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Environmental Risk Evaluation System (ERES) for Offshore Wind

Mock-Up of ERES
Fiscal Year 2010 Progress Report

Environmental Effects of Offshore Wind Development

RM Anderson
AE Copping
FB Van Cleve

November 2010

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Abstract

The purpose of this project is to develop tools that examine the environmental effects of offshore wind development, in order to streamline and facilitate the siting and permitting of wind farms in the U.S. During FY 2010, the conceptual framework for the environmental risk evaluation system (ERES) and the knowledge management system (*Zephyrus*) to house environmental effects data was developed. This report provides a visualization of that framework. The framework has not yet been developed; the examples shown are mock ups but are indicative of real data and analysis needs for facilitating siting and permitting offshore wind farms in the U.S. Descriptions of environmental data that will be collected within the system, ancillary engineering and ocean space use data, and examples of analytical tools are provided. Each example is visualized within the mockup of *Zephyrus*. PNNL expects to build out ERES and *Zephyrus* in future phases of the project.

PNNL's offshore wind program hosted two undergraduate researchers during the summer of 2010. Each student undertook a project that supports the development of the offshore wind ERES. One student examined the use of visualization tools for visual effects of offshore wind farms; the other gathered and analyzed geospatial data on migratory animals that may be affected by offshore wind farms. Their reports are included at the end of this report.

Acknowledgements

The authors especially thank A.W. Piatt and E.L. Hamilton for their assistance in producing the figures in this report.

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1.0 Introduction

The purpose of this project is to develop tools that examine the environmental effects of offshore wind development, in order to streamline and facilitate the siting and permitting of wind farms in the U.S. Over the course of this project, Pacific Northwest National Laboratory (PNNL) will identify the highest environmental risks by 1) providing a science-based system to evaluate risk information, and making that information available to all parties; 2) developing risk analysis tools and applying them to identify environmental risks associated with offshore wind development; and 3) providing offshore wind developers, regulators, and stakeholders with in depth information as background for permitting discussions. During FY10, PNNL has: developed the conceptual framework for the environmental risk evaluation system and the knowledge management system to house environmental effects data; engaged project developers to understand the barriers to siting and permitting of offshore wind farms; and assessed the technology needs for environmental monitoring of offshore wind farms.

Previous approaches to addressing offshore wind development impacts, in Europe and North America, have been developed to satisfy regulatory requirements, including the National Environmental Protection Act (NEPA) in the U.S. However, such sector-by-sector studies do not provide the integrated spectrum of information that decision makers and stakeholders need to capture the actual risks of offshore wind energy development. Regulators and stakeholders need access to information and procedures that systematically and consistently identify risk and uncertainties in order to make risk-informed decisions; this information will support financing, planning, operating and regulating of offshore wind farms.

In this report we describe the Environmental Risk Evaluation System (ERES), a risk-informed analytical process for estimating the environmental risks associated with the construction and operation of offshore wind energy generation projects. The development of ERES for offshore wind is closely allied with a concurrent process to examine environmental effects of marine and hydrokinetic (MHK) energy generation; specific risk-relevant attributes will differ between MHK and offshore wind. During FY2010 a conceptual design of ERES for offshore wind has been developed. This report includes selected figures from the design, offered as examples of the visualization interface to explain the tool’s functionality. We anticipate that a fully functional version of ERES for offshore wind will be developed in a subsequent phase of the project.

This report briefly describes elements of a hypothetical project titled the *Cape Green Offshore Wind Project*. Figure 1 is a schematic of the analytical process contained within ERES. The analysis begins at the *analysis case* as (in the lower blue box) which specifies the project phase (e.g. installation, operation or decommissioning), system design (e.g., base and rotor design, layout of wind farm), and the project site (Anderson et al. 2010). The analysis case would also identify different *receptors* (e.g., marine species and food webs, human uses) that might be at risk due to wind farm installation and operation, as well as stressors or mechanisms for risk exposure (e.g., shipping collision, chemical release, acoustic stress, electromagnetic fields, etc.). Rather than presenting comprehensive details of an analysis, this report illustrates the functions of ERES that will guide more detailed risk modeling to and analyses of proposed offshore wind farms.

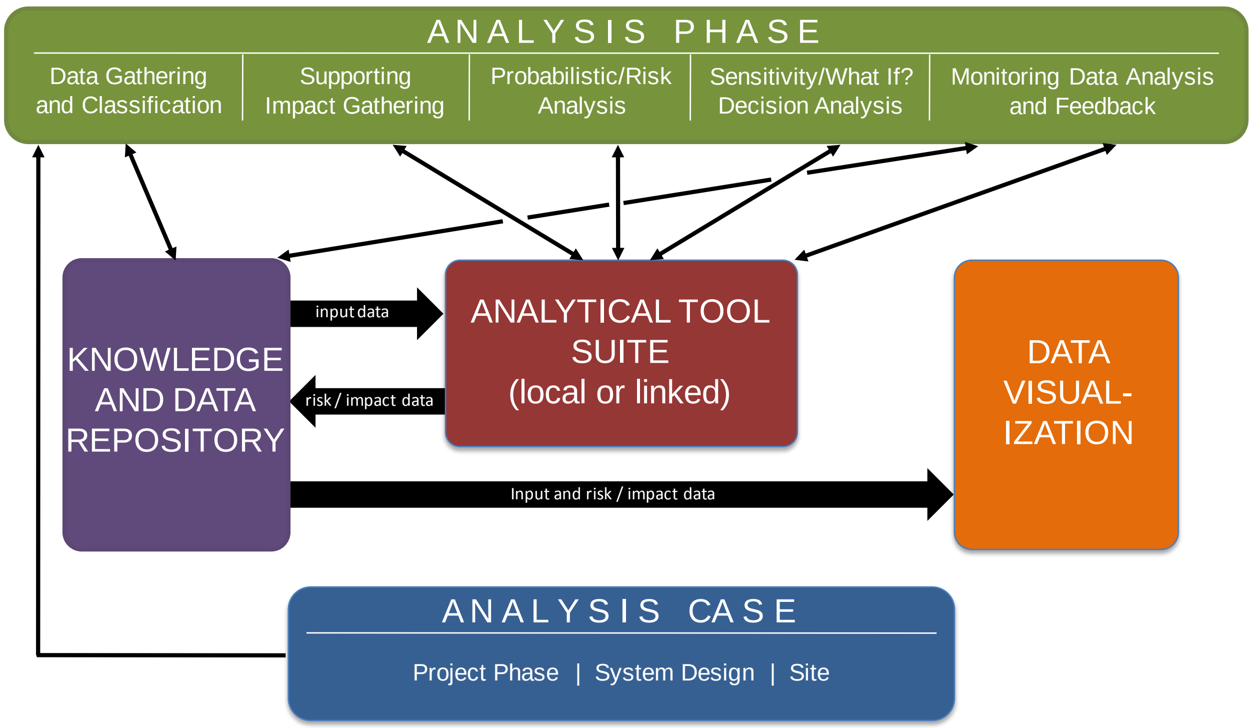


Figure 1. Schematic of ERES for risk analysis of environmental effects of offshore wind installations.

2.0 Functionality of ERES for Offshore Wind

Analysis of environmental effects for offshore wind development is conceptualized as three functional components. First, a computer-based knowledge management system named *Zephyrus* will bring together all forms of information on the environmental effects of offshore wind energy development. *Second*, the Environmental Risk Evaluation System (ERES) for offshore wind, a system that includes a flexible suite of analytical tools to provide a range of risk analysis functionality will draw from the data in *Zephyrus*. And *third*, visualization tools incorporated into *Zephyrus* will facilitate summarizing and viewing of risk analysis output.

Progress on ERES during FY10 focused on outlining the ERES process, and preparing a visual representation of the system outputs. There was not sufficient time or budget to complete the development of *Zephyrus*, collect and enter data, or establish measures of risk. Subsequent work will complete these steps.

The ERES/*Zephyrus* system will be accessed through a wiki-based web user interface, an example of which is shown in Figure 2. Figure 2 shows an environmental data set on average wind speed vs. elevation for locations off New Jersey USA. The location of a hypothetical wind farm (dubbed "Cape Green Offshore Wind Project") is shown in the two hatched areas drawn on the map. This visualization illustrates how contours of wind speed at rotor elevation might be used to aid in siting offshore wind farms. In addition to environmental data, *Zephyrus* will also provide access to analytical tools that are both embedded within ERES as well as external tools that can be launched from within the interface but are housed and executed externally. Information and visualizations can also be used to ensure that all interested parties have access to similar information, allowing *Zephyrs* to be used as a forum for stakeholder engagement on offshore wind projects, as well as a space for project developers and regulators to learn about ongoing project plans and analyses.

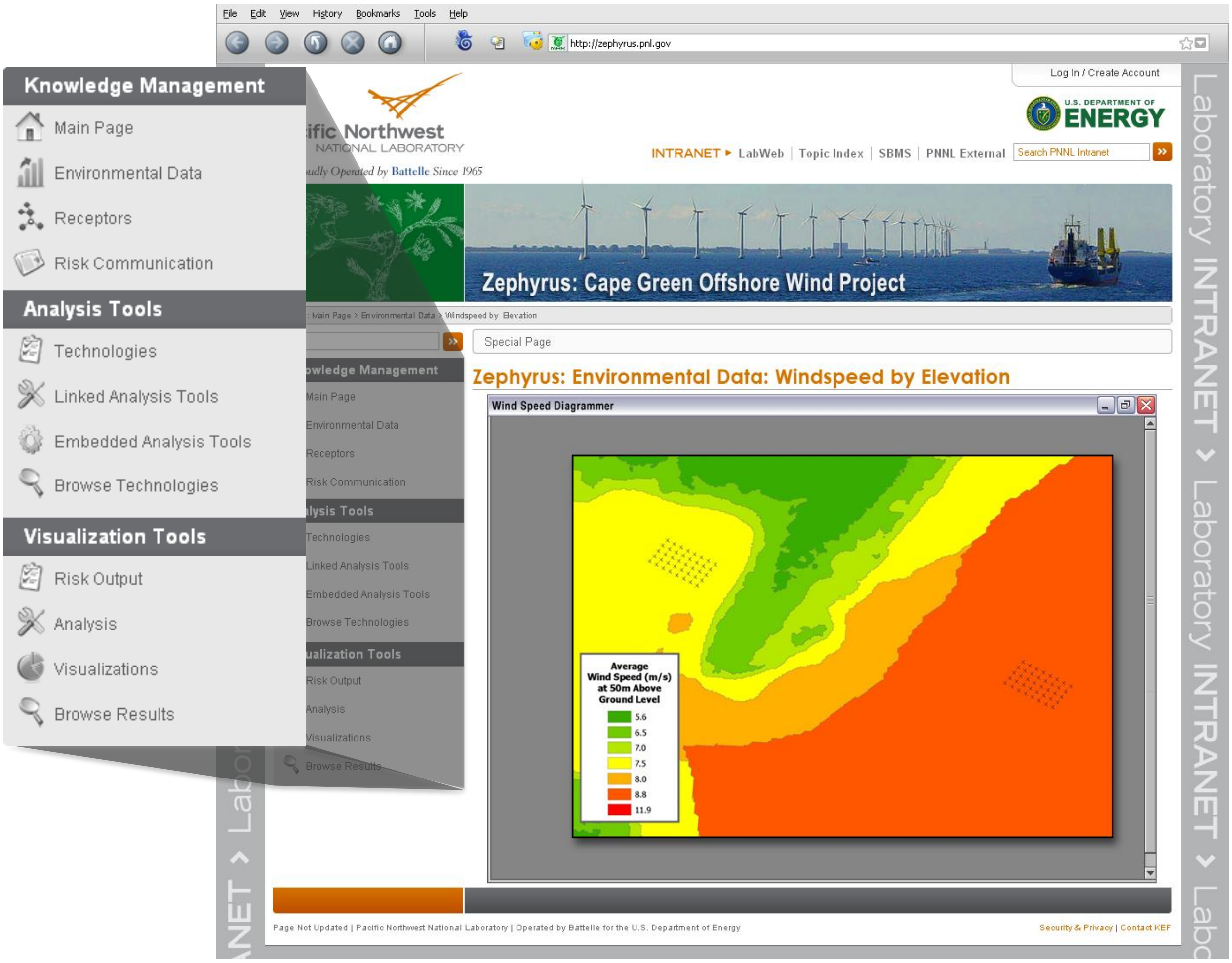


Figure 2. Wiki-based Web User Interface for ERES for offshore wind information, housed within Zephyrus. This visualization shows wind speeds at rotor height, and two locations for the hypothetical Cape Green Offshore Wind Project (hatched areas).

2.1 Characterization of an ERES Analysis Case, using *the Cape Green Offshore Wind Farm* as an Example

2.1.1 Environmental Data.

The offshore wind knowledge management system *Zephyrus* will house diverse data related to offshore wind energy development, focusing on environmental effects data. However, in order to understand the context and regulatory significance of environmental effects data, other information is needed, including characterization of the wind resource by area and season, the location and presence of biological resources such as marine animals and sensitive habitats, as well as potential conflicts with other ocean uses. Figures 3 and 4 illustrate some of these data. Table 1 lists categories of receptors that may be affected by an offshore wind installation and for which ERES will support risk analysis.

2.1.2 Additional Data Sources

Table 2 lists a range of additional data types that will also be housed in ERES, in order to carry out specific analyses. These data may include engineering data for offshore wind turbines. Early offshore installations in Europe deployed small (< 1 MW) wind turbines. The early 2000s saw models in the 2 – 4 MW range (Figure 5). More recently, larger turbines (> 4 MW) have been designed specifically for the offshore wind environment. *Zephyrus* will include specification and performance data for various designs, as illustrated in Figure 5.

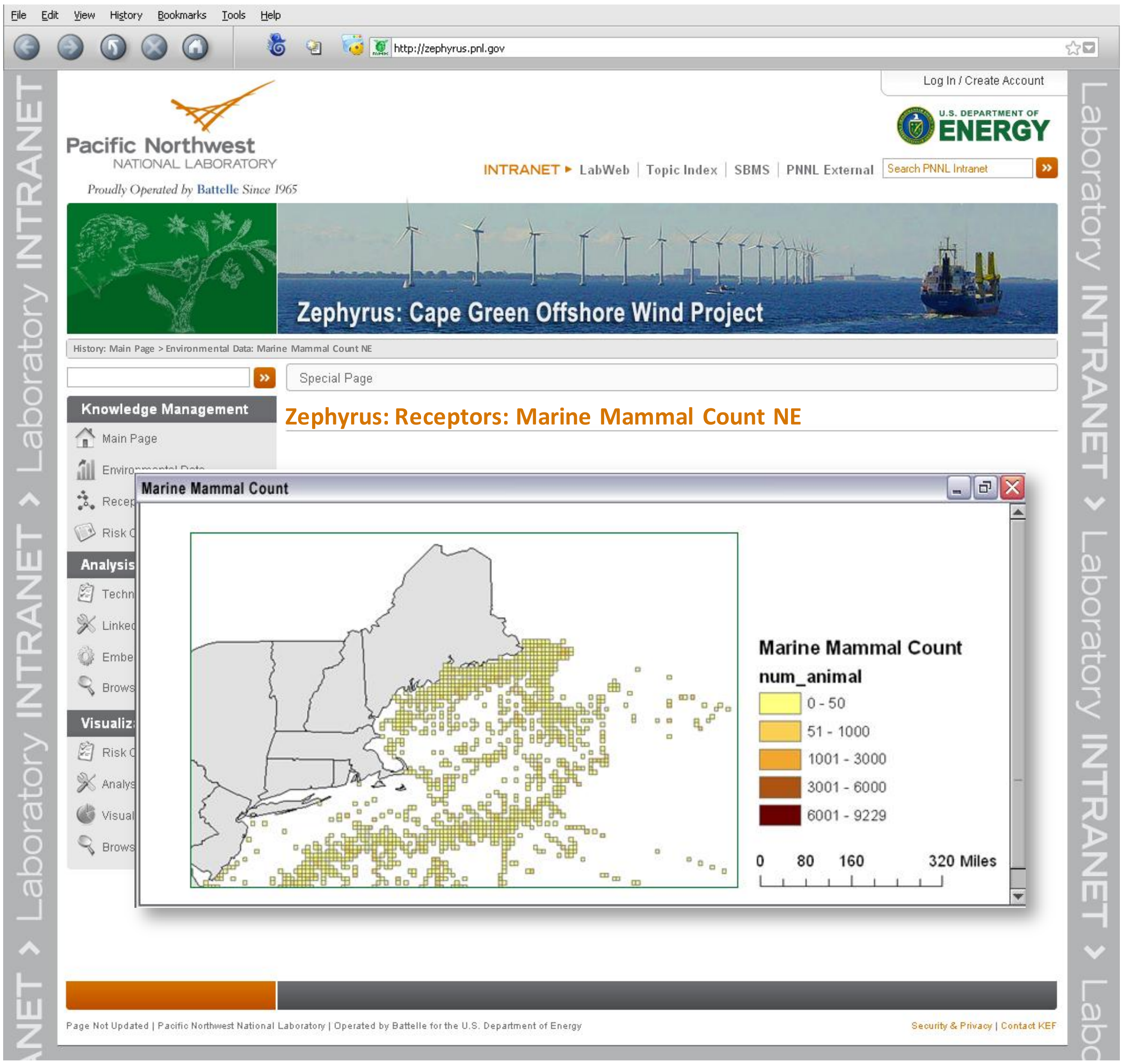


Figure 3. Geospatially explicit counts of marine mammals off the northeast U.S., from a variety of sources, including NOAA Fisheries observations. These data could be housed within Zephyrus and/or accessed from outside databases linked to the system.

