`Harnessing Ocean Observing Technologies to Improve Beach Management: Examining the Potential Economic Benefits of An Improvement in the Southern California Coastal Ocean Observing System

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1. Introduction

Despite efforts to reduce coastal water pollution, bacterial contamination continues to affect beaches in Southern California; often these contamination events result in the closure of beaches to swimming. Between 1999 and 2002[1], Los Angeles and Orange Counties suffered an average of 147 beach closure days annually (where one beach closure day represents a closure of access to the water at one beach for one day). These closures represent 0.7 percent of all possible beach days. In addition, during 2000, 2001, and 2002, there were an average of 2456 days of beach postings in Los Angeles and Orange Counties (NRDC 2003)[2] representing more than 12% of all possible beach days. The economic impacts of such closures, postings, and the contamination that leads to these closures could be substantial. Beach closures reduce recreational opportunities for beach goers and deprive coastal businesses of revenues. Further, the methods for determining when beaches should be closed are imperfect; failures to quickly detect the bacterial contamination that leads to closures may result in serious exposure of beach goers to viruses and other human pathogens.

Improved coastal monitoring, especially through improvements in the Coastal Ocean Observing System, could significantly improve the way in which coastal managers monitor beach water quality and mitigate the exposure of beach goers to potentially hazardous water quality conditions. In this paper, we briefly examine the most serious shortcomings of current beach water quality monitoring in Southern California and

[1] Data on closures are taken from Morton and Pendleton and the State Water Resource Control Board updated database on beach closures.

[2] The State Water Board reports an average of 6819 days of beach postings for the period, including many Orange County beaches that were posted continuously through the period.

explore ways in which improved coastal water monitoring technologies could be used to improve coastal water management.

1.1 The Economic Value of Beach Recreation in California

Beach recreation is a cornerstone of the California coastal economy and even California culture. For at least four decades, Hollywood has carefully documented the California beach life. A more complete and accurate assessment of the number of actual beach users and the economic value of beach use, however, has only just begun. Nevertheless, the emerging picture of beach visitation and the potential value of market and non-market economic impacts of beach use in California corroborate the obvious importance of beach visitation for the California coastal economy.

The California Coastal Act protects access to public beaches throughout California. As a result, beaches are an important source of recreational open space for Californians with as many as 63.4% of all Californians making at least one visit to a California beach each year – 2.5 times the national average (California Department of Boating and Waterways 2002). Philip King of the San Francisco State University conservatively estimates that as many as 378.5 million day trips were made to California beaches by Californians in 2001 (California Department of Boating and Waterways, Chapter 3). The United States Life Saving Association estimates that as many as 146 million visitor days were made to southern California beaches alone (USLA 2002). In another study Morton and Pendleton (2001) estimate that total beach attendance in Los Angeles and Orange County in 2000 exceeded 79 million visits. Morton and Pendleton's estimates, detailed in a report to the State Water Resources Control Board, are taken directly from lifeguard records.

Day trips to beaches generate two distinct sources of economic value for the coastal and ocean economy: market expenditures and non-market consumer surplus values. First, day visitors to beaches spend money locally on food, beverages, parking, and beach related activities and rentals (e.g. body boards, umbrellas, etc.). These expenditures partially represent a transfer of expenditures that may have been made elsewhere in the state (e.g. gas and auto), but are largely expenditures that would not have been made in the absence of the beach trip. We use two previous studies to estimate the average expenditures per person per day trip ($/trip/person) for visits to California beaches. A survey of beach goers in southern California (Hanemann et al. 2002) found that per person per trip expenditures on beach related items and services were $23.19 for beach goers that took at least one trip in the summer of 2000. In another study by King (California Department of Boating and Waterways 2002), average beach related expenditures (excluding gas and automobile costs) were $29.66. Based on these two studies, we conservatively estimate the average per trip per person beach related expenditure for California beach visits to be $25 and the total annual beach related expenditures to be $9.46 billion. We estimate the total annual expenditures for beach goers in Los Angeles and Orange Counties to be $1.8 billion.

Visitors to beaches also place a value on beach visits above and beyond what they spend at the beach – the consumer surplus of beach visits. Unlike many marketed goods, access to the beach is largely free (aside from parking fees) in California. Because of the low cost of beach access and the importance of beach recreation to Californians, numerous studies have estimated the consumer surplus of beach going in California to better measure the true value of beaches and beach management in the state. Two primary methods were used to value consumer surplus estimates: the travel cost method and the contingent valuation method. Chapman and Hanemann (2001) argue that to date contingent valuation estimates of California beach visits have been flawed and generate unreliable estimates of beach values, largely because the contingent valuation surveys often are not site specific and fail to account for varying travel costs to beaches around the state.

Travel cost estimates of consumer surplus for beach visits have been employed to estimate the value of visits to beaches, largely along the central and southern California coast. Table 1 provides estimates of consumer surplus values for visits to beaches in California. Consumer surplus estimates range from a low of $10.98 (in 2001 dollars) for visits to Cabrillo Beach in Los Angeles County (Leeworthy and Wiley 1993) to a high of greater than $70 (in 2001 dollars) per person per trip for visits to San Diego beaches (Lew 2002). In 1997, Michael Hanemann estimated the value of the consumer surplus of beach visits to Huntington Beach at $15/visit (Hanemann 1997). Hanemann's estimate of beach related consumer surplus was later discounted by ten percent and used as the basis for a jury award regarding lost beach recreation due to the American Trader oil spill (Chapman and Hanemann 2001). More recent results, still under review, by the Southern California Beach Valuation project indicate that in Southern California alone, the non-market value of swimming at beaches may exceed $1 billion[3] and the value of visits to beaches for swimming and non-swimming activities may exceed $2 billion.

1.2 *Current Procedures for Determining Beach Closures*

An improved and substantially modified in the Coastal Ocean Observing System could improve the accuracy of the system used to determine when and where beaches are closed in Southern California. The state of California, through State Bill AB 411, mandates the closure of beaches that are thought to be contaminated by sewage and requires the "posting" of beaches that exceed specific levels of bacteriological concentrations. Currently, the procedures used to close beaches to swimming rely on a notification of sewage spills by sanitation authorities or *in situ* measures of bacteriological water quality. Only rarely are sewage spills detected immediately and sometimes even known spills are not reported to the public.[4] Heal the Bay reports that between April 2002 and March 2003 there were 222 sewage spills in Los Angeles county, none of which led to beach closures (including one spill that emitted 745 gallons of untreated sewage into the waters of Will Rogers State Beach)[5]. More commonly, water quality impairment is discovered by the daily water sampling that is conducted at stations along California's beaches; sewage spills are often reported by beach goers and residents. These samples are collected in the surf zone and sent to labs for analysis.

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[3] The estimates of Hanemann et al are not weighted to reflect sampling bias and so should be considered as an order of magnitude estimate for non-market swimming values.

[4] For instance, on March 3, 2004 the Hyperion Treatment plant released more than 150,000 gallons of partially treated effluent into Santa Monica Bay, but the release was not reported publicly until March 5, 2004.

[5] See www.healthebay.org

Three serious shortcomings exist in the methods used to monitor water quality and inform the public about water quality contamination. First, weekly and even daily water sampling is known to be an extremely imprecise means of detecting water quality contamination by bacteria (see for instance Leecaster and Wiesberg 2001 or Kim and Grant 2004.) The effects of tides, lunar cycles, and other vagaries in near shore oceanographic conditions can seriously impair the effectiveness of surf zone and "point zero" storm drain monitoring. Temporarily high bacteria readings may not indicate continued serious coastal water contamination while at other times a false negative reading may mask serious contamination problems. Leecaster and Weisberg (2001) found that only thirty percent of positive first day readings were associated with significant water quality contamination during the following day. The findings of Leecaster and Weisberg indicate that by the time water quality contamination is detected, water quality has returned to normal in seventy percent of the cases. Kim and Grant (2004) estimate that at Huntington State Beach, current water quality methods result in errors of public posting that can reach forty percent at times.

A second serious problem with current water quality monitoring efforts is that a significant time lag exists between water sample collection and the reporting of laboratory results; the time between sampling and the determination of water quality can take up to three days. This lag suggests that potentially harmful water quality conditions may exist for as long as three days before the public is notified. (The time lag is even longer for beaches that have only weekly sampling.) Further, water quality conditions may have improved substantially by the time that results are reported. The practical result of these time lags is that many beaches remain open when they should be closed and are closed after they should have been re-opened. The economic impact of this dissonance between monitoring and closures is that a) beach goers may get sick from swimming at beaches where water quality has been shown to be impaired and b) recreational beach goers may be prevented from visiting beaches that are no longer contaminated and therefore need not be closed.

Finally, the indicator bacteria currently monitored by water quality agencies provides an inexact determination of the source of water quality contamination. Indicator bacteria are not specific to human beings and may result from natural sources. The reliance on these indicator bacteria as proxies results in two types of monitoring errors. First, positive indications of water quality contamination may be inappropriately linked to human sources. This may have been the case at Huntington Beach during the closures of 1999. Second, without primary data indicating the presence of human pathogens, some contaminated beaches may remain open because the actual link between human sewage and bacteria levels remains undetected. Without knowledge of an active sewage spill or other source of contamination by human wastes, beaches may only be posted and not closed; the result is that bathers may continue to use posted waters believing that the contamination risk is less serious than during a closure[6].

Once a high level of bacteria has been detected, managers must determine the extent of beaches that may be impacted. If a sewage spill is known to be associated with high

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[6] There are no empirical data that indicate the effect of postings on swimmer behavior.

levels of water borne bacteria, managers often close large sections of beach. If two or more sampling stations indicate high-levels of potentially sewage-related bacteria, then beach areas adjacent to and between stations will be closed. Such extensive closures are intended to provide closures that err on the side of precaution. Nevertheless it is known that bacteria from point sources (e.g. stormdrains or breaks in sewer lines) are not dispersed uniformly throughout the surf zone. Instead, bacteria and pathogens follow local near shore currents. The results are hotspots of bacterial contamination that may affect only very small sections of the shoreline. Steve Weisberg, Director of the Southern California Coastal Water Research Project, estimates that the geographical imprecision of current beach closure protocols may result in the closure of as much as two times more shoreline than is needed to protect beach goers from coastal bacterial water pollution. The economic result of this imprecision is that beach goers are unnecessarily displaced from beaches; non-market values and expenditures are diminished unnecessarily.

For the purposes of analysis, we group the policy errors associated with the shortcomings of the current protocol for monitoring and reporting water quality data into two types of errors in the execution of beach closure policy (we follow the example of Rabinovici et al. 2004). First, in some the current protocol causes beaches to be closed when these beaches are, in fact, in compliance with water quality standards; we refer to these types of errors as Type I errors and note that these errors largely impact the recreational value of beaches. Second, time lags in reporting and a failure to adequately identify human pathogens in coastal water quality leads to a Type II error in which beaches are not in compliance with water quality standards for safe swimming, but beaches are not closed to swimming (in many cases these beaches may be posted with advisories). Type II errors result primarily in public health costs. Of course, it is unlikely that Type I and II errors could ever be eliminated completely. Nevertheless, in the discussion that follows we begin to estimate an upper bound for the value of the elimination of these errors in the management of beaches in Los Angeles and Orange Counties.

1.3 Using the SCCOOS To Better Manage Beach Postings and Closures

We use a basic framework of "models" to explore and evaluate the potential policy impacts of improvements in the SCCOOS that could improve the monitoring of coastal water quality. The first model in the framework begins with a description of the proposed technologies and the resulting data and analyses that would be part of the improved SCCOOS. We call this model "NOWCASTS AND FORECASTS." New raw data and analyses will become part of the portfolio of information that coastal managers use to make decisions regarding coastal water quality and beach closures. In the DECISION MODEL we describe these basic decisions and how they are affected by the information that could be generated by improvements in the SCCOOS. The decisions made by coastal managers in turn result in real changes in the behavior, health, and well being of beach goers. In the PHYSICAL MODEL, we describe the policy and behavioral outcomes of that result from better decision making. Finally, in the ECONOMIC MODEL we begin to put the physical outcomes in the context of potential economic changes that might result from this potential, but hypothetical, use of improved coastal ocean observing technology.

2. NOWCAST AND FORECASTS

The Southern California Coastal Ocean Observing System could be modified to better detect, track, and monitor coastal ocean contamination; two primary technologies could be employed towards this end. First, several technologies, broadly known as Rapid Microbial Indicator Methods, now exist that permit the immediate detection and identification, and thus reporting, of bacteriological pathogens in coastal waters (ACT 2003). In June 2004, the Southern California Coastal Water Research Project began a test of three principal types of rapid microbial indicator methods: Immunoassays, Chromogenic Substrate Analyzers, and Polymerase Chain Reaction Methods. These methods could improve beach water quality monitoring by a) providing continuous monitoring of water quality (thus providing more data to help overcome the temporal vagaries that affect water quality testing), b) more accurate detection of human pathogens, and c) real time (or near real time) notification of health risks (i.e. reduced time lag between sampling and reporting). Secondly, oceanographic buoy data (e.g. wind, waves, current, temperature) can be combined with satellite data to more accurately model, and thus predict, the fate of water borne pathogens near the coast. Systems like the CODAR (personal communication, Eric Tyrell, Scripps Institute of Oceanography), already part of the Southern California Coastal Ocean Observing System, have demonstrated the potential for more accurately tracking the source and dispersion of contaminants in coastal areas of San Diego County including the Tijuana River outfall. Stanley Grant of the University of California, Irvine proposes a similar system in which HF Radar data, NEOCO data, mooring data, and ocean current modeling efforts will be linked to existing water quality monitoring programs, to create a water quality forecasting algorithm suitable for deployment at coastal sites (personal communication). Better prediction of the fate of contaminants will allow managers to more narrowly target beaches for closure and also will allow authorities to close beaches that are likely to be affected by contaminant flows in advance of actual detection at those beaches.

3. DECISION MODEL

The data from the potential improvements in the SCCOOS, described above, will be used to inform three types of policy actions:

1) when pathogens levels are sufficiently high to warrant beach closures, which beaches should be closed,

2) the provision of accurate information to the public regarding the geographical extent and duration of water quality contamination events, and

3) the determination of the existence of human pathogens in coastal waters.

By better informing these three areas of policy decision making, the improved SCCOOS could substantially reduce the kinds of errors in identification and reporting of water quality contamination problems.

4. PHYSICAL OUTCOMES MODEL

4.1 General Outcomes

The provision of more timely and accurate data about the extent and duration of coastal water quality contamination would result in a number of tangible policy outcomes. We review these outcomes here and in the next section describe and begin to place a value upon the economic impacts of these outcomes.

4.2 Type I and Type II Errors in Closing Beaches

As described above, an improved SCCOOS could potentially improve the accuracy of water quality monitoring and in turn would improve the economic and public health efficiency of the current system of beach monitoring and closures. Following Rabinovici et al. (2004), we examine the ways in which an improved SCCOOS could reduce the two primary errors made by beach managers: Type I errors in which beaches are in compliance with water quality standards, but are inappropriately closed to swimming and Type II errors in which beaches are not in compliance with water quality standards, but are not closed to swimming.

4.2.1 Type I Errors

Specifically, the improved SCCOOS could potentially

- reduce false positive pathogen indications that are caused by temporally varying water conditions and sampling regimes,
- reduce false positives that are caused by non-human bacteria, and
- improve the geographic accuracy of closures by using models and real time data collection to determine areas most likely to be contaminated following a detection.

We begin our exploration of the economic benefit of reducing Type I errors by focusing on the gains from a better geographic understanding of the fate of waterborne pathogens and assume that the economic value of such improvements would come from reducing by half the spatial extent, and thus the number, of unnecessary closures.

4.2.2 Type II Errors:

Improvements in the SCCOOS could reduce the number of days in which beaches are contaminated and should be closed, but are not closed. These Type II errors occur for two primary reasons: 1) the time lag between sampling and monitoring means that severe water quality impairment is not reported to the public until two or more days after the water quality event and 2) some contaminated beaches are not closed if authorities cannot determine a link between human sewage and high levels of bacteria. Type II errors primarily have public health impacts; swimmers on these days are likely to get sick more frequently than on uncontaminated days.

Turbow, et al. (2003) show that most illnesses occur even when beaches remain open, but are posted. The deployment of rapid microbial indicators methods could lead to an improvement in the accuracy of detection of human pathogens and the ability to accurately differentiate between high levels of non-human fecal bacteria and the more virulent human pathogens. As noted at the beginning of this report, the NRDC reports that, on average, more than 2450 beach postings are made Los Angeles and Orange County. In fact, the State Water Board's beach posting database indicates as many as 6000 postings on average over the period 1999-2002. Many of these postings are likely to represent serious human health hazards; with better pathogen identification many of these posting might become closures. (Postings are likely to be an imperfect means of eliminating swimming at contaminated beaches. Therefore, the conversion of postings to closures when appropriate would further reduce exposure to pathogens and represent a further decline in the number of Type II errors that are made by beach managers.)

5. ECONOMIC OUTCOME MODEL

5.1 Recreational Impacts

We begin by examining an upper bound for the value of reducing Type I errors that create inappropriate closures and thus diminish recreational values associated with beach use. Beach closures represent a loss of recreational opportunities for beach goers in Southern California. Rabinovici et al (2004) show that for Great Lakes beaches, a beach closure represents a net economic loss to society even when the beach should have been closed under public health guidelines. In our analysis, we focus only on the value of beach closures during which visitors may have been prevented from swimming on days when water quality might have fallen within the range of bacteriological levels deemed safe by public health standards. As stated above, we limit our analysis here to the value of reducing by half the number of unnecessary beach closures in Los Angeles and Southern California. Under this scenario, there would be an additional 73.5 beach days available to beach goers in Southern California.

Hanemann et al. (2004) show that the exact value of a beach closure in Southern California depends on the beach in question and the season of the closure. Predicting which beaches will close in the future, when, and how long those beaches might remain closed or open more often with an improved COOS is not possible. Nevertheless, we examine an upper bound for the potential value of reduced unnecessary beach closures by assuming that future unnecessary beach closures would be random.

On average, in Los Angeles and Orange Counties there were 147 beach days lost to closures each year from 1999 to 2002. Based on 51 primary public beaches in Los Angeles County, these closures represent approximately 0.07% of all possible beach "day trip" recreational possibilities. In fact, the entire beach is rarely closed to visitors; instead isolated stretches of beach are closed and often these closures apply only to swimmers. As an upper bound, we assume that the entire beach is closed due to a beach closure, but we limit this closure to that proportion of visitors that would swim at the beach. Pendleton et al. (2001) found that 38.4 % of beach goers in Los Angeles planned to swim during their trip to the beach. In a more recent study, Hanemann et al. (2004) found that 28% of all trips made to the beach by a panel of beach goers in four southern California counties include a water based activity. In this study, we assume that 28% of all beach day trips in Southern California include a water-based activity.

We explore two methods for calculating the economic value of reduced unnecessary closures: 1) an estimation of the increase in total beach visitation and thus an increase in per trip non-market values and expenditures and 2) an estimation of a proportional increase in total non-market and expenditure values for Southern California beach visitation.

METHOD 1: VALUING AN INCREASE IN TOTAL BEACH VISITATION

In the first method, we use an average daily attendance figure for beaches closed in 1999 and 2000 to estimate the total number of beach visits that could be recovered. Average daily beach attendance, at all reporting beaches in Los Angeles and Orange Counties during 1999 and 2000 was 8,142 visitors/beach day. (The average daily attendance, two days before closure, at closed beaches in 1999 was 8,606 visitors/beach day[6]. This indicates that from an attendance perspective, the beaches that were closed in these years were slightly less more heavily visited than beaches on average; in other words, popular beaches were being closed.) Based on the assumptions outlined above, approximately 167,500 new beach visits could have been made were there better geographic resolution of beach closures. As described earlier, we value a beach visit at $13.50/visit/beach day and the per person expenditures are estimated to be $25/visit/beach day.

Method 1: Non-market valuation -

> (Average visits/day) x (proportion of visitors that swim) x (additional beach days) x (value of a beach day) = recreational value of reducing unnecessary closures.
>
> (8142 visits/beach day) x 28% (swimmers/total visitors) x 73.5 beach days x $13.50/visit = $2,262,000

Method 1: Market Valuation

(8142 visits/beach day) x 28% x 73.5 beach days x $25/visit/beach day= $4,189,000

METHOD 2: VALUING A PROPORTIONAL INCREASE IN TOTAL VALUES

As a check on our estimates from Method 1, we consider the change in value that would have resulted had there been a proportional increase in the total non-market value and total expenditures associated with beach visits in Los Angeles and Orange Counties. In reality, a proportional increase assumes that the provision of more beach recreational opportunities would lead to a linear increase in value. Such a proportional increase should be considered an upper bound on the potential impact of additional beach days. First, a proportional increase assumes that the non-market value of additional beach days is equal to the average value of all other beach days. In fact, the value of these additional beach days depends on whether or not these additional beach days represent better than average or worse than average beach recreational opportunities. Second, it may be the case that a proportional increase in beach opportunities will not lead to a proportional increase in beach visits of the same size. Therefore, our estimates of the value of a proportional change in beach expenditures also should be considered an upper bound.

Method 2: Non-market Valuation

Current total non-market value of water related activities x (additional beach days/ total beach days) = change in non-market value

$1 billion[7] x (0.0035) = $3,500,000

Method 2: Market Valuation

Current total expenditures x (swimmers/total visitors) x (additional beach days/ total beach days) = change in market value

$9.46 billion x .28 x .0035 =$9,270,000

Using the more conservative estimates from the two methods, we find that better geographic accuracy in closures could yield potential economic benefits of: $2,262,000 for non-market values and $4,189,00 for expenditures for a total of $6, 451,000/year.

