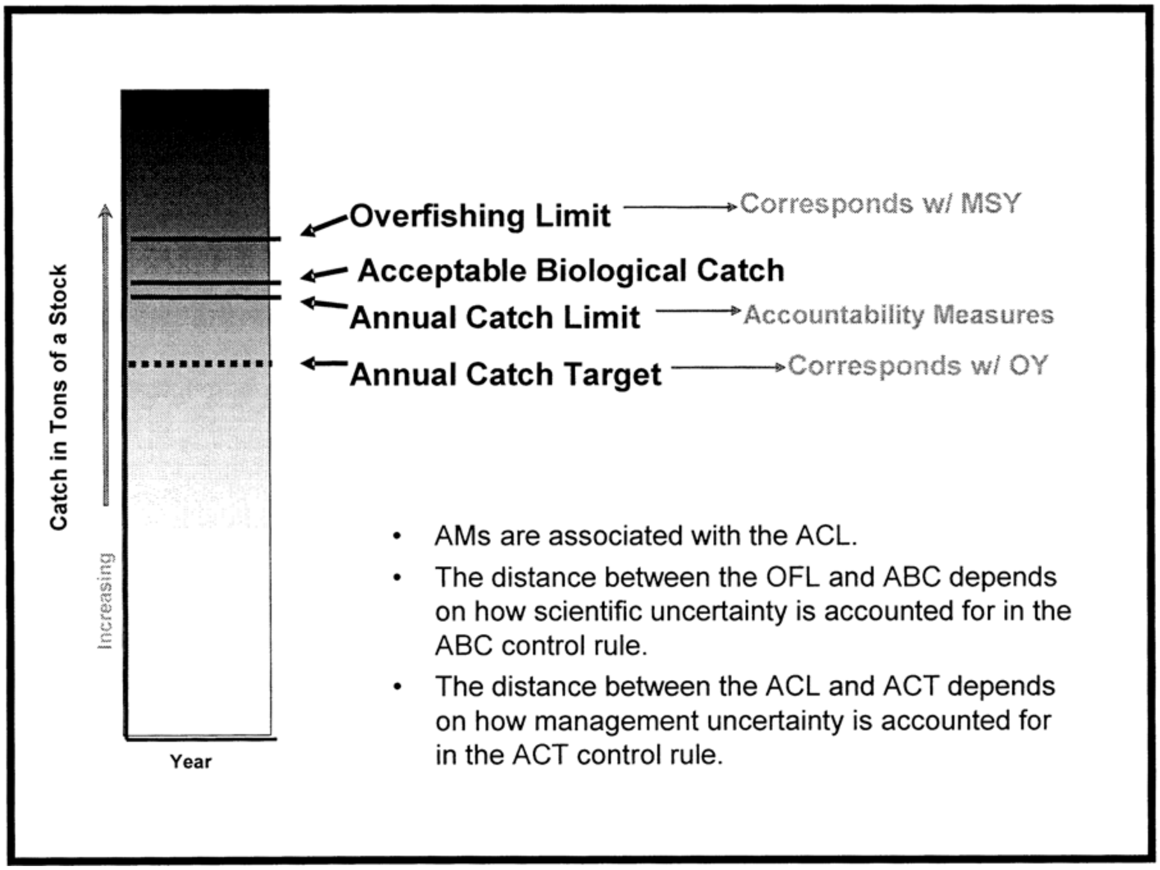
In the present context, the important relationship involves the difference between the intended annual catch limit (ACL) and the annual catch target (ACT). Under the new guidelines the ACT must be lower than the ACL by an amount that is determined by the level of uncertainty associated with ACT and how to achieve it.

The economic value of the difference between the ACL and the ACT, therefore, is a direct measure of the cost of uncertainty in terms of foregone economic value of the annual harvest and associated fishermen incomes. The economic multiplier effects associated with reductions in economic activity associated with that foregone harvest - measured in terms of lost business sales, jobs, household incomes, taxes and so on - is a measure of the indirect and induced costs of that uncertainty.

These measures of direct and indirect costs associated with uncertainty about fish stocks can be used to measure the value (reductions in costs) associated with information that helps reduce that uncertainty. For purposes of our analysis it is important that: 1) under the new fishery management guidelines ACTs will be higher when fishery scientists become more certain about the catch level required to achieve the ACL; and 2) based on our survey results, a major source of uncertainty regarding fish population dynamics is a lack of understanding of ocean/fish interactions which results, in part, from inadequate data regarding ocean conditions.

We can use these two relationships to develop a first approximation of the potential fishery related benefits associated with MARCOOS ocean observations.