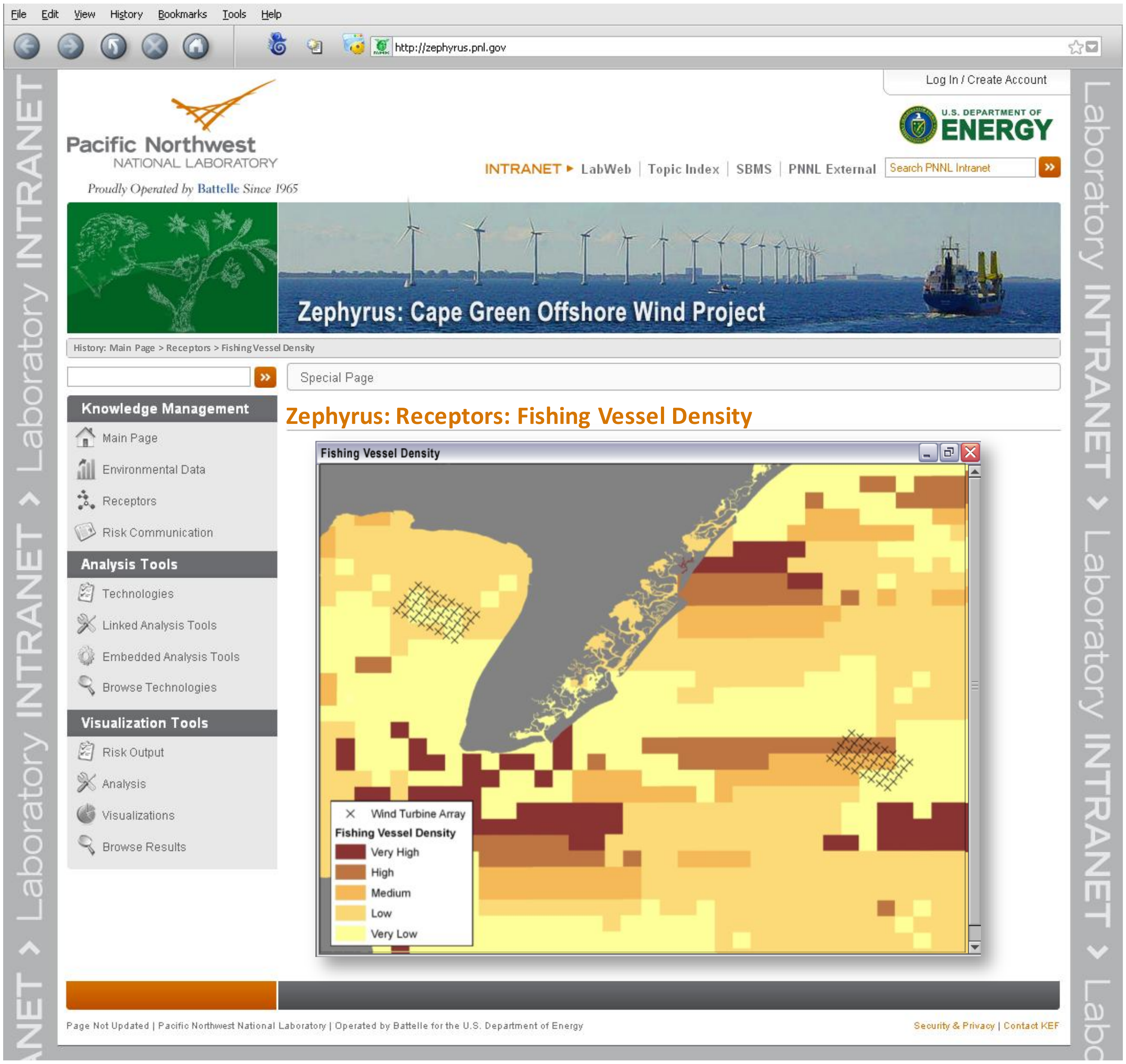


Figure 4. Data on fishing vessel density off Cape Green, New Jersey USA, may be housed within Zephyrus and used as a geospatial overlay to evaluate and avoid potential conflicts with other ocean uses, in the siting of offshore wind farms.

Table 1. List of receptor categories for which ERES will support analysis.

Receptor Categories	
Avian	Benthic community
Bat	Fish/shellfish
Whales	Marine food web
Dolphins/porpoises	Human safety
Pinnipeds	Viewshed
Benthic habitat	

Table 2. List of additional data/information types that will be contained within Zephyrus to support ERES analyses.

ERES Offshore Wind Data/Information Types
Engineering
Meteorological
Physical
Hydrodynamic
Geographical Information System (GIS) data
Maps
Wind resources
Species densities
Species migration data
Species physical characteristics
Ecological sensitivity information
Waterway use/traffic/shipping data
System design data/drawings
System construction/installation data
Operational data (maintenance)
Operational data (abnormal events)
Existing risk studies
Science/industry/news literature relevant to impacts/stressors/events (Journals/proceedings, reports, journalistic, social media)

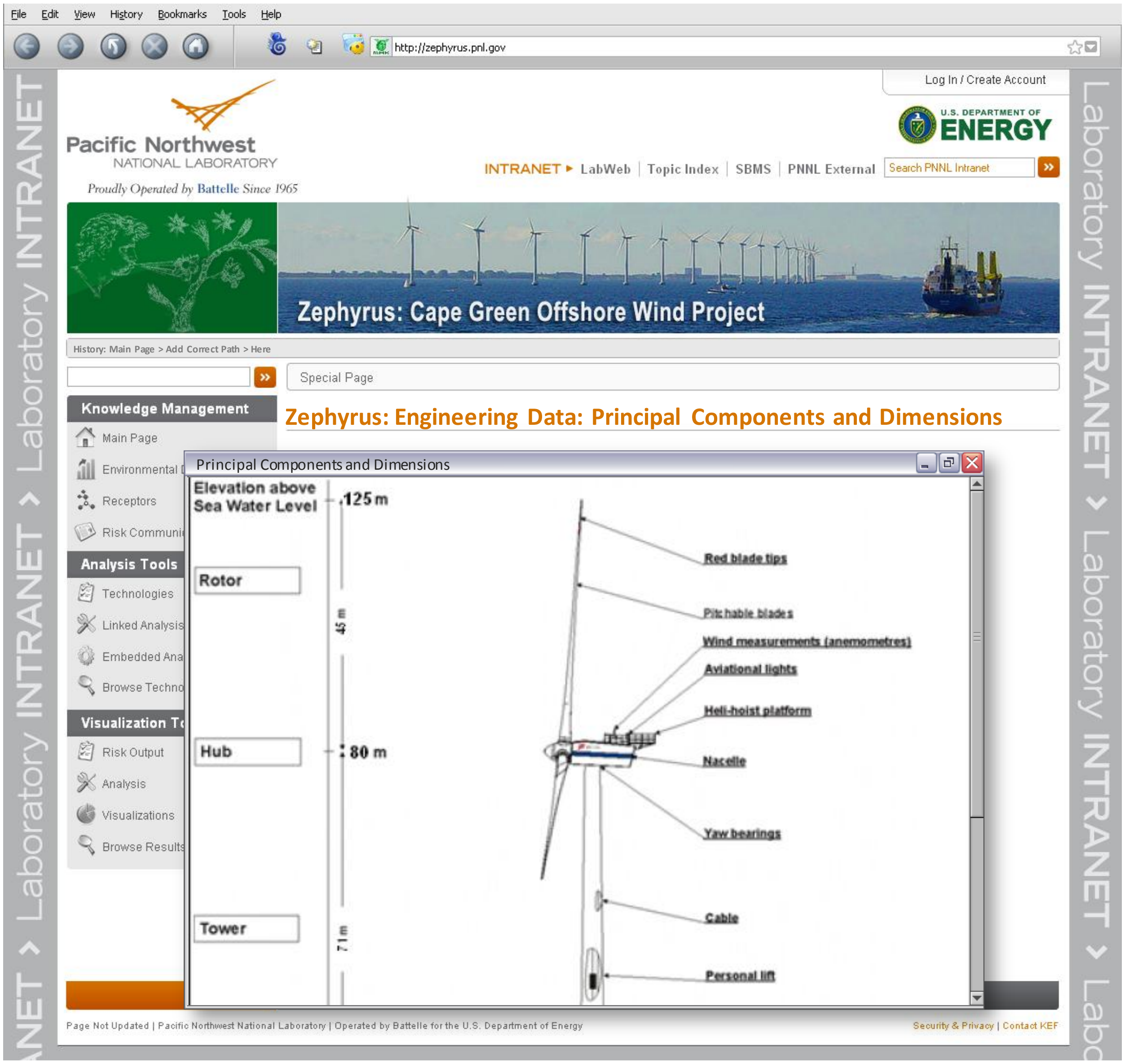


Figure 5. Engineering data on the principal components and dimensions of offshore wind turbine generator technology (2 – 4 MW).

2.2 Capturing Risk Analysis Output

Zephyrus will house environmental effects data from offshore wind projects under development as well as data collected for other purposes. Figure 6 displays an analysis performed in support of a demonstration offshore wind installation project planned for Cuyahoga County in Lake Erie, USA. Extensive environmental data have been gathered for Lake Erie for many purposes, allowing for analysis of potential effects on aquatic animals and other receptors of concern without further data collection. Such analyses are based on a broad range of existing use and receptor data, including navigable waterways, fish populations and fisheries catch, and valuable habitats for shorebirds.

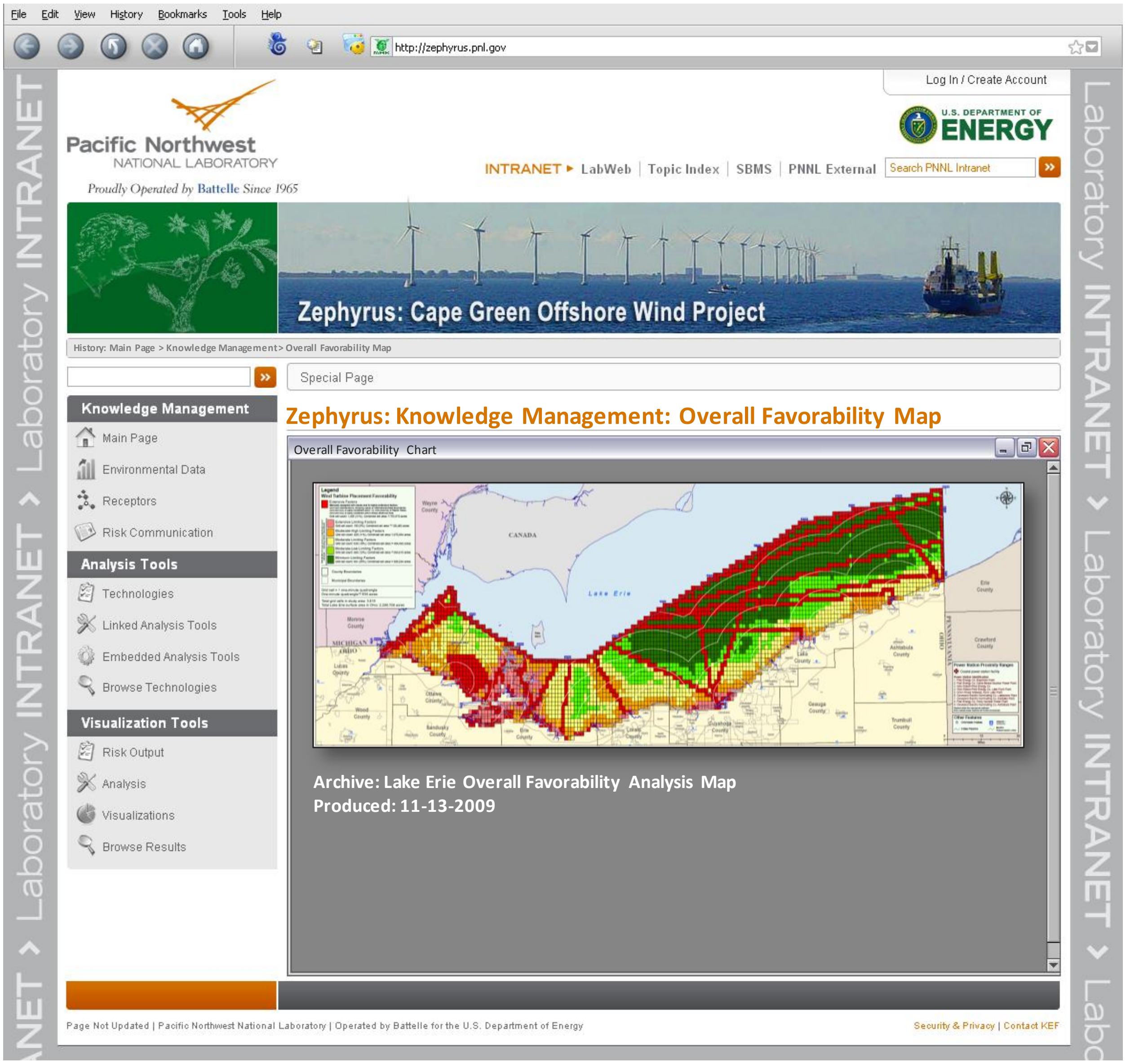


Figure 6. Results of analyses for siting of offshore wind farms for Cuyahoga County, Lake Erie, USA. Such a map could be created by capturing geospatial environmental data collected for purposes other than offshore wind farm siting.

2.3 Analysis Tools

2.3.1 Analytical Tools Inherent to ERES

Analytical tools will be developed as part of ERES to describe the effects and risks associated with different *risk scenarios* between stressors (i.e. components of offshore wind farms) and environmental receptors (i.e. animals or other components of the ecosystem). Table 3 lists some of stressors/mechanisms that will be a focus for analysis using ERES tools. These stressors are categorized as causing chronic, intermittent, or episodic risk (Figure 7). Episodic scenarios involve sudden, discrete (accidental) events and are thus characterized by their likelihood or rate of occurrence as well as by severity of consequences. An example of an episodic scenario would be collision of a shipping vessel or aircraft with an offshore wind turbine or array of turbines. The likelihood of occurrence would be related to factors such as vessel or aircraft traffic volume and proximity of shipping or flight lanes to the devices. Consequences could include environmental damage due to spills, financial loss due to damaged property or loss of generation of power, and human injury or fatality. In contrast, chronic risk scenarios involve continuous conditions where risk is characterized in terms of uncertainty associated with the resultant consequences. An example of a chronic risk scenario would be low-level chemical releases from anti-biofouling coatings used on device structures. Between these two extremes, intermittent events are episodic but occur at high enough frequency that they can be anticipated. Intermittent risk includes adverse impacts to birds or bats associated with the rotation of turbine blades, such as blade strike.

Table 3. Partial list of categories and mechanisms of stressors for which ERES for offshore wind will support analysis.

Categories and Mechanisms of Stressors	**Temporal Aspect**	**Offshore**
Oil, other chemical spills due to ship operations, accidents	Episodic	Operation
Severe weather	Episodic	Operation
Operational breakdown	Episodic	Operation
Acoustic output of devices disturbing marine animals	Chronic	Operation
Sonic vibration from pile driving	Chronic	Deployment
Physical presence causing attraction/avoidance by marine animals	Chronic	Operation
Electromagnetic fields affecting marine animals	Chronic	Operation
Blade strike/pressure drop affecting birds	Intermittent	Operation
Toxic chemical release from devices (paints, coatings, lubricants)	Chronic	Operation
Compromise of waterway use, tourism, property values	Chronic	Operation

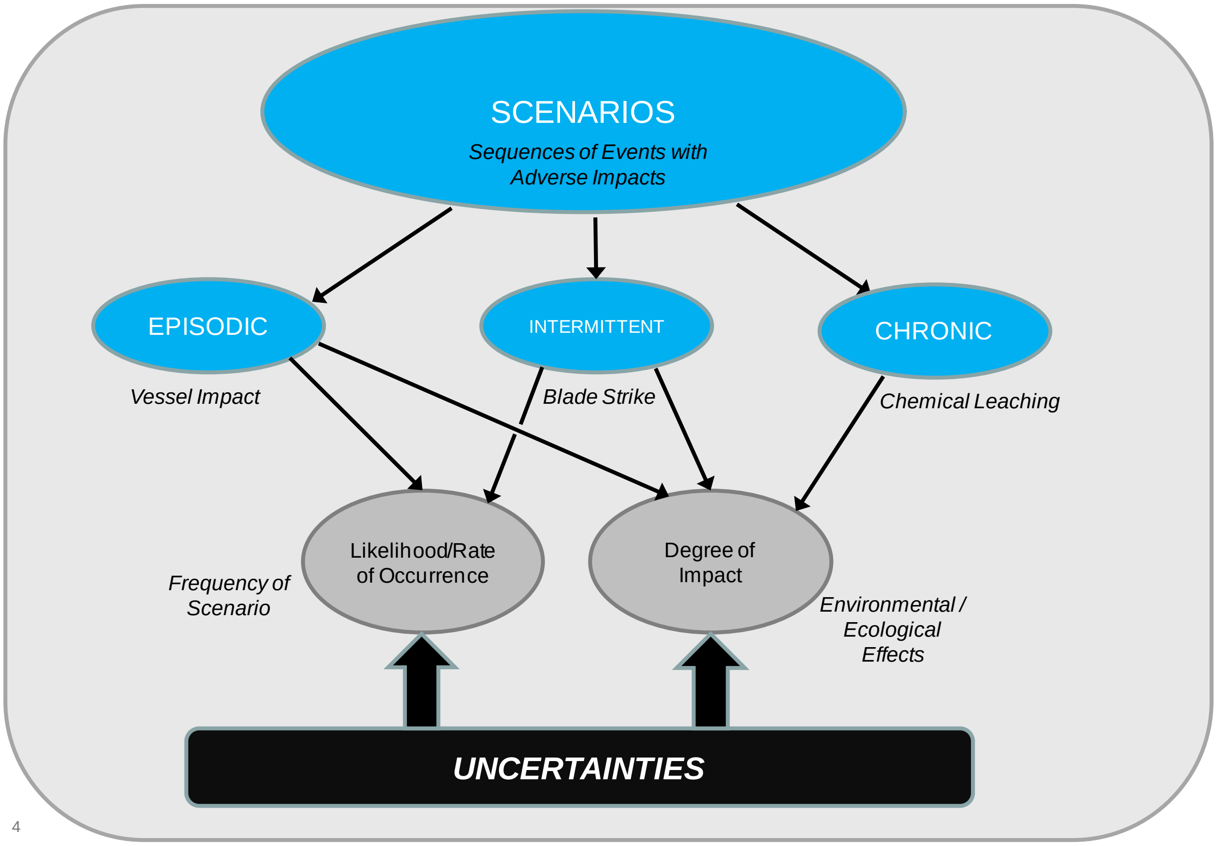


Figure 7. Mechanisms of Risk.

The risk to marine animals from noise associated with the operation of an offshore wind farm can serve as an illustration of the use of environmental receptor data and wind farm stressor data: noise generated by the wind rotor could frighten birds away from rich feeding grounds, or interfere with communication or navigation of marine mammals or pelagic fish as the sound propagates underwater. By understanding the acoustic profile of the wind farm, the contribution of noise spectra in air and water that may affect flying birds or swimming marine mammals or fish, could be calculated (Figure 8). Where regulatory thresholds exist for noise (for example, harassment thresholds for marine mammals under the Marine Mammal Protection Act), developers may anticipate regulatory needs, redesigning the structure or operation of the wind farm to mitigate the effect.