(We remind the reader that the above analysis focuses exclusively on beach closures. To date, the impact of beach postings on beach visitation has not been quantified. If beach postings effectively eliminated beach visitation by swimmers, then our approach here could be applied to beach postings as well. The NRDC reports an average annual number of beach posting days in Los Angeles and Orange County of 2456. This represents sixteen times more days than in the closure analysis above.)

5.2 Public Health Impacts

In the short run, public health benefits of an improved SCCOOS could come from the reduction in the time lag between sampling and reporting water quality impairments that would be possible with the deployment of telemetric rapid microbial indicators (i.e.

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[7] The estimates of Hanemann et al are not weighted to reflect sampling bias and so should be considered an order of magnitude estimate for non-market swimming values.

microbial indicators that could transmit data in real time or near real time). Reducing this time lag, in turn, could reduce the number of days in which beaches are contaminated, but not closed (Type II errors in compliance). Further public health benefits would result from the deployment of rapid microbial indicators that could differentiate between human pathogens and non-human pathogens. This more precise species identification of pathogens could potentially reduce closures that are mistakenly linked to sewage spills, but also could increase the overall number of closures by leading authorities to close beaches that might otherwise have been posted. (These increased closures would result in a loss of recreational values. Rabinovici et al., 2004, argue that even appropriate closures result in recreational value losses that may exceed gains in public health values.) We focus only on the gains in public health values that could result from a reduction in Type II compliance errors.

5.2.1 Cost of water related illnesses

Recreational contact with marine bathing water has been shown to result in an increased likelihood of a suite of human illnesses including upper respiratory infections, gastrointestinal infection, ear and eye ailments, and fever. Prüss (1998) reviews the literature prior to 1998, while a number of more recent studies further explore and model these links (including Henrickson et al. 2001, Wymer and Dufour 2002). Even in the absence of known contamination by human sewage, coastal swimmers can be subject to elevated risk levels for disease (see Cabelli et al. 1982, Calderon et al. 1991, and Haile et al. 1999). Pathogens in bathing water can come from marshes (see Grant et al. 2004) and surface water run-off (see for instance Haile et al. 1999 and Jiang et al 2001). Known contamination of coastal waters by human sewage has been shown to increase the relative rates of illness even more (see Fleisher 1996 and 1998). The literature does not indicate whether the rates of illness are additive or whether these symptoms appear in clusters (with swimmers getting one or more illness simultaneously).

In this study, we focus exclusively on the public health impacts of bathing waters that should be closed to swimming due to contamination by human sewage (the principle criterion for beach closures in Los Angeles and Orange County). Specifically, we examine illnesses that may have resulted from a lag between sampling and the closure to swimming of beaches in Los Angeles and Orange Counties. To begin, we consider only excess illnesses that may have resulted exposure to sewage contamination. In Table 2, we provide adjusted relative risk rates for the most common categories of illness associated with swimming in coastal waters contaminated by sewage. Column 1 gives the proportion of swimmers that came down with illnesses after swimming in sewage contaminated waters in the United Kingdom (Fleisher et al. 1998). For our purposes, the appropriate risk measure is that for the additional risk that comes from swimming in marine water contaminated by sewage compared to swimming in marine water generally. Haile et al. (1999) provide estimates for the risk of illness associated with swimming in the marine waters of Santa Monica Bay, California having very low concentrations of fecal bacteria. Column 3 gives the excess risk of swimming in sewage contaminated waters (based on Fleisher et al.) compared to non-contaminated waters (based on Haile et al.). Of course, it is likely that the populations considered in the studies by Fleisher et al. and Haile et al. have different background levels of illness, even for non-swimmers. In fact, the rates of illness for swimmers in “clean” areas of Santa Monica Bay is generally equal to or lower than the background levels for non-swimmers in the study by Fleisher et al. Because the background levels of sickness differ between the two studies, we use assume the net excess risk associated with swimming vs. non-swimming in the sewage contaminated waters as a more conservative estimate of the potential excess illness that could result from swimming in sewage contaminated marine waters in Southern California.

Gastrointestinal illness and ear ailments are the most common illness associated with recreational water contact when sewage contamination is present with excess rates of illness of 8.4 and 4.6 illnesses per 100 swimmers, respectively. Eye ailments are also common more common when sewage is present, but at lower rates (2.5).

The economic impact of swimming related illnesses has not been estimated directly. Rabinovici et al (2004) use the estimated willingness to pay of $280 (in real terms adjusted to year 2000 dollars) to avoid a mild case of food-related gastrointestinal illness (estimated originally by Mauskopf and French 1991.) Bloomquist et al. (2001) value illnesses associated with coastal bathing water by using the estimated costs of a case of influenza, $380 (including the willingness to pay for illness avoidance, cost of treatment, and lost wages) originally estimated by Nichol (2001). Because gastroenteritis is 2.5 times more likely in beach goers than flu-like symptoms, we follow Rabinovici et al and use a figure of $280 for each case of excess illness.

We estimate the cost of Type II errors in compliance by assuming that bathers are exposed to contaminated water for up to two days before beaches are closed. The assumption of a two day exposure is conservative; in many cases the time delay is three days and sometimes as long as a week. Leecaster and Weisberg (2003) and Kim and Grant (2004) show that indications of water quality impairments on one day do not necessarily result in impairments on following days. Given the unknown duration of water contamination during the two-day period between sampling and reporting, we assume that bathers would be exposed to contaminated water: a) for only the initial day of sampling when a beach closure lasts for one day and b) for the two days preceding a closure when a beach closure lasts for two days or more. To estimate the number of bathers exposed, we combine beach attendance data and beach closure data for 1999, the only year for which both sets of data are available[8]. As before, we assume that 28% of beach goers went swimming and that water quality along the entire beach was impaired. We also assume that the swimmer may have gone swimming elsewhere had the beach in question been closed and thus are exposed only to the additional risk associated with swimming in sewage contaminated marine water as compared to background levels of risk from swimming in the same water. Following these assumptions, we find the cost of Type II errors that could be corrected by an improved SCCOOS at just over $1.25 million, using the following formula:

[8] For 9 closure days, we did not have attendance data. In these cases we used figures from the prior year or a nearby beach.

$$\left(\sum_{i,\ \text{closed} > 1\ \text{day}} \text{Visits}_{i,\ t-1} + \text{Visits}_{i,\ t-2} + \sum_{j,\ \text{closed}\ 1\ \text{day}} \text{Visits}_{i,\ t-2} \right) \text{x (proportion of swimmers) x}$$

$$\text{(adjusted excess risk x cost of illness) = cost of excess illness}$$

(313,760 Visits) x .28 x (5.1/100) x $280 = $1,254,538

While the previous analysis focuses entirely on the public health benefits of reducing Type II errors associated with beach closures, identical technology and analysis could be applied to beach postings. Turbow et al. (2003) show that most illnesses occur when beaches are not closed. Bacteria levels during postings are comparable to those during closures and potentially could lead to substantial exposure to gastrointestinal illness of a similar magnitude (see Cabelli et al 1982). As stated earlier, there are approximately 16 times more beach posting days than beach closure days in Los Angeles and Orange Counties. As a result, if the analysis were to be extended to beach postings and closures, the public health value would rise substantially (provided that beach postings lead to substantial declines in swimming at posted beaches).

6. Conclusion

The current protocol and method of monitoring recreational water quality in the United States is known to be imperfect. On site sampling, off site laboratory analysis, and a reliance on fecal indicator bacteria instead of human pathogens result in two principle types of errors associated with water quality monitoring (Rabinovici et al 2004): 1) Type I errors in which beaches are closed even though water quality parameters are within a “compliance” range thought to be safe for swimming and 2) Type II errors in which water quality parameters exceed safe “compliance” levels yet beaches are not closed. The causes of these errors include a) precautionary beach closures when a source of contaminants are known, but the exact fate of contaminants in near shore waters is not known and b) lag times of two or more days between sampling and notification of water quality impairment. Type I errors lead to a loss of recreational value when beachgoers are prevented from swimming at safe beaches. Type II errors result in public health costs when swimmers are not adequately warned about water quality contamination.

Water quality engineers in Southern California are now testing a number of technologies, including the use of rapid microbial indicator methods and oceanographic methods, that could potentially reduce the incidence of Type I and II errors in beach closure policy in Southern California. These new technologies would require modifications of the current California Ocean Observation System including the deployment of rapid microbial indicator devices on nearshore buoys and better integration and analysis of oceanographic data from buoys and satellites.

This study conservatively estimates the potential benefits of improving water quality monitoring methods in Southern California. A complete elimination of the most basic types of errors in water quality monitoring Los Angeles and Orange County could result in an annual economic savings of between $7.7million and $14.0million. These savings are conservative because they only consider the value of public health impacts and the non-market values of current beach users. In addition to current beach users, many residents and tourists are likely to avoid swimming at Southern California beaches because of concerns about water pollution (Pendleton 2001). Better water quality monitoring could have significant impacts on the public's perception of beach water quality. Better monitoring could improve the public's confidence that beaches that are open for swimming are, in fact, safe. This, in turn, could increase the number of people visiting Southern California beaches. The potential value of these changes in perceptions has, to date, remained undocumented, but could significantly add to the overall value of improvements in water quality monitoring.

Finally, in Southern California, beach closures are limited to those days in which fecal indicator bacteria levels exceed safe standards and the source of bacteria is believed to be associated with human sewage. Beach closures represent less than six percent of the total number of incidences during which water quality contamination exceeds recommended "safe" levels for swimming, but beaches are only "posted" with warning signs. The improvements in the coastal ocean observing system described here could be extended to the monitoring and posting of beaches, even in the absence of sewage contamination. A better understanding of the impacts of these "postings" on public health and recreational values is required before we can estimate the potential impacts of a reduction in Type I and II errors in the context of beach postings.

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Tables

Table 1: Estimates of the Consumer Surplus Value of Beach Visits in California

Consumer Surplus/Trip	**US$(1990)**	**US$ (2000)**
Cabrillo-Long Beach[1]	$8.16	$10.98
Santa Monica[1]	$18.36	$24.71
Pismo State Beach[2]	$26.20	$35.26
Leo Carillo State Beach[1]	$51.94	$69.91
San Onofre State Beach[2]	$57.31	$77.14
San Diego[2]	$60.79	$81.82

Source: Environmental Damages in Court: The American Trader Case, published in The Law and Economics of the Environment, 2001, Anthony Heyes, Editor, pp. 319-367. The data are extracted from 1) Leeworthy and Wiley (1993) and 2) Leeworthy (1995).

Consumer Surplus/Day **US$ (2001)**

Individual Surplus/Day	Carpinteria	Encinitas	San Clemente	Solana Beach
Method 1	$20.48	$18.84	$25.70	$14.58
Method 2	$24.43	$22.17	$30.58	$17.35

Source: Philip King, The Economic Analysis of Beach Spending and the Recreational Benefits of Beaches in the City of San Clemente, 2001. Note: Method 1 - dependent variable is a discrete random variable, CS calculated as the sum of a series of rectangles, each one day wide, touching the demand curve at its upper right corner. Method 2 - CS calculated as the sum of a rectangle for the area under the curve between zero and one, and the definite integral for the area between one and the average number of trips.

Total Value of Beach Trip (San Diego) **US$(2002)**

Statistic	Two-step Heckman	Two-step HFS	Joint Heckman	Joint HFS
Mean	$71.43	$74.86	$43.97	$33.70
Median	$74.03	$77.33	$46.31	$36.13
Standard Deviation	$10.57	$10.79	$9.70	$9.77

Source: Dissertation by Daniel Kevin Lew, University of California Davis. Valuing Recreation, Time, and Water Quality Improvements Using Non-Market Valuation: An Application to San Diego Beaches.

Table 2: Excess Rate of Illness Associated With Bathing Waters

Illness	**Adjusted Rate of Illness (x/100) when water contaminated by sewage** [a]	**Excess Adjusted Rate of Illness (x/100) when water contaminated by sewage (compared to non-swimmers)**[a]	**Excess Adjusted Rate of Illness (x/100) when water contaminated by sewage (compared to swimmers in Santa Monica Bay where TC<1000cfu/100ml)**[a]	**Excess Duration of Illness**[a]
Gastroenteritis	**14.8**	**5.1**	8.4	.2
Acute Febrile Respiratory Illness	5.0	2.0	0.1	0.6
Ear ailments	**8.2**	**5.4**	4.6	**2.7**
Eye Ailments	4.5	2.4	2.5	-1.3

[a] From Fleisher et al. (1998). [b] From Haile et al. (1999). **Bold** indicates significantly different from background at < 0.10 level.

The Impact of Weather and Ocean Forecasting on Hydrocarbon Production and Pollution Management in the Gulf of Mexico

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Abstract. Weather delay is a common risk in offshore energy production, and the occurrence of tropical cyclones regularly force operators to shut-down production, cease drilling and construction activities, and evacuate personnel. Loop currents and eddies can also have a serious impact on offshore operations and may delay installation and drilling activities and reduce the effectiveness of oil spill response strategies. The purpose of this paper is to describe the manner in which weather and ocean currents impact hydrocarbon production and pollution management in the Gulf of Mexico. Physical outcome and decision models in support of production and development activities and oil spill response management are presented, and the expected economic benefits that may result from the implementation of an integrated ocean observation network in the region are summarized. For effective planning and decision-making, reliable forecasts of weather and ocean current conditions are required. Improved ocean observation systems are expected to reduce the uncertainty of forecasting and to enhance the value of ocean/weather information throughout the Gulf region. The source of benefits and the size of activity from which improved ocean observation benefits may be derived are estimated for energy development and production activities and oil spill response management.

Keywords: Benefit analysis, hydrocarbon development activities, ocean observation systems.

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1. Introduction

The Outer Continental Shelf (OCS)[1] of the Gulf of Mexico (GOM) is the most extensively developed and mature offshore petroleum province in the world. More than 40,000 wells have been drilled in the OCS since offshore production began in 1947, and there are currently over 4,000 active structures in water depths ranging up to 7,000 ft. About 25 percent of the United States domestic oil and gas supply comes from the OCS, and in 2002, OCS lands averaged daily production of about 1.6 million barrels (MMbbl) of oil and 14.5 billion cubic feet (Bcf/d) of natural gas. The Minerals Management Service estimates that oil production levels will rise to at least 2 MMbbl/d and perhaps as high as 2.5 MMbbl/d by 2006, while gas projections through 2006 offer contrasting scenarios[2], with production estimated to range between 11 Bcf/d – 16.4 Bcf/d [1]. The deepwater GOM is America's newest production frontier and now accounts for more than half of the Gulf's total oil production [2].

Weather plays a major factor in human activities in the GOM, and extreme weather in particular, can have an enormous impact on the cost of "doing business." Storms and hurricanes regularly challenge and endanger the coastal community and energy infrastructure throughout the Gulf region. Every year about 10 storms form over the tropical portions of the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico, and about half of these storms will grow into 75 mph hurricanes (www.nws.gov). Of these five hurricanes, two-three are likely to strike the coast of the United States (Table 1, Figure 1). Tropical storms cause damage to physical, economic, biological, and social systems, but the severest effects tend to be highly localized.

When a hurricane enters the GOM, oil production and transportation pipelines shut down, crews are evacuated, and refineries along the Gulf coast close. Drilling rigs pull pipe and move out of the projected path of the storm, if possible, or anchor down, and supply vessels, commercial ships, and barges may be moved into one of Louisiana's many bayous where they have more protection from the storm. Ocean-going vessels transiting into or out of the GOM near the time of the event use hurricane forecasts to plot course to avoid the storm. The Louisiana Offshore Oil Port (LOOP), the biggest and only deepwater oil port in the country, closes to shipping and flows through on-shore pipelines are halted. Crude oil from the Gulf to the Midwest via the Capline pipeline, and the gasoline and distillate fuel conduit the Colonial Pipeline, also shut down ahead of the storm.

Hurricanes are not the only extreme weather event that impacts offshore oil and gas production activities. As operators have pushed into deeper waters in the GOM in search for oil and gas, the impact of loop currents on operations have become increasingly problematic. The Loop Current is an offshoot of the Gulf Stream, a major North Atlantic Ocean boundary current located off the east coast of the United States. The loop is

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[1] The OCS of each coastal state generally begins 3 nautical miles from shore for all but two states – Texas and Florida – which are 3 marine leagues (9 nautical miles), and extends at least 200 miles through the Exclusive Economic Zone.

[2] Although oil and gas production in the heavily leased shallow waters of the GOM has been steadily declining, the MMS estimates that there is up to 55 trillion cubic feet (Tcf) of natural gas still available in the deep shelf areas.

formed when the Gulf Stream enters the Gulf of Mexico through the Yucatan Straights and "loops" through the basin in a clockwise direction before exiting through the Straits of Florida (Table 2, Figure 2). When the loop exits through the Florida Straight, it often becomes pinched and sheds some of its flow into a separate eddy of warm water which migrates backward, southwest across the GOM bringing strong loop current forces into active E&P areas [3]. Some oceanographers refer to the Loop Current as the equivalent of a hurricane beneath the water, and its impact on deepwater installations is increasing as operators have moved into deeper and more eddy prone areas.

The Loop Current is a persistent feature in the GOM characterized by strong surface current velocities (2-4 knots) with its position and intensity varying over time. The warm-core eddies that break away from the northern extremity of the Loop Current are characterized by intense current velocities which can cause serious impact to offshore operations. Typically, two to three eddies form each year. Currents influence rig selection, riser design, many aspects of offshore operational planning, and the design and installation of production systems, moorings, subsea components and pipelines. Of particular importance is fatigue associated with dynamic response to current loading [4]. For effective planning and decision making in the GOM, operators require reliable forecasting[3] of future current conditions.

The National Oceanographic Partnership Program (NOPP) formulated a plan for an Integrated, Sustained Ocean Observing System (ISOOS) in a 1999 report to Congress [5], intending to move the United States from what is now a largely ad hoc and fragmented approach to ocean observation to a coordinated and sustained activity similar to the existing national weather information system [6-8]. Implementation of ISOOS will require investments in infrastructure and ongoing support for new and existing observation systems in the open and coastal ocean, and the benefits of federal investment will depend on the expected costs and benefits of the resulting system. The importance of a national network of ocean observation systems has recently been reiterated by the U.S. Commission on Ocean Policy [9].

The purpose of this paper is to describe the manner in which weather and ocean data is used in planning and decision making activities in offshore energy development and production and oil spill response management, and to identify and quantify the expected economic benefits of improved weather/ocean forecasting on these activities. For a description of the capabilities of each system, the NOAA website (www.csc.noaa.gov) maintains links to each system. The reports [10-15] provide useful summaries of individual systems.

The standard economic approach to valuing information requires:

- A description of the information being valued and of the uncertainty in the phenomena it describes;

[3] A number of initiatives are underway by the academic, government and commercial scientific community to develop and verify current models of oil and gas basins around the world. The CASE (Climatology and Simulation of Eddies) joint industry project, Oceanweather's WANE (West Africa Normals and Extremes) joint venture between Fugro and the Nansen Environmental and Remote Sensing Center at the University of Bergen, and the U.S. Navy are all working on advanced ocean current modeling programs [4].

- A model of how this information is used to make decisions;
- A model of how these decisions affect physical outcomes;
- A model of how physical outcomes can be translated into economic outcomes.

User sector representatives were identified to define the base case and improved information scenarios, and then information was obtained regarding the natural variation of the phenomena being described, including critical variables to nowcast/forecast, the forecast horizon, spatial and temporal resolution. A decision model is then sketched describing how users incorporate information into their choices and decisions. The physical outcome describes how outcomes result from the decision parameters and the variation in the natural phenomena. Finally, a simple economic outcome model describes how the physical outcomes translate into economic changes.

The outline of the paper is as follows. In §2, the methodology of the economic valuation is presented. In §3-6, the decision, physical outcome, and potential benefits of improved observation systems to energy exploration, development, and production activities are described, and in §7, the decision, physical outcome and economic outcome models related to oil spill response management are discussed. In §8, conclusions complete the paper.

2. Valuation Strategy

The state of knowledge of ocean data is incomplete and uncertain, and so improved ocean/weather observation systems are expected to enhance the value of the information and create additional network externalities [6]. Weather information is valuable, and to the extent that improved ocean observation systems can improve the data on which weather/ocean forecasts is based, is potentially very beneficial to energy production activities and pollution management in the GOM.

The potential impact of savings that may be incurred from improved ocean observation systems was first estimated by Kite-Powell and Colgan in a study focused on the Gulf of Maine [16]. Kite-Powell and Colgan performed order-of-magnitude assessments for general categories of benefits using the following methodology:

Step 1. Value activity A that uses and/or is impacted by ocean forecasts, $V(A)$.

Step 2. Assume that the benefit of improved ocean observation systems is expressed by some small factor, $e(A) > 0$.

Step 3. Compute the value of improved observation systems in region R,

$$V(R) = \sum_A e(A)V(A) .$$

The valuation strategy is based on estimating $V(A)$ from public sources of information and hypothesizing the value of $e(A)$ for each activity identified. The selection of $e(A)$ is hypothetical but not unreasonable within the framework of the model and the scope of the valuation. Ideally, it would be desirable to derive the value of $e(A)$ from fundamental data or to ascertain the cost to achieve a desired level of $e(A)$, but establishing such relationships are beyond the state of knowledge of observation systems. Further, no direct link between $e(A)$ and $V(A)$ can be "derived" and it is difficult to "justify" $e(A)$ on a fundamental level. The default condition is to assume $e(A)$ "small" (e.g., 1%, 1 day, etc.), and this is considered a "reasonable," and in all instances, a conservative estimate of the expected benefits to be incurred.