Figure 2. Relationship between OFL, ABC, ACL and ACT (see discussion of the ABC and ACT control rules below).



Graphic Source: NOAA 2008b

The MARCOOS Illustration

Table 4 shows that the annual economic value of commercial fish landings in the MARCOOS region is roughly $1.0 billion.[16] Therefore, if improved ocean observations can contribute to a better understanding ocean/fish interactions in the region that results in a one percent reduction in uncertainty that allows allowable catch limits (ACLs) to increase by 1% it would result in annual fishery-related economic benefits of about $10 million.[17]

This $10 million is probably a conservative estimate of fishery related values of MARCOOS data since it is associated only with potential increases in the allowable commercial harvest that result from the use of OOS data in fishery science and management. It does not include the additional economic value of "real time" information about ocean conditions that can be used by commercial and recreational fishermen to reduce search time and fishing costs and better target allowable fish stocks. It also does not include the "nonmarket" economic benefits associated with the use of real time ocean observations by fishermen to avoid by-catch problems and reduce the incidental kills of marine mammals, sea birds, and other non-target species. So, if OOS data for the MARCOOS region were used to reduce uncertainty about fish stocks and thereby result in a 1% increase in the allowable commercial harvest and also to reduce search time for commercial and recreational fishermen, and reduce unintended by-catch problems it is not unreasonable to expect that related annual fishery-related benefits could be significantly higher than $10 million.

Table 4. MARCOOS Region Commercial Fisheries Landings, 2007

State	Finfish ($)	Shellfish ($)	Total ($)
Massachusetts	109,161,589	311,015,875	420,177,464
Rhode Island	24,961,633	48,577,449	73,539,082
Connecticut	3,270,438	38,782,110	42,052,548
New York	19,979,274	39,633,895	59,613,169
New Jersey	24,171,423	127,281,222	151,452,645
Pennsylvania	126,872	0	126,872
Delaware	1,256,927	6,637,266	7,894,193
Maryland	11,925,260	46,755,787	58,681,047
Virginia	45,737,549	86,874,770	132,612,319
North Carolina	36,208,007	46,123,792	82,331,799
TOTAL	**276,798,972**	**751,682,166**	**1,028,481,138**

Source: http://www.st.nmfs.noaa.gov/st1/commercial/landings/gc_runc.html Site last reviewed September 30, 2009.

Conclusions and Recommendations

General Conclusions

As discussed in earlier sections of this article, a number of factors can explain the increase in the value of ocean observations in fisheries, even though this value may be difficult to measure in terms of dollars. Currently, there is growing interest in "ecosystem-based fishery management" and "marine spatial planning" which both represent a more holistic view of management than traditional narrowly focused (e.g., single species) management. Ecosystem-based management operates under the principle that a target-species may be more effectively managed by understanding and potentially preserving the biotic and abiotic factors that influence its productivity. These factors may include abundances of predators, biomasses and production of lower trophic levels and physical factors such as dissolved oxygen, salinity and availability of habitat. Marine spatial planning is based on the understanding that marine populations are not homogenous over space and time and therefore, protection should be afforded to species in certain areas during critical periods. Some habitats will be important to fish productivity and the level of this productivity will vary over time as a result of multiple factors.

Understanding the spatial and temporal variability in fish productivity and the factors that influence it are essential to effective spatial management. OOS data is valuable to both ecosystem-based and spatial fisheries management approaches because it provides important data on the factors influencing fish populations, by which management decisions can be made. Additionally, changing ocean conditions associated with global warming are expected to affect fish population dynamics and the abundance, availability, catchability, and spatial distribution of fish stocks. The value of ocean observations is also increasing as the cost of using these observations in fishery research decreases and the efficiency of incorporating these data into fishery science increases through improvements in computing capacity, data storage and retrieval systems, and web-based communication.

Improved technology and increased focus on coupled physical-biological models are also proving their value in many fishery applications that directly affect fishery values and require ocean observations. Value is also increased through the improved accessibility of online real-time observations about ocean conditions, enabling more effective targeting of fish stocks, reducing search time and related costs and energy use, and also allowing fishermen to minimize by-catches of at-risk fish stocks, marine mammals, and sea birds. Finally, the precautionary principle being implemented by U.S. fishery managers means that there is a significant economic reward for reducing uncertainty about status of fish stocks.