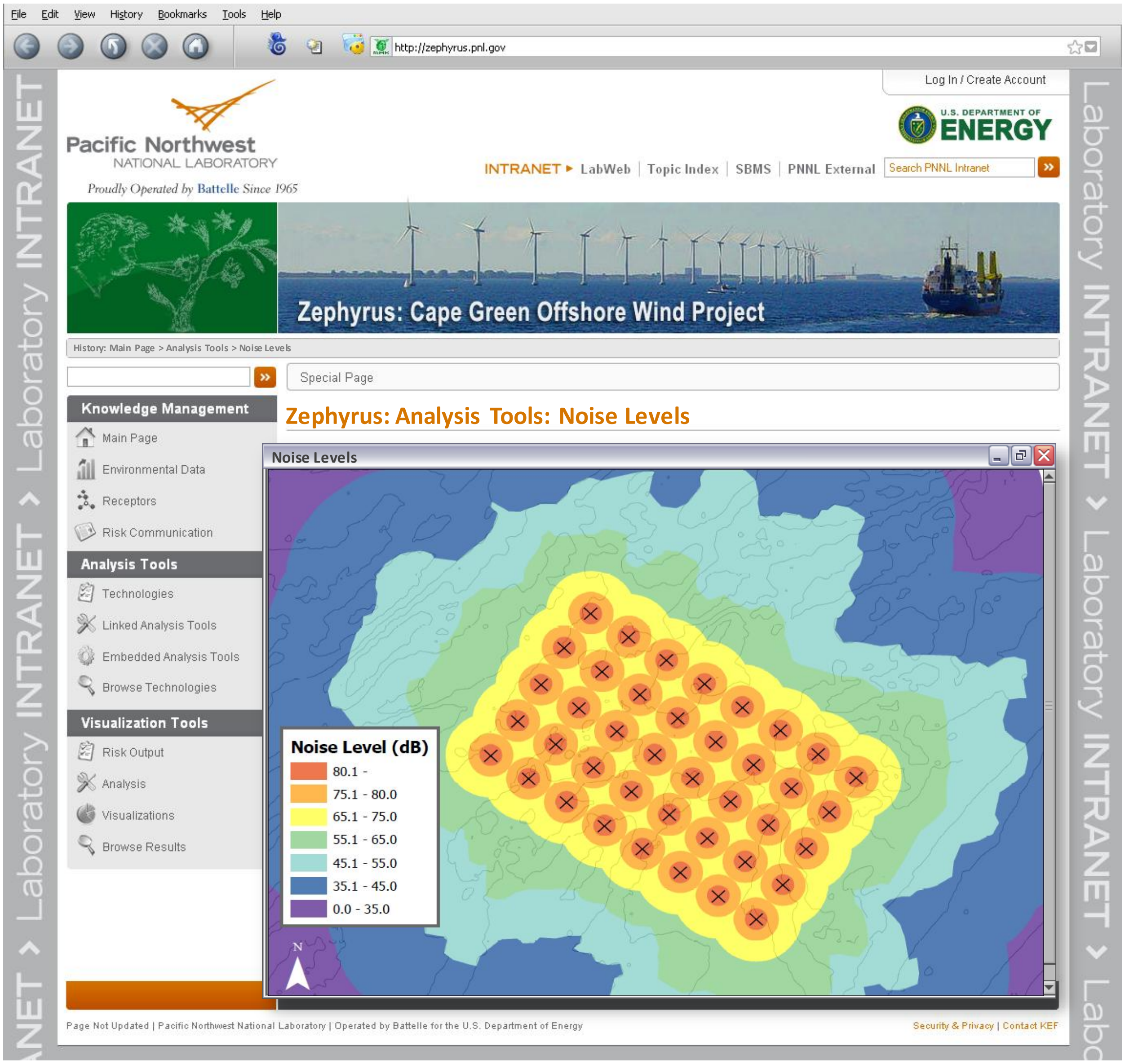


Figure 8. Analysis of acoustic signatures of an offshore wind farm off Cape Green New Jersey USA. The acoustic profile will support analyses for siting and efficient permitting of offshore wind farms.

2.3.2 Links to Analytical Tools Outside ERES

It will be impractical to integrate very large or proprietary models into ERES, including many hydrodynamic or GIS-based models; these analytical tools will be accessed with data ported from *Zephyrus* and analyzed outside the system. Simpler tools, providing Monte Carlo simulation, sensitivity/what if?, and other types of analysis will be embedded within ERES. Figure 9 displays a risk matrix, an analytical tool that could be used to determine which risk scenarios involve the greatest risk at a screening level of analysis. This ordering could distinguish between high-risk scenarios that should be examined in greater, quantitative detail, and those constituting negligible risk, which therefore require no further analysis.

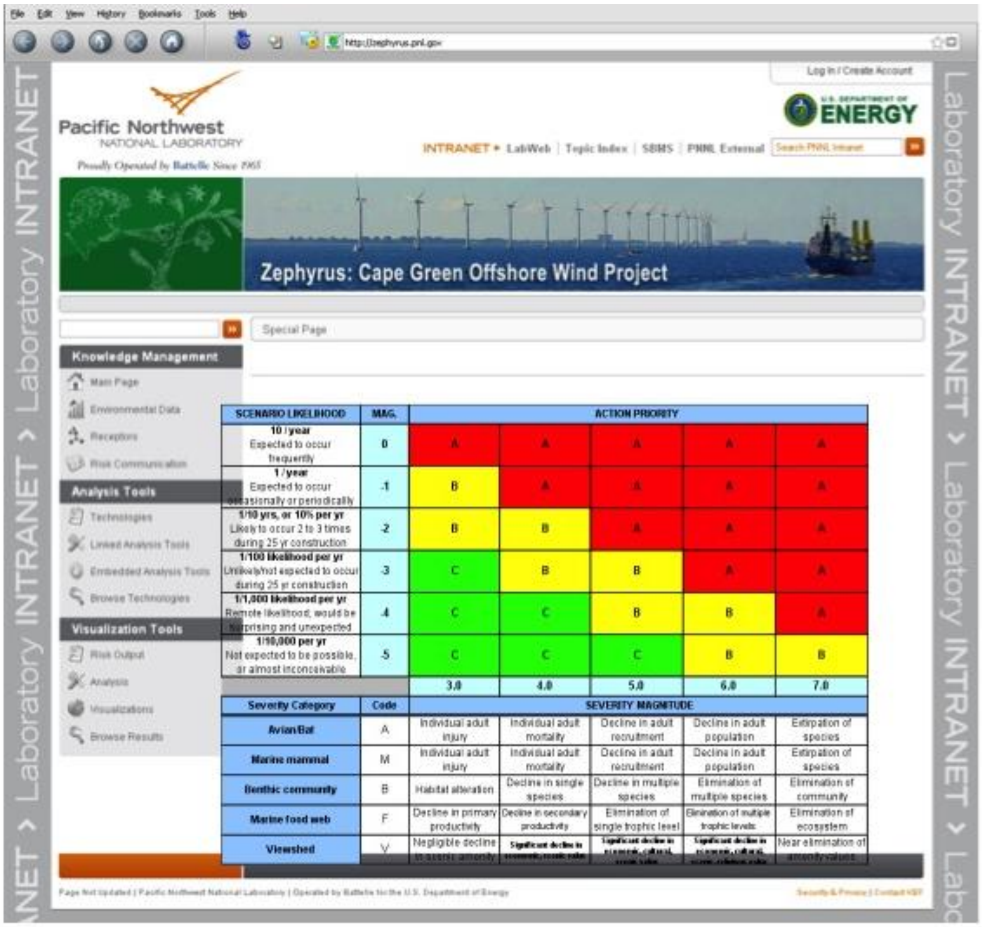


Figure 9. Risk matrix developed from analysis tools under ERES to characterize the risk associated with offshore wind siting scenarios.

2.3.3 Integrated Analyses

Some analytical functionality will be housed directly within ERES (e.g., the risk matrix, Figure 9), while some will be accessed from outside data sources and modeling tools (e.g., the noise level model, Figure 8). *Zephyrus* will support both types within a single platform. Another example of coupling of data within the system with sophisticated analytical tools created for other purposes is illustrated in Figure 10. Siting of an offshore wind farm will require knowledge of navigation obstructions, including the location of shipping lanes. Data on shipping lanes would be housed in *Zephyrus* and uploaded to a remotely located complex model to compute collision risk. The results would be stored in *Zephyrus* to assist in wind farm siting.

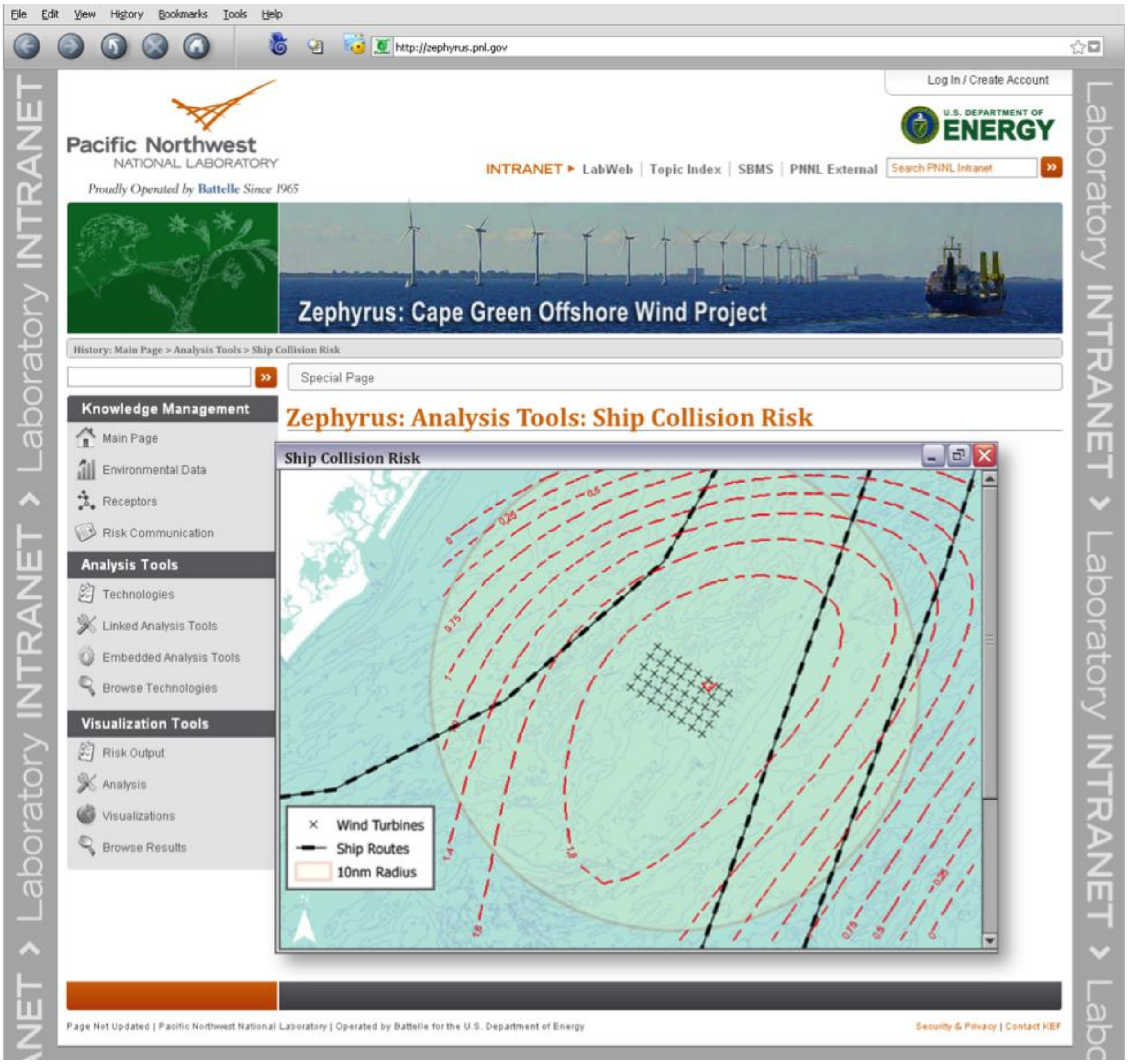


Figure 10. Ship collision risk for a location off Cape Green New Jersey USA. Collision risk is computed using modeling tools located outside ERES and data housed within Zephyrus.

2.4 Probability Component of Risk

ERES risk calculations are made up of two parts: vulnerability and probability. By examining the magnitude of the potential effect that a stressor may have on a receptor, we establish the vulnerability of a receptor. However, understanding the risk to that receptor also requires understanding how likely it is that the occurrence will happen. The calculation of probability requires more sophisticated modeling, which can take several different approaches. In Figure 10, spatial probability density is computed externally then downloaded to *Zephyrus*. However, in Figure11, a risk model relating collision to collision energy (i.e. velocity of the ship times its mass) is run within *Zephyrus*, using functionality that propagates uncertainty through model runs to produce cumulative distributions comparing siting options.

The magnitude of the collision energy, coupled with the likelihood of collision, is important in considering whether a collision with a ship may cause significant damage to a wind platform. Further functionality, also residing within *Zephyrus*, could provide for sensitivity analysis and *what-if* analysis (e.g. Figure 12).

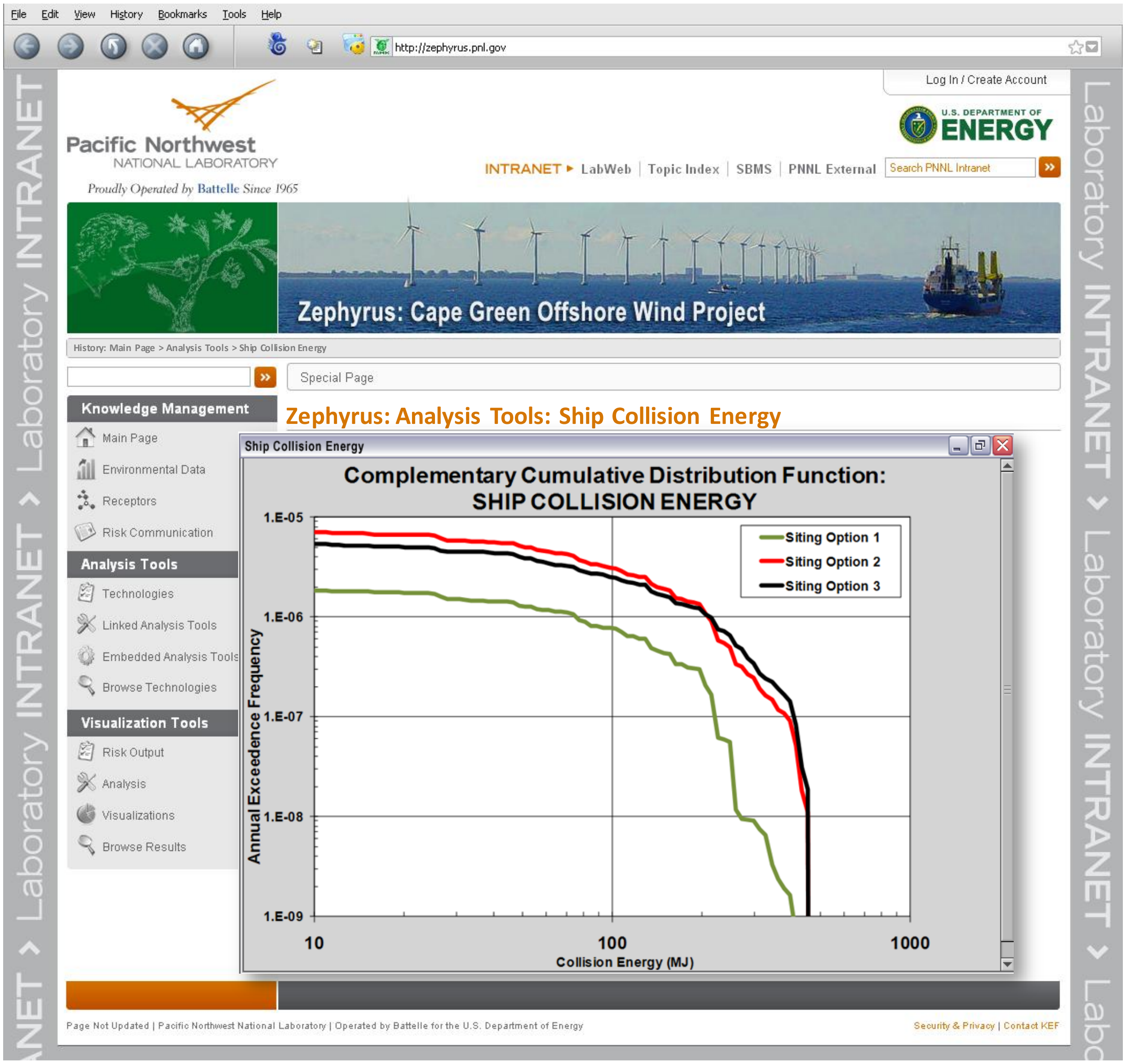


Figure 11. Ship collision energy risk, computed using functionality located within ERES that propagates uncertainty into the model output.

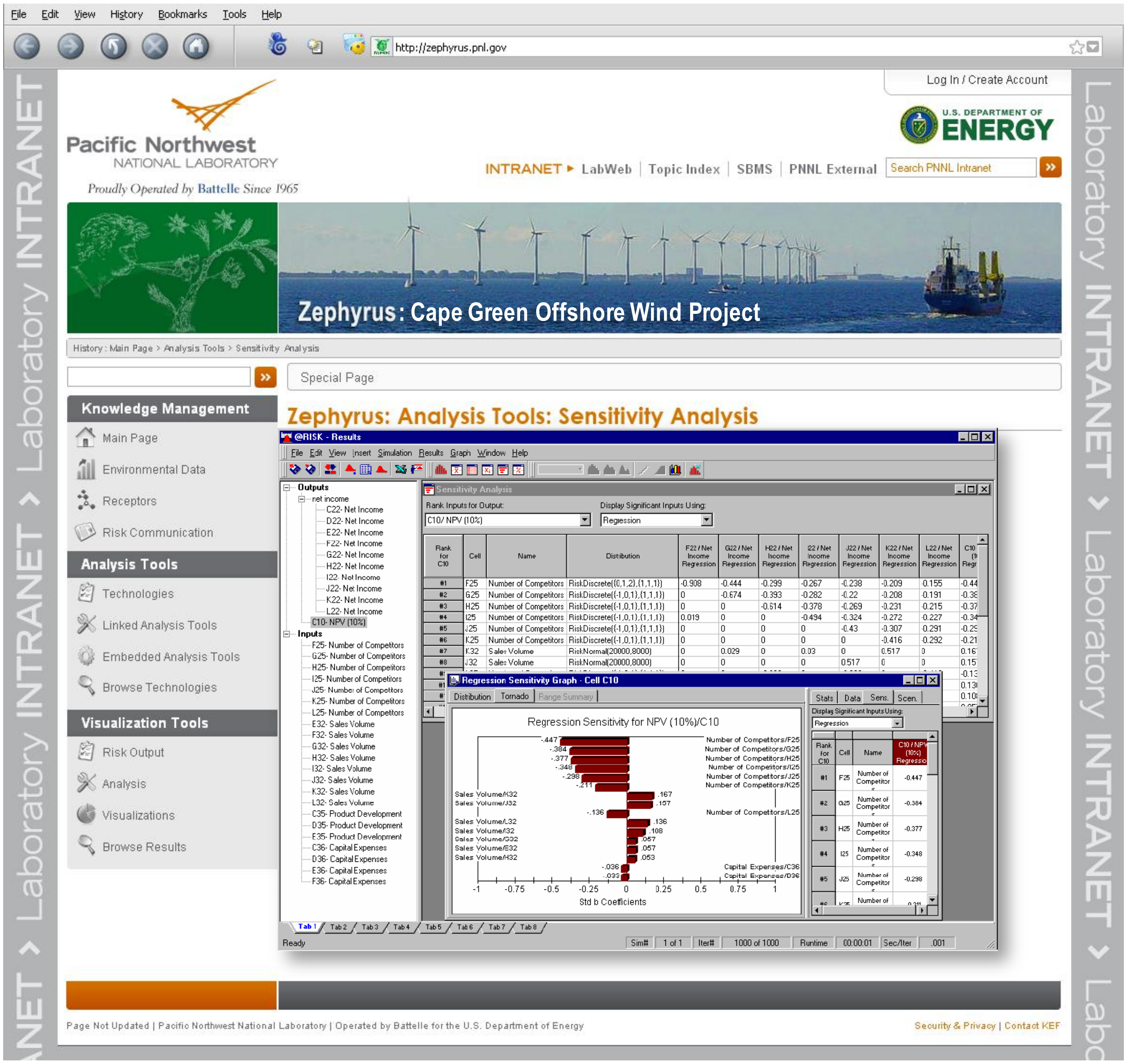


Figure 12. This figure depicts the output of a sensitivity analysis, which examines one parameter at a time in a so-called Tornado diagram. The tools to carry out this analysis will be housed within ERES.