3. Stages of Offshore Energy Development

A four-stage sequence of activity is generally followed in offshore energy development projects:

1. Exploration,
2. Development,
3. Production, and
4. Decommissioning.

In the exploration stage, areas that are considered to have prospects of containing oil and gas reserves are drilled with exploratory wells and stratigraphic test wells. In the development stage, the mineral deposit is prepared for commercial production. This includes the acquisition, construction, and installation of facilities to extract, treat, gather, and store the oil and gas. In contrast to a single exploratory well for which drilling can last anywhere from 2 weeks to 3 months, drilling the wells off a platform can last many months and extend over several years. Development activities typically include drilling and equipping development wells and service wells, and the construction and installation of production facilities. The ongoing operation of the facility is considered the production phase. In production, the oil and gas is gathered, lifted to the surface, treated, processed, and possibly, stored. When the useful life of a production platform is reached, the equipment and structure is removed and the well casing severed and closed below the seabed.

4. Drilling Activities

4.1. Decision Model

Offshore drilling may be subject to significant delays caused by the weather, and weather downtime can play an important factor in the total costs of the operation. Waves are one of the most obvious environmental concerns for offshore operations and constitute the primary cause of downtime and reduced operating efficiency. Weather downtime can impact drilling operations in various ways; e.g., weather too severe for operations involving supply boats may lead to delay if stock levels on the rig decline to a critical level; weather may impact anchoring up and moving time; weather may be too severe for drilling to occur; and extreme weather may result in damaged or lost drill strings and risers. If operating limits are exceeded because wave heights, ocean currents, or eddies are too strong, drilling operations will be temporarily abandoned and resumed when conditions fall within the operating capabilities of the equipment.

Safe working conditions for many offshore operations may be approximately specified by the critical values of wind speed and wave height, and for deepwater drilling activities, current profile, as shown in Table 3. The GOM is a fairly benign operating environment for most of the year, but downtime due to weather can be an important factor in determining the total drilling costs, and in the deepwater, usually plays a more significant role because of the day rate of the drilling rig. Empirical evidence suggests that 1-3% of drilling cost is due to waiting on weather [17], although this is subject to significant variation depending on the time of year of drilling activity and the water depth of the operation. In deepwater, floating rigs are able to maintain position over the tops of wells through a dynamic positioning system that compensates for wind, waves, and currents to keep the vessel stationary relative to the seabed.

Drilling activities generally follow three stages:

1. Start limits. Weather must be below these limits before an operation will start (or restart after abandonment).
2. Suspend limits. Work will be paused if the environment exceeds these limits. Work recommences as soon as weather conditions drop back below the threshold.
3. Abandon limits. Task will be abandoned if these limits are exceeded. Work will not be restarted until weather conditions fall below the start limits.

The occurrence of a hurricane warning or alarm is enough to disrupt drilling operations, and a significant amount of operating time can be lost to “false alarms” [18-20]. In deepwater operations, loop currents and eddies associated with them are also common phenomena that may damage drilling strings/risers and impact the drilling schedule [21]. In drilling operations, eddies may induce vortex-induced vibrations that reduce the fatigue life of equipment. Eddies can hold currents of four knots or more at the surface and extend several hundred meters deep and measure as wide as 250 miles in diameter. The operational limit for diver operations is half a knot or less, while deployment of tubulars and risers can usually be safely performed in currents up to 1.5 knots.

4.2. Physical Outcome

To a large extent, the impact of severe weather on drilling depends on the choice of rig the operator has chosen for the operation. Many different rigs can be used to drill an offshore well and rig selection depends upon factors such as the type of well being drilled, water depth and environmental criteria, the type and density of the seabed expected drilling depth, load capacity, frequency of moves, ability to operate without support and rig availability.

If weather and environmental conditions are expected to be a problem, then sophisticated all-weather semis can be used to hedge against weather downtime. The increase in availability is achieved through the higher capital cost of the equipment; which in turn is passed to the operator in higher day rates. Jack-ups are cheaper but are more prone to weather delay. The choice is up to the operator: the trade-off is between drilling availability and day rate.

The cost of deepwater drilling can represent a significant portion of the total field development costs, perhaps as much as 20-40% of total costs, and so operators pay close attention to the environment to minimize the magnitude of the risk. Because of the potentially catastrophic effect a powerful eddy can have on a drilling riser, it is common to monitor the approach of an eddy and pull the riser or circulate the stroke pipe before the eddy actually reaches the platform. In April 2003, strong eddy currents and tropical storm Bill and hurricane Claudette impacted several deepwater operations; e.g., Shell's Nakika was delayed 1 week; Total's Matterhorn TLP was delayed 6 weeks; Heerema's Balder experienced several delays in BP's Mardi Gras pipeline installation [3].

"Eddy Watch" and "Eddy Net" are monitoring systems operated by Horizon Marine (www.horizonmarine.com) that provides real-time ocean current maps (Figure 2). Horizon Marine's Eddy Watch is a weekly report published since 1984 that contains information on eddies in the GOM. The data is gathered through 45 drifting buoys equipped with Argos GPS satellite transmitters that float in the currents and track movements. The buoy data is combined with infrared satellite imagery, altimetry and remote sensing to compile the Eddy Watch report. Eddy Net is a real-time, rig-mounted ADCP system in 500-800 m water depth installed in 6 sites in the GOM (Figure 3) with plans to have 20 sites by 2005. Operators also directly monitor currents through their own site surveys of current meters installed on boats, rigs, and platforms; e.g., Shell uses the ADAM system (ADCP Data Acquisition Manager). ChevronTexaco, BP, and Marathon use ADCP on various active production facilities and drilling rigs.

4.3. Economic Outcome Model

The *Joint Association Survey on Drilling Costs* estimated that the total cost of drilling in the GOM in 2000 was $4.6 billion [22], and over the past few years, the total annual offshore drilling cost ranged between $3-5B. If we assume 1-3% of the total drilling cost is due to waiting on weather and that improved ocean observation systems can mitigate 1% of these costs, the expected annual savings due to improved ocean observation data is estimated to lie between $300,000 and $1.5M.

5. Development Activities

5.1. Decision Model

One of the primary goals in any construction project is predictability, but because of the nature and location of the operation, offshore construction activities will always be uncertain and unpredictable. There are numerous independent uncontrollable variables in the offshore environment, such as adverse sea conditions and weather, availability and performance of equipment, defects in plans and specifications, and work conditions that result in delay, and often, significant financial repercussions. Delay is a common risk in offshore construction projects and the parties of the contract apportion risks for delays that may be encountered. In the case of weather risk, construction contractors will frequently quote a lump sum (base) bid that includes weather downtime, except downtime due to named tropical storms, for work during the prime season (May 15 to October 15).

There are a wide variety of construction vessels used in the GOM and contractors plan their operations using ocean/weather forecast to avoid adverse weather and operating conditions. Typical offshore construction craft include crane vessels, drill ships, dive support vessels, survey vessels, cable lay vessels, pipelay vessels, multi-purpose support vessels, dredging vessels, and trawling vessels. The vessels come in a variety of shapes and sizes, from rectangular barges to jack-ups and semi-submersibles.

Offshore construction vessels differ from merchant ships because they do not trade cargo between ports and their most critical operations and loading conditions occur while working on the high seas (and not at the start or end of their voyage). Construction vessels also differ from passenger ships since they are much stronger and the design standards have to satisfy a multitude of strict safety regulations.

There are guidelines for marine operations such as barge transportation, platform mating and lift-off, etc. In barge transportation for example, weather forecasts are normally provided at 12-hour intervals and contain forecasts for the next 24 and 48 hours, with the weather outlook for the coming 3-to-5 day period. Tows are designed to withstand a 10-year return period for extreme environmental conditions for the most exposed part of the route for the month or months during which the transportation takes place. For long duration tows passing through areas having different characteristic sea states, the worst sea state for the route is identified and used in the design of the cargo, grillage, and sea fastenings [23, 24]. In installation operations, time-sensitive equipment such as ROVs and heavy lift vessels may not be able to operate in high current.

5.2. Physical Outcome

During construction activities, a moving vessel is installing (or removing) something on a fixed seabed, which leads to the requirement that vessel motions be minimized as much as possible to maximize the operational window. There are typically two options by which major projects are installed and completed offshore: floatover, in which the unit is lowered into place from its transportation vessel, or heavy lift, in which the unit is lifted into place with large vessel-mounted cranes. The transportation and installation limitations of the construction approaches dictate the size, weight and weight distribution of the modules. The heavy-lift method of installation is able to complete installations in challenging sea-states but the use of such equipment is also more costly. Lay barges for instance are designed to operate at different wave heights, allowing the operator to choose the barge to the sea conditions in the area. The prime risk factor is the weather, and specifically, wave heights. A barge that can operate in 2-m wave height cost about $250,000/day while the cost for a 5-m wave height lay barge cost about $500,000/day. The application of reliable ocean forecasting in pipe laying is obvious. If pipeline installation is finished late, or delayed by unexpected ocean conditions, the direct cost of delay expressed in terms of the day rates and the opportunity cost of nonproductive structures and wells is likely to be substantial.

5.3. Economic Outcome Model

Order-of-magnitude savings for construction and transportation activities in the GOM are estimated as follows. With the occurrence of a hurricane event, weather forecasting model improvement is assumed to provide a 10% or more accurate prediction of the storm path and arrival time saving 3-5 days work time.

(1) Operator Savings – Construction

Assumptions:

- Activity: 50 installed structures/yr, 50 removed structures/yr
- Construction activity level at time of hurricane passage: 50% total structures
- Number of structures in hurricane path: 50% total structures
- Derrick barge cost: $100,000/day

Expected Savings:

(50+50)(0.50)(0.50)(0.10)($100,000/day)(3-5 days) = $0.75-1.25M/yr.

(2) Operator Savings – Supply Vessel

Assumptions:

- Number of active supply vessels: 500/day
- Number of supply vessels in hurricane path: 50% total structures
- Supply vessel cost: $20,000/day

Expected Savings:

(500)(0.50)(0.10)($20,000/day) (3 days) = $1.5-2.5M/yr.

6. Production Activities

6.1. Decision Model

What is considered to be severe weather varies with each platform and drill site. Companies develop emergency procedures for each type of rig and manned platform they operate, and there is no standardized shutdown or evacuation procedure in the event of an extreme weather event or disaster. Shut-down and evacuation procedures vary from company to company and depend upon the rig type and design, the location of the operation, and the behavior of the weather.

The decision to shutdown or evacuate and the actions taken by the crew ensure that no employees are injured, damage to the operation or rig is minimized, and drilling/production can be resumed as soon as possible after the event passes. The drilling superintendent and marine superintendent establish in writing specific procedures for the operation, evacuation, and securing of their particular rig or platform in adverse weather. The location and design of the rig determine the actions to be taken. Submersible, jack-up and semisubmersible rigs are usually not moved from location. On submersible rigs, the rig is typically moved across from the wellhead to prevent damage, and on jack-up rigs, the hull is jacked up to avoid high seas. On semisubmersible rigs, the drill string hangs off in the wellhead and the anchors are slackened to reduce tension. If weather is extremely severe and the rig rolls excessively, mud and bulk material may be dumped.

Drill ships and drilling barges follow most of the same procedures but may be moved to inland waters out of the storm's path.

The evacuation and shutdown action plan generally follow a well-defined sequence of activities:

1. Regional tropical cyclone climatology is reviewed for area of operation.
2. National Hurricane Center analysis/forecast charts are obtained, including surface, upper level, and sea state (wind/wave) charts.
3. Tropical waves, disturbances, and tropical cyclones are located and plotted.
4. The closest point of approach[4] and time to tropical cyclone is calculated.
5. Decisions on the course of action to follow on the latest safe departure time are made and executed.
6. Actions are reviewed when new meteorological analysis and forecast information becomes available.

Approximately 5-7 days before the expected arrival of the hurricane, the evacuation and shutdown action plan is initiated. Storm path, speed, and intensity forecast information is typically supplemented by in-house/consulting meteorologist and/or local weather service providers[5]. Team leaders, operational managers, and meteorologist meet twice a day to plan and schedule evacuation activities with primary consideration given to the latest safe departure time for personnel[6].

Operators are responsible for the safety of all personnel on their structures, and 2-5 days prior to the arrival of the storm, all nonessential personnel are evacuated during daylight hours. Essential personnel are the last to go and are transported to shore after wells are closed and topside equipment secured 1-2 days before the storm is expected to hit. In the 1960's operators considered 3 days the minimum time window to evacuate personnel and shutdown operations, while today with better and more reliable weather forecasting, 1-2 days is considered a safe window. Shut down can be performed automatically, in fact nearly instantaneously, using automatic control systems on wells where it is deployed, and for manned platforms, shut down is performed in stages according to facility requirements.

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[4] The 1-2-3 Rule of Thumb is the most important aid in assessing "track error," the distance between the predicted position of a storm's center and its actual position. The 1-2-3 Rules of Thumb is derived from the latest 10-year average track error associated with hurricanes in the North Atlantic:

1-100 mile error radius for 24-hr forecast

2-200 mile error radius for 48-hr forecast

3-300 mile error radius for 72-hr forecast

[5] The size of the private/commercial meteorological value added sector is estimated to employ approximately 4,000 people with $400-700M in annual gross receipts [26]. Most of the firms are sole proprietorships.

[6] It is possible for crews on manned platforms to bunker down and weather out most hurricanes in the GOM, but for safety and family concerns, all personnel are usually evacuated. The safety record associated with offshore production has been exceptional over the past two decades. The last major event occurred with Hurricane Juan in 1985, where several rigs and boats capsized and in total nine lives were lost offshore.

6.2. Physical Outcome

Severe weather procedures vary according to the type of rig [25].

Submersible and jackup rigs

- On submersible rigs, move back enough from the wellhead to prevent wellhead damage, and increase ballast so that high seas will not move the rig off location.
- On jackup rigs, jack up the hull to avoid high seas. Jackup rigs are usually not moved in severe weather.
- Remove all drill pipe in the derrick on both submersible and jackup rigs.

Semisubmersible rigs

- Suspend drilling and hang off the drill string in the wellhead before the extreme weather arrives.
- If waves are expected be extremely large, pull the upper package. Slacken lee anchors to reduce anchor tension on windward anchors.
- Lay down and secure the cranes.
- Deballast the rig to allow waves to pass beneath the rig.
- Apply thrusters to relieve tension on the windward anchors.
- Keep a constant check on anchor tension.
- If the upper package was pulled, make sure the station-keeping equipment is monitoring a beacon attached to the lower package.
- Make sure that the standby boat is kept downwind or abeam.
- If the weather is extremely severe and the rig is rolling excessively, dump mud and bulk material.

For drill ships and barges, most of the above procedures are followed but need to be performed sooner. Drill ships and drilling barges may be moved out of the path of the storm and to inland waters out of the storm's range.

Companies transport crews offshore in helicopters, crew boats, and workboats according to their operational guidelines. The major environmental parameters in offshore emergency evacuation are the wind speed and wave height, and safe working conditions for many offshore operations may be approximately specified by critical values of these parameters (recall Table 3). The limiting conditions for the operation of helicopters are usually defined in terms of wind speed (typically 40-50 mph), and visual flight rules specify that the operating minimum for single-engine helicopters is a 3-mile visibility with a 500-ft ceiling. The minimum operating conditions for multiengine helicopters is a 2-mile visibility with a 300-ft ceiling. Wave height must fall below a given threshold (typically 5-8 ft) to ensure safe transfer operations with the crew or workboat. Evacuations are performed in the daytime and the method of evacuation depends on the sea state, distance to shore, climatic conditions, and availability of transportation equipment. Thunderstorm activity will restrict helicopter usage. The number of personnel involved in an evacuation depends on the type of structure: a small drilling rig may have a crew less than 10 while a large production platform could have over 100. In the GOM, there are currently about 25,000 offshore workers on any given day.

Some of the large operators in the GOM own a fleet of helicopters and will maintain annual contracts with service boats moored at various offshore production sites. Smaller operators reserve space on crew boats and helicopters[7] subject to availability, but there is usually sufficient capacity to ensure crews are transported in a safe and timely manner. For the planners and managers of evacuation activities, however, work conditions remain stressful and difficult during a hurricane event until all personnel arrive safely on-shore.

The occurrence of an extreme weather event requires operators to decide what facilities to shut down and when personnel should be evacuated. Current GOM operating philosophy requires the evacuation of all personnel before the latest safe departure time and the shutdown of most, if not all, production activity. Shutting down production has an immediate negative economic impact on the operator, but because of the extreme risk involved with tropical storms, a "conservative" approach is normally taken in planning activity. The safety record associated with offshore evacuation has been exceptional over the past two decades[8].

6.2. Physical Outcome

Immediately following a storm, the MMS will issue a Notice to Lessees requiring operators to conduct a Level *X* (*X* = I, II, III) survey for a *Y*-mile corridor around the storm path; e.g., Level I surveys are a visual inspection from the topside and the complexity of the inspection increases with the level specified. Damage can take many forms [28]:

- Platforms, caissons, and flare piles can list (lean), topple, or are condemned.
- Drilling rigs, barges, and workboats can be grounded or capsize.
- Flowlines and pipelines can be damaged by a dragged anchor.
- Topsides equipment such as pumps, tank batteries, power generators, etc. may have water damage.

The damage incurred to a structure translates to a direct economic loss to the operator since many are self-insured. Operators, and to a lesser extent, insurers, absorb the cost of a hurricane, while service companies performing underwater inspections and emergency repair and construction and equipment suppliers benefit from the business derived from the event. The cost associated with a hurricane and borne by operators is thus "balanced" to some extent by the economic stimulus that follows in the wake of the storm.

[7] Typical dayrates for a 34 ft crew boat is $600-800/day, while for a 190 ft crew boat, $2,000-4,000/day. Typical helicopter rates are $1,000-1,500/hr. A crew boat can transport up to 90-130 people; a helicopter up to 25 depending on its size. Unscheduled, weather-related evacuations add approximately $10,000 per production facility and $50,000 per drilling rig over and above normal transportation cost [21].

[8] The last major event occurred with Hurricane Andrew in 1992, where 164 structures were destroyed, including 22 major platforms [27].

Starting up production and re-pressurizing wells after shutdown can be problematic and usually takes a few days, especially when inspections need to be performed. Engineers must spend time inspecting pipes, pumps, and process facilities before the spigots are reopened. Wells that have been shut off can suffer from temporary shifts in the underground pressure, reducing initial output for weeks or months. In other fields, shutting down can help rebuild pressure and enhance production rates. The success of start-up operations depend in large measure on the damage caused by the storm, the characteristics of the geologic formation, and the complexity of the wellbores. Since most GOM crude oil is light and in primary production, start up activities are mostly performed without consequence, and assuming no storm damage, fixed structures may come back on-line within 48-72 hr of evacuation. Individual wells may be off production for several weeks or even months. Floating production systems, which operate in the deep waters of the GOM and where hydrates may form, may take up to one week to resume production.

6.3. Economic Outcome Model

A company will typically include anywhere from 3-5 days of weather-related production losses each year in their business plans to account for the uncertainty of weather. Operators incur the cost associated with deferred production, evacuation cost, damage assessment, and facility repair, if any, prior to the resumption of production. Most of these costs, with the exception of deferred production and human life consequences, cannot be mitigated or reduced, since offshore production facilities cannot be moved out of the path of the storm or otherwise avoid the storm's impact.

The direct cost involved with a hurricane event includes shut-down cost, C_1; evacuation cost, C_2; downtime cost, C_3; damage assessment cost, C_4; facility repair cost, C_5; and start-up cost, C_6. Improved ocean observation systems are expected to allow *some* of these costs to be reduced, delayed, or possibly avoided – in particular C_2 and C_3 – although it is clear that *no* observation system cannot mitigate the actual damage of the event unless boats and drilling vessels are moved out of the track of the storm that otherwise would not have been moved. Shut-down and start-up cost (C_1, C_6), damage assessment cost (C_4), and facility repair (C_5) depend on the track and strength of the storm and the amount of damage inflicted and are not influenced by improved ocean observation systems except in the development design stage[9].

Hurricane motion is controlled by the state of the surrounding atmosphere, and forecasts based upon more accurate and timely measurements of that state are themselves more accurate. If the forecast associated with a hurricane event can be improved, then production can stay on-line a greater period of time without sacrificing safety or environmental considerations, and in the best case, perhaps not shutdown at all. Order-of magnitude estimates for evacuation and lost production savings are provided as follows.

(1) Operator Savings – Evacuation

[9] The optimal design of an offshore facility, especially floating production facilities in the deepwater GOM, requires knowledge of the response of the structure to environmental loading, which in turn, is critically dependent on the acquisition of reliable data on current profile and wave height. It is important to assess seasonal and inter-annual variability in dynamic conditions, but it is seldom possible or cost-effective to undertake multiple-year site-specific measurement programs in support of field development.

Assumptions:

- Manned platforms in hurricane path: 750
- Rigs in hurricane path: 100
- Evacuation cost: $10,000/platform, $50,000/rig
- Weather forecasting model improvement: 10-20% more accurate prediction on hurricane path/zone to avoid evacuation

Expected Savings:

(750)(0.10-0.20)($10,000/platform) + (100)(0.10-0.20)($50,000/rig) = $1.25-2.5M/yr

(2) Operator Savings – Lost production

Assumptions:

- Net income margin per BOE: $5/BOE
- One-half of GOM production shut-in: 1.5 MMBOE/day
- Weather forecasting model improvement: 0.5-1 day continued production

Expected Savings:

(1.5 MMBOE/day)($5/BOE) = $3.8-7.5M/yr

7. Oil Spill Management and Response

7.1. Decision Model

The risk of oil spills arise from activities associated with the exploration, development, production, and transportation of offshore oil and gas resources, as well as from the transport of oil across the ocean to port facilities [29, 30]. During the 1970s and early 1980s most of the crude oil and products moved by water was associated with inland barges or coastwise movement between U.S. production/processing and consumption regions. By the mid-1980s, waterborne commerce of foreign imports of crude oil and petroleum production exceeded coastwise transportation, and today is completely dominated by foreign imports.