Specific Conclusions

Our research also led us to a number of conclusions about the use of ocean observations in fisheries. First, using the "1% rule," the annual value of ocean observations in fisheries, based on their potential use for reducing uncertainty and increasing the allowable harvest, is about $10 million. In addition to this direct economic impact, there are other economic benefits associated with the use of real time ocean observations by fishermen, which include reductions in search time and associated costs, reductions in by-catch, and reductions in incidental kills of non targeted species. The types of most useful observations vary by user-group. Specifically, time-series of certain ocean observations are particularly important in the context of both fisheries science and fisheries management while real time observations of other ocean conditions are more important to fishers. Finally, our research indicated that the frequency and resolution of ocean observations affect how they can be used in fishery science and management and by fishermen.

Recommendations

Our research into the value of ocean observations has led us to make several recommendations. First, the ocean observation community should strive to improve the ocean observing system to provide the most useful observations at frequencies and resolutions that are most likely to be utilized by both intermediate and end users on the Ocean Data Value Chain. Additionally, there should be a focus on the development of "value added" information products that use basic ocean observations to develop leading and concurrent indicators of ocean changes that will affect fish stocks, improve measures used in fish population dynamics, and improve understanding of the distribution of fish and other species both spatially and in the water column. Finally, there should be a focus on the effective use of leading indicators in fishery science, fishery management, and marine spatial planning.

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Appendix 1. Estimates of the Value of IOOS and Regional Ocean Observing Systems.

Authors	Year	Region	Type of Benefit	General Approach	Results
Adams, et al.	2000	U.S.	Weather Forecasting Benefits for Agriculture, Hydroelectric Power Generation, Coastal Management, and Other Industries	Initial study notes that the study team was unable to quantify the magnitude of benefits precisely at the time.	First order estimate suggests IOOS benefits of hundreds of millions of dollars annually
Adams, et al.	2002	Mexico	Benefits to Mexican Agriculture of ENSO Early Warning System	Measured the expected increase in economic benefits due to changes in cropping patterns, production and consumption arising from the yield changes under each ENSO phase forecast, assuming 70% accuracy	$10 million annually for five-state Mexican region.
Bouma, et al.	2009	North Sea	Benefits to Fisheries Managers of Early Warning System for Harmful Algal Blooms	Combination of Bayesian decision theory and expert consultation	24,000 Euros per week
Australian Academy of Tech. Sciences and Engineering and West Australian GOOS	2006	Australia	Industries Including Agriculture, Oil and Gas Production, Fisheries/Aquaculture	Assumptions about better decisions for planting/harvest; 1% rule of thumb for improved productivity in fisheries; reduction in lost days for oil and gas production.	$87 million annual benefit to agriculture; $114.7 million to oil and gas production; $39.4 million to fisheries/aquaculture.
Dumas and Whitehead	2008	Southeast U.S. (NC, SC, Georgia, Florida)	maritime transportation, commercial fishing, recreational fishing and boating, search and rescue operations, oil spill management and prevention, hurricane evacuation warning systems, beach recreation opportunities, cruise line operations, beach erosion management	1% rule-of-thumb benefit from increased efficiency due to better information for most industries; for fisheries, assume one extra favorable fishing day per season.	$170 million annual benefit
Flemming	2001	Europe	EuroGOOS Benefits to Sectors Including Transport, Energy, Environmental Protection, Mineral	1% as a conservative estimate for the improvement in efficiency for marine-related industries in Europe	$1.4-2.3 billion annually

Authors	Year	Region	Type of Benefit	General Approach	Results
			Extraction, Fisheries, Tourism, Agriculture		
Kite-Powell	2007	Houston and Galveston Ports	Benefits from NOAA Physical Oceanographic Real-Time System (PORTS) for Safety, Recreation, Vessel Efficiency, Oil Spill Response	For most industries, applied 1% rule-of-thumb	$14.1-$15.6 annually
Kite-Powell and Colgan	2001	Gulf of Maine	Maritime Transportation, Commercial Fishing, Recreational Fishing and Boating, Search and Rescue, Oil Spill Management/Prevention	For most industries or uses, applied 1% improvement or increase in effectiveness due to improved information	$33 million annual first-order estimate
Kite-Powell, Colgan and Weiher	2008	U.S.	Overview of Studies Compiled in *Coastal Management* Issue on Ocean Observations		
Kite-Powell, et al.	2004	U.S.	Recreation, Transportation, Health & Safety, Energy, Commercial Fishing	Benefits from avoided false positives/negatives (energy, recreation); improved spatial/temporal accuracy (health & safety, storm prediction, search and rescue); increased catch (commercial fisheries)	Order of magnitude annual social-surplus estimate ranging from $223-$236 M; other value estimates ranging from %596-$684M.
Pendleton	2008	California	Recreational Beach Use	Estimated lost recreational value from beach closure decisions	$6 million in annual beach-related recreational spending; $3 million in public-health savings
Richert, Bogden and Quintrell	2008	Gulf of Maine		Survey of selected users of GoMOOS information	
U.K. Inter-agency Committee on Marine Science and Technology	2004	United Kingdom		Market price paid for marine measurement data; Proxies to market price (i.e., cost savings, value added, cost of obtaining alternative data); WTP of users	
Wellman and Hartley	2008	Alaska	Commercial Fisheries	Bayesian methodology to analyze value of reduced uncertainty in decision-making by fisheries managers about stocks and fishing quotas.	$600 million in additional annual revenue to Alaska groundfish fisheries.

