28.

Ecological Value Map (EVM) for the Rhode Island Ocean Special Area Management Plan – May 2011 Update

by

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Applied Science Associates, May 20, 2011

Extended Abstract

A key challenge in siting an energy facility or other commercial or industrial project is balancing the needs of the diverse interests and resources that could be affected by the project while complying with regulatory standards and meeting project objectives. The ecological valuation approach and maps developed in this study provide a screening tool for initial renewable energy facility siting considerations in the Rhode Island ocean ecosystem, and are intended to be evaluated in conjunction with other environmental information, regulatory and management priorities, and stakeholder interests. The approach may be extended to other areas as part of marine spatial planning efforts to evaluate the cumulative impacts of multiple uses of marine resources.

A framework was developed to model ecological values of marine biological resources and was applied to the area being considered in the Rhode Island Ocean Special Area Management Plan (RI Ocean SAMP). Ecological Value Maps (EVMs) were generated at various levels of detail: on the species level (termed component EVMs); at the group level (category EVMs); and over all resources, providing a composite EVM. Categories considered for the Ocean SAMP application of the EVM framework included the benthic ecosystem, the pelagic ecosystem, fish, birds, sea turtles, and marine mammals. Bats were also considered in the development of the EVM, but were not included in the EVM due to insufficient spatial data.

Synthesized spatial distribution data were gathered from various studies performed by University of Rhode Island (URI) researchers as input to the EVM modeling effort. Data received by ASA to date include marine mammal data (received fall 2009), sea turtle data (received fall 2009), benthic rugosity data (received March 2010), high resolution benthic data for waters immediately south of Block Island (received March 2010), avian data from ship-based studies (received June 2010 and updated in December 2010), and fisheries-independent fish abundance data (received March 2010). Avian data from aerial surveys and high resolution benthic data for the entire Ocean SAMP area were not available in time for inclusion in this analysis.

The definition of "ecological value" was based on that used in other recent marine spatial planning valuation efforts, such as an on-going European effort (Derous et al., 2007a,b,c), i.e., the intrinsic value of biodiversity without reference to anthropogenic use. At the species level, the component EVMs are based on measures of aggregation: density, contribution to fitness, productivity, rarity, or uniqueness of attributes. Weighting schemes were applied to normalized

component and category EVMs and the modified results summed to compute the next-higher EVM level. Different questions such as the regional/global importance of local species, robustness of the data, potential for impact by a project, etc. can change the relative importance of the component EVMs to the higher-level category and composite EVMs. The weighting schemes used in this analysis are considered exploratory and provide a range of potential results. Flexible weighting schemes are envisioned at the category-to-composite EVM level, such that managers can integrate stakeholder input and analyze various configurations of the composite EVM. Other weighting schemes may be discussed and evaluated in the future as issues and concerns arise. One of the strengths of the EVM approach is the weightings implicitly made in any trade-off decision-making process are explicitly stated with a criteria-related basis, making the decision-making process transparent and documented.

Building on the EVM model development performed under US Department of Energy (DOE) funding to the University of Rhode Island as part of the RI Ocean SAMP project, the "Developing Environmental Protocols and Modeling Tools to Support Ocean Renewable Energy and Stewardship" project, funded by the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE, contract # M10PC00097) will expand the approach to a national level and develop a framework and model to address cumulative impacts of offshore renewable energy development. The overall goals of this project are to 1) Develop methods to design and test a new conceptual framework and approach for a cumulative environmental impact evaluation of offshore renewable energy development; 2) Outline an overall Siting Evaluation Model (SEM) that considers both ecological values and socio-economic (human) uses; 3) Integrate various ecological data inputs into an Ecological Value Model (EVM) considering multiple levels of organization, i.e., first into ecological components (e.g., individual species) and then ecological categories (e.g., birds, fish, benthic ecosystem); 4) Quantify weighting factors and uncertainties for compositing ecological categories into an Ecological Value Index (EVI); and 5) Quantify weighting factors and uncertainties for modifying the ecological category weights in the EVI related to potential impacts of development in order to generate a Cumulative Impact Model (CIM-Eco), which would become part of the framework for an overall Siting Evaluation Model. The results of the CIM-Eco may be combined with the results of a parallel human use model CIM-HU, which addresses the impacts of development on human uses (ecological services) of the marine environment. The Human Use Index would include weighting based on relative (human use) service values. Using these tools, a decision maker could evaluate the impacts of a development, and ideally, the topology of the composite index (including uncertainties) would identify areas most suitable for alternative-energy development.

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Acknowledgements

This research was funded in part by a US Department of Energy grant to the University of Rhode Island (URI Contract # FY20105446-500-2306-0000S0000860), the sponsoring agency being the RI Coastal Resources Management Center. The initial work was expanded under a project funded by the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE, contract # M10PC00097) entitled "Developing Environmental Protocols and Modeling Tools to Support Ocean Renewable Energy and Stewardship." This document serves as an interim report for the BOEMRE project.

Abstract

A key challenge in siting an energy facility or other commercial or industrial project is balancing the needs of the diverse interests and resources that could be affected by the project while complying with regulatory standards and meeting project objectives. The ecological valuation approach and maps developed in this study provide a screening tool for initial renewable energy facility siting considerations in the Rhode Island ocean ecosystem, and are intended to be evaluated in conjunction with other environmental information, regulatory and management priorities, and stakeholder interests.

A framework modeling ecological values of marine biological resources was applied to the area of the Rhode Island Ocean Special Area Management Plan (RI Ocean SAMP). Ecological Value Maps (EVMs) were generated at various levels of detail: on the species level (component EVMs); at the group level (category EVMs); and over all resources, providing a composite EVM. Categories included in the EVM are: the benthic ecosystem, the pelagic ecosystem, fish, birds, sea turtles, and marine mammals. Bats were also considered, but were not included in the EVM due