Oil spills in coastal waters are especially damaging and clean up can be very expensive. The Oil Pollution Act of 1990 [31] requires that response activities deal with the legal constraints and interest of various political entities as it attempts to minimize ecological damage and the quality of human life. Better knowledge of wind and water currents will assist in the management and clean up of oil spills.

Four factors influence oil spill response: the type of oil (e.g., heavy crude, distillate fuel, etc.); the amount of oil spilled; the spill conditions, which are described by sea temperature, ocean current, wind and weather conditions; and proximity to ecologically sensitive areas. Once notice has been received that a spill has occurred *all* of these factors are assessed to determine the spill response.

Information to support operational decisions during an oil spill is provided through a variety of sources. Typically, decision-making is aimed at supporting a "minimum regret" as opposed to a "maximum win" strategy [14]. In a "maximum win" strategy, the best estimates of wind, currents, and the initial distribution of the pollutant is collected and the resulting forecast taken as the threat. A "minimum regret" strategy on the other hand uses whatever analysis techniques are available as input data. The situation unit presents the command with not only the "best guess" of where the oil will go but also with alternate possibilities that might present a significant threat. Reliable near-time data on the wind and wave conditions is essential for good decision-making.

7.2. Physical Outcome

Oil spill response is site specific and occurs within a complex, dynamic, and uncertain environment. The environmental effects of oil spills vary widely depending on factors such as the amount and type of oil spilled, weather conditions, the location of the spill relative to natural resources, the quality and sensitivity of effected resources, seasonal factors, and the thoroughness and speed of cleanup and restoration efforts (Figure 4).

Clean up operations employ one or more methods such as mechanical systems, chemical dispersants, burning, and bioremediation depending on prevailing spill conditions. Timing is critical to effective clean up. Floating oil spreads rapidly, and a slow response may allow oil to spread over a large area so that boom is not effective in containment. Floating oil also emulsifies as it mixes with water lending treatment with dispersants ineffective after a given time window has passed.

7.3. Economic Outcome Model

There are many social costs associated with an oil spill. Many costs can be measured as direct economic cost such as the cost of clean up, while indirect cost such as damage or harm to wildlife cannot be measured in a market transaction. Indirect social costs are typically valued using "willingness-to-pay" techniques or an assessment of the loss in consumer surplus. The estimated unit cost of a barrel of oil spilled or reaching shore across the OCS planning areas is summarized in Table 4 [32]. The total estimated cost for the GOM region is assumed to range between \$(888, 1445) per barrel of oil spilled.

The number of spills in the U.S. Coast Guard District 8, which includes Texas, Louisiana, Mississippi, Alabama, and the Florida panhandle, and the volume of spills is shown in Table 5. Roughly one half of the volume spilled came from tank vessels, and 60% of the volume involved crude or heavy oil. The 8th District was responsible for nearly 40% of the spills and 38% of the total volume across the United States. Eleven percent of the total volume of oil spill occurred in the open ocean (12-200 miles), which would normally not realize a significant improved response with enhanced ocean forecasting.

The impact of a 1% improvement in oil spill response is estimated to result in the following cost savings:

$$(74{,}000 \text{ bbl/yr})\$(888/\text{bbl}, 1445/\text{bbl})(1-0.11)(0.01)=\$(0.58\text{M/yr}, 0.95\text{M/yr}).$$

8. Conclusion

Oil and gas technological advancements over the past two decades have been remarkable, but no matter how ingenious, operators still cannot overcome extreme weather events. Weather information is valuable, and to the extent that improved ocean observation systems can improve the data on which weather/ocean forecasts is based, is potentially very beneficial to energy production and pollution management in the GOM. Primary applications of ocean observation data are to provide nowcasts/forecasts of weather, wind speed, surface wave, current, and general circulation patterns. Order of magnitude benefits derived from ocean observation systems to energy related activities in the GOM are conservatively estimated to range between $8.3-15.3M (Table 6). The actual benefits derived are expected to be a positive multiple of this factor.

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Table 1. Tropical Storm and Hurricane Events in the Gulf of Mexico

Hurricane	Year	Magnitude
Larry	2003	0[a]
Henri	2003	0
Grace	2003	0
Erika	2003	1
Claudette	2003	4
Bill	2003	0
Lili	2002	4
Isidore	2002	3
Hanna	2002	0
Fay	2002	0
Edouard	2002	0
Bertha	2002	0
Gabrielle	2001	1
Barry	2001	0
Allison	2001	0
Keith	2000	4
Gordon	2000	1

Source: National Climatic Data Center

Footnote: (a) A tropical storm is denoted by a magnitude of 0.

Table 2. Eddy Events in the Gulf of Mexico

Eddy	Year	Size
Titantic	2003	Huge
Sargassum	2003	Huge
Rebel	2002	Small
QE-2	2002	Small
Quick	2002	Huge
Pelagic	2002	Huge
Odessa	2001	Medium
Nansen	2001	Medium
Millenium	2001	Huge
Lazy	2000	Small
Kinetic	2000	Small
Juggernaut	1999	Huge
Indigo	1999	Small
Haskell	1999	Small
Gyre	1999	Small

Source: Horizon Marine, Inc.

Table 3. Limiting Conditions for Offshore Weather-Sensitive Activities in the GOM

Activity	Limiting Conditions
Evacuation by crew boat	WH[a] < 5 ft, Daylight
Evacuation by helicopter (fixed structure)	WS[b] < 40 mph, Daylight
Deepwater drilling	WS < 80 mph, WH < 8 ft, CV[c] < 2 knots
Tubular and riser deployment	WS < 80 mph, WH < 8 ft, CV < 1.5 knots
Lifting and coupling	WH < 5 ft
Evacuation by helicopter (floating structure)	WS < 50 mph, WH < 5 ft, Daylight
Diving operations	CV < 0.5 knots
Boom containment	WH < 1 ft

Footnote: a) WH = Wave height
b) WS = Wind speed
c) CV = Current velocity

Table 4. Estimated Unit Cost Elements per Barrel Spilled and Reaching Shore

OCS Planning Area	Control[a] ($)	Cleanup ($)	Property Lost ($)	Recreation and Tourism ($)	Wildlife and Ecological[a] ($)
Straights of Florida	(64, 99)	(565, 872)	272	(133, 448)[b]	30[b]
Eastern GOM	(66, 103)	(546, 843)	46	(90, 320)	154
Central GOM	(55, 85)	(650, 1002)	46	(52, 190)	154
Western GOM	(58, 90)	(249, 385)	46	(143, 514)	116
AVERAGE	(61, 94)	(503, 776)	103	(107, 368)	114

Source: MMS
Footnote: a) Per barrel spilled
b) Mid-Atlantic region

Table 5. Number and Volume of Spills for the 8th Coast Guard District

Year	Number of Spills	Volume of Spills (1000 barrels)
1990	3,205	117
1991	3,572	14
1992	3,616	23
1993	3,477	15
1994	3,465	26
1995	3,363	36
1996	4,678	19
1997	4,699	15
1998	4,224	11
1999	3,836	18
2000	4,177	21
Average (1973-2000)	3,132	74

Source: U.S. Coast Guard

Table 6. Summary of Potential Benefits of Improved Ocean Observation Systems to Energy Development Activities and Oil Spill Response Management in the GOM

Application	Nature of Benefit	Annual Potential Benefits ($M)
Drilling activity	Improved operations	(0.3-1.5)
Construction activity	Improved operations	(0.8, 1.3)
Supply vessels	Improved operations	(1.5, 2.5)
Evacuation	Improved operations	(1.3, 2.5)
Lost production	Reduced production	(3.8, 7.5)
Oil Spill response	Improved response	(0.6, 1.0)
TOTAL		(8.3, 15.3)

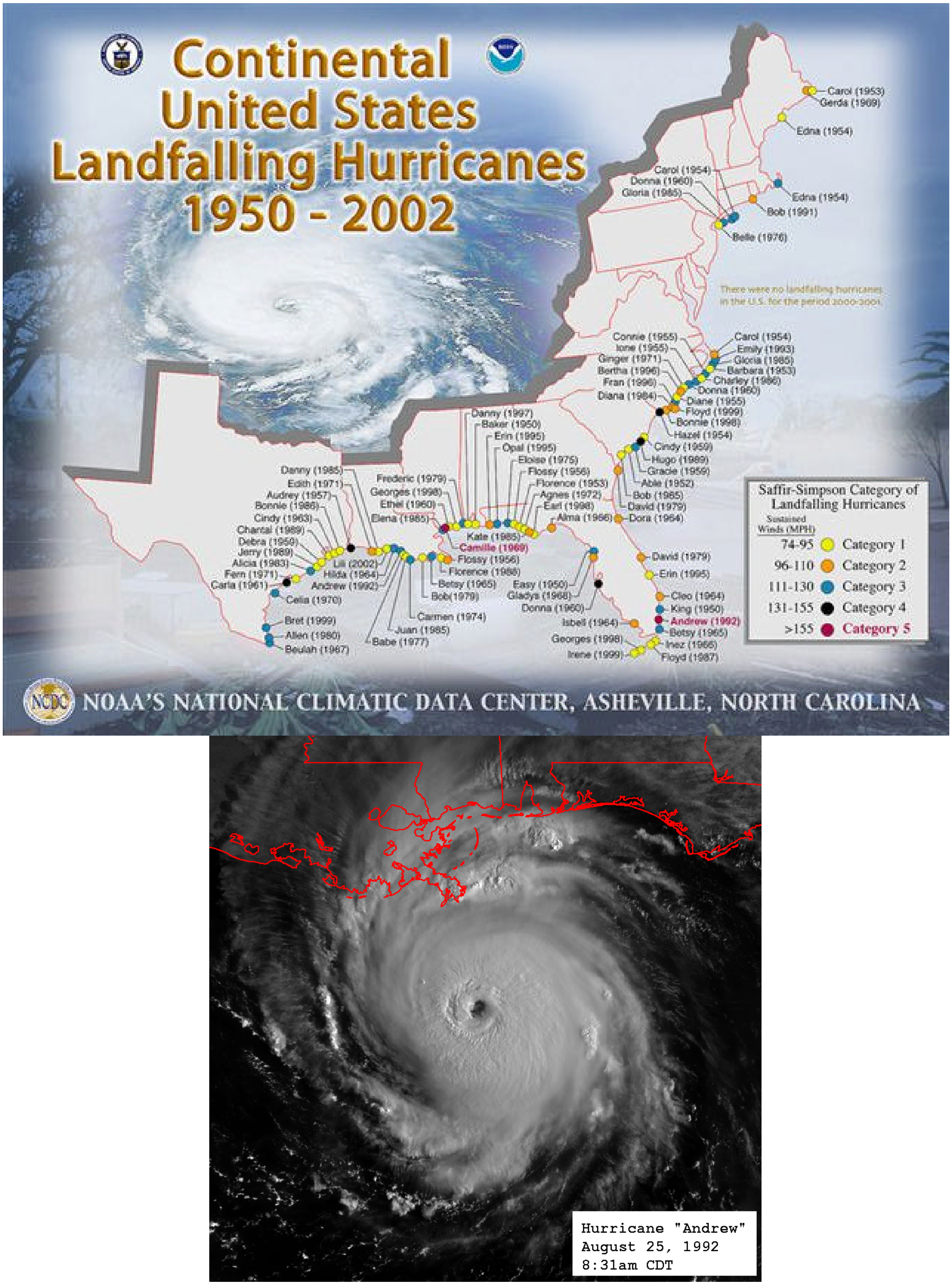

Figure 1. Continental United States Landfalling Hurricanes (1950-2000) and Hurricane Andrew (August 1992). Source: National Climate Data Center

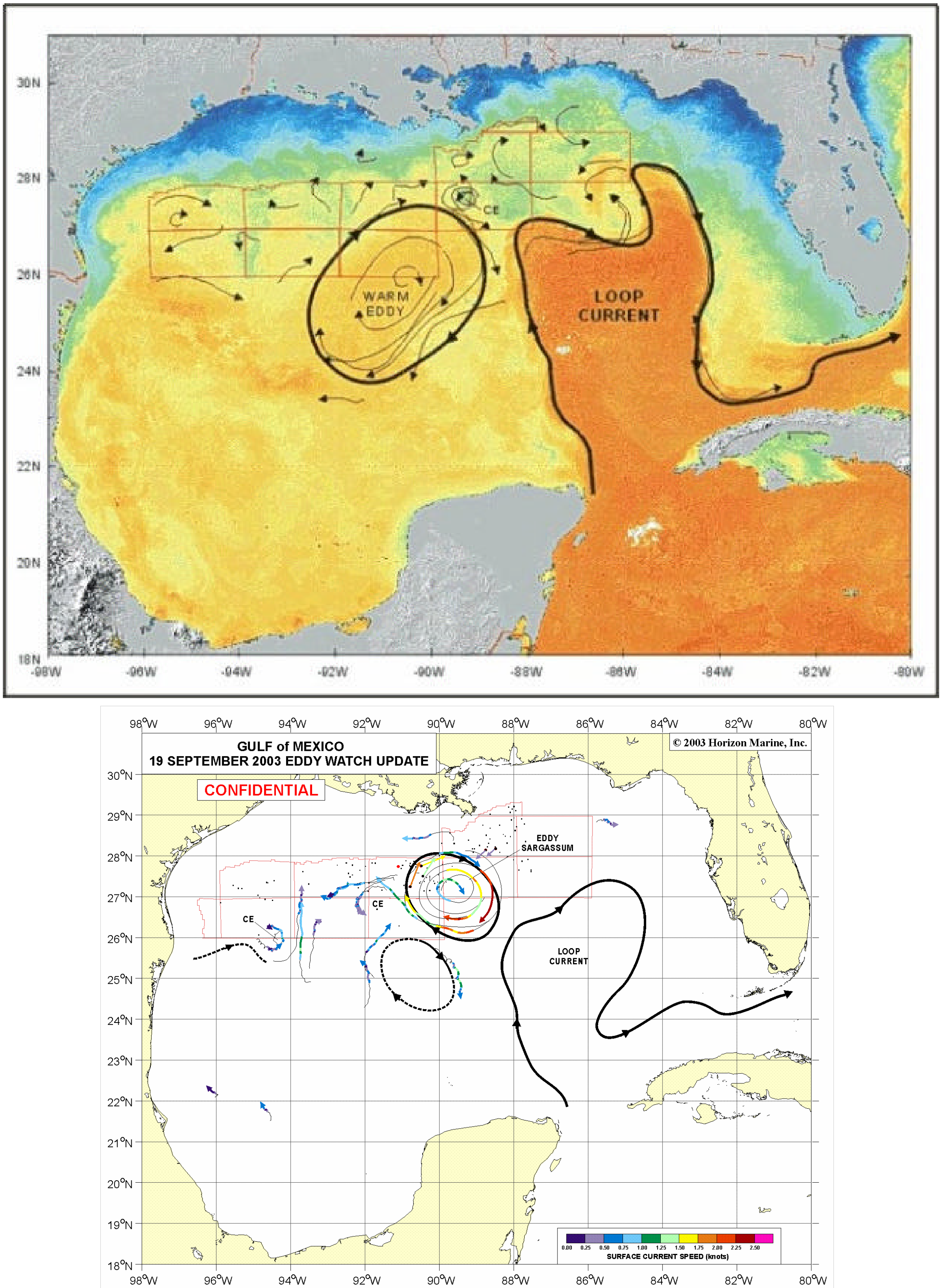

Figure 2. Loop Current Pattern and Eddy Sargassum (September 2003). Source: Horizon Marine, Inc.

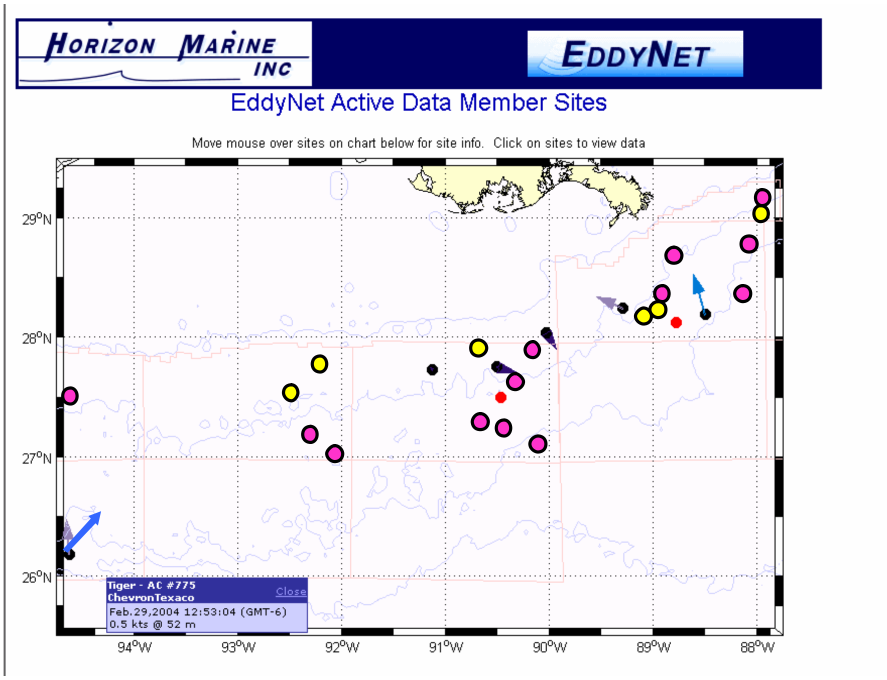

Figure 3. EddyNet Data Collection Sites. Source: Horizon Marine, Inc.

Figure 4. Oil Spill Response Strategies

DRAFT
Final Report

The Benefits of Enhanced Coastal Ocean Observing Systems: Commercial Fishing in the Alaska Region

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&
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June 27, 2004

1 Introduction

Alaskan commercial fisheries can be expected to realize benefits from enhancements to the Alaska Ocean Observing System (AOOS). We have identified and attempted to quantify potential benefits in three areas:

1) Increased harvests
2) Avoidance of overfishing
3) Enhanced business planning

In working towards an assessment of the value of improved coastal ocean observing systems (COOS) to the commercial fisheries of the Alaska region we have found that the use of COOS data in research, stock assessment and ultimately fisheries management varies considerably from fishery to fishery. As such we have generated a case study approach where we look at 3 specific Alaska fisheries. These include: (1) Bering Sea and Gulf of Alaska groundfish; and (2) Kodiak king crab and (3) Bristol Bay salmon. These case studies offer a qualitative discussion of the current and optimal COOS information scenario, decision-making and physical outcomes and a quantitative analysis of economic outcomes based on plausible scenarios. All assumptions and limitations to the economic assessment of the value of improved COOS are stated explicitly.

The analysis and final conclusions of this report were generated using information provided through interviews with Directors of the Alaska Ocean Observing System (AOOS) and Northwest Association of Networked Ocean Observing Systems (NANOOS) and over 25 biologists, oceanographers, fisheries managers, and fishers. We also relied on scientific studies, North Pacific Fisheries Management Council Stock Assessment Fishery Evaluation reports, and relevant secondary literature (please see literature cited section).

2 Overview of Commercial Fisheries in Alaska

This section provides a general overview of the commercial fisheries in Alaska and documents the importance of Alaska fisheries within the US. It provides a summary table showing the five major fisheries by species in Alaska and goes on to provide additional details for groundfish, salmon and crab, the top three fisheries by weight and value.

These three fisheries are likely to benefit most from an enhanced ocean observing program.

Commercial fisheries of Alaska are among the largest in the world and contribute the vast majority of US commercial fishery products and value. As seen in Table 1, landings of commercial fisheries in Alaska were 53 percent all US commercial landings by weight in both 2000 and 2001, and 26 percent of harvested value (or ex-vessel value). In addition, the top three Alaska ports with respect to landed weight—Dutch Harbor/Unalaska, Kodiak and Akutan—consistently rank in the top 6 of all US fishing ports, and the top 10 Alaska ports all rank among the top 50 US fishing ports[1] [NMFS, and NPFMC].

Table 1. US Commercial Fishing Landings and Value

Regions and States	2001 Thousand Pounds	2001 Thousand Dollars	2002 Thousand Pounds	2002 Thousand Dollars
New England	635	646	584	685
Middle Atlantic	835	347	702	342
South Atlantic	200	176	215	173
Gulf of Mexico	1,606	798	1,716	693
Pacific (WA, OR, CA, HI)	24	55	24	52
Great Lakes	19	18	18	16
Alaska	5,036	870	5,066	812
Total, United States	9,492	3,228	9,397	3,092
	Percent of US Total			
Alaska Percent of US	53.1	26.9	53.9	26.2

Source: NMFS, 2003. Adapted from information contained in *Fisheries of the United States, 2002.*

Alaska's fisheries are very diverse in terms of geography, species, the types of vessels and gears used and the way the fisheries are managed. That diversity makes it very difficult to generalize the effects of an improved ocean observation system. For example, biological and oceanographic data that is beneficial for stock assessments for one species may not be that useful for other species. Table 2 provides a detailed list of Alaska commercial fisheries by geographic location, species, and gear type.

[1] The ports of Akutan, King Cove, and Sand Point are typically not listed among top US ports because each has only one fish processor/buyer, and therefore, data regarding total landed weight and value at these ports are confidential. However, the American Fisheries Act of 1998 opened data associated with BS Pollock fisheries to public scrutiny, and based on Bering Sea pollock data alone, the three communities would all be in the top 50 in terms of landed weight with Akutan ranking number 5 in front of Kodiak. Other ranked Alaska ports include Ketchikan (14), Sitka (15), Cordova (20), Petersberg (22), Homer (29), and Kenai (37).