Authors	Year	Region	Type of Benefit	General Approach	Results
Wieand	2008	Florida	Recreational Fisheries	Bayesian methodology to estimate impacts of improved coastal information on marine recreational fishing	$91 million annual benefit in Florida
Woods, et al.	1997	Europe	EuroGOOS Benefits to Marine-Related Industries		2-5 billion ECU annually

Endnotes

[1] For a brief history of IOOS, see The Business Case for Improving NOAA's Management and Integration of Ocean and Coastal Data (NOAA 2008a).

[2] Macauley (2005) summarized this literature. Several studies by Centrec between 2003 and 2007 evaluated economic benefits associated with NOAA programs including the Geostationary Operational Environmental Satellites (GOES) and National Environmental Satellite Data and Information Service (NESDIS), and the economic value of selected NOAA products within the railroad sector (CENTREC 2003, CENTREC 2005, CENTREC 2007).

[3] See Coastal Management 36:2

[4] See NOAA (2008a).

[5] The concept of a "value chain" as it is applied to the use of business intelligence is described in Brackett (1999).

[6]See Kite-Powell, et al. (2008).

[7] The "one per cent rule" of the value of the output of industries using more refined weather forecasts is discussed in Nordhaus (1986).

[8] For a discussion of the challenge of developing precise estimates of the value of information, see Kite-Powell et al. (2008).

[9] For FY2009, $14.81 million was awarded to regional ocean observing systems to establish coordinated regional observing and data management infrastructures, develop applications and products for regional stakeholders, and craft regional and national data management and communications protocols. In addition, regional associations received $4.38 million in planning grants designed to assist them in stakeholder engagement, education and outreach, and long-range planning, and an additional $1.67 million was provided for nationwide technical support for the complete system. http://ioos.gov/library/regionalfactsheets_2009.pdf

[10] For further discussion of the potential for improved ocean observation information to increase fishing days and/or sustainable yields in different regions, see Kite Powell and Colgan (2001) (Gulf of Maine); Wellman and Hartley (2008) (Alaska); Dumas and Whitehead (2008)(SE).

[11] See Fogarty et al. (1996).

[12] See Edwards and Miller (2009)

[13] Information about the 2006 amendments to the Magnuson Stevens Act and planned implementation strategies are available at www.nmfs.noaa.gov/msa2007.

[14] Wellman and Hartley (2008) cite an Alaska example of NMFS stock assessments for Pollock only being correct 60% of the time.

[15] As a point of reference, in December 2008, NMFS reported to Congress that it has established "overfished" thresholds for only 173 of the roughly 230 economically significant U.S. fish stocks ,and that of those 173 stocks, 45 are overfished. Additionally, NMFS reported that "overfishing" thresholds had been established for 188 of the 230 stocks and that 40 of these stocks are currently "experiencing overfishing." Considering fish stocks that are already overfished, those experiencing overfishing, and those that are both overfished and experiencing overfishing, regulators are required under the recent MSA amendments to significantly tighten regulations governing fishing for roughly 26% of the economically-significant fish stocks in U.S. waters for which overfished and overfishing thresholds have been established. See: NOAA (2009).

[16] The MARCOOS region generates an estimated $7.4 billion in recreational spending on saltwater fishing, including expenditures for party charter, private/rental, shore-based, and equipment/durable goods (see King, Wainger and Cantrell 2008, based on data from the National Ocean Economics Program). It is important to distinguish between the value of commercial landings and the recreational economic impacts. The recreational amount is noted solely to demonstrate that there are potential economic values from MARCOOS beyond the commercial fishing application.

[17] Assuming that ocean observations in the MARCOOS region will result in a 1% increase in annual commercial fish harvest in the MARCOOS region is a very weak basis for estimating the fishery-related economic benefits of MARCOOS programs. At the present time, however, there is no basis for generating a more reliable estimate so, following the precedent established in earlier studies listed in Attachment A we have applied the 1% rule here.