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Ecosystem Services Measurement and Assessment Project

Executive Summary

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EXECUTIVE SUMMARY

INTRODUCTION

The Arctic coastal and marine environment is a complex and diverse ecosystem characterized by weather extremes and seasonal ice formation. An adaptive management approach will be required to manage these ecosystem resources sustainably while also preserving traditional uses and introducing new uses. The Ecosystem Services Measurement and Assessment Project, funded by ExxonMobil Upstream Research Company, takes steps towards this approach and has the overall objective to “document ecosystem management tools and metrics that may be used in coastal, offshore and Arctic regions and then determine which tool(s) could be most applicable.” This project aims to identify, assess, and recommend remote sensing technologies and ecosystem services models and methodologies appropriate for the Arctic marine and ice ecosystem. The basic components of the project’s conceptual framework are the remote sensing technologies which gather data on ecosystem attributes and the ecosystem services models which evaluate the benefits received by humans from the working environment.

The project is designed in two phases with the first phase focusing on a review of existing remote sensing technologies and ecosystem services models by reviewing literature, identifying and contacting various experts in relevant fields, and holding two workshops designed to bring together experts and other stakeholders regarding the potential technologies and methods. The second phase applies selected remote sensing technologies and ecosystem services models in a pilot study to test the approach.

DESCRIPTION OF THE ARCTIC MARINE ENVIRONMENT

The area that makes up the Arctic marine environment is comprised of the Arctic Ocean which is made up by the Eurasian and Canadian basins and several continental shelf seas. The Arctic marine environment is characterized, and heavily influenced, by extremes of sunlight, darkness, temperature, and salinity, with occurrence of both seasonal and multi-year ice.

Sea ice, both permanent and seasonal, is perhaps the dominant physical factor influencing the Arctic marine environment - peaking in March and at a minimum in September. Influences on the extent of sea ice include atmospheric pressure, wind patterns, freshwater discharge, and inflows of water from the Atlantic and Pacific Oceans. It is reported that the “distribution of sea ice” is the most important influence on how the Arctic marine ecosystem functions (Loeng, 2005). However, this ecosystem is also impacted by temperature, wind, and snow. Sea ice serves two important roles for the polar marine ecosystem: 1) seasonal habitat for sea algae and 2) release of organisms during spring melt that are important for productivity (Krembs and Deming, 2009). In terms of biodiversity, the Arctic marine ecosystem experiences relatively less diversity and productivity compared to other ecosystems. Despite generally low levels of productivity, there are regions of high seasonal productivity, including the Barents Sea, the Chukchi Sea, the Bering Shelf, and polynyas that support a significant food web that includes fish, mammals, and sea birds.

The seasonal formation of sea ice mitigates both ordinary wave action and storm impacts that contribute significantly to coastal erosion. If the freeze-thaw cycle is shortened, coastal areas are much more susceptible to the impacts of diminished shoreline stability due to greater influence of waves and storms as well as lowered integrity of shoreline due to loss of ice in sediments. This is especially critical to communities with low resiliency and high vulnerability. Sea ice also provides a habitat to many forms of Arctic life, and therefore also serves as hunting grounds for both humans and animals.

REMOTE SENSING IN THE ARCTIC

Satellite and aerial remote sensing techniques have been used to study a variety of ecosystem attributes in Arctic Regions. Although remote sensing techniques can be effectively applied under the right conditions, there are some limitations and challenges to remote sensing in the Arctic region that should be considered. Optical remote sensors face the greatest challenge in terms of Arctic ecosystem monitoring, as they can only capture attributes on the ground that are not obscured by darkness or cloud cover. Another challenge is the large solar zenith angles associated with long summer days, which make at-nadir data capture difficult due to low signal-to-noise ratios. Finally, remote sensing studies in the Arctic are faced with increased costs of field sampling in remote areas.