2.5 Other Uses of the Marine Environment.

Stakeholders may raise concerns about the siting of offshore wind farms as they may perceive possible deleterious consequences or conflicts with other beneficial uses of the environment. For example, stakeholders may have an adverse reaction to the visual appearance of a proposed offshore wind farm. Bringing together data that provide a realistic visualization of how the seascape and landscapes might be affected provides a useful tool for engaging stakeholders in a discussion of potential effects of offshore wind development (Figure 13).

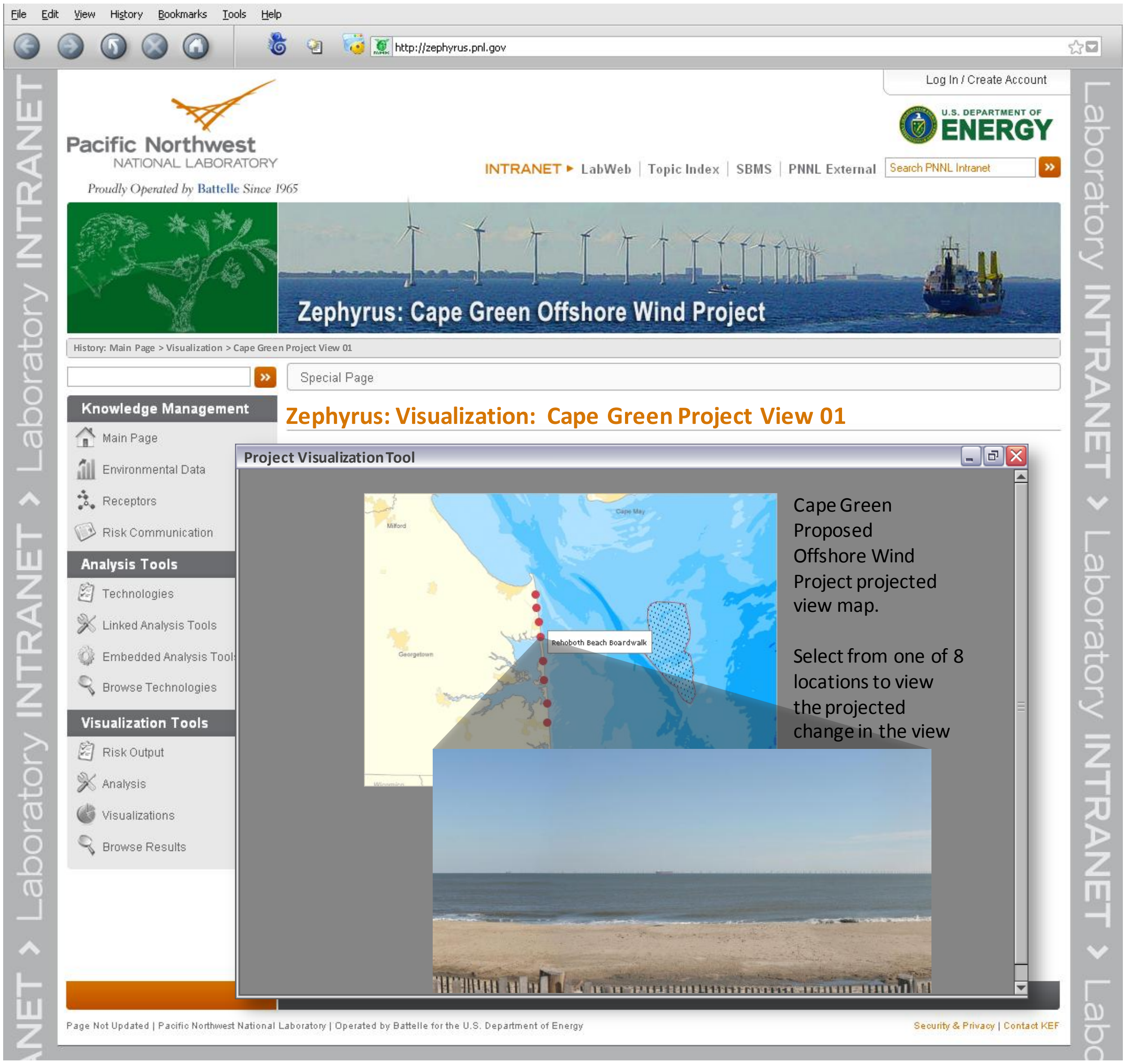


Figure 13. Application of data collected by ERES and stored in Zephyrus, allowing for a visual representation of an offshore wind farm location.

3.0 Communicating Risk

The ability to store and visualize data makes *Zephyrus* an ideal mechanism for communicating between and among researchers, offshore wind developers, regulators, and stakeholders. Adding interactive functionality to *Zephyrus* will encourage the use of the tool as a forum for dialogue and discussion on a broad range of offshore wind-relevant topics (Figure 14). *Zephyrus* will support queries of technical and performance specifications for a range of wind turbines through custom semantic forms. These queries can facilitate comparing options, conducting sensitivity/what if? analyses of trade offs of environmental risk among different wind turbines, and communicating outcomes among stakeholders (Figure 15).

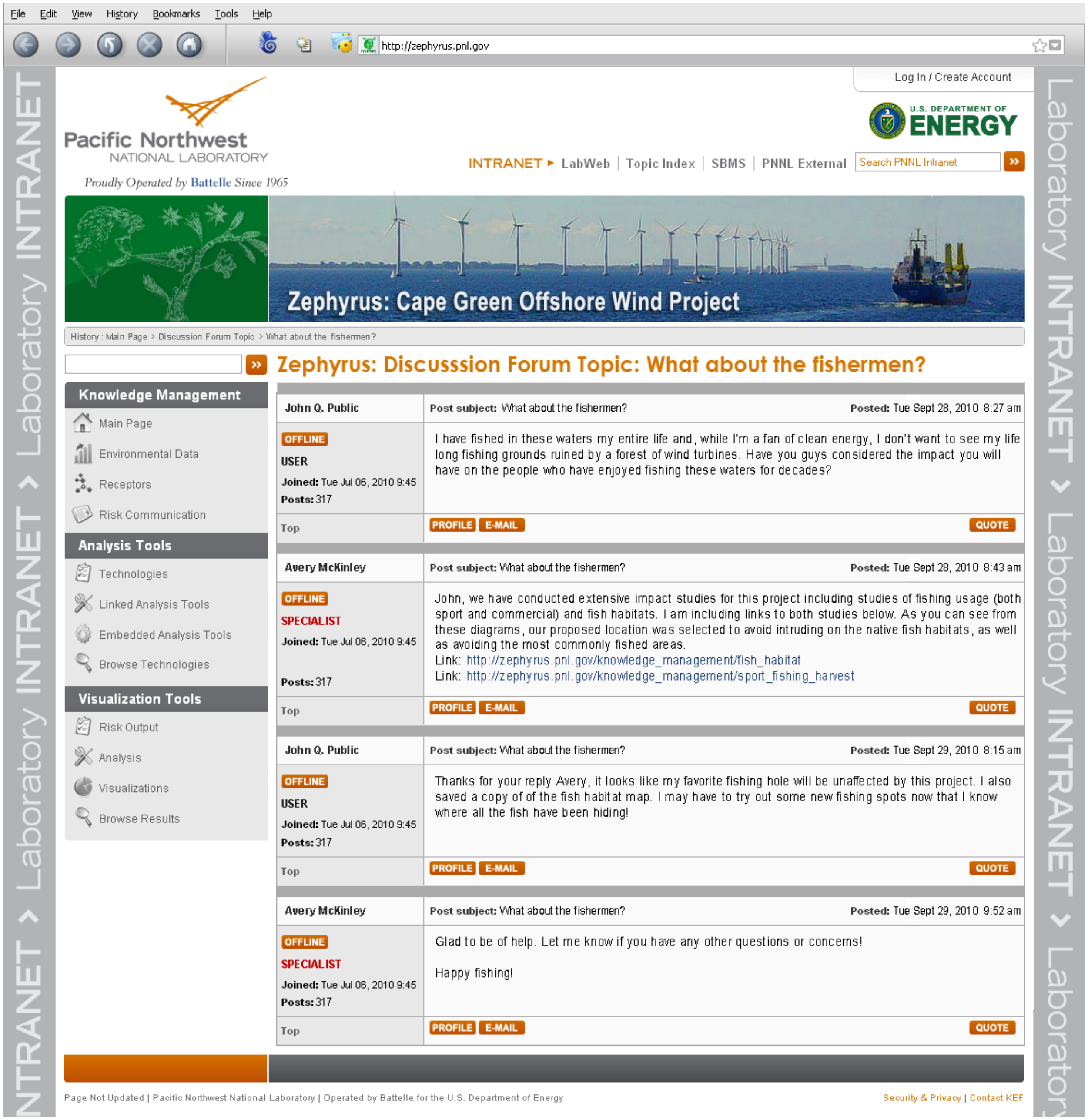


Figure 14. Example of a discussion forum on offshore wind development that might be supported by Zephyrus.

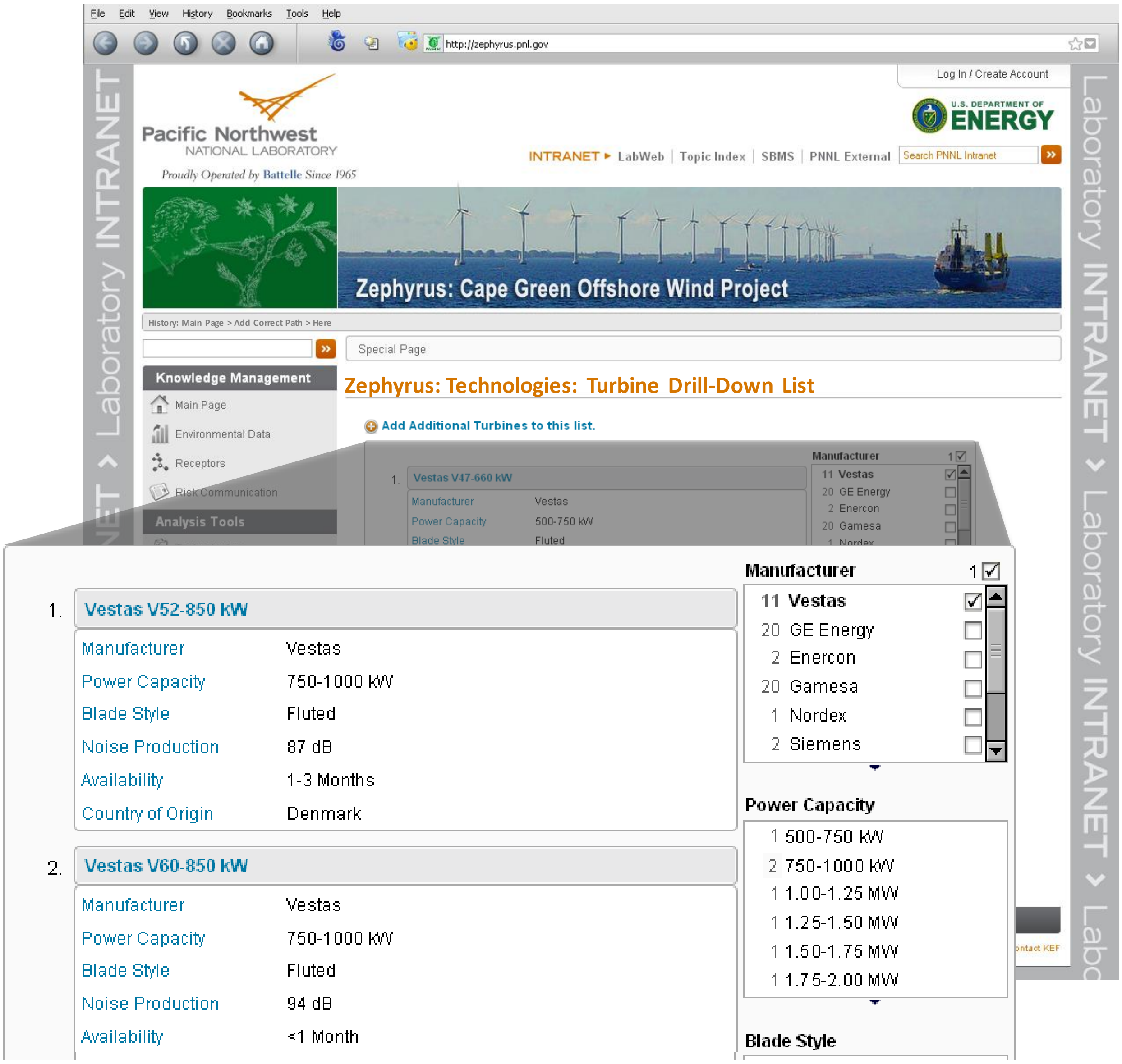


Figure 15. Custom semantic forms can be used to access technical and performance specifications of wind turbines.

4.0 Next Steps

This report has provided a preview of the functionality of ERES for offshore wind. In parallel with development of ERES for marine and hydrokinetic energy development, ERES for offshore wind holds promise to bring an unprecedented degree of collaboration, transparency, and efficiency to the process of understanding and addressing environmental risk. As an interactive tool, it will promote consistency in approach and allow the user community access to emerging data, models, results, and insights. We anticipate that it will provide critical decision support to technology developers, regulators, and other stakeholders with an interest in the offshore wind industry.

Over the next year, PNNL proposes to develop the full functionality of ERES and *Zephyrus*, to populate *Zephyrus* with available environmental effects data, and to carry out initial risk assessments of offshore wind farms on the marine environment.

5.0 References

Anderson, R.M., S.D. Unwin, and F.B. Van Cleve. 2010. Identification and Prioritization of Analysis Cases for Marine and Hydrokinetic Energy Risk Screening. PNNL-19535, Pacific Northwest National Laboratory, Richland, WA. 24 pp.

Appendix A

Development of a GIS-Based Model for Evaluating Visual Impacts of Offshore Wind Farms

Development of a GIS-Based Model for Evaluating Visual Impacts of Offshore Wind Farms

Adam Lynch (James Madison University, Harrisonburg, VA, 22807) Richard Anderson and Stephen Unwin (Pacific Northwest National Laboratory, Richland, WA, 99352).

ABSTRACT

As a clean and inexhaustible source of electricity, offshore wind power has the potential to play a key role in the United States' movement toward a sustainable energy infrastructure. However, public concerns over the visual impact of offshore wind farms on historic and scenic resources have hampered efforts to implement one in the United States. This study explores basic geographic information systems applications in visual impact assessment and presents a framework for estimating visual impacts on coastal regions adjacent to offshore wind developments. The GIS-based model proposed could allow developers and regulators to better understand the farms' visual impacts, helping them to mitigate related concerns through informed site selection and site-specific public outreach. Visual impact on a given land area is a function of two factors, the visual magnitude of a wind farm and the sensitivity of the area of interest. Spatial analysis was conducted in ArcGIS to determine a terrestrial viewshed, which was subsequently divided into separate districts for individual visual impact analysis. Visual magnitude of the wind farm from each district was estimated by modeling angular turbine size and obstruction by Earth's curvature as a function of distance. Sensitivity of each district was estimated by integrating spatial analysis into an established system of sensitivity assessment. Visual magnitude of the wind farm and district sensitivity were then scaled appropriately and integrated into a formula that quantifies visual impact. The metric was applied to an offshore wind development proposed for Cuyahoga County, Ohio, USA, as a case study, and maps and graphics were produced. Results showed that the model, while preliminary, could in future work be adjusted and utilized in a risk and decision framework for siting offshore wind developments.

INTRODUCTION

As a clean and inexhaustible source of energy, offshore wind has the potential to play a key role in the United States' movement toward a sustainable energy infrastructure. However, actual progress in developing such an infrastructure has been slow, and to date (July 2010), no offshore wind farms have been constructed in the United States. One major reason for this lack of advancement has been public hostility toward proposed projects. Several proposed large-scale commercial offshore wind farms, particularly Cape Wind in Massachusetts, have faced intense criticism from local land owners, environmentalists, politicians and other stakeholders who oppose the development [1]. A large number of the concerned parties argue that the visual impacts associated with the development would be too great. Many worry that appearance of 400-foot tall turbines on the horizon would have negative impacts on surrounding properties and scenery [1]. Public resistance, by way of legal action or political pressure, is capable of spoiling a project [2]. This relentless debate over the visual impacts of offshore wind development highlights the need for a decision metric that reasonably estimates visual impacts. Thorough preparation and understanding of visual impacts can help government officials and developers more effectively handle public scrutiny, by assisting them in identifying design flaws and planning site-specific community outreach. The goal of this project is to develop a GIS-based metric for evaluating visual impacts of offshore wind farms on land areas.

Visual impact assessment aims to predict "changes in the appearance of the landscape or seascape, and the effects of those changes on people" [3]. Before moving into the evaluation, it should be made clear that the visual impacts of a wind farm, or any large building, are personal and subjective and dictated entirely by the preferences of the viewer. Because of this fact, the model put forth in this report cannot claim to produce any exact calculation of visual impact.

However, using large-scale factors and trends, it can provide a rough estimation of the relative visual impacts to receptors within the wind farm's viewshed.

METHODS

The primary factors influencing visual impact are the sensitivity of the receptor and magnitude of the change in the visual field [3]. Ultimately, these two factors will be quantified and integrated into a formula that estimates the visual impact of a turbine array on a given coastal zone. To test the model that was developed as part of this analysis, it was applied to a case study. The proposed Great Lakes Wind Energy Center (GLWEC), off the coast of Cuyahoga County, Ohio, on Lake Erie, was selected as the case study, principally because the local terrain was flat and the physiology of the surrounding coastline was simple, which provided a relatively straightforward visual field assessment. The GLWEC Final Feasibility Report calls for the construction of 2 to 10 turbines, to be located at a distance of three to five miles offshore and totaling 5 to 20 MW of energy capacity. Five turbines were assumed, each with a hub height of 80 meters and a rotor diameter of 100 m. Spatial data on turbine location contained in a map in the Final Feasibility Report were digitized to shapefiles and displayed using ESRI ArcGIS as a base map. The feature classes utilized throughout development of the model were layered over this base map using ArcGIS.