Table 2. Major Commercial Fisheries in Alaska

Region	Fishery
Southeast Alaska—10 Fisheries	Troll Fisheries for King and Silver Salmon Wild Seine Fisheries for Pink and Chum Salmon Hatchery Seine Fisheries for Pink and Chum Salmon Statewater Longline Fisheries for Sablefish Federal Water Longline Fishery for Sablefish Longline Fishery for Halibut Sitka Herring Fishery (and possibly other herring fisheries) Southeast AK King Crab Fisheries Shellfish Dive Fisheries (Geoduck, Oyster, Urchin, Sponge) Oyster and Mussel Mariculture Fisheries
Prince William Sound and Cook Inlet—9 Fisheries	Wild Seine Fisheries for Sockeye, Silver and Pink Salmon Hatchery Fisheries for Sockeye, Silver and Pink Salmon Drift Gillnet Fisheries for King, Sockeye, and Silver Salmon Set Gillnet Fisheries for King, Sockeye, and Silver Salmon Statewater Longline Fisheries for Sablefish Federal Water Longline Fishery for Sablefish Longline Fishery for Halibut PWS Herring Fishery Oyster and Mussel Mariculture Fisheries
Central and Western Gulf of Alaska—10 Fisheries	Trawl Fisheries for Pollock, Pacific Cod, Rockfish, Deep- & Shallow-water Flatfish Federal Water Longline Fishery for Sablefish Longline Fishery for Halibut Statewater Pot and Jig Fisheries for Pacific Cod Kodiak Seine Fisheries for Sockeye and Pink Salmon Kodiak Setnet Fisheries for Sockeye Salmon Chignik Seine Fisheries for Sockeye and Pink Salmon Alaska Peninsula Seine Fishery for Sockeye, Pink, Chum, and Silver Salmon Alaska Peninsula Drift Fishery for Sockeye Alaska Peninsula Setnet Fishery for Sockeye
Bering Sea and Aleutian Islands—6 Fisheries	Trawl Fisheries for Pollock, Pacific Cod, Atka Mackerel, Rockfish, Flatfish, including fisheries off Adak for Pollock and Pacific Cod Federal Water Longline Fishery for Pacific Cod Longline Fishery for Halibut Statewater Pot and Jig Fisheries for Pacific Cod Pot Fisheries for Red King Crab, Opilio Crab in Bering Sea and Pribilofs Pot Fisheries for Brown King Crab in Aleutians
Western Alaska—7 Fisheries	Bristol Bay Drift Sockeye Bristol Bay Setnet Sockeye Kuskokwin River Chum, Silver and King Salmon Yukon River Chum, Silver and King Salmon Togiak Herring Norton Sound Red King Crab Kotzebue/Arctic Chum Salmon

In 2001 the ex-vessel value (the amount paid to fish harvesters) of Alaska commercial fisheries totaled nearly $1 billion. Typically, the fisheries are divided into 5 major species groups including groundfish, crab, salmon, halibut and herring. Table 3 shows the value of raw fish (ex-vessel value) in Alaska by species group for the years 1993-2002. Table 4shows estimates of participation, employment and payments to labor in the groundfish fisheries for 2001.

The major Alaska crab fisheries are now primarily in the Bering Sea (opilio tanner crab) and Bristol Bay (red king crab) and currently constitute approximately 15 percent of the total ex-vessel value of Alaska fisheries. The relative value of the crab fisheries is down from 1993 when it generated 28 percent of total value. Historically there were major king crab fisheries in Kodiak and significantly larger king crab fisheries in Pribilof and St. Matthews Islands, but these have declined in recent years. The Kodiak fishery has been closed since 1983. Smaller fisheries for both king and dungeness crab continue in Southeast Alaska.

The salmon fisheries have the greatest number of participants and generate high levels of employment. However, in recent years the salmon fisheries have become less valuable because huge increases in farmed salmon—primarily from Chile and Norway—have saturated markets and reduce prices. In 1993 salmon generated 1/3 of the ex-vessel value of Alaska fisheries, but in 10 years prior to 1993 salmon accounted for as much as 67 percent of the value of raw fish from Alaska. Currently salmon accounts for approximately 20 percent of ex-vessel value.

In 1991 groundfish surpassed salmon as the largest fishery in Alaska in terms of ex-vessel value, and now generates over 50 percent of the value of Alaska fisheries. The groundfish fishery consists primarily of bottom fish including Alaska Pollock, Pacific cod, Black Cod, rockfish and Atka Mackerel and flatfish, including rock sole and yellowfin sole as well as several other types of flounders and soles.

While Pacific Halibut is technically a flatfish it is managed and reported separately from other groundfish species. Most participants in the halibut fisheries also participate in either the groundfish fisheries or the salmon fisheries. The Halibut fishery has increased in value since 1995 when it was rationalized from a one-day derby fishery to an individual quota fishery. Currently halibut accounts for over 10 percent the ex-vessel value from Alaska's fisheries.

Herring while much smaller in terms of value than the other fisheries, continues to be an important fishery supplementing incomes for participants in other fisheries.

Table 3. Ex-Vessel Value of Major Alaska Fisheries, 1993-2002

Year	Crab/Shellfish	Salmon	Herring	Halibut	Groundfish	Total
			Ex-Vessel Value $ Millions			
1993	386.1	459.7	16.6	63.0	477.9	1,403.2
1994	369.5	488.2	24.8	97.4	565.6	1,545.7
1995	318.8	558.8	44.1	67.0	646.0	1,634.6
1996	193.6	382.9	49.5	82.0	552.9	1,261.0
1997	186.7	268.8	17.2	115.5	619.9	1,208.0
1998	234.3	260.0	11.6	100.8	411.1	1,017.8
1999	286.5	365.3	15.0	123.5	487.8	1,278.1
2000	147.4	255.0	9.9	139.4	612.9	1,164.7
2001	124.4	189.9	10.5	120.2	546.9	992.0
2002	148.8	129.9	9.1	128.9	566.4	983.1
Average	239.6	335.9	20.8	103.8	548.7	1,248.8

Source: *Economic Status of the Groundfish Fisheries Off Alaska, 2002*, by Terry Hiatt et al. Al.
Note: Values shown are not adjusted for inflation.

Alaska's fisheries are an important source of employment not only in the harvesting sector, but also in fish processing. Because of its remoteness, relatively little of the output of Alaska commercial fishery harvests is sold fresh. Most is processed into frozen or canned products. The additional value added by Alaska's seafood processing sector brings the total output of Alaska's commercial Seafood industry to over $2.4 billion annually (Northern Economics, 2003). As seen in Table 4, fish harvesting generated employment of over 10 thousand full time equivalent (FTE) jobs while fish processing added an additional 15,000 FTEs. Overall it is estimated that direct payments to labor and owners exceeded $1.3 billion in 2001.

Table 4. Direct Economic Effect of Alaska's Commercial Fisheries, 2001

Species	Permits Fished	Estimated Harvesting Employment (FTE)	Ex-Vessel Value ($ Millions)	Estimated Processing Employment (FTE)	First Wholesale Value ($ Millions)	Estimated Payments to All Labor ($ Millions)
Crab & Shellfish	1,699	560	123.5	1,390	194.1	98.5
Salmon	7,372	4,400	188.5	6,090	537.5	290.4
Herring	815	220	10.4	190	171.2	72.6
Halibut	2,461	580	109.0	1,230	108.6	87.0
Groundfish	1,959	4,430	542.8	6,190	1,391.8	773.8
Total	14,306	10,190	974.2	15,090	2,403.2	1,322.4

Source: Northern Economics, Inc. 2003. Data provide by Alaska Department of Fish and Game and reported in *Impact of the Seafood Industry on Alaska's Economy*.

2.1 Alaska Groundfish Fisheries

This section provides an overview of the Alaska groundfish fisheries and summarizes catch by species, ex-vessel and wholesale values, and employment. Also briefly discussed are the methods used to set annual harvest amounts. Annual harvest are currently very conservative and take into account the uncertainty of many predictive variables, are likely to benefit directly from an enhanced ocean observation program.

With better information a less conservative harvest policy could be used, and quotas could be set higher with resulting increases in catch and values. The benefit estimates of the enhanced ocean observation program in the groundfish fisheries are discussed in Section 5.

Alaska's groundfish fisheries are managed primarily by the Federal government (the National Marine Fisheries Service (NMFS) and the North Pacific Fishery Management Council (NPFMC or Council)).[2] Management of the groundfish fisheries are based on Fishery Management Plans (FMP) (one FMP for the Bering Sea and Aleutian Islands (BSAI) and one FMP for the Gulf of Alaska (GOA)) summarized in the Alaska Groundfish Fisheries Final Programmatic Supplemental Environmental Impact Statement (SEIS) (NMFS, 2004). Much of the information used in this summary of the groundfish fishery is drawn from the 2004 SEIS.

The Alaska groundfish fisheries are dominated by harvests of walleye pollock, which since 1998 have been between 60 to 75 percent of harvests by volume (Table 5). During that same period harvests of Pacific cod and flatfish have averaged roughly 12 percent while harvests of other species are much smaller by volume.

Table 5. Alaska Groundfish Harvests by Species Group, 1998-2002

Year	Pollock	Black Cod	Pacific Cod	Flatfish	Rockfish	Atka Mackerel	Total
			Alaska Total -- millions of pounds				
1998	2,756.2	36.2	568.6	491.8	76.9	126.5	4,056.2
1999	2,395.1	33.7	534.6	534.6	97.9	124.6	3,720.5
2000	2,668.2	38.6	541.4	541.4	83.6	104.5	3,977.8
2001	3,220.7	33.3	481.5	379.2	86.2	135.8	4,336.7
2002	3,387.0	31.9	515.8	391.2	94.1	105.3	4,525.3

Source: *Economic Status of the Groundfish Fisheries off Alaska, 2002*, by Terry Hiatt et al. Al.

Ex-vessel and processed product values of Alaska groundfish from 1998-2002 are shown in Table 6. Ex-vessel value of harvests (the estimates value of raw fish harvested)[3] increased significantly from 1998 – 2000 primarily because of the rationalization of the pollock fishery under the 1998 American Fisheries Act (AFA). AFA allowed vessels to form cooperatives and effectively ended the "race for fish" in the pollock fishery. A similar increase in the wholesale values is seen over the same period. The additional value of the pollock fishery can be attributed to efficiency gains achieved through the reduction of active vessels in the pollock fishery and the coordination of effort through the cooperative system. A full report on the effects of the AFA can be found in a report to Congress compiled by the NPFMC in 2001.

[2] The State of Alaska has some management authority over Pacific cod and black cod when they are harvested in state waters.

[3] Estimates of ex-vessel value include an implicit value for fish harvested by vessels that both catch and process groundfish (catcher processors or CPs). In reality there is no monetary transaction of involving raw fish with CPs, and therefore no actual ex-vessel value is recorded. Implicit values are estimated using the prices received for raw fish by catcher vessels when they deliver fish to processors.

Table 6. Value of Alaska Groundfish by Species Group, 1998-2002

Year	Pollock	Black Cod	Pacific Cod	Flatfish	Rockfish	Atka Mackerel	Total
Ex-Vessel Value of Harvest ($ Millions) [1]							
1998	179.6	52.9	98.8	36.2	8.0	7.9	383.6
1999	211.2	57.0	141.9	30.2	11.0	9.8	461.4
2000	298.0	75.8	157.7	41.1	9.8	9.5	592.5
2001	295.2	61.9	124.8	31.5	7.9	21.1	542.6
2002	321.6	64.4	121.7	37.2	9.7	11.2	566.2
First Wholesale Value of Processed Products ($ Millions) [2]							
1998	492.3	68.3	213.6	83.4	18.7	17.5	1024.8
1999	690.2	73.0	273.6	70.7	20.7	21.9	1178.1
2000	814.3	87.1	285.9	91.9	19.0	21.2	1345.8
2001	929.8	79.5	235.4	61.5	15.6	44.6	1390.8
2002	987.0	81.5	245.2	86.1	22.5	24.9	1482.8

Source: *Economic Status of the Groundfish Fisheries off Alaska, 2002*, by Terry Hiatt, et. Al.

1. Estimates of ex-vessel value include an implicit value for fish harvested by catcher processors.
2. Estimates of wholesale value are based on values reported by processors as product leaves the plant.

Note: Values shown are not adjusted for inflation.

It should be noted that both ex-vessel and wholesale product values are reported in Table 6. Reporting only the value of raw fish (ex-vessel value) significantly understates the value of the fisheries, particularly in the case of the fisheries that include catcher processors (CPs). CPs, which both catch and process fish account for approximately 54 percent of the wholesale value of Alaska groundfish harvests. In addition, motherships, large processing ships that take deliveries of raw fish at sea, account for approximately 6 percent of the wholesale value. The remaining 40 percent of wholesale value is generated by traditional shore-based processing plants. As seen in Table 7 Alaska groundfish fisheries generated over $600 million in direct income for fishing crews and processing labor, and boat and facility owners, and employ over 10,000 FTE in 2001.

Table 7. Value, Payments to Labor and Employment in Alaska Groundfish Fisheries by Sector, 2001

Sector	Value ($ Millions)	Payments to Labor ($ Millions)	Employment (FTE)
Catcher Processors	743.9	265.9	3,876.7
Motherships and Shore-based Processors	682.9	266.9	4,490.5
Catcher Vessels	288.5	115.4	2,015.7
All Sectors	1,426.9	648.2	10,383.0

Source: Alaska Groundfish Final Programmatic SEIS. NMFS, 2004.

Note the total value of all sectors does not add the value earned by catcher vessels—those values are a cost to motherships and shore-based processors and are included in the total wholesale value.

2.1.1 Groundfish Stocks Assessment and Annual Harvest Quotas

In general, the groundfish fisheries are quota-based fisheries. The annual harvest quotas, or Total Allowable Catch (TAC), are determined on a species by species basis within each FMP. Each summer and fall, fisheries scientists review new data and augment predictive models to assess stocks of each species and to determine how much can be harvested without putting the stocks at risk of falling below the Maximum Sustainable Stock Threshold (MSST). The level at which each species may be harvested is known as the Allowable Biological Catch (ABC). The scientist's recommendations for ABCs, which are generally quite risk averse are based on the "best available scientific data" and the amount of uncertainty, are forwarded to the NPFMC where they are reviewed by the senior scientists comprising the Council's Scientific and Statistical Committee (SSC). The Council's Advisory Panel (AP), comprised of representatives from the public and the seafood industry, takes the ABCs forwarded by the SSC and recommends TAC levels for each species. The AP's TAC recommendations take into consideration factors such as the level of demand for specific species and other business/political factors. In the GOA, the recommended TACs are often very similar to recommended ABCs. In the BSAI however, a 2 million metric ton (MT) cap (4,409.2 billion pounds) limits the overall harvest of groundfish, even though the sum of ABCs of the various species in the BSAI far exceeds the cap.[4]

Table 8 shows estimates of the total biomass, spawning biomass, the ABC and actual total catch and exploitation rates of Alaska groundfish by major species groups in 2002. The estimates (Ianelli, 2003) demonstrate the relatively conservative harvest policy employed in the North Pacific. Overall exploitation is less than 8.5 percent of total biomass, but more importantly harvests are 70 percent of ABCs.

Table 8. Biomass, Allowable Biological Catch, and Catch of Alaska Groundfish, 2002

Species Group	Total Biomass (millions of lbs.)	Spawning Biomass (millions of lbs.)	ABC (millions of lbs.)	Catch (millions of lbs.)	Exploitation [2] (percent)
			Bering Sea and Aleutian Islands		
Pollock	28,586	8,114	3,843	3,276	11.46
Black cod	181	65	16	4	1.99
Pacific cod	4,260	892	644	403	9.47
Flatfish [1]	11,143	4,080	778	320	2.87
Rockfish [1]	826	303	62	46	5.58
Atka mackerel	1,057	261	144	105	9.92
BSAI Total	46,054	13,715	5,492	4,155	9.02
			Gulf of Alaska		
Pollock	1,502	300	388	111	7.40
Black cod	449	161	40	28	6.30
Pacific cod	1,253	216	164	112	8.97
Flatfish [1]	4,002	2,455	399	71	1.79
Rockfish [1]	1,105	401	70	48	4.34
Atka mackerel	NA	NA	1	0	NA
GOA Total	8,311	3,533	1,183	438	5.27
			Alaska Total		
Grand Total	54,365	17,247	6,675	4,594	8.45

Source: Ianelli, James, 2003. "North Pacific Multi-Species Management Model" in NMFS 2004.

1. Biomass estimates of several species in this group are unavailable.
2. Exploitation is calculated by dividing catch into total biomass.

2.2 Alaska Salmon Fisheries

This section provides a summary of Alaska's salmon fisheries. The summary provides information on the ex-vessel and wholesale value of salmon fisheries by species and management area, and then summarizes the forecasts of salmon returns in Bristol Bay to

[4] This "optimum yield" cap was approved as part of Amendment 1 to the BSAI Groundfish FMP by the Council and the Secretary of Commerce and implemented in 1984 to insure that fisheries would not be over-harvested.

demonstrate the levels of uncertainty under which salmon harvesters and processors operate. It is surmised in Section 5 that reducing this uncertainty through an enhanced ocean observation program can significantly improve the value of the salmon fisheries.

Alaska's salmon fisheries are among the worlds largest, and are managed by the Alaska Department of Fish and Game (ADF&G). As shown in Table 9, although the value of salmon has declined in recent years, the fisheries still generate over $500 million in processed product. Sockeye salmon are the most important species in terms of value, but pink and chum salmon are also very important. In 2002, sockeye generated 43 percent of the wholesale value of Alaska's salmon fisheries while pinks accounted for 29 percent and chum 19 percent.

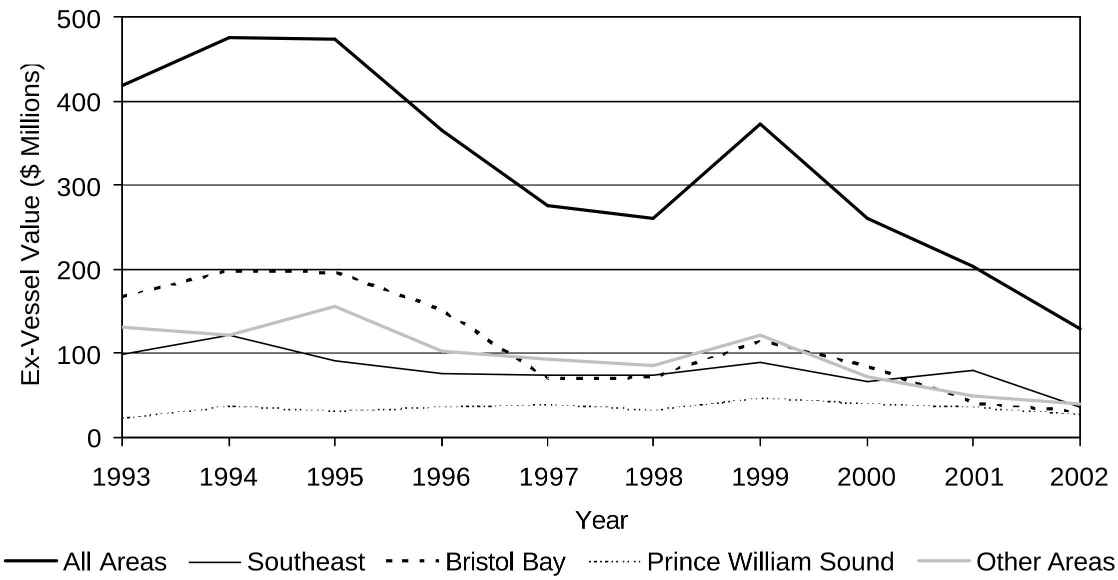
Table 9. Wholesale Value of Salmon Fisheries by Species, 2001 – 2003

Species	2000	2001	2002	2003
		Wholesale Value ($ Millions)		
Chinook	15.5	15.5	19.2	NA
Chum	166.9	96.6	84.0	NA
Coho	41.8	33.6	36.5	NA
Pink	165.6	219.9	154.3	NA
Sockeye	333.3	230.7	219.0	NA
All Species	**723.1**	**596.3**	**513.0**	**NA**

Source: ADF&G Commercial Operator Annual Report Data, provided by ADF&G in June 2004.
Note: Values shown are not adjusted for inflation.

ADF&G manages the salmon fisheries on a regional basis with limits on the number of vessels or operations that can participate. The ex-vessel value generated in the major salmon management areas in recent years are shown in Table 10 for the years 2000-2003, and graphically for selected areas from 1993 – 2002 in Figure 1. As seen in Figure 1, the value of salmon fisheries has declined significantly since 1993 in all areas. The largest relative declines have come in Bristol Bay. Prior to 1997 Bristol Bay accounted for more value than any other management area. Now both Southeast Alaska and Prince William Sound generate as much value as Bristol Bay. Estimates of wholesale value are shown in Table 11. In 2 of the 3 years shown Southeast Alaska have generated more wholesale value from salmon than other management areas.

Figure 1. Ex-vessel Value of Salmon by Management Areas, 1993 – 2002



Source: *Basic Information Tables* from Commercial Fishing Entry Commission Internet site at www.cfec.state.ak.us. Accessed in June 2004.
Note: Values are shown in nominal dollars.

Table 10. Ex-Vessel Value of Salmon Fisheries by Management Area, 2001 – 2003

Management Area	**2000**	**2001**	**2002**
	Ex-Vessel Value ($ Millions)		
Alaska Peninsula	24.3	8.6	7.6
Bristol Bay	84.4	40.9	29.4
Chignik	12.6	8.4	4.6
Kodiak	23.1	22.1	12.2
Cook Inlet	9.8	8.5	13.0
Prince William Sound	39.3	35.4	25.9
Southeast	66.1	79.6	34.6
Other	2.4	1.2	2.0

Source: *Basic Information Tables* from Commercial Fishing Entry Commission internet site at www.cfec.state.ak.us. Accessed in June 2004.
Note: Values shown are not adjusted for inflation.