Radar sensors do not face the same darkness and cloud-cover limitations as optical remote sensors, as they are active sensors that use long wavelengths that penetrate clouds. Additionally, they do not require light to capture data and can thus collect data at night. However, the ecosystem attributes that can be studied using Radar data are more limited than those using data collected by optical sensors, and often involve a greater level of inference as attributes must be derived from surface geometry, roughness, and moisture content. Similarly, LiDAR sensors do not face the same cloud-cover limitations as optical data, as they can penetrate all but very thick cloud cover, but face limitations in terms of the ecosystem attributes that can be detected – all must be derived from surface topography, geometry, and roughness.

ECOSYSTEM SERVICES ASSESSMENT AND VALUATION

The valuation of ecosystem services has generally been pursued for one of two reasons: 1) to estimate a snapshot of the value of existing ecosystems services relative to other economic activities or 2) to conduct scenario analysis to better understand the tradeoffs involved with development or management choices. The vast majority of these types of studies have been one-off location-specific studies and the set of economic tools has remained fairly constant, but with advances over time in the methodology for implementing these tools.

There are a wide range of manuals, guidelines and tools that have been developed regarding the valuation of ecosystem services. There have also been several comprehensive surveys of models and tools. Several existing ecosystem services valuation models and guidelines were identified from the literature. Two models of interest due to their adaptability and previous application are the InVEST Model (Integrated Valuation of Ecosystem Services and Tradeoffs) and the MIMES (Multiscale Integrated Earth Systems Model). These models best fit the interests of the project as they are able to use spatial data as input, have a strong valuation/tradeoff focus, and are relatively well developed. Unfortunately, neither of the ecosystem services tools has a working marine nor an Arctic component (although, both InVEST and MIMES have plans to build marine components).

Development of an ecosystem response function is necessary for modeling marginal changes in ecosystem services. While there is a substantial amount of information regarding various aspects of the marine and ice ecosystems in the Arctic, it is not clear that there are established ecosystem response functions that could make the linkage. An ecosystem response function will allow both 1) a quantitative link between ecosystem attributes and ecosystem services and 2) an ability to model scenarios or marginal changes in the ecosystem.

PILOT STUDY

A shoreline stability modeling study of a 40 km section of the North Slope coast was conducted with the goals: (1) to determine the extent to which shoreline stability could be calculated based

on remotely sensed data, (2) to account for at least one coastal erosion mechanism, (3) to project shoreline stability into the future accounting for different scenarios, and (4) to demonstrate that shoreline stability modeling could be conducted in a framework compatible with the MIMES model. The study area was continuous but included two distinct stretches: (1) Drew Point coast and (2) Smith Bay coast. This area consists of 3 m high tundra bluffs fronted by small beaches. The bluffs are composed of ice (~80% by volume) and fine sediments.

Most of the environmental variables that affect shoreline stability can be remotely sensed – to some extent. One of the project goals was to project future shoreline stability. This cannot be done based solely on remotely sensed data. Instead, models which project environmental data for future time periods are required.

The environmental data was generally calculated by models. However, some environmental data were estimated based on aerial photos or based on data in the literature. Meteorological data was obtained from a meteorological station at Barrow Alaska. Near-shore water temperature and sea ice extent were calculated using a coupled ocean-sea ice model developed by Jinlun Zhang (University of Washington). Measured data for these variables are also available through various government agencies.

The shoreline change model calculated an average erosion rate of about 8 m/yr for the Drew Point Coast, and 1 to 2 m/yr for the Smith Bay Coast, for the time period 1955-2002. Shoreline change rates in a future period 2036-2044 were also determined for the study site. The calculation was forced based on output from a global climate model considered to be in the middle range of the selection assessed by the Intergovernmental Panel on Climate Change. One modeled scenario predicted a global temperature rise of 8°C by 2100. With this forcing, the erosion model predicted an erosion rate of about 30 m/yr on the Drew Point coast and about 6 m/yr on the Smith Bay coast. A second scenario, corresponding to a 4°C global temperature increase estimated the 2036-2044 erosion rates at about 20 m/yr and 4 m/yr for the Drew Point and the Smith Bay coasts, respectively.