Initial Preparation

Before evaluating the visual impacts of a wind farm, two steps must be taken. First, the viewshed of the wind farm must be established. A viewshed is a geographical area from which a particular object is theoretically visible. The nature of a viewshed depends heavily on the characteristics of the land area surrounding the object, especially the terrain and obstructions such as buildings and trees. Because of the flat terrain and high incidence of obstruction surrounding the GLWEC, the wind farm's viewshed was assumed to penetrate 500 m inland at all points along the coastline. Second, the viewshed must be divided into separate districts. This district division is necessary because (1) each geographical area perceives a unique view of the WTG development and (2) each district responds differently to changes in visual field. For the purposes of this model, the viewshed was divided into 11 districts and selections were based primarily on zoning. Figure 1 displays the assumed viewshed and the district divisions.

Figure 1. Districts used in GLWEC case study

Estimating Visual Magnitude

When estimating the visual impact of a large terrestrial object such a wind turbine (WTG), researchers often begin by calculating how large the object appears on the horizon [5], [4]. Visual impact studies often use a value called angular size (θ) to represent how tall objects appear on the horizon [4]. In this model, a two dimensional value called angular area (Ω), which is the product of the angular x (θ_x) and y (θ_y) dimensions of the WTG, was used to quantify visual magnitude. Calculating the angular area of an offshore WTG from a given district required four steps: (1) estimating the WTG's cross-sectional area in meters, (2) rendering the WTG as a rectangle, (3) calculating the effect of the Earth's curvature on the visibility of the WTG and (4) determining the visual dimensions of the WTG at a given distance. The visual magnitude of the wind farm was calculated for every district in viewshed.

Using methods outlined by Möller [4], shown in equation (5) the total cross-sectional area of the WTG (A_{WTG}, in meters^2) can be estimated by inputting hub height (H_H, in meters) and rotor diameter (D, in meters). Next, the WTG is rendered as a rectangle. Treating the WTG as a rectangle helps simplify the process needed to calculate the amount of WTG that is blocked by the curvature of the Earth. Because the WTG is highly complex and has moving parts, the formula needed to calculate the exact obstructive effect of Earth's curvature would be extremely intricate. Instead, the WTG is converted to a rectangle that has the same cross sectional area (A_{WTG}), and whose height equals the true WTG's peak blade height, H_B. The width (w) of the rectangle is simply A_{WTG} divided by H_B.

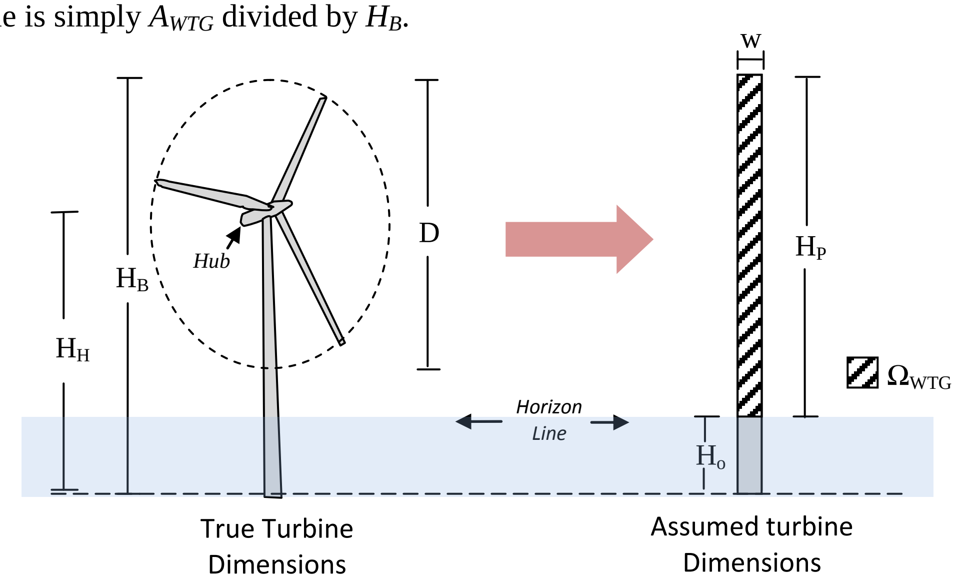


Figure 2. Diagram of variables used in calculating visual magnitude of a WTG

Once A_{WTG} for a single turbine has been calculated and the turbine has been rendered as a rectangle, it is necessary to consider the effect of the curvature of the Earth on the visibility of the turbine. The amount of WTG obstruction is modeled as a function of distance between the WTG and the district under investigation. The farther a WTG is located from the district, the more of that WTG is hidden beyond the horizon. The vertical obstruction H_o, is the height of turbine that falls below the viewer's horizon line. Equation (6) estimates the relationship between the vertical obstruction, H_o, and distance from the viewer, d, in meters, assuming a viewer height of 1.7 m [3]. Subtracting H_o from the peak blade height yields a practical height, H_P, which is the height of the rectangular "turbine" that is visible above the horizon, in meters.

Finally, the angular size of the rectangular "turbine" can be determined using basic trigonometry in equations (1) and (2):

(1)

(2)

where θ_x and θ_y are angular dimensions of the rectangular "turbine," measured in arcminutes, w is the rectangle width, H_P is the rectangle's height above the horizon and d is the distance between the district and the centroid of the WTG array, in meters. Multiplying θ_x and θ_y reveals Ω_{WTG}, which is the angular area of one turbine, in square arcminutes. The total angular area for a multi-turbine development, Ω_{tot}, can be estimated multiplying Ω_{WTG} by n, the number of WTGs in the array.

The visual magnitude, whose units were in square arcminutes, was then adjusted to a 1-10 scale. This was done by calculating a maximum Ω (220 000 arcmin^2, determined using a 'worst case scenario' calculation) and lowering it to 10 by raising it to the 0.187 power ($220\,000^{0.187} = 10$). Applying this exponent to each Ω value reduces the wide range to a 1-10 scale. Once Ω is converted to a 1-10 scale, it becomes M—the visual magnitude.

Estimating District Sensitivity

Sensitivity varies by geographic area and must be quantified at each district, as well. Unlike visual magnitude, which is an objective and quantifiable variable, sensitivity depends entirely on personal preference and, therefore, is impossible to precisely nail down. Sensitivity is a measure of the capacity of some entity (a district, property, etc.) to accommodate change, in that a highly sensitive entity has a low capacity to accommodate change before suffering negative effect. Figure 3 displays a scale of receptor sensitivity. While evaluating the sensitivity of a single receptor such as a house is relatively straightforward, quantifying the sensitivity of a district that contains many different types of receptors can be challenging. To organize this process, a reference map and record sheets were used to display spatial information and organize variables that determine sensitivity, respectively. The reference map (Figure 4) was composed by layering several feature classes over base imagery in ArcGIS. The record sheets organize scaled variables that contribute to sensitivity and allow the evaluator to weigh various criteria and reach a final sensitivity value. A separate record sheet was used for each of the 11 districts in the GLWEC viewshed. Figure 4 is a reference map used for assessing sensitivity, while Figure 5 is a record sheet used for tallying sensitivity values.

Figure 3. Guide to Visual receptor sensitivity [3]

Figure 4. Map used for evaluating district sensitivity

Sensitivity Record Sheet

Zoning	7	Highly Residential	7	6	5	4	3	X	1	0	Highly Industrial	2
NRHP Sites	3	Many					X	2	1	0	None	3
Beaches	2	Many						2	1	X	None	0
Public Parks	2	Many						2	X	0	None	1
Total	**14**											**6**
											Sensitivity	**0.43**

Figure 5. Record sheet for estimating district sensitivity using multiple criteria

Figure 5 shows a record sheet composed of four criteria (Zoning characteristics, abundance of National Register of Historic Places-listed properties, amount of beachfront and abundance of public parks), each weighed on a different scale, that factor into sensitivity. To determine a sensitivity value, *S*, the total of the “Score” column was divided by the total of the “Weight” column.

Calculating Visual Impact

Once the visual magnitude of the wind farm (M) and the sensitivity (S) of each district were quantified, each was inserted into equation (3) that estimates the visual impact of the wind farm on a particular district:

(3)

where *I* is the visual impact of a wind farm (1-10) on a given district, *M* is the visual magnitude of the development (1-10) from the perspective of the district and *S* is the sensitivity of the district (0-1). Sensitivity is assigned to be the exponent because it is assumed to be more influential than the visual magnitude. As a result, impact *I* is more reactive to adjustments in sensitivity than it is to adjustments in magnitude.

RESULTS

Data from the Great Lakes Wind Energy Center case study were inserted into equation (4), which is an expanded version of Equation (3). The equation’s base is equal to the angular area Ω in arcminutes^2, while the exponent adjusts to a 1-10 scale and integrates sensitivity *S*.

(4)

Variable	**Unit**	**Description**
I	1-10 scale	Visual impact on a district
A_{WTG}	m^2	Cross-sectional area of one WTG
d	m	Distance from district to centroid of WTG array
H_H	m	Height of turbine hub above ground
D	m	Turbine rotor diameter
H_o	m	Vertical obstruction by Earth's curvature
n	WTGs	Number of turbines in array
S	0-1 scale	District Sensitivity

Table 1. List of variables, with units and descriptions included, used in impact formulae

Equations (5) and (6) are used to fill in the A_{WTG} and H_o values for equation (4)

(5)

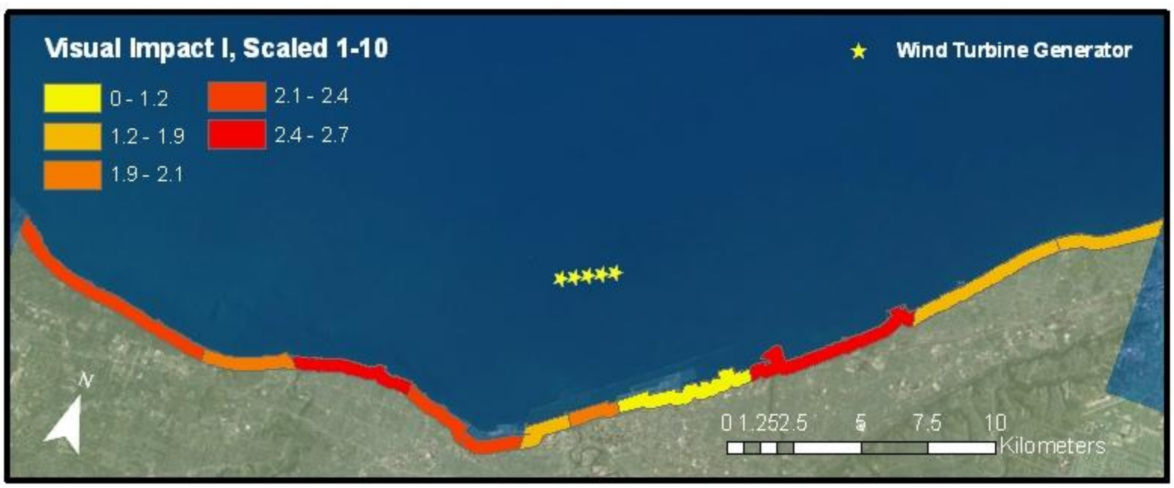
(6)

District by district calculations above were performed using a Microsoft Excel spreadsheet, by integrating the variables in Table 1 into the correct equation.

Thematic Maps

After calculations were performed for every district in Excel, the spreadsheet was joined to a geodatabase in ArcGIS. The following thematic maps were compiled using ArcMap:

Figure 6. Map of sensitivity (S) by district within the GLWEC case study



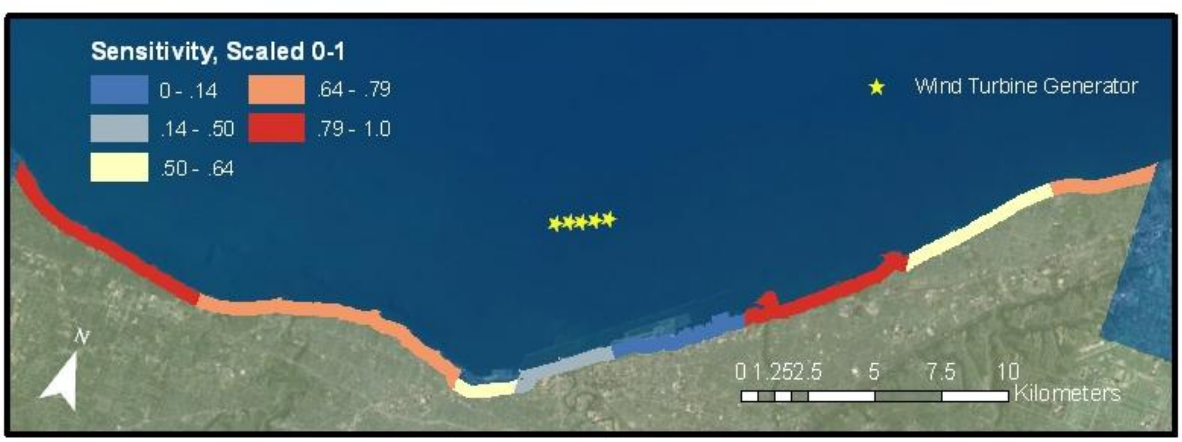


Figure 7. Map of visual impact (I) by district within the GLWEC case study

DISCUSSION

In order to generate a simple and understandable prototype model, many assumptions were made about the nature of the WTGs and landscape, and omissions occurred from a lack of data. These types of imperfections are to be expected, considering the lack of quantitative data concerning visual impacts of offshore WTGs. First, perfect visibility was assumed, since weather and air clarity can be difficult to model. Hazy, foggy or rainy conditions can reduce the size of an object's viewshed, and certain localities are affected more than others. Also, the visual magnitude calculations assumed unobstructed views of every turbine. This would not be an acceptable assumption for a working model, because the obstructive effect of land and of turbines on other turbines can be substantial. Some relevant variables were also omitted due to a lack of necessary data. First, the contrast between the turbine and the background was not included. The difference in color between a turbine and its backdrop helps determine how visible it is from any given point of view [5]. Some evaluation of contrast must be included in later models. Also, the arrangement of WTGs within a farm, which drastically affect its aesthetic quality, was also not addressed within the model [3]. Turbine arrangement was not considered in this analysis because no data on the aesthetic value of various arrangements of offshore units is currently available. These, among other assumptions and omissions, need to be addressed in future evaluations of the model.

CONCLUSION

Quantifying visual impact is a relatively new pursuit in the infant science of offshore wind power. The impact (*I*) value generated by this model is designed to provide a rough estimation of the visual impact of a wind farm on selected districts within its viewshed. Understanding how a wind farm visually impacts different districts can help developers and regulators predict public scrutiny and plan site-specific public outreach. The *I* value can also be used to compare the effects of one wind farm on a nearby land area, with the effects of another wind farm on its own local receptors. This can aid developers in making siting decisions and allow regulators to conduct better-informed oversight. In the future, with more analysis, this model could be used to estimate the total visual impact to the surrounding land area created by a given WTG development. In addition, quantifying visual impact begins to open the door for GIS-based wind farm site siting models that integrate environmental, social and economic factors.

Finally, it cannot be emphasized enough that visual impact assessment is an imprecise science, since visual impact is subjective and depends wholly on the personal preference of the viewer. However, this report has demonstrated that it is possible to use large-scale factors such as distance from the WTGs and zoning to predict how various land-based receptors will react to the addition of a wind farm in their visual field, if only for comparative purposes. Although this model is oversimplified, it provides a basic framework that could be supplemented with additional variables such as weather conditions and color contrast to produce a usable metric.

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Appendix B

Availability and Applications of Migratory Species Spatial Data for Offshore Wind Development Purposes

Availability and Applications of Migratory Species Spatial Data for Offshore Wind Development Purposes

Brittani Bohlke (University of Wisconsin, La Crosse, WI) Andrea Copping, and Brie Van Cleve. (Pacific Northwest National Laboratory, Seattle WA 98109)

ABSTRACT

In recent years, offshore wind power has been recognized as a major renewable energy source for development in the United States. Wind farms at sea have the potential to capture an immense amount of energy but several challenges and concerns exist that are limiting development. The potential environmental effects on marine species are among the major concerns but risk assessments and mitigation strategies are underdeveloped. In order to create the necessary solutions, conclusive information is needed on marine organisms, especially data on migratory species such as marine mammals, seabirds and sea turtles. Marine spatial planning has the potential to assist in siting offshore wind farms, but high quality spatial data on marine organisms are needed. The purpose of this study is to examine the availability of spatial data, and to identify and assess the quality of existing data on migratory marine mammals and endangered seabirds. Research found the Multipurpose Marine Cadastre and the Ocean Biogeographic Information System (OBIS) to contain the greatest wealth of marine geospatial data. Data downloaded from OBIS, using ArcGIS software, were used to gather, organize, analyze and display species data in the context of offshore wind development. Analysis identified the National Oceanic and Atmospheric Administration (NOAA), the Bureau of Ocean Energy Management Regulation, and Enforcement **(BOEMRE**) and Point Reyes Bird Observatory Conservation Science (PRBO) as providing the most useful data. The Pacific region of the United States was found to have the most available data, which may simply indicate a greater sampling effort that other part of the country, as opposed to being an indication of greater species abundance. We conclude that migratory species data are inadequate to support siting of offshore farms. Improved geospatial information is needed for siting, development of mitigation strategies and to support leasing and permitting decisions.

INTRODUCTION

Offshore wind power is an important renewable energy source that has potential to make significant contributions around the world. Offshore wind resources are much stronger than terrestrial souces, and, unlike other ocean energy sources, technologies developed for land-based wind harvest can help inform offshore wind technologies. It is estimated that offshore wind resources in the United States could provide 908,000 MW of electricity, while the generation capacity of all other energy sources including nuclear, renewable and fossil fuel energy is 914,000 MW [1]. In order to develop offshore wind, however, the vulnerabilities of migrating seabirds and marine animals and habitats must be considered. Siting and permitting of offshore wind resources is considered as a major stumbling block for accelerated deployment of wind farms. Installing, maintaining and transmitting wind energy at sea requires new technologies, techniques and involves a variety of risks. Current offshore wind technologies include a variety of designs and anchoring techniques depending on depth of the water, wind speed and substrate composition (Figure 1).