Table 11. Wholesale Value of Salmon Fisheries by Management Area, 2001 – 2003

Management Area	**2000**	**2001**	**2002**	**2003**
	Wholesale Value ($ Millions)			
Alaska Peninsula	61.6	34.3	33.0	NA
Bristol Bay	181.8	121.2	104.6	NA
Chignik	18.4	16.5	12.3	NA
Kodiak	72.7	72.1	43.8	NA
Cook Inlet	52.8	46.2	49.9	NA
Prince William Sound	111.0	83.5	100.9	NA
Southeast	219.8	208.7	167.1	NA
Other	4.9	13.8	1.5	NA
All Areas	**723.1**	**596.3**	**513.0**	**NA**

Source: ADF&G Commercial Operator Annual Report Data, provided by ADF&G in June 2004.
Note: Values shown are not adjusted for inflation.

2.2.1 Bristol Bay Salmon Fishery and Forecasts

The Bristol Bay sockeye salmon fishery is the world's largest wild salmon fishery (Link, 2002). The fishery is also highly variable in terms of run size, and yet extremely compressed in terms of the amount of time fish are available for harvest. Typically, harvests begin in earnest the third week in June and peak on July 4th. . By the end of the second week in July most of the fish have escaped the fishery and entered their spawning rivers. The fishery is also relatively remote. Bristol Bay is accessible only by air or by boat. The remoteness of the area, the compressed season, and the variability makes the fishery relatively expensive to prosecute. Processing companies have to bring in by barge all of their cans and other packing material for the year. Because of the compact season there is no time to attain additional supplies while the fishery is underway. Furthermore, all of the processing labor must be flown in, and again because of the compact season, it is impractical to increase or decrease the amount of labor in-season. The processing materials and labor are major components of the costs of processing. If plant managers guess wrong about the size of the harvest, too much or too little labor or material can spell financial disaster (Van Vacter, 2004). Thus the accuracy and the reliability of run forecasts can make or break the year for processors and, because the processors create markets for the harvesters, the harvesters incur costs as well.

Table12 shows the run forecasts and harvests for Bristol Bay from 1997 – 2004. Of particular importance are the range of potential run sizes and the differences between forecast inshore harvests and actual harvests. In 1997 for example, harvests of 24.8 million fish were forecast, but actual harvest came in at only 50 percent of that level. A similar shortfall was seen in 1998. In 1999 the opposite occurred—harvests were forecast at 13.8 million fish, but nearly twice that amount was actually harvested. Since 2000 forecasts have been more accurate, but the long-term record of relatively unreliable run forecasts mean processors will likely continue to operate very conservatively.

Table 12. Forecasts of Bristol Bay Sockeye Salmon Runs, 1997 – 2004

	1997	1998	1999	2000	2001	2002	2003	2004
				Millions of Fish				
Forecast Total Run:	35.8	32.1	26.2	35.4	24.3	16.8	24.1	46.6
Escapement Goal:	8.8	9.6	11.1	11.1	7.3	7.3	7.3	11.9
Forecast Inshore Harvest:	24.8	20.6	13.8	22.3	15.6	9.7	16.8	34.7
Range of Potential Run Size	NA	11 – 54	9 – 43	18 – 53	9 – 39	5 – 29	11 – 37	36 – 58
Actual Harvest	12.2	10.0	25.7	20.5	14.2	10.6	14.9	NA

Source: *Bristol Bay Historical Information* from ADF&G Division of Commercial Fisheries at www.cf.adfg.state.ak.us.

2.3 Alaska Crab Fisheries

This section provides a summary of Alaska's crab fisheries with a focus on its notable booms and busts. The section shows historical values of the fisheries back through 1993, and then looks at harvests over successively longer periods to depict the precipitous increases and subsequent collapses of various crab fisheries in the state. In Section 5 we discuss arguments of fishery scientists that information attained in an enhanced ocean observation program could reduce or eliminate major crab fishery collapses such as those experienced in Alaska.

Historically, Alaska's crab fisheries have generated ex-vessel values approaching those generated in the salmon and groundfish fisheries (see Table 33). Table13 shows ex-vessel values of Alaska crab harvests by species for 1993 – 2002. During the 1990's the tanner crab has been the primary species, but since 2000, the value of king crab harvests have surpassed the value of other species.

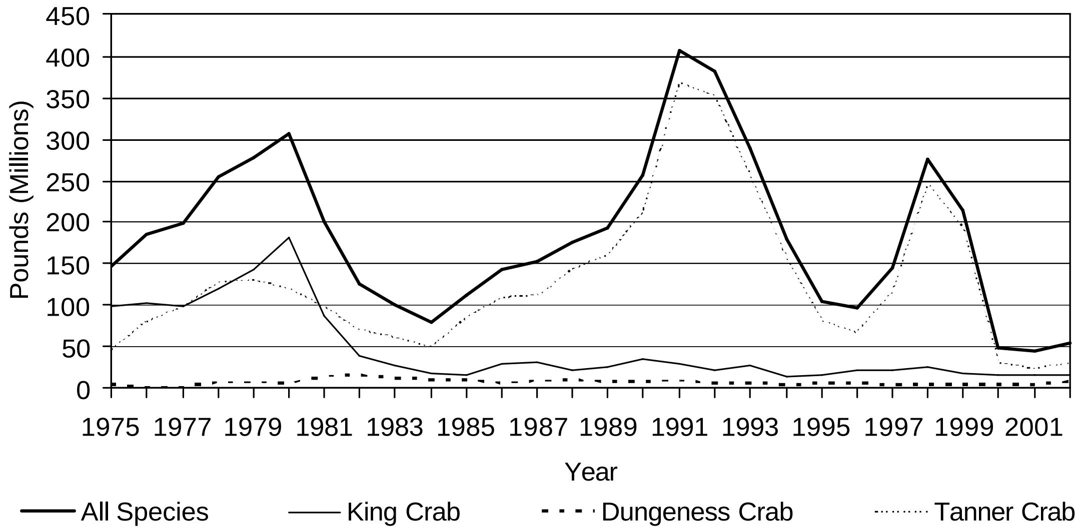
Table 13. Ex-Vessel Value of Alaska Crab Fisheries by Species, 1993 – 2002

Year	King Crab	Dungeness Crab	Tanner Crab	Other Crab	All Crab Species
		Ex-Vessel Value ($ Millions)			
1993	93.5	5.0	219.4	3.1	321.0
1994	59.9	5.5	241.7	5.8	312.9
1995	48.6	9.2	192.8	5.4	256.1
1996	67.8	6.0	94.4	1.9	170.1
1997	60.3	10.7	92.9	2.1	166.0
1998	60.6	4.3	139.7	0.8	205.5
1999	92.4	6.6	188.8	0.7	288.5
2000	62.2	4.5	56.7	0.0	123.5
2001	64.7	7.5	37.7	0.0	109.8
2002	81.3	8.6	42.0	0.0	132.0

Source: *Basic Information Tables* from Commercial Fishing Entry Commission internet site at www.cfec.state.ak.us. Accessed in June 2004.
Note: Values are shown in nominal dollars.

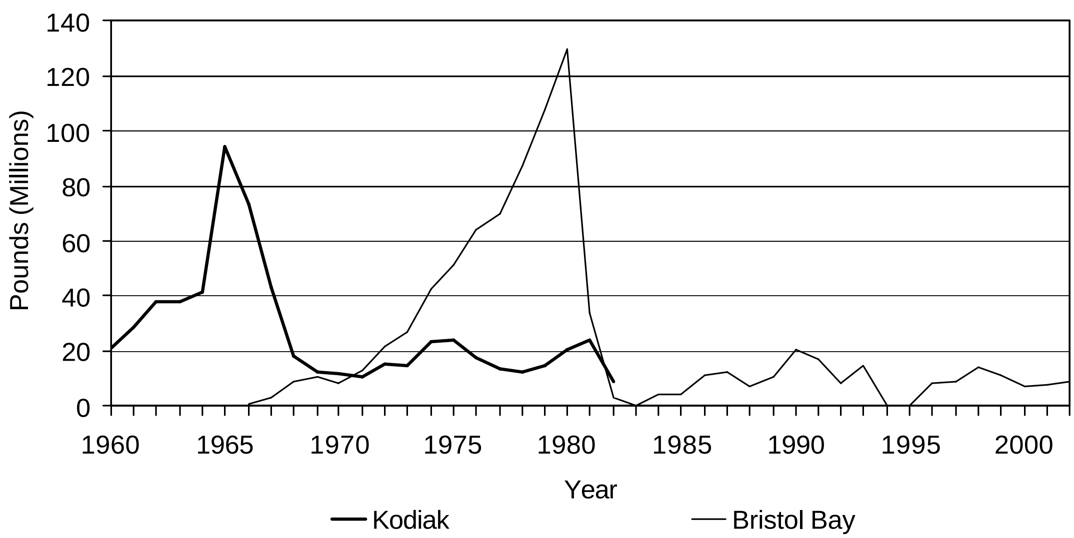
Figure 2 looks at the crab harvests by species over a 30-year period. The figure shows that king crab harvests peaked in 1980 and then fell to approximately 25 percent of peak levels. The tanner crab fishery (also known as snow crab) peaked in 1991 and then fell dramatically, peaked again in 1998 and since 2000 has been harvested at levels less than 15 percent of record harvests. As shown in Figure 3 that offers an even longer perspective, demonstrates how different king crab fishery areas have seen different peaks and declines. During the 1960's the Kodiak area was a major producer of king crab with a peak in 1965 and a precipitous decline by the end of the decade. The Kodiak fishery continued at low levels until 1982 when the fishery was closed. It has remained closed ever since. Following the collapse of the Kodiak fishery in the late 1960s, fishing effort migrated into Bristol Bay. The Bristol Bay fishery expanded rapidly during the 1970s and peaked in 1980, then collapsed similar to the Kodiak fishery. The Bristol Bay fishery has continued albeit at relatively low levels and with periodic closures.

Figure 2. Pounds Landed in Alaska Crab Fisheries by Species, 1975 – 2002



Source: *Basic Information Tables* from Commercial Fishing Entry Commission Internet site at www.cfec.state.ak.us. Accessed in June 2004.

Figure3. The Rise and Fall of Major King Crab Fisheries in Alaska, 1960 – 2002



Source: *Westward Region Shellfish Report*, 2002. ADF&G. Kodiak Alaska, 2003.

3 Phenomena and Now/Forecasts

The Alaska Ocean Observing System (AOOS) is part of a growing national net work of integrated ocean observing systems that should improve the ability to rapidly detect changes in marine ecosystems and living resources, and predict future changes and their consequences for the public good (http://www.aoos.org). While AOOS is just in its developmental stage the system covers three zones including (1) the Gulf of Alaska/Southeastern Alaska; (2) the Aleutian Islands/Bering Sea; (3) the Artic Ocean/Beaufort Sea/Chukchi Sea. Currently data collected in these zones by various institutions and programs include atmospheric measurements (Doppler radars, wind profilers, meteorological stations, FAA Weathercams, and Satellite), oceanic measurement (NOAA buoys, UAF buoys, CODAR, tide gauges, NOS/NDBC water temps, and satellite), and river, soil and snow measurements (USDA SNOTEL Met Stations, Toolik Lake Research Station, USGS Streamflow data, USDA SCAN Met Stations, NWS/USGS River Stage and Flow Data, and NWS/USGS Snow Data Sites). Related programs include DOE/Atmospheric Radiation Measurement Program PWSSC Nowcast/Forecast Project, GEM Project, SALMON Project, GLOBTEC, and the Alaska Sea Life Center Research. The types of measurement and level of coverage varies across the three Alaskan zones (Please see http://www.ims.uaf.edu:8000/caos/zone_1.html; zone_2.html; zone_3.html for details.)

AOOS represents a partnership that has been formed to develop a regional program in Alaska. Partners include the State of Alaska; federal agencies such as the National Oceanic and Atmospheric Administration and the Department of Interior; Academic institutions including the University of Alaska and University of Washington; research organizations such as the North Pacific Research Board, the Alaska SeaLife Center, the Prince William Sound Science Center, and the Barrow Artic Science Consortium; and industry groups including fisheries and aquaculture associations. AOOS' goal is to provide a centralized location for (1) new buoys, proving wind and current speed and direction, wave height, sea temperature, and salinity, (2) enhancements to existing NOAA weather buoy data for specialized local needs; (3) processed satellite data providing Alaska-wide information on sea-surface temperature, ocean color (chlorophyll) and wind; (4) geographically comprehensive surface current data from high frequency radar; and (5) data about fish, birds and marine mammals, the environmental effects of human activities, and any other information that can be used with the physical data to predict future changes to ocean ecosystems.

In general, from our research we have found that a fully developed AOOS has the potential to provide fishery managers with the tools to maximize the sustained use of fishery resources. In particular, enhanced data collection and dissemination will reduce the uncertainty (increase confidence) in establishing exploitations rates by, among other things improved predictions of recruitment failures or successes. It is well known and accepted that errors in forecasts of fish populations are in part due to environmental unknowns. The parameters that appear to be of most concern among fishery stock assessment scientists and managers are upwelling, temperature, currents (including tidal currents), salinity, chlorophyll, and the strength of oceanfronts. These are all factors that affect rates of maturation and migration and are more or less important depending on the fishery in question. In addition, it is felt that more precise[5] data, that is, more data points both spatially (throughout the entire North Pacific Rim) and temporally would translate some unknowns into knowns and would enhance understanding of fish growth and predictions of productivity and migration patterns.

For the past several years stock assessment scientists (Ianelli et al, 2003) have been evaluating the effect of bottom temperature (Tt) on survey catchability of pollock in year t:

$$Q(t)= U(q) +BqTt$$

[5] Some of the North Pacific fisheries scientific community would love to have data collected throughout the year by means of an establish grid system of permanent monitoring buoys throughout the Pacific Rim which collect data on currents, temperature, salinity, and chlorophyll.

Where Uq is the mean catchability and Bq represents the slope parameter. Bottom temperature was collected during the NMFS summer bottom-trawl surveys. It was shown that temperature affects the distribution of pollock on the shelf and by extension could affect the availability of the stock to survey. That is, temperature may affect the proportion of the stock that is within or outside of the standard survey area. These patterns were further examined by comparing Pollock density with selected on-bottom isotherms. This shows that 2002 was warmer than usual and that, in general, pollock densities are rare at temperatures lower than 0 degrees. The latter illustrates the significant value of the understanding of the effect of this physical parameter on the evaluation and determination of allowable biological catch in fisheries management.

Another growing body of scientific evidence supports hypotheses about the direct and indirect effects of the environmental change on salmon production (NPAFC Science Plan 2001-2005, BASIS). For example there is a strong correspondence between salmon catch and climate indices. In addition, there appears to be a correlation between water temperature, blooms of coccolithophorid and salmon survival (Jack Helle, Alaska Fisheries Science Center, Auk Bay Lab May, 2004). Over the last 6 years there have been two significant long-term blooms in the Bering Sea (the blooms being an indication of sterile ocean conditions). According to Helle, coccolithophorid blooms appear to be water temperature related. If the scientists have better forecasts on water temperature they could better predict the occurrence of these blooms and thus be better able to predict juvenile salmon survival.

It is also hypothesized by Alaska Department of Fish and Game that physical oceanographic data can improve management of Cook Inlet sockeye salmon through improvements in season salmon run projections (Willette and Pegau, 2002). In 1999, the Alaska Board of Fisheries adopted a sliding range of inriver escapement goals for late-run Kenai River Sockeye salmon that were based upon preseason and inseason projections of the annual return of this salmon stock. The ADF&G offshore test fishing (OTF) provides the primary source of information used to project the return of this stock inseason. Achievement of inriver escapement goals and allocation of salmon to commercial, personal use and recreational user groups is thus largely dependent on the accuracy of these projections. The accuracy of the population estimates provided by OTF typically increases as the season processes. Projections made on July 20 have ranged from –5.4% to +103% of the actual run. Errors in OTF program estimates or run size appear to be due to interannual changes in migratory timing and catchability.

The OTF program often fails to accurately predict runs that are earlier than normal. Failure to accurately predict very large runs can result in large escapements, loss of revenue to the commercial fishery, and reduced production in future years due to overgrazing of plankton stocks by large fry populations in rearing lakes. Failure to accurately predict weak runs can result in over harvest by the commercial fishery and reduced production in future years. Errors in OTF program estimates of run size appear to be due to interannual changes in migratory timing and catchability. Migratory timing is defined as abundance as a function of time in a fixed geographic reference frame (Mundy, 1982). The sockeye run entering the Cook Inlet normally peaks on July 15, but peak migratory timing has varied from Jul6 to July 19. According to Willette and Pegau, variations in migratory timing are likely due to a range of biotic and physical factors that affect rates of maturations and migrations. Ocean temperature (Burgner, 1980), the strength of oceanic fronts (Mundy, 1982), and tidal currents (Stasko et al., 1973) are all likely important physical factors affecting both the rate of maturation and migration of salmon. Catchability is defined as the fraction of the population captured by a unit of fishing gear. The OTF program estimates cumulative catchability to date from the ratio of cumulative catch per unit of effort (CPUE) obtained from the test fishing vessel and estimates of total return to date. Cumulative catchability varies by a factor of 2 among years. Variations in catchability are likely due to biotic factors (e.g. fish size) as well as physical factors that affect the vertical and horizontal distribution and migration rate of salmon (Hakoyama, 1995).

The migration of salmon into the Cook Inlet is clearly influenced by the strength and location of tiderips. Fishermen working the inlet are very aware of the tiderips and use the rips to locate and capture migrating salmon (Wilson and Tomlins, 1999). Salmon have likely evolved behaviors that allow them to use rip tides and associated current structures to minimize the energy expended to reach their natal rivers (Scholz et al. 1972). According to Willette and Pegau, (2004) although tiderips clearly result from strong velocity gradients, they also represent boundaries between water masses and may be associated with strong salinity gradients.

Willette and Pegau have proposed to test several hypotheses regarding the effects of changing oceanographic conditions on the migratory behavior and catchability of salmon entering Cook Inlet. Better understanding of these effects may allow for improvement in the accuracy of inseason sockeye salmon populations estimates and thus improved accuracy of short and long-term forecasts of salmon runs. The latter suggests that with ongoing oceanographic data collection through AOOS ADF&G might be able to better manage for inriver escapement goals and maximize sustained yield thus benefiting the economy of the Upper Cook Inlet area and nation as a whole.

Currently, OOS information is not readily used in the crab industry. Sometimes fisheries managers use weather data to adjust fishing seasons (for safety reasons). In addition, bottom temperature information is sometimes used as an indicator of species distribution and correlated over time to stock size. However, in general, according to our sources, the greatest benefit to the Alaskan king and tanner crab industry from enhanced AOOS would be in the long term with the collection of appropriate time series data. Biological and oceanographic data could be correlated with trawl surveys and allow fisheries biologists to better predict crab recruitment and productivity. This information could be used to develop harvest rate models that more adequately reflect the state of the ecosystem. According to Gordon Kruse (ADF&G) oceanographic conditions (upwelling, temperature and currents) are critical to the development of larvae for nearly all species of crab. For example, egg and larvae development are temperature sensitive. Larvae feed on phytoplanktons that are light sensitive. If winter/spring is cold then it is likely that phytoplankton blooms will occur before the crab larvae are developmentally ready. Better oceanographic data would allow fisheries scientists and fisheries managers to better predict poor and good recruitment and thus allow for more accurate determinations about when to close and or open a fishery.

In addition to the above, we have learned that the value of AOOS will probably be highest in the rationalized fisheries. The fleet may benefit from more detailed knowledge of the distribution of fish by age and season. This would allow them to minimize unintended catch of non-targeted species (an unintended consequence but of significant value to society) minimizing fuel and crew costs. For example, if scientists knew enough to state that during the summer months, adult pollock will follow a particular frontal feature and can identify where that front is located they could provide the fleet with forecasts of prime fishing locations for target species.

Finally, we have learned that there are also benefits or value from enhanced data collection and dissemination through AOOS to fisheries managers as relates to Essential Fish Habitat Provisions, Marine Protected Areas and marine mammal protection. Fisheries managers need and want better data to allow them to now deal with the complex spatial and temporal dimensions associated with ecosystem-based management tools that are the underpinnings of the above management tools.

One scenario that we have not explored but for which potential economic benefits of enhanced OOS may be accrued is the shellfish aquaculture industry and human health and safety more generally. If, for example, scientists could more accurately predict blooms of PSP (paralytic shellfish poisoning) industry would know to terminate production activities and thus avoid significant health and safety consequences. PSP is a fairly significant issue in the Washington aquaculture industry and better information about the timing and extent of algal blooms could have measurable economic benefits in the near future as opposed to the relatively more speculative and long term future benefits of better recruitment forecasts and stock assessments as described above.

4 Qualitative Discussion of Fishery Management Decision Making

Prediction of fish stocks or population levels plays a critical role in fisheries management decision-making. Prediction of stock size is critical to the underlying principals or goals of sustainable fisheries management. As such the role of fishery scientists is great in the overall decisions about harvest strategies. However, there continues to be tremendous uncertainty in stock size projections and thus continued potential for less than perfect decision making at the management level. Authors such as Solow et al (1998) have been able to use data on enhanced forecasts of oceanographic conditions to formulate predictions of crop yields which are then used by farmers to optimize cropping patterns. The Bayesian decision theory approach that they use could potentially provide a methodology to aid fisheries managers in optimizing fish harvest (given the constraints of provisions of the MSFMCA and other pertinent legislation and regulation and fishery management objectives through the ten National Standards for Fishery Conservation and Management). The Bayesian approach could be used as a management tool to make predictions and explore the consequences of alternative scenarios for a particular fishery within a particular ecosystem. The aim of this approach would be to develop a model as a tool for guiding decision making in a variety of areas including the conduct of a fishery, and the targeted collection of information to improve understanding of the system and its response to change (Goodman et al, 2002).