No economic valuations were attempted during the pilot study as a substantial participatory approach involving the area's many stakeholders would be necessary for this. As a result, MIMES was not used, but instead a similarly-formatted and simpler related model was developed to facilitate a valuation study if one should be pursued in the future. The ALaska COastal Erosion (ALCOvE) Model was developed to model the physical environment for shoreline stability.

For Drew Point, the model was then run for the time period 1955-2007. Remote-sensing-derived shoreline position data from 1955 were entered into the model to represent baseline conditions. Data for 2007 were used for the endpoint. The results indicate an acceleration of erosion in the period 1990-2000 as compared to 1955-1985 of almost 2.5 times. A comparison of modeling results and actual data indicate that the modeled rate of erosion is slightly slower than the actual rate of erosion. This can be explained by the fact that there are still several important variables missing from the model (e.g. wind speed and bathymetry).

The Smith Bay model results showed that after only 20 years almost all the modeled coastal land area has eroded. The fit between the Smith Bay actual situation and modeled results is not very good compared to the Drew Point results. The Smith Bay model based its end points on two maps; one from 1947 and the other from 2007. The 2007 map is smaller than the 1947 map which resulted in difficulty in determining how the cells for the two maps fit together. The Smith Bay model also incorporates the wave height and water temperature data for Drew Point

starting from 1957. There is potential for error in this, particularly due to differences in the orientation of the two coasts towards the Arctic ice.

In general, the models can adequately capture shoreline erosion dynamics. The models generally give good results, but would benefit from 1) additional calibration and 2) models, rather than data sets, to predict wave height and water temperatures (i.e. models that take into account the factors of wave generation). Such an approach would solve the problem of non-matching data sets (in time and space) in addition to generating more location-specific results.

CONCLUSION AND NEXT STEPS

A literature review and interviews with experts revealed that a large volume of existing data and research exists on the Arctic environment and ecosystems. Regarding ecosystem services modeling, there has been only limited work on marine environments and almost none on Arctic environments. In this respect, the current study is breaking new ground in an important area of science.

The work on remote sensing has identified limitations of certain remote sensors in the Arctic while simultaneously identifying sensors that can overcome some of these limitations. A matrix has been developed that identifies which ecosystem attributes are detectable by each type of remote sensing technology. The work on ecosystem services models showed that the MIMES model is potentially applicable to such a study. Other ecosystem services models have not yet been evaluated.

Developing quantified relationships is likely to remain an imprecise science. For future research, it will be important to be aware of the tradeoff between the precision of modeling results and the costs of developing the ecosystem response functions. During the course of the research, it became apparent that forming long-term relationships with Arctic researchers and stakeholders would be extremely beneficial for future research efforts. This will be especially important in Alaska if future efforts are made to develop the social or economic aspects of ecosystem services modeling.

This study has successfully concluded a first step in developing a framework and tool for monitoring and assessing ecosystem services in the Arctic. In moving forward, there are four general areas of priority including:

- Expanding and improving the current pilot study;
- Conducting additional pilot studies on other ecosystem services;
- Conducting more in-depth research on ecosystem services valuation; and,
- Initiating the participatory component of ecosystem services valuation studies and continuing to build a network of stakeholders and researchers.

This study has successfully reviewed and identified appropriate and promising remote sensing technologies and ecosystem services evaluation models. In fact, the study has been groundbreaking in attempting to link these technologies, especially in both a marine environment and in the Arctic. However, while the technology and modeling is promising, there remain gaps regarding knowledge of the ecosystem functions and research. The approach studied here will benefit from greater stakeholder participation along the North Slope as well as with various government agencies and universities. Areas of continued work have been outlined above and should serve as a basis for designing future research.