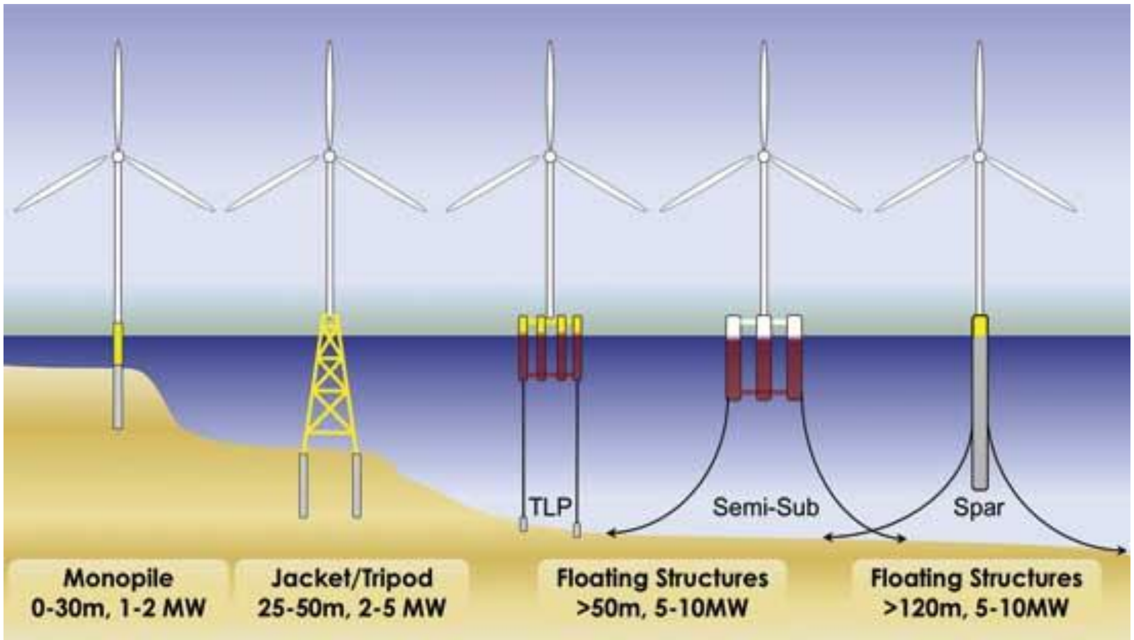


Figure 1. Common offshore wind turbine designs at corresponding depths and typical amounts of power generated [2].

http://memagazine.asme.org/Articles/2010/April/Floating_Wind_Turbines.cfm

Installing and operating offshore wind structures creates a variety of social, economic and environmental risks. The environmental effects of offshore wind structures include potential risks to benthic communities, electrosensitive organisms, marine mammals and seabirds. Adverse effects may be seen in behavioral and foraging patterns of marine animals and other aspects of overall fitness of marine mammals, sea turtles, fish and seabirds. Marine mammals can be affected by the noise associated with pile driving operations and the presence of the wind monopole or platform. The large turbines are known to cause displacement, collisions and mortality in seabirds and shorebirds. Risk assessments of offshore wind hazards are just beginning.

Marine mammals, sea turtles and seabirds enjoy special protection under the Endangered Species Act, Marine Mammal Protection Act and the Migratory Bird Treaty Act, yet little is known about exact breeding areas, habitats, migration routes and flight patterns. These parameters must be understood to grasp how these species may be affected by the technology, to minimize risks and to optimize wind farm siting, and to meet permitting requirements. Comprehensive baseline data on marine mammals, sea turtles and seabirds must be available to meet siting and permitting requirements. The goal of this study is an initial assessment of the status of spatial data on marine animals and seabirds, and the identification of future research needs for data collection in support of offshore wind energy development.

METHODS

Data collected on migratory animals were collected and assessed for U.S. coastal areas. In order to be useful, data on migratory species must be accessible and collated for easy analysis. Maps of migratory animal data were generated with an emphasis on species counts. The study focused on regions of the country where wind resources were adequate for commercial development. The most detailed analyses were carried out along the Pacific coast, with special focus on Oregon and Washington. Geographic Information System (GIS) data was gathered from the *Ocean Biogeographic Information System-Spatial Ecological Analysis of Megavertebrate Populations* (OBIS-SEAMAP), an integrated webpage source for marine species data established by the Census of Marine Life [5]. Shapefiles were downloaded from OBIS-SEAMAP, and ArcGIS 9.2 software was used to visualize information and perform GIS analyses (ESRI 1999-2006).
Marine mammal and endangered seabird data were examined for the U.S. and organized by region, data provider, and the time span during which studies were performed (Appendices 1 and 2). These data were analyzed based on duration and geographic extent of the surveys, as well as quality (functionality) of the data; a subjective ranking was given to each data provider, based on these factors. (Tables 1 and 2). Duration takes into account the length of individual studies performed and how consistently the data have been produced. A top rank ("1") was assigned to data collection efforts that exceed 20 years and/or a combination of studies spanning several decades. Rankings of "2" and "3" indicate survey durations of approximately 10 and 5 years, respectively. Geographic extent is defined by how much area the surveys have covered over time; a rating of "1" indicates a strong focus on a specific area and/or coverage of a large geographic area. Data quality, or functionality, is based on data compatibility with other datasets and ease of use for analysis, taking into consideration scale and format of the data. For example, if data polygons overlap onto land or if data are too far out at sea to be relevant to the offshore wind industry, quality (functionality) ratings will be low.
Datasets from providers that scored highest were merged together to display marine mammal species counts for all regions; examples are included in this report (Maps 1A, 1B, 1C, and 1D). Endangered seabird counts were pooled for all regions, using all data sources except: the International Pacific Halibut Commission, USGS Alaska Science Center and Canadian Wildlife Service (Map 2A and 2B), as these data suffered from formatting issues. Bands of offshore wind were identified by examining studies performed by the National Renewable Energy Laboratory (Figure 4).

A focus on endangered seabird and marine mammal data for the Pacific Northwest region were brought together with offshore bathymetry data to visualize depths and species counts in areas where offshore wind development may be viable (Map 3). A simple test of the coincidence of migratory species and potential offshore wind farms with distance from shore was carried out by calculating the coincidence of migratory species at three distances from shore: 0-3 miles; 3-30 miles, and greater than 30 miles (Figures 2 and 3). GIS analysis tasks used to develop these maps include: select by location, select by attribute, switch selection, create layer from selected features, merge, buffer, symbology and statistics functions.

RESULTS

Through the investigation and compilation of migratory species data we were able to reach several conclusions: 1) two data repositories provide the most appropriate spatial information for visualization and direct use in offshore wind analysis. They are the Multipurpose Marine Cadastre (MMC) and the OBIS-SEAMAP. MMC is a compilation of data provided by BOEMRE and NOAA Coastal Services Center for the purpose of supporting coastal marine spatial planning. Data in the MMC includes: marine jurisdictional boundaries, infrastructure, geology, ecosystems and specific species layers on pinnipeds and gray whales [4]. OBIS-SEAMAP compiles simple point count surveys from a variety of sources and appears to be the best available option for information on migratory marine organisms. Exploration of data from other websites and associations revealed that little additional spatial data exist for migratory marine mammals and seabirds.

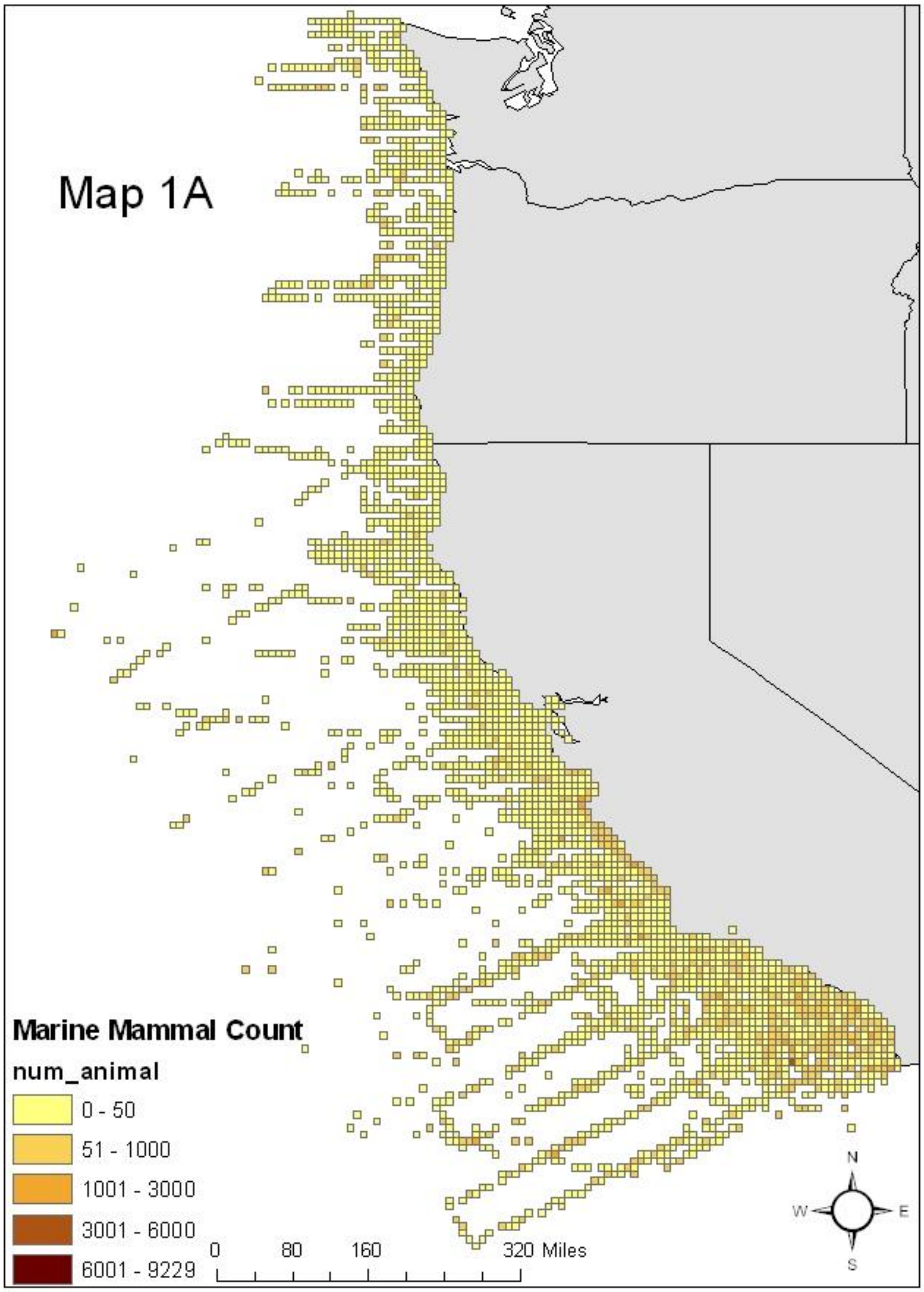
OBIS-SEMAP provides data from over 100 sources and includes spatial data on marine mammals, endangered seabirds and sea turtles. For the purposes of detailed analyses, we used OBIS to compare data availability by region, to identify the best data providers, and to display and analyze data. The results are an assessment of the status and functionality of each dataset and identification of data gaps. Examination of the data by region showed that the Pacific region has the most comprehensive and integrated datasets; other regions lacked functional, organized data from top data providers with a track record of providing the most comprehensive data. Data sources with the highest scoring datasets include: the National Oceanic and Atmospheric Administration (NOAA), the Bureau of Ocean Energy Management Regulation, and Enforcement **(BOEMRE**) and Point Reyes Bird Observatory Conservation Science (PRBO) (Tables 1 and 2). Maps 1A-1D, maps 2A-2B, and Figures 2 and 3 display examples of these marine mammal and endangered seabird species counts, compiled from OBIS data. Distribution patterns from the coast to over 30 miles offshore reveal fairly even distribution for marine mammal counts, while the majority of data for endangered seabirds lie in state waters (0-3 miles offshore) (Figures 2 and 3). However, it is difficult to conclude whether areas of high species concentration are the result of collection effort, data availability, or species abundance.
Map 3 shows that data layers of importance to the offshore wind industry, such as bathymetry and marine animal counts can be combined to display intriguing spatial results. By bringing together multiple layers, optimal wind farm sites may be visualized. Wind power assessments by the National Renewable Energy Laboratory show that the highest wind capacity in the country occurs in Southern Oregon, Northern California and the Alaskan Peninsula (Figure 4). Analysis of marine species data in these regions indicate that long term studies are needed in Southern Oregon while studies extending further offshore are needed for Northern California. The Alaskan Peninsula currently has data only from the National Marine Mammal Laboratory, pointing out the need for data from other sources and over longer time spans (Appendices 1 and 2).

Table 1. Summary of available marine mammal datasets, from OBIS-SEAMAP website. Data are organized by data source, region/state and time span over which single or multiple surveys were performed. Data providers are rated in three categories and assigned an overall score. Individual datasets are ranked on their usefulness for the state listed. Each rating is classified according to the value of the information, with "1" being Very Good information, colored red ( ); "2" indicating Adequate information, colored orange ( ); and "3" Inadequate information, colored yellow ( ).

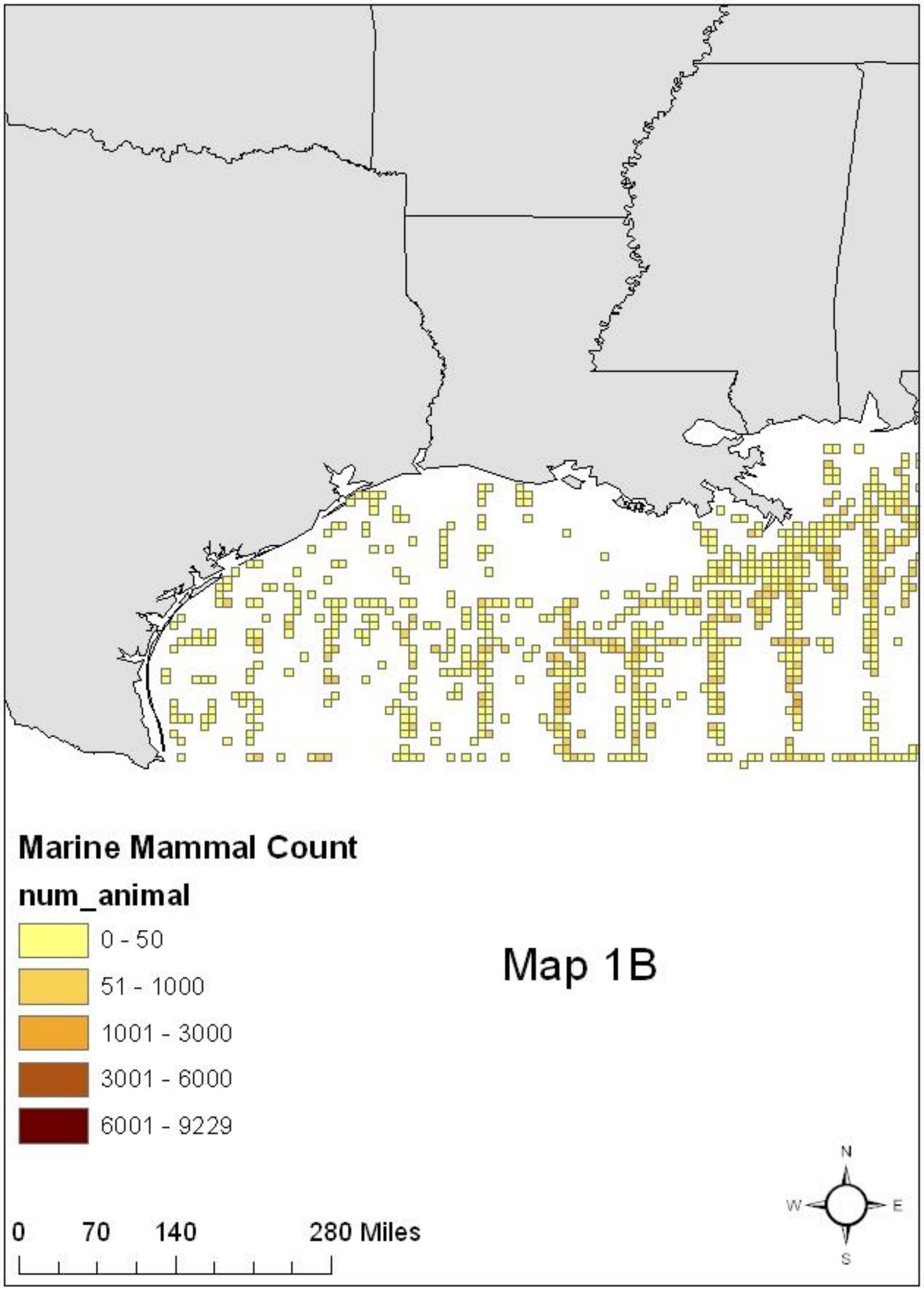
Data Provider		NOAA	BOEMRE	PRBO Conservation Science	NMML	Cascadia Research	Canadian Wildlife Service	University of RI	College of the Atlantic	UK Royal Navy	Duke University
Duration		2	1	2	2	1	1	3	1	1	3
Geographic Extent		1	2	3	3	3	1	1	2	2	3
Functionality		1	1	1	1	2	3	2	3	3	2
Overall		**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**3**	**3**
Pacific	AK				1992-2000						
	WA	1996	1989-1990								
	OR	1996	1989-1990								
	CA	1991-1996	1975-1997	1987-2006		1972-2004	1965-1992			1947-2003	
	HI					2000-2006					
Gulf	TX	1992-2001					1965-1992	1978-1982			
	LA	1992-2001					1965-1992	1978-1982			
	MS	1992-2001					1965-1992	1978-1982			
	AL	1992-2001					1965-1992	1978-1982			
Southeast	FL	1990-2004					1965-1992	1978-1982		1947-2003	2009-2010
	GA	1992-1995					1965-1992	1978-1982		1947-2003	
	SC	1992-1999					1965-1992	1978-1982		1947-2003	2007
	NC	1992-1999					1965-1992	1978-1982		1947-2003	2004-2007
	VA	1995-2004					1965-1992	1978-1982		1947-2003	
	MD	1995-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	DE	1995-2004					1965-1992	1978-1982	1976-2003	1947-2003	
Northeast	NJ	1995-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	NY	1995-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	CT	1995-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	RI	1991-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	MA	1991-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	NH	1991-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	ME						1965-1992	1978-1982	1976-2003	1947-2003	

Table 2. Summary of all available endangered seabird data setsfrom OBIS-SEAMAP. Data providers are rated in three categories and assigned an overall score. Individual datasets are ranked on their usefulness for the state listed. Each rating is classified according to the value of the information, with "1" being Very Good information, colored red; "2" indicating Adequate information, colored orange and "3" Inadequate information, colored yellow, following the pattern in Table 1.. There is a lack of species data for the northeast region although Canadian Fish and Wildlife and Dalhousie University have both performed spatial surveys in the area, documenting seabirds.