That said it is instructive to qualitatively outline the decision model that is used in fisheries management decision-making in the Alaska region. Goodman et al (2002 pp.1-2) provides an excellent guide for lay persons of the very complex process by which harvest strategies are chosen. The following is taken from that report which explicitly focuses on Alaska groundfish species management.

The current harvest decision making strategy is essentially a maximum sustainable yield (MSY) single-species approach, modified by some formal safeguards incorporated to ward against overfishing as defined from the single-species stand point, and with opportunities of a less-structured nature for reducing harvest rates further in response to perceived social, economic and ecological concerns. No quantitative standards or specific decision rules are stated for these latter considerations, except as they are imposed, from outside the MSFCMA, by the Endangered Species Act or the Marine Mammal Protection Act.

The overfishing level (OFL) set for each stock is an estimate either of the fishing mortality rates associated with MSY (Fmsy) or an estimate of a surrogate for Fmsy. The OFL is treated in the management system as a limit that should not be exceeded except with a very low probability. The acceptable biological catch (ABC) set for each stock is an estimate of a target rate, which is intended to establish some margin between it and the OFL. The hope is that managing so as to achieve this target on average will accomplish the desired compliance with exceeding the limit (OFL) only rarely. The ad hoc downward adjustments of harvest in response to other social, economic, and ecological considerations takes place in the deliberations where the total allowable catch (TAC) is set subject to the constraint that it be less than or equal to the ABC.

The formulaic component of the reduction of harvest rate from the theoretical MSY harvest rate (from OFL to ABC) is by an amount that is often modest, when expressed as a fraction of the harvest rate; but in terms of the total tonnage involved, or its dollar value, the amount is considerable. The margin is also small relative to real natural variation, and small relative to the practical uncertainty about stock status or population parameters for many of the target stocks and indeed for most of the ecosystem. By contrast, in actual practice, the reduction in TAC from ABC has for some stocks and some years been quite large, but there is no explicit and general formula for this reduction. Many stock assessment scientists believe that this buffer should be better linked to uncertainty in both the measurement and process error (Anne Hollowed, personal conversation 2004).

The formal and standardized quantitative portions of the process for determining OFL and ABC begin with the assignment of each stock to one of six “Tiers” based on the availability of information about that stock. Tier 1 has the most information, and Tier 6 the least. The so-called F40% construct plays a prominent role in some of the Tiers but not others. F40% is the calculated fishing mortality rate at which equilibrium spawning biomass per recruit is reduced to 40% of its value in the equivalent unfished stock. This is an esoteric, but useful, measure of the amount by which the associated fishing rate reduced the stock size, in the long run. The useful features of this particular measure are two-fold. First, its calculation is less sensitive to the details of the stock-recruitment relationship than is the calculation of Fmsy, so it is practical to estimate F40% for stocks that are not well enough studied for estimation of Fmsy. The second is that for a range of dynamics encompassing many, but not all, of the BSAI/GOA target groundfish stocks, for example, modeling studies have shown that harvesting at F35% accomplishes about the same thing as harvesting at Fmsy, so harvesting at the slightly lower rate, F40% established a modest margin of safety.

Currently management of king and Tanner crab fisheries are under the jurisdiction of the Alaska Department of Fish and Wildlife and National Marine Fisheries Service. An annual stock assessment and fishery evaluation (SAFE) report is required of them by the North Pacific Fisheries Management Council. The SAFE summarizes among other things, guideline harvest levels (GHL) and analytical information used for management decisions or changes in harvest strategies. According to the 2003 SAFE for King and Tanner Crab Fisheries sin the Bearing Sea and Aleutian Islands, the Federal requirements for determining the status of the stocks are the minimum stock size threshold (MSST) and the maximum fishing mortality threshold (MFMT). These requirements are contained in the Fisheries Management Plan (FMP). The MSST is 50% of the man total spawning biomass (SB or TMB= total mature biomass) for the period 1983-1997, upon which the maximum sustainable yield (MSY) was based. A stock is overfished if the SB is below the MSST. The MFMT is represented by the sustainable yield (SY) in a given year, which is the MSY rule applied to the current SB (the MSY control rule is F=0.2 for king crabs and F=0.3 for Tanner and snow crabs). Overfishing occurs if the harvest level exceeds the SY in one year. GHLs are developed from joint NMFS and ADF&G assessment of stock conditions based on harvest strategies developed by ADF&G.

Regular trawl and hydoraccoustic survey results for five stocks (Pribilof blue king crab, St. Matthew blue king crab, Bristol Bay red king crab, eastern Bering Sea Tanner crab (*c. bairdi*), and eastern Bering Sea snow crab (*c. opilio*) are compared to thresholds established by the State of Alaska harvest strategies and regulations. ADF&G uses these thresholds to determine if a fishery should be opened and to calculate GHL. For example, the Bering Sea Tanner crab fishery was closed in 1997 due to near record low stock abundance in the 1997 NMFS survey and poor performance in the 1996 fishery. ADF&G will reopen the fishery when the female biomass is above the threshold and the fishery GHL is above the minimum identified in the rebuilding harvest strategy or MSY biomass defined in the FMP as 189.6 million pounds of total mature biomass.

The traditional approach to fishery science, that is, the primary input to the harvest strategy outlined above, has been to assess the state of the stocks on a single-species basis, using catch and biological data as input to the models and then forecast what will happen if things (usually total catches) stay as they are or get changed somewhat. This leads to decisions being made based on expected outcomes. Some sense of the robustness of decisions can be made by running the forecasts with different assumptions or from different starting points but this sort of exploration has traditionally been limited and ad hoc. A more recent approach is instead to create models of the fishery systems and to use computer simulations to test systematically what would happen if different management strategies (combinations of data collection, assessment and decisions following specific rules) were adopted. This sort of analysis is aimed at systematically revealing how different management approaches compare in meeting sets of objectives. Unfortunately given the scope of this work we are not able to explore and implement this approach at this time. In general, however, we have been able to ascertain that enhanced AOOS offers the potential greatest benefits at the scientific level where science can monitor, assesses forecasts within bounds and generally inform and support decision making. At this point stock assessment scientists feel limited in their capabilities and feel that more atmospheric, oceanic, biological and ecosystem data would be of tremendous benefit. Once such data is made more available they feel several years of improved predictions (better than correct 60% of the time) will be required in order to gain the trust of fisheries managers and the fishing community and ultimately have their recommendations for such metrics as total allowable catch (TAC) to be readily accepted.

5 Assessment of the Economic Value of an Enhanced Ocean Observation Program

An enhanced ocean observation program has the potential to provide significant benefits to Alaska commercial fisheries. This section discusses three areas where better information and less uncertainty could generate higher values:

1) Better information could improve the reliability of forecasts that in turn will enhance the ability of fishery businesses to plan their fishing seasons and profitably prosecute their fisheries. In Alaska salmon fisheries it is estimated that reducing the uncertainty due to unreliable run size and timing forecasts, would lead to increases in net revenues for salmon processors by $77 million per year
2) Better information and more certainty could allow a more aggressive harvest policy in the Alaska groundfish fisheries without placing stocks under undue risk of overfishing. Improvements due to better information could generate an estimated $504 million in additional wholesale value per year.
3) Better information and more certainty could allow a more aggressive harvest policy in the Alaska groundfish fisheries without placing stocks under undue risk of overfishing. Improvements due to better information could generate an estimated $504 million in additional wholesale value per year.

5.1 Enhanced Business Planning – Alaska Salmon Fisheries

Analysts at Northern Economics interviewed key informants at three of the top five Alaska salmon processors—Don Giles at Icicle Seafoods, Terry Gardiner at Norquest, and Norm Van Vacter at Peter Pan Seafoods. Processors were asked to describe how improved certainty in run forecasts would help their operations with particular reference to Bristol Bay. All three agreed separately, that if an enhanced ocean observation system could significantly improve run size and timing forecasts, then the benefits to their bottom lines would be very significant. In general it was felt that improvement in profits from Bristol Bay could range from $25 to $50 million per year.

Improvements would come in three areas: 1) from cost savings and efficiency gains, 2) from increased processing amounts when forecast runs are high, and 3) from higher wholesale prices on average.

Cost savings and efficiency gains would be generated if processors could rely on run size and run timing forecasts, and if the range of the forecasts was smaller. The savings would be realized in the amount of processing materials and labor that are deployed to the facility. With greater certainty the amount of material and labor can be optimized.

With high levels of uncertainty processors tend to be conservative in their planning. In years with high run size forecasts most processors will plan on harvests in the low end of the forecast range. The costs of underestimating labor and material needs are lower than the costs of overestimating. Once the material and labor is acquired and deployed they become sunk costs, and if the runs fail to materialize then operating losses are likely. Thus if there is greater certainty and reliability in the forecasts, processors will learn to be more aggressive in their planning and will be able to process additional volumes rather than letting harvestable salmon escape.

Finally, the lack of certainty on run size and timing reduces processors' ability to work with buyers. The inability to guarantee a buyer that a certain quantity of product will be delivered on a certain date limits the price that buyers are willing to pay. Currently Bristol Bay processors are generally unable to pre-sell the majority of their product.

For purposes of this study, we assume that the enhanced ocean observation system can in fact lead to improved reliability of run forecasts, and that improved net revenues for processors in the Bristol Bay salmon fishery will amount to at least $25 million per year. Similar improvements can also be expected for salmon fisheries in other areas, but the magnitude of those improvements will depend on several factors. In particular we believe that five key factors determine the potential for improved net revenue resulting from greater certainty. These are:

1) The relative remoteness of the area
2) The length of the season
3) The current variability in run forecasts
4) The need for non-resident labor
5) The ability of the particular fishery to improve

For each of these factors, we scored the major salmon fisheries in Alaska on a scale of 0 to 4 relative to Bristol Bay. A score of '4' indicate a factor is on par with that factor in Bristol Bay. A lower score means the factor is less important for the particular area. Each factor was assigned an equal weighting and the average score was calculated to determine the relative increase in wholesale value. For example the Alaska Peninsula fishery was assigned an overall average score of 3, and therefore the increase in wholesale value is 75 percent of the increase assumed for Bristol Bay where increases were 24 percent. Thus the wholesale value of Alaska Peninsula fisheries is expected to improve by $5.9 million per year ($33 million × 75 percent ×24 percent = $5.9 million). Over all areas it is estimated that improved certainty could add $77 million annually in wholesale net revenues for salmon processors.

Table 14. Estimated Improvement in Salmon Processor Annual Net Revenues Due to Improved Certainty of Run Size

Management Area	Bristol Bay	Alaska Peninsula	Chignik	Kodiak	Cook Inlet	Prince William Sound	Southeast	All Areas
Factor	**Score (0 to 4, with 4 meaning the factor is equivalent to Bristol Bay)**							
Remoteness	4	4	4	2	1	1	1	2.4
Short season	4	3	1	1	1	1	0	1.6
Variability	4	2	1	2	1	2	2	2.0
Non-Resident Labor	4	3	2	0	2	1	2	2.0
Room for Improvement	4	3	0	2	1	2	2	2.0
Overall Average	4	3	1.6	1.4	1.2	1.4	1.4	2.0
Proportional Score	100	75	40	35	30	35	35	63
Results	**Annual Wholesale Value ($ Millions)**							
Base Case Wholesale Value	104.6	33	12.3	43.8	49.9	100.9	167.1	511.6
Net Revenue Increase from Improved Certainty	25.0	5.9	3.7	6.1	5.2	10.6	20.5	77.0

Source: Developed by Northern Economics, Inc. Estimates of wholesale value are from Table 11.

These benefits are measures of producer surplus as most of the improvement would be a result of reduced costs to harvesters and producers. There might also be some improvement in product quality as fish are harvested earlier in the season and a shift to fillets (with greater value added) from headed and gutted (lower value added) also leading to improvements in both producer and consumer surplus. Finally, because of increased product quality and greater value added, total processed product output (1st wholesale value) from the region would increase resulting also in increased regional economic impacts.

5.2 Increased Harvests – Alaska Groundfish Fisheries

As indicated in Section 2, stock assessments and harvest quotas for groundfish take into account the amount of uncertainty in each of the utilized species. Scientists recommend relatively low ABCs for species with high levels of uncertainty in key variables, but will recommend relatively high ABCs for species where there is more certainty. It is suggested (Anne Hollowed, NMFS/REFM) that use of temperature data can be used to reduce stock size forecast error. Currently NMFS is correct only 60% of the time in their annual pollock stock assessment. The risk adverse nature of groundfish harvest strategies is furthered by an absolute limit on TACs in the Bering Sea of 2 million metric tons. Without this “OY Cap” harvests in the Bering Sea could significantly increase.

For purposes of this study fishery scientists from NOAA’s Alaska Fishery Science Center were asked what harvests levels of groundfish might look like if enhancements to AOOS led to significant improvements in their ability to accurately predict (on a relative scale) stock sizes and recruitment of major groundfish species. Scientists indicated that constraints imposed within their stock assessment models to account for uncertainty could be reduced and that recommended ABCs would increase significantly for many of the groundfish species. Furthermore if there was a longer track record of improved stock assessments it is surmised that political decisions to limit overall harvests would eventually be removed and that TACs would approach recommended ABCs.

While not developed specifically for this study the "North Pacific Multi-Species Management Model" developed by Dr. James Ianelli includes an assessment of groundfish harvests under the assumption that uncertainty in stock levels and recruitment are greatly reduced, and that artificial caps on harvests are eliminated. The model was originally developed for use in the *Alaska Groundfish Fisheries Final Programmatic Supplemental Environmental Impact Statement (*NMFS 2004) and the assessment of harvests with the assumption of high levels of certainty corresponds to Alternative 2.1 in the SEIS. The model results for the base case and the case with improved information are shown in Table 15. The results demonstrate the possibility that with improved information catch and value in the fisheries can be improved significantly. The long run average increase in wholesale value projecting out 20 years from the base year (2002) is over $500 million annually. While projections of overall biomass are expected to decline, constraints in the model assures that exploitation rates do not cause stocks to fall below sustainable levels.

Table 15. Estimated Value of Improved Information in Alaska Groundfish Fisheries

Scenario	Base Case			With Improved Information			Difference		
Year	**Total Biomass Pounds (Millions)**	**Catch Pounds (Millions)**	**Whsle. Value $ Millions**	**Total Biomass Pounds (Millions)**	**Catch Pounds (Millions)**	**Whsle. Value $ Millions**	**Total Biomass Pounds (Millions)**	**Catch Pounds (Millions)**	**Whsle. Value $ Millions**
2003	43.3	4.4	1,360.7	43.3	6.3	2,048.5	0.0	1.9	687.8
2004	42.0	4.4	1,354.9	38.5	5.4	1,768.5	-3.5	1.0	413.6
2005	41.8	4.1	1,262.9	37.0	4.9	1,629.9	-4.8	0.8	367.0
2006	42.0	4.0	1,224.5	37.0	5.0	1,638.2	-4.9	1.0	413.6
2007	42.4	3.9	1,204.1	37.5	5.2	1,705.9	-4.9	1.3	501.8
6-year Avg.	42.3	4.2	1,281.4	38.7	5.4	1,758.2	-3.6	1.2	476.8
Long-Run Avg.	NA	4.1	1,248.3	NA	5.4	1,753.1	NA	1.3	504.8

Source: Biomass and catch estimates are taken from Alaska Groundfish Final Programmatic SEIS. NMFS, 2004; estimates of wholesale value are estimated by Northern Economics based on the average wholesale value per ton of harvest from 2002 as shown in Table 6

In order to assess the benefits from improvements in coastal ocean observing systems for the groundfish fisheries we assume that better data results in stock assessments that are significantly more accurate and that scientists are better able to make long range (3-10 year) projections because of the enhanced ability to predict spawning success. This would greatly increase the confidence that scientists, decision makers, and the interested public (including environmentalists) have in the process. We assume as a result that decision makers can drop the 2 million OY Cap in the Bering Sea and Aleutian Islands (BSAI) and allow TAC in both the Gulf of Alaska (GOA) and BSAI to rise to Maximum Sustainable Yield levels (currently MSY levels are generally higher than ABC levels). Harvest of groundfish could nearly double under this scenario. Therefore, our initial model results for groundfish (which assumes no price effect with significantly increased harvest supply; i.e., wholesale prices are perfectly elastic in our model) indicate that wholesale groundfish revenues of total output (gross revenues) would increase by over $1 billion per year for the first five years. Over time the increase would stabilize at levels of approximately $400 million greater than the current fishery is projected to generate as the stocks are fished down to stable MSY levels. Please note that additional increases in wholesale value may also result from reductions in incidental catch and subsequent discards as well. We have not been able to measure this affect. Regardless, because of the assumption of perfect elasticity, our total estimate is an upper-end estimate. There would most likely be a price effects resulting from such a significant increase in harvests.

5.2.1 Avoidance of Overfishing -- Kodiak King Crab Fishery

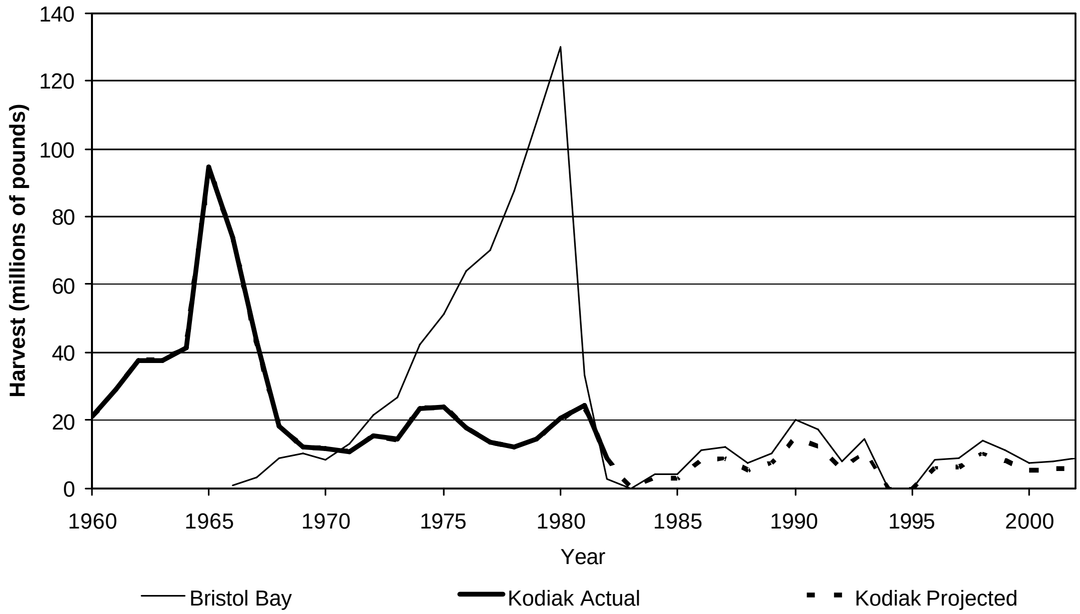
The chief crab scientist for ADFG, Gordon Kruse, indicates that an aggressive harvest policy in the face of uncertainty about recruitment is the primary culprit in the collapses of crab fisheries (Kruse, 2004). According to Kruse, successful reproduction of various crab stocks requires not only sufficient numbers of spawning adults, but also on favorable ocean conditions, currents and temperatures in particular. While estimates of spawning adults can be attained using catch data and trawl surveys, ocean conditions linked to successful reproduction are not easily monitored. An enhanced ocean observation program would significantly improve scientists' ability to successfully predict reproduction events.

Kruse goes on to say that the collapse of king and tanner stocks can be linked to recruitment failures that occurred over several successive years. Even though the spawning biomass was adequate for sustainable harvests, ocean current and temperatures caused reproduction failures. Because new year classes were not being produced as assumed, overfishing resulted. The first major failure occurred in the Kodiak king crab fishery. By the time scientists realized that recruitment failures were occurring, the stock was fished below minimum stock size thresholds levels from which the stock has never recovered. In the case of the Bristol Bay king crab collapse, scientists and managers recognized the pattern from Kodiak and scaled back harvests enough to keep the stock above the minimum threshold, and thus the fishery continues albeit at much lower levels.

Kruse believes that an enhanced ocean observation system could have provided scientists with enough additional information, that the total closure of the Kodiak king crab fishery could have been avoided. At a minimum, with the additional information, a scaled back king crab fishery could have been maintained at levels proportional to current levels in Bristol Bay. Thus this study assumes that an enhanced ocean observation system could have prevented overfishing in Kodiak and that the Kodiak fishery would continue today.

Figure 4 is a copy of Figure3 except that hypothetical harvests are assigned to the Kodiak fishery assuming they are proportional (based on peak harvest years) to harvests in the Bristol Bay king crab fishery. The heavy dashed line shows the projected catches. The additional catches would have generated approximately $62.7 million annually in wholesale value per year at 2002 prices. While this estimate is relatively speculative (the collapse of the Kodiak crab fishery cannot be prevented after the fact) it does provide insight into the potential benefits of enhanced oceanographic information systems if it results in overfishing.

Figure 4. Projected Kodiak King Crab Harvests if Better Information Were Available



Source: Data from *Westward Region Shellfish Report*, 2002. ADF&G. Kodiak Alaska, 2003. Projections of Kodiak from 1982 – 2002 were developed by Northern Economics.

6 Conclusions

Our estimates of the potential value of an enhanced AOOS to Alaska commercial fisheries include:

- $77 million annually in increased net revenue in Alaska salmon fisheries,
- $504 million annually in increased total wholesale value in Alaska groundfish fisheries, and
- $63 million annually in lost wholesale value that might have been avoided.

These three types of improvement should not be viewed as additive. The groundfish figure is an estimate of increased value of total output to processors, of which perhaps 20 25%[6] might be considered a net increase in revenues above costs to both harvesters and processors. The remaining 75-80% represents economic impacts that potentially could be generated throughout the region. The estimate of benefits to the salmon industries reflects cost reductions and higher output values, or a change in net revenues or producer surplus. The value assigned to the crab fishery is an estimate of foregone output or avoided cost/losses of which again, only 20-25 percent might be considered a net increase in revenues above costs to both processors and harvesters.

[6] The 20-25 percent is a rule of thumb estimate of the portion of total output that is likely to be considered a "return on investment" by owners of the processing facilities and harvesting vessels, after fixed (including facility maintenance and replacement of production units—e.g. machinery, engines, etc) and variable costs.

Furthermore it should be noted that in developing our estimates of the value of enhanced AOOS information we found it difficult to specify quantitative decision and physical outcome models. Many of the scientists we talked to were able to speculate about the benefits of more/better defined and accessible AOOS data but were only in early stages of considering how to add oceanographic parameters to their stock assessment/recruitment/escapement models. Regardless, these scenarios are very difficult to model due to the complexity of nonlinear interactions in biological systems and the broad array of influential parameters. Development of management decision making that takes environmental, ecological and ecosystem effects into account will require considerable amounts of monitoring, understanding of the behavioral relations among fishers, the fish they catch and the prey of the harvested species (Langton and Haedrich, 1997). As such our analysis takes a significant leap between decisions to open or close a fishery and economic outcomes and it is difficult to say, therefore, with confidence that additional biological and oceanographic data generated through enhanced AOOS will with complete certainty lead to better decision outcomes in fisheries management. In addition, in the long term, as the complexity of information requested from fisheries scientists increases, and as more and more complex models are utilized, predictability and certainty may not necessarily increase. In fact, the more complex the models, the more they have to depend, in practice, on assumptions and presumptions rater than data. This may have implications for the value of information provided by AOOS overtime.

That said, in the spirit of this project, as illustrated in the previous sections, we have attempted to estimate the benefits that improvements in AOOS could generate. In particular we have shown that enhanced AOOS could generate over $500 million annually in additional value in select Alaska's commercial fisheries (e.g. Alaska groundfish fisheries). However, there are several factors, as explicitly outlined below, that may lead to the uncertainty around those estimates.

1) It is unknown whether the proposed changes to the ocean observation program will actually deliver more and "better" data.
2) Assuming better data is delivered, it is unknown whether or when those data will be integrated into stock assessment and run forecast models.
3) Assuming better data are integrated into the models it is unknown whether the new data will actually improve the reliability of the models.
4) Assuming the reliability of the models is improved, it is unknown whether or when the improvements will be accepted by managers or industry members.

These types of uncertainties lead to a more conservative expected value of information estimate. To assess benefits to the Alaska groundfish fishery, for example, of enhanced data, a value of information model (using hypothetical probabilities) might be expressed as follows:

1) There is a 75% probability that groundfish scientists will be able to use the data to refine their analyses
2) There is a 50% probability that what scientists think today will be borne out by their further analyses and data

3) There is a 50% probability that the NPFMC and NOAA NMFS will lift the 2 million MT TAC cap, once a track record is established
4) There is a 50% probability that groundfish stocks will be in the same shape they are in 25 years from now

An expected value model combines the above probabilities multiplicatively. Thus based on the hypothetical probabilities described above, there is only a 9 percent chance (0.75 × 0.5 × 0.5 × 0.5), that the improvements generating $504 million (in today's dollars) will be realized.

In addition to the probabilistic model described above, the fact that the benefits of the enhanced ocean observation system are not expected to be realized for many years after the system is upgraded means that the cost and benefits stream must be discounted to present values. If we assume conservatively, for example, that:

1) The cost of the observation system upgrades in Alaska are $100 million and occur in 2005,
2) The cost of operating and maintaining the system for the next 50 years (until 2055) are $10 million per year,
3) The benefits of the program to the groundfish fishery ($504 million per year) begin to accrue 15 years (in 2020) after the system is upgraded and continue until 2055,
4) The social discount rate is 7.5 percent;

Given the above assumptions, the net present value of enhancements to AOOS to Alaska groundfish fisheries is reduced to only $17.5 million. If we further assume there is only a 9 percent probability that the benefits of an enhanced system for the groundfish fishery will be realized then, the net present value becomes negative.

7 Transferability of Models and Results

While the approach taken in this analysis may be transferred to other fisheries around the U.S. it is not necessarily appropriate to transfer the estimates generated. Fisheries around the nation are each unique and managed as such. In addition the uncertainties inherent in value of information models across fisheries will be unique. We have learned that the complexity of the biological and stock assessment models that are the basis for harvest rates and fisheries management generally make it very difficult to transfer applications even between fisheries within a region. We believe that best approach to modeling the value of enhanced COOS to fisheries across the United States will be through explicit case examples that illustrate the sign and potential magnitude of benefits.

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DECISION MODEL TO ESTIMATE THE VALUE OF IMPROVED WAVE HEIGHT FORECASTS FOR GREAT LAKES RECREATIONAL BOATING

Phase II Case Study
Coordinated Regional Benefit Studies of Coastal Ocean Observing Systems
(Great Lakes Region)

Draft Report

June 30, 2004

Funded through the **National Ocean Partnership Program**, supported by the National Oceanic and Atmospheric Administration, National Science Foundation, Office of Naval Research, U.S. Environmental Protection Agency, US Geological Survey, Mineral Management Service, U.S. Coast Guard, Defense Advanced Research Projects Agency, Department of State, the U.S. Army Corps of Engineers, and the National Aeronautics & Space Administration.

TABLE OF CONTENTS

Executive Summary

The Great Lakes Forecasting System (GLFS) provides lake surface and wave height forecasts for each of the Great Lakes.

Based on the assumption that GLFS forecast accuracy can be further improved through the deployment of enhanced ocean observing technologies and / or analytical practices, this study posits a decision model to estimate the economic value of better information (improved forecast accuracy) for Great Lakes recreational boaters.

Per Table 1, the decision model indicates that for every 1% of additional forecast accuracy, Great Lakes recreational boaters can be expected to enjoy 97,000 additional boating days and $21 million of incremental economic benefits.

On the basis of conservative assumptions, improving forecast accuracy from 80% to 85% could result in 483,000 additional boating days and $ 103.5 million of incremental economic benefits.

Table 1: Economic Impact of Improved GLFS Forecast Accuracy ($ Million)

FORECAST ACCURACY	ADDITIONAL BOATING DAYS	INCREMENTAL ECONOMIC BENEFIT
80%	BASELINE	BASELINE
81%	96,689	$ 20,711,000
82%	193,377	$ 41,421,000
83%	290,066	$ 62,132,000
84%	386,755	$ 82,843.000
85%	483,444	$ 103,554,000

Wave Phenomena and Wave Forecasts

Discussions with marina operators, staff of recreational boating associations, and editors of recreational boating journals and outlets indicate that weather forecasts are considered to be very important by Great Lakes recreational boaters. In particular wave heights and wave periodicity (choppiness) are key concerns relative to safety and enjoyment.

While the type of vessel (sailing vs. motor boat), the size of the vessel, and the skill and experience of the operator are important sources of variation, expert input would indicate that in seas with 18” wave heights and higher, coupled with choppy conditions, amateur sailors and motor boaters will have a less than pleasurable experience and may find conditions unsafe.

Since recreational motorboats are generally less seaworthy than sailing vessels and are “made to go fast”, wave height is a particularly important constraint relative to enjoyable recreation. We therefore posited that

- “Good” surface conditions are associated with wave heights under 18” and
- “Bad” surface conditions are associated with wave heights at or over 18”.

Wave height along with wave periodicity information is forecasted by the NOAA Great Lakes Forecasting System (GLFS), on an hourly basis, for a 5 km grid (except for Lake Superior where the grid is 10 km).

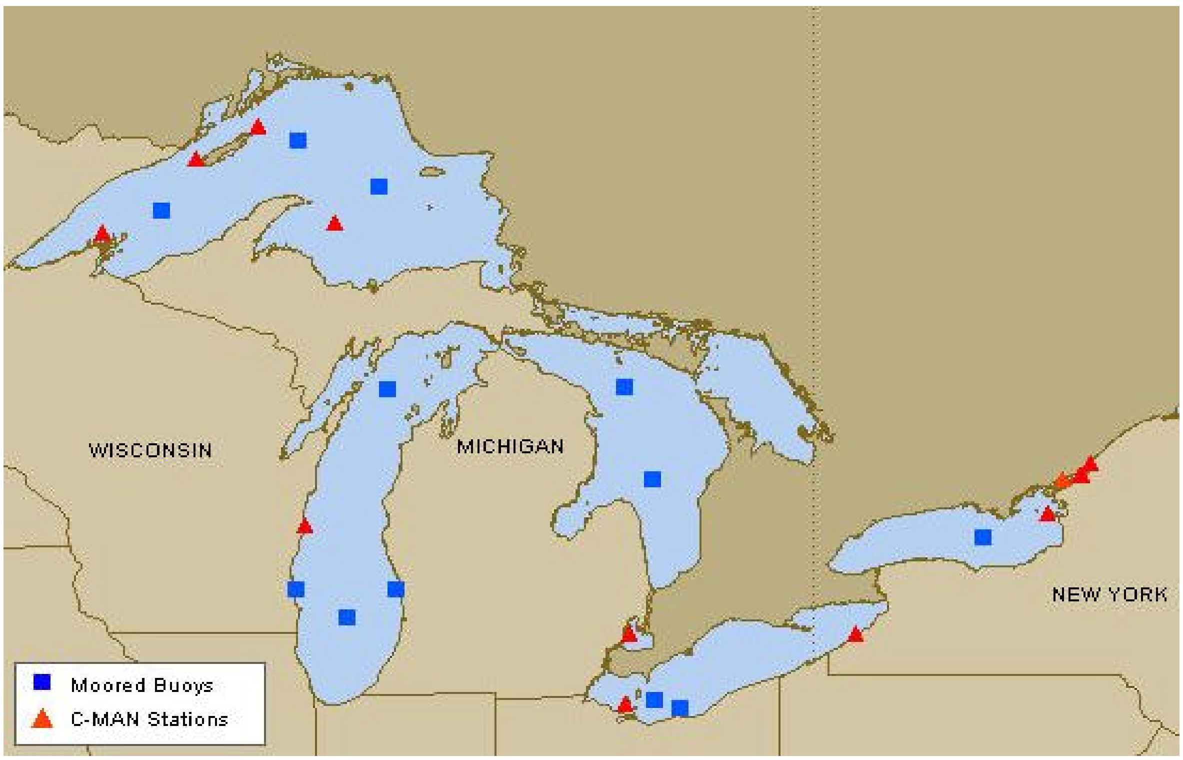
The initial implementation of the GLFS for Lake Erie was completed in 1993. GLFS has since been extended to the other four Great Lakes. GLFS operates with two components (1) an atmospheric input module (a step coordinate Eta model) to force a (2) numerical ocean module (Princeton Ocean Model).

Great Lakes marine forecasting is relatively difficult due to “the presence of small scale coastal features which can generate local convergence / divergence regions and the presence of strong air-lake fluxes, rapid upwelling, and seiches. The Great Lakes Forecasting System uses the output from the Eta model as input to the wave or ocean model and there is no feedback between the waves that develop and the winds that generate them” (Sousounis).

Wave Height Observations

The National Buoy Data Center (NBDC) operates 12 moored buoys in coastal and offshore waters of the five Great Lakes. Additional surface information is also collected by on-shore C-MAN stations (Figure 1)

Figure 1: Great Lakes Surface Data Collected by NDBC Buoy's



Based on NDBC 1981 to 2001 time-series of empirically observed wave patterns, the arithmetic mean wave heights for the Great Lakes during the five and half month recreational boating season have a tendency to exceed 18 inches 70 percent of the time (Table 2).

Table 2: Mean Wave Heights for Great Lakes May 1- October 15, 1981-2001 (Inches)

	MAY	JUNE	JULY	AUGUST	SEPT	OCT (1-15)
Lake Erie - Sandusky	15.76	11.82	15.76	19.7	27.58	31.52
Lake Michigan South	15.76	11.82	19.7	23.64	35.46	39.4
Lake Michigan North	19.7	15.76	19.7	23.64	35.46	43.34
Lake Huron Central	19.7	15.76	19.7	23.64	35.46	43.34
Lake Superior Central	19.7	15.76	11.82	19.7	35.46	47.28

Source: National Data Buoy Center, Historical Time Series

However, when reviewing actual (as opposed to mean wave heights), 2002 and 2003 hourly data for three of the twelve NDBC buoys, only 40 percent of hourly readings (during the May to October period) exceeded 18”.

Since it can be further assumed that the bulk of recreational boating takes place during the months of June, July, and August, hourly readings for these 3 months indicate that wave height exceeds 18” only 31.5 percent of the time.

Accordingly, on the basis of the above empirical evidence, we assumed that lake surface conditions are “Good” 68.5 % of the time and “Bad” 31.5 % of the time.

Decision Model and Physical Outcome Model

The following assumptions were used for a base-case decision model.

- GLFS forecasts are able to correctly identify "Good" lake surface conditions 80% of the time and fail to do so 20% of the time.

- GLFS forecasts are able to correctly identify "Bad" lake surface conditions 80% of the time and fail to do so 20% of the time.

- During subsequent analysis, forecast accuracy was deemed the independent variable and frequency of "Good" forecasts was stepped in 1% increments from 80% to 85%

In addition, three decision rules were posited to drive recreational boater behavior:

- Forecast of "Good" lake surface conditions will result in a decision to "go out" by 100% of boaters, planning to go boating or inclined to go boating any particular day (this is equivalent to a condition of "all other things being equal".

- 15% of boaters who have appropriate expertise to navigate in difficult lake conditions or who lack such expertise and recklessly ignore forecasts of "Bad" lake surface conditions and "go out" anyway.

- 85% of boaters, who tend to be more cautious or realize that "Bad" wave conditions do not make for an enjoyable experience, will act in conformity with available forecasts. When the forecast indicates "Bad" lake surface condition, these 85% of boaters will stay in harbor.

Finally, as "the Great Lakes Forecasting System uses outputs from the Eta model as input to the wave (or ocean) model and there is no feedback between the waves that develop and the winds that generate them" (Sousounis), for purposes of modeling recreational boater behavior, we assumed a condition of independence between wave forecasts and observed wave conditions.

Reflecting the above assumptions, a base-case decision model is indicated in Figure 2.

As forecast accuracy is incremented (relative to a base case decision model) for each one percent improvement in forecast accuracy, the probability of the combination "Good"

Surface Conditions – Incorrect Forecast – Decision to Stay in Harbor (i.e., the probability of lost boating days) decreases as indicated in Table 3

Figure 2: Decision Model, Boater Behavior as Function of Forecast Accuracy

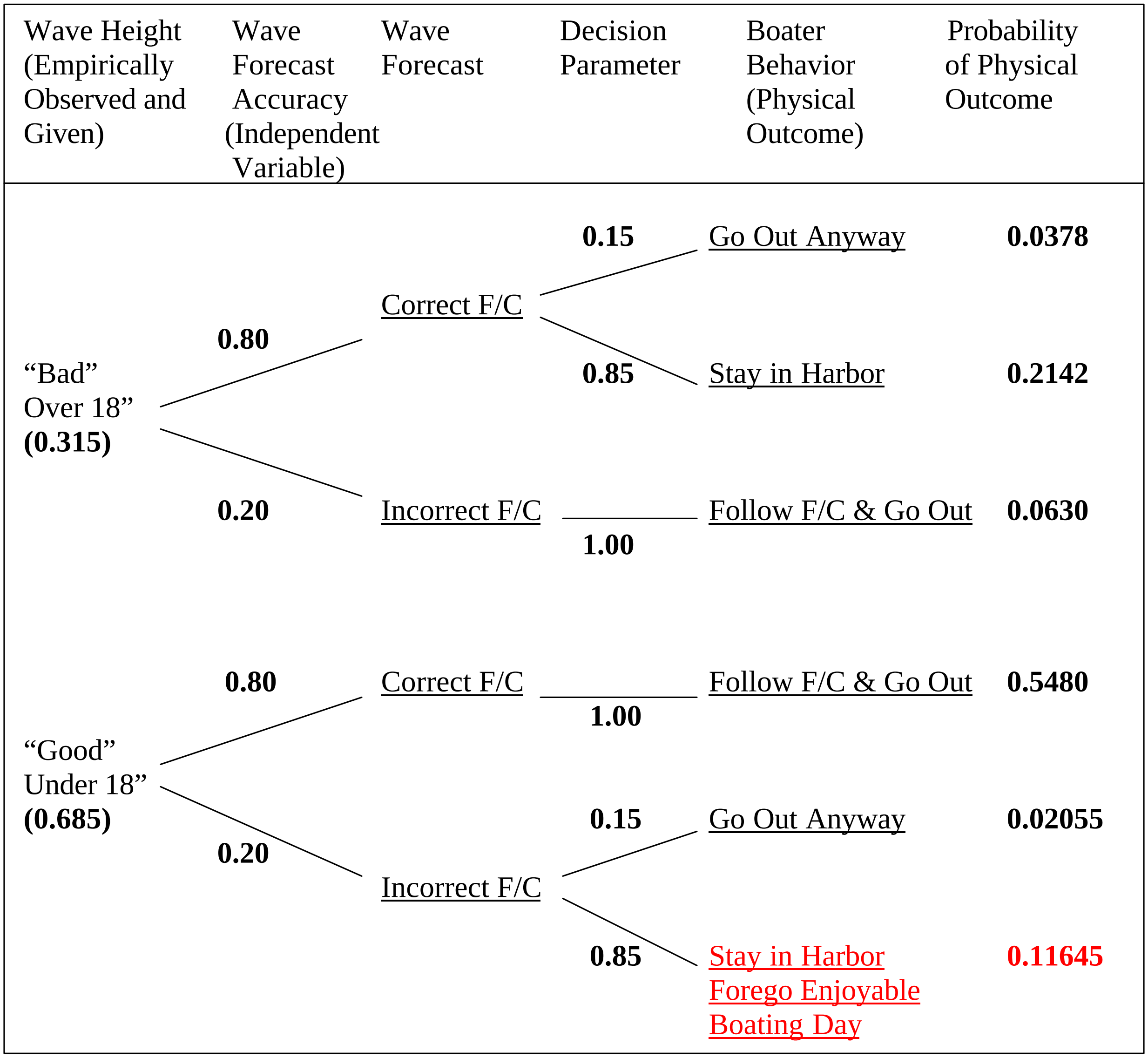


Table 3: Improving Forecast Accuracy and the Probability of Lost Boating Days

Forecast Accuracy	Probability of Lost Boating Days
Base-case 80%	0.11645
81%	0.1106275
82%	0.104805
83%	0.0989825
84%	0.09316

85%	0.0873375

Economic Outcome Model

The Economic Outcome Model incorporates the following additional assumptions:

- For Michigan, Ohio, Wisconsin, and Illinois, Great Lakes boating days are derived from the number of recreational boats registered statewide. It is assumed that these boats average 12.1 boating days per year (NSRE) and that 50 percent of boating days are spent on the Great Lakes, as opposed to rivers and smaller lakes.

- For New York, Pennsylvania, Indiana and Minnesota, boating days are derived from the number of boats registered in Great Lake coastal counties. It is assumed that these boats average 12.1 boating days per year (NSRE) and that 90% of boating days are spent on the Great Lakes. This adjustment is due to the extensive saltwater component in New York and Pennsylvania and to the very large internal (non-Great Lake) component in Indiana and Minnesota.

- Based on the above approach, boating days for the five Great Lakes are estimated at 16.6 million days per year (Table 4, Column 4).

Based on a 1999 Study of the economic impact of recreational boating in Ohio (Hushak), daily expenses for travel, meals, boat-fuel, marina fees, etc. are assumed to average $ 187 per day for all Great Lakes boating days. This average value excludes capital investments for boat acquisition and major upgrades and is adjusted to 2003 dollars to yield $ 214 per day.

Table 4: Economic Impact as a Function of Forecast Accuracy

Forecast Accuracy	Probability of Lost Boating Days	Delta: Decreased Probability Lost Days	Great Lakes Boating Days Per Year	Increase in Great Lakes Boating Days	Average Value of Boating Day ($)	Economic Benefits from Improved Forecasts)
(1)	((2)	(3)	(4)	(5)	(6)	(7)
80%	0.11645	0	16,606,049	0	214.2	0
81%	0.1106275	0.0058225	16,606,049	96,689	214.2	$ 20,711,000
82%	0.104805	0.011645	16,606,049	193,377	214.2	$ 41,421,000
83%	0.0989825	0.0174675	16,606,049	290,066	214.2	$ 62,132,000
	0.09316	0.02329	16,606,049	386,755	214.2	$ 82,843,000

84%						
85%	0.0873375	0.0291125	16,606,049	483,444	214.2	$ 103.55mill

Table 4, Columns 5 and 7 indicate that for every 1% of additional wave height forecast accuracy, Great Lakes recreational boaters are likely to enjoy 97,000 additional boating days corresponding to $21 million in incremental economic benefits.

On the basis of conservative assumptions, improving current wave height forecast accuracy from 80% to 85% would thereby generate 483,000 additional boating days and $ 103.5 million of incremental economic benefits.

Applicability to Other Regions

The above approach may be applied to other coastal regions if the assumptions, appropriate for the Great Lakes region, are adjusted to reflect conditions in other coastal regions. In particular,

- Assumptions about feedback loops in ocean surface forecasting systems,
- Wave height time-series observations for a relevant recreational season,
- Assumptions about number of boating days and the value of boating days, etc.

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