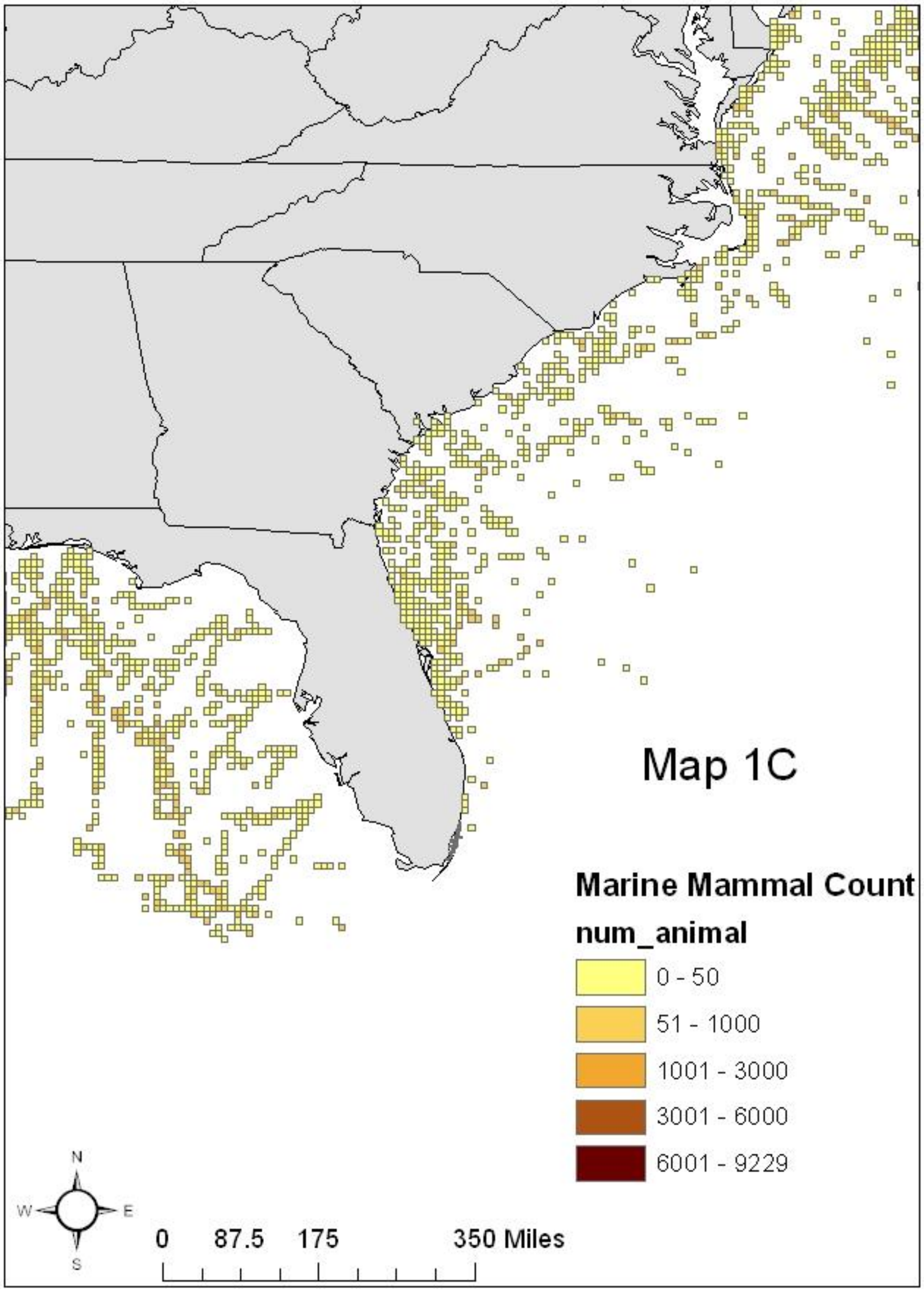
Data Provider		NOAA	BOEMRE	PRBO Conservation Science	USGS Alaska and U.S. Fish and Wildlife Service	Canadian Wildlife Service	Dalhousie University	Washington Department of Fish and Wildlife	International Pacific Halibut Commission
Duration		2	1	1	1	1	3	3	2
Geographic Extent		1	2	3	2	1	2	3	3
Functionality		1	1	1	3	3	2	2	3
Overall		**1**	**1**	**1**	**2**	**2**	**3**	**3**	**3**
Pacific	AK				1940-2004				1998-2002
	WA		1989-1990					1996	
	OR		1989-1990		1940-2004				
	CA		1975-1997	1987-2006	1940-2004				
	HI								
Gulf	TX	1992-2001							
	LA	1992-2001							
	MS								
	AL	1994-1996							
Southeast	FL	1992-2001				1965-1992			
	GA	1998							
	SC	1999					2004		
	NC					1965-1992			
	VA	1999				1965-1992			
	MD					1965-1992			
	DE								



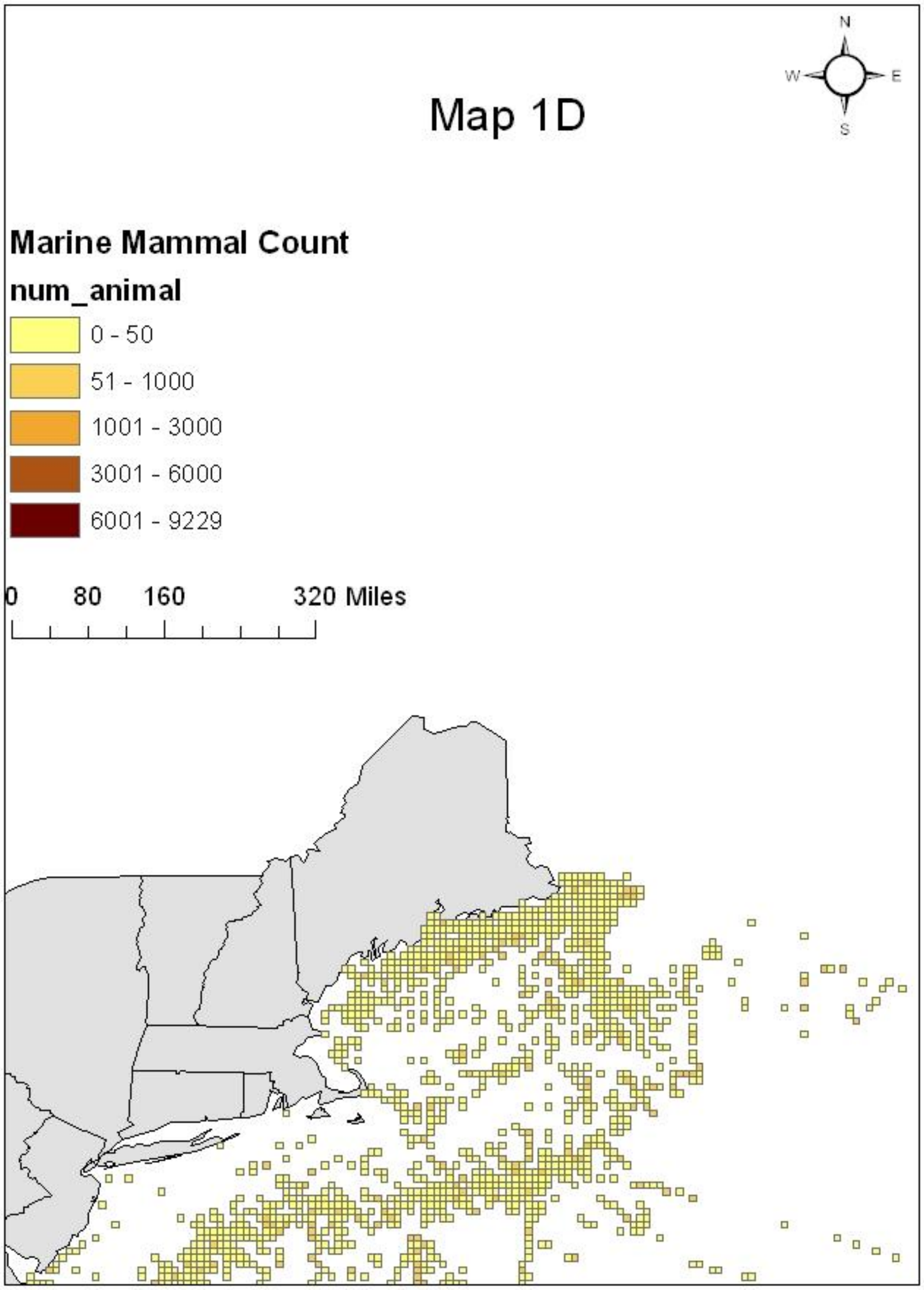
Map 1A. Marine mammal survey counts for the Pacific coast. Data provided by NOAA, BOEMRE and PRBO Conservation Science through OBIS-SEAMAP.



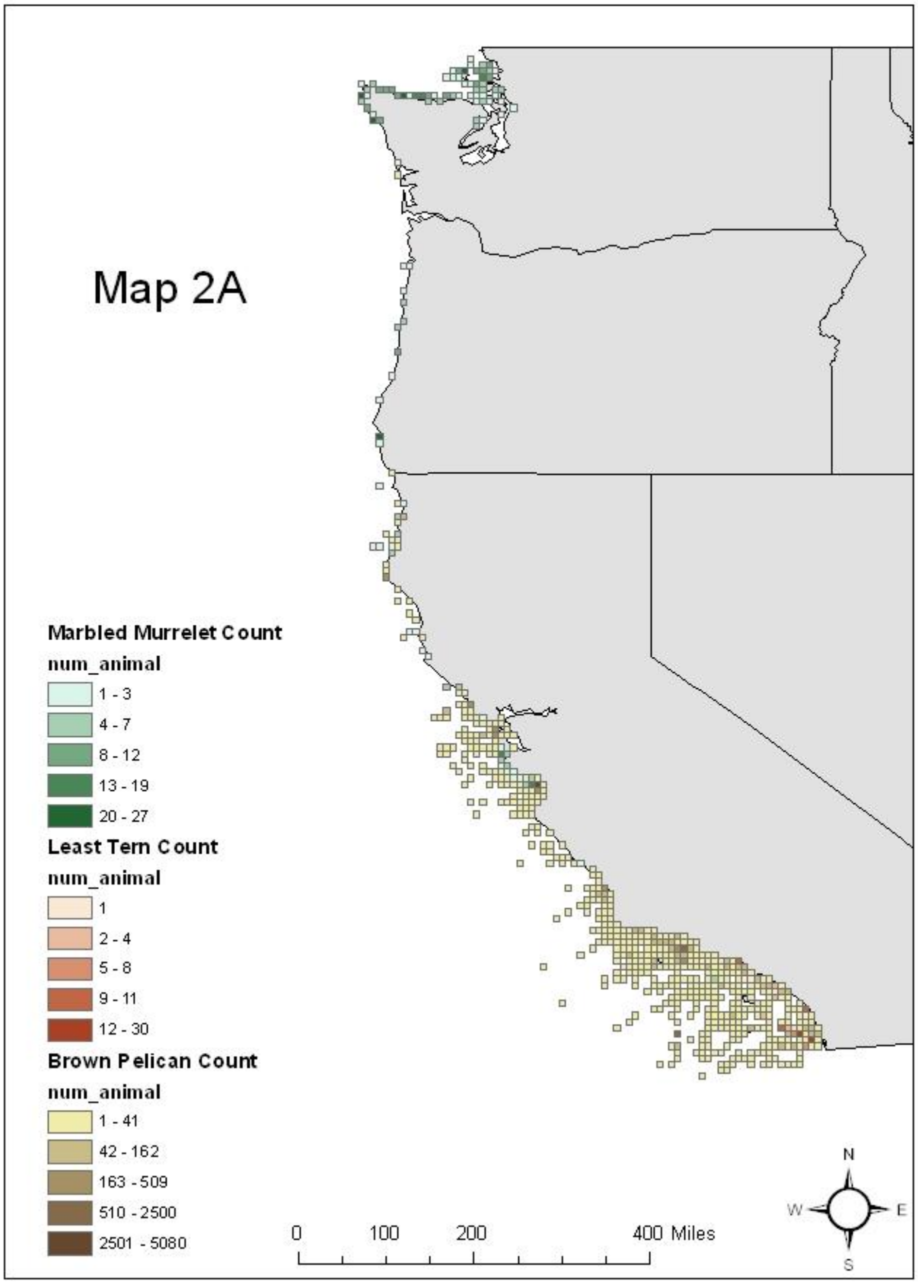
Map1B. Marine mammal survey counts for the Gulf of Mexico. Data provided by NOAA through OBIS-SEAMAP.



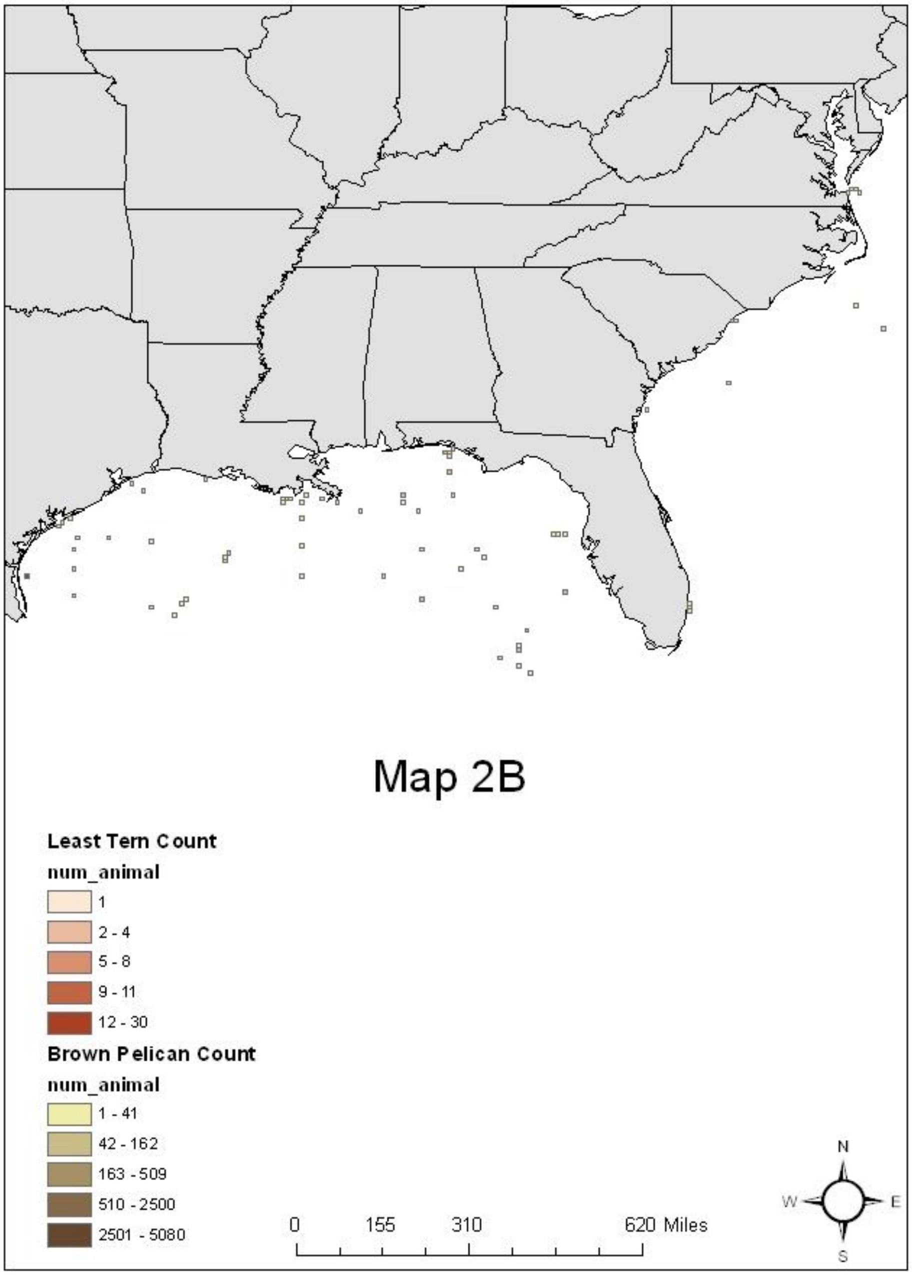
Map1C. Marine mammal survey counts for the southeast region of the US. Data provided by NOAA through OBIS-SEAMAP.



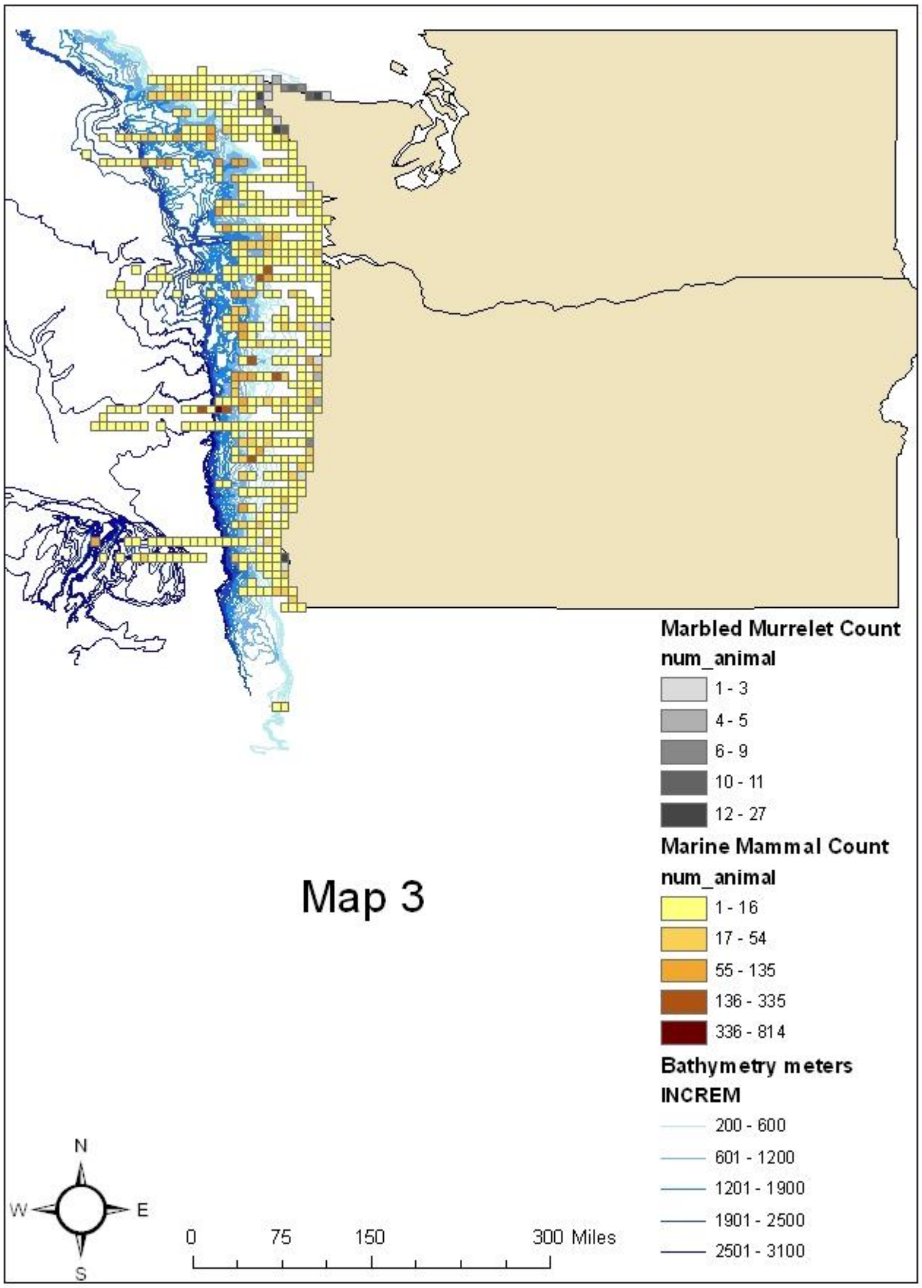
Map1D. Marine mammal survey counts for the northeast region. Data provided by NOAA through OBIS-SEAMAP.



Map2A. Endangered seabird survey counts for the Pacific coast. Data provided by BOEMRE, PRBO Conservation Science, and Washington Department of Fish and Wildlife, through OBIS-SEAMAP.



Map2B. Endangered seabird survey counts for the Gulf of Mexico and the southeast region. Data provided by NOAA and Dalhousie University through OBIS-SEAMAP.



Map 3. Marine mammal, endangered seabird and bathymetry layers for the Pacific Northwest. Data provided by NOAA, BOEMRE, and Washington Department of Fish and Wildlife.

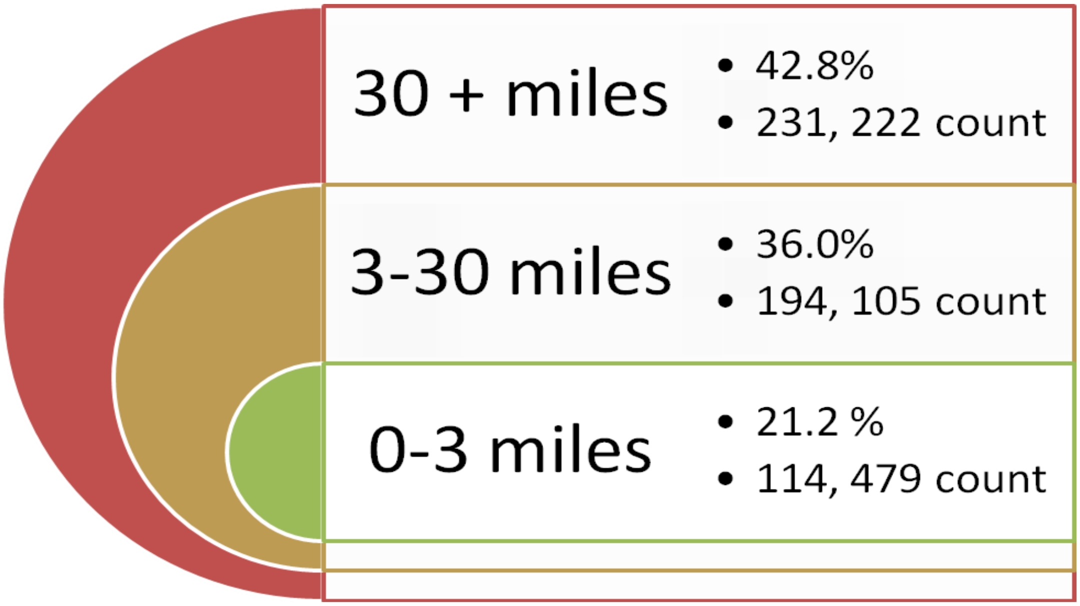


Figure 2. Marine mammal counts and percent species distribution for the coastal U.S., for distances of 0-3, 3-30 and 30+ miles from shore (drawn from OBIS 2010).

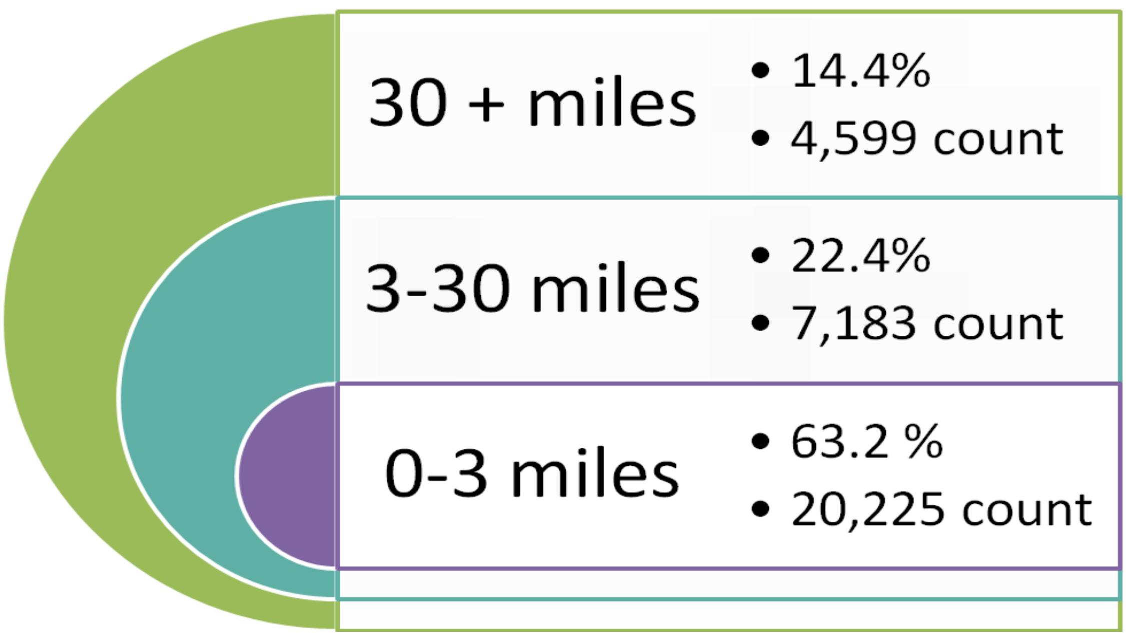


Figure 3. Endangered seabird counts and percent species distribution for the coastal U.S., for distances of 0-3, 3-30 and 30+ miles from shore (drawn from OBIS 2010).

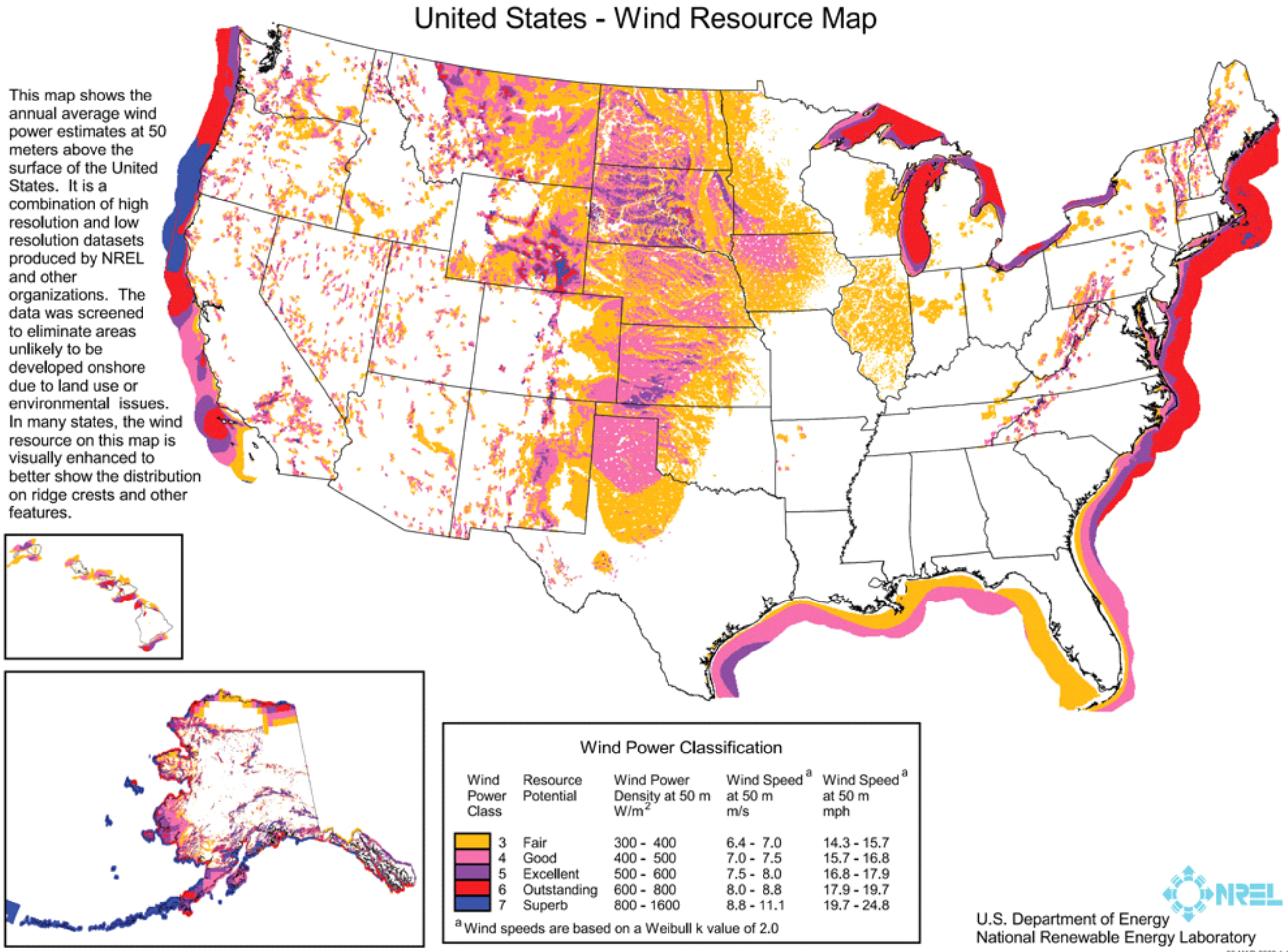


Figure 4. Estimated annual average wind power at 50 meters elevation. Areas with resource potential classified as outstanding or superb are almost exclusively offshore. Map by National Renewable Energy Laboratory [6].

DISCUSSION

In this study, MMC and OBIS were identified as the best online sources for spatial data for migratory marine species. MMC can be an excellent resource for the offshore wind industry, and provides data layers that are beneficial for siting and permitting processes; however the system lacks adequate data on marine migratory animals. MMC provides species data layers on pinnipeds and gray whale migration routes for the state of California but lacks any other data on marine mammal and seabird populations and migration routes. OBIS provides a broader range and depth of geospatial data on migratory marine species. However data from OBIS does not necessarily provide a straightforward pathway towards analysis, even when data from many the sources are organized, correlated and analyzed. Limitations of the data stems form several sources, most notably the variety of observational platforms used in data collection, differing time increments, lengths of surveys, and geographic extent of surveys used to collect the data. Many data in OBIS combine different marine mammal or seabird species into a single survey, making it difficult to ensure that interannual or periodic survey data are comparable. This confusion raises questions whether areas that appear to be biological hotspots, migration routes or habitats are in fact the result of increased sampling efforts in certain areas.

There are no spatial data on Least Terns and Brown Pelicans, both endangered species, for the northeast region contained in the OBIS-SEAMAP databases (Map 2B). This may indicate that these species are not present in the region, or that few surveys for these birds have been conducted in the area, or that existing survey data are not available in digital format. Further investigation revealed that Canadian Fish and Wildlife and Dalhousie University scientists have performed spatial surveys of seabirds in the region; suggesting that if these endangered seabirds are present in the region, documentation would exist. Data from the Cornell Lab of Ornithology indicate that Least Terns and Brown Pelicans do not range into the northeast region of the U.S. (Figures 5 and 6), supporting the theory that these species probably are not present in the region.

Figure 5. Estimated range of Least Terns by Cornell Lab of Ornithology. For the United States, most exist along coastal Gulf of Mexico during summer months [3].

Brown Pelicans are found year round in coastal Texas and Florida and also winter in California (Figure 6), producing the expectation that higher species counts of Brown Pelicans would be expected in the Gulf of Mexico. However, in comparing available spatial Brown Pelican data from California and the Gulf of Mexico, they indicate that higher populations of Brown Pelicans are present in California that the Gulf (Map 2A and Map 2B). Geospatial seabird data from the Gulf of Mexico is supplied by NOAA, while NOAA and two other providers contribute seabird data for the California region (Appendix 2). It can be concluded that the sparse seabird data in the Gulf of Mexico is probably not representative of species abundance but rather the result of lower sampling effort.

Figure 6. Estimated range of Brown Pelicans by Cornell Lab of Ornithology. For the United States, most exist year round along Texas and Florida [3].

The OBIS website currently provides the most comprehensive marine migratory species data and was used in this study to assess the availability and accuracy of data. Tables 1 and 2 provide a subjective estimate of the value of data provided by each of the data providers through a simple ranking system based on duration, geographic extent and longevity of surveys. Of the top data providers, NOAA supplies the greatest number of datasets, covering every region of the country, largely from the NOAA Fisheries Regional Science Centers. However, NOAA's coverage of the Pacific region lacks considerable coastal and functional data, as well as very sparse data for Alaska and Hawaii. BOEMRE has been performing marine surveys since the 1970's using a wide range of techniques. BOEMRE surveys span multiple years and generally have specific goals. However, BOEMRE's geospatial data is largely concentrated in the Pacific region. After the two federal agencies with marine mandates, the best data source is PRBO Conservation Science. PRBO Conservation Science has performed boat surveys for 19 consecutive years documenting marine mammals, seabirds and turtles. Although this organization supplies data only for the state of California, the studies are comprehensive make a significant contribution to the current assessment of migratory marine animals.

Appendices 1 and 2 provide an overview of the data available for different regions and the years in which studies were performed. Organizations collecting these data may have performed single or multiple surveys within the time spans noted. The Pacific region was found to have the most inclusive datasets with high species counts. California has the highest quality and most abundant data available in the country for both marine mammals and endangered seabirds. Data available for the Gulf of Mexico is sparse with few data contributors; this part of the country has little harvestable offshore wind resources so the lack of migratory animal data may not be of great significance for this study. The southeast and northeast regions have similar data availability from sources since most east coast cover the entire coastline and have lasted over many years. Future data collection efforts for the east coast should be focused particularly on the northeast region, as offshore wind resources are promising for energy development in this region (Figure 4).

Marine mammal and endangered seabird maps produced from OBIS data demonstrate how spatial information can be used, analyzed and displayed. Marine mammal maps were generated using data only from the top data providers to ensure accuracy and display of comparable data (Maps 1A-1D). All available data were used for endangered seabird maps except data from the International Pacific Halibut Commission, USGS Alaska Science Center and Canadian Fish and Wildlife as the scale and format of the data from these sources were incompatible with other data sources (Map 2A and 2B). Figures 2 and 3 indicate where the majority of data lie in relation to shore. In order to be most useful for offshore wind siting and permitting, migratory animal surveys need to extend further offshore, particularly in the 3-30 mile band of promising wind resources [1].

We found that migratory animal data from other organizations, websites and studies can be found in text files, tables or figure formats within scientific papers; these data cannot currently be easily merged with data from MMC or OBIS for geospatial analysis. Marine spatial planning is considered necessary for future economic and ecological objectives, indicating the need for conversion of tabular data and further geospatial studies on migratory marine species. Satellite telemetry provides excellent geospatial tracking of migratory species. Unfortunately the high cost and difficulties in working with endangered species prevent more than a small number of migratory marine mammals, sea turtles, or seabirds from being tracked. Most marine satellite tracking to date has been performed on endangered sea turtles, while tracking of marine mammals and seabirds has been minimal [5]. Oregon State University and NOAA's Northwest Fisheries Science Center are among the few organizations currently conducting satellite research on marine mammals but this information has to be yet published; more research is needed to develop significant datasets [7]. Efficient data collection of migratory animals might be achieved by assigning different organizations to collect data from specific regions of the country, providing more comprehensive coverage.

More comprehensive collection of migratory animal data to define movement, behavior and critical habitats, is needed in order for the responsible development of offshore wind in any region of the country.

Conclusion

The development a sustainable offshore wind industry in the U.S. faces significant technological and financial challenges; however the greatest uncertainties facing the industry arise from siting and permitting wind farms to avoid harm to listed marine mammals, seabirds and sea turtles. Data on which to make responsible decisions about offshore wind farms for migratory species. It is imperative that an increased effort to collect these data in advance of significant wind farm development. While offshore wind developers must be responsible for collecting site specific information, data on migratory species that range over hundreds and thousands of miles cannot be assumed to be collected for individual projects. There is a national interest in the collection of robust and comprehensive migratory animal data.

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Appendix 1. Summary of all available marine mammal data from OBIS-SEAMAP. Data organized by data source, region/state and time spans of data. Colorcode indicates number of datasets or surveys taken within the given time frame.

Data Providers		NOAA	BOEMRE	PRBO Conservation Science	NMML	Cascadia Research	Canadian Wildlife Service	University of RI	College of the Atlantic	UK Royal Navy	Duke University
Pacific	AK				1992-2000						
	WA	1996	1989-1990								
	OR	1996	1989-1990								
	CA	1991-1996	1975-1997	1987-2006		1972-2004	1965-1992			1947-2003	
	HI					2000-2006					
Gulf	TX	1992-2001					1965-1992	1978-1982			
	LA	1992-2001					1965-1992	1978-1982			
	MS	1992-2001					1965-1992	1978-1982			
	AL	1992-2001					1965-1992	1978-1982			
Southeast	FL	1990-2004					1965-1992	1978-1982		1947-2003	2009-2010
	GA	1992-1995					1965-1992	1978-1982		1947-2003	
	SC	1992-1999					1965-1992	1978-1982		1947-2003	2007
	NC	1992-1999					1965-1992	1978-1982		1947-2003	2004-2007
	VA	1995-2004					1965-1992	1978-1982		1947-2003	
	MD	1995-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	DE	1995-2004					1965-1992	1978-1982	1976-2003	1947-2003	
Northeast	NJ	1995-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	NY	1995-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	CT	1995-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	RI	1991-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	MA	1991-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	NH	1991-2004					1965-1992	1978-1982	1976-2003	1947-2003	
	ME	1991-2004					1965-1992	1978-1982	1976-2003	1947-2003	

Number of Datasets

1-3 4-6 7-9 10-12 12+

Appendix 2. Summary of all available endangered seabird data from OBIS-SEAMAP. Data organized by data source, region/state and time spans of data. Colorcode indicates number of datasets or surveys taken within the given time frame.

Data Providers		NOAA	BOEMRE	PRBO Conservation Science	Dalhousie University	Canadian Wildlife Service	Washington Department of Fish and Wildlife	USGS Alaska and U.S. Fish and Wildlife Service	International Pacific Halibut Commission
Pacific	AK							1940-2004	1998-2002
	WA		1989-1990				1996		
	OR		1989-1990					1940-2004	
	CA		1975-1997	1987-2006				1940-2004	
	HI								
Gulf	TX	1992-2001							
	LA	1992-2001							
	MS								
	AL	1994-1996							
Southeast	FL	1992-2001				1965-1992			
	GA	1998							
	SC	1999			2004				
	NC					1965-1992			
	VA	1999				1965-1992			
	MD					1965-1992			
	DE								

Number of Datasets

1-2 3-4 5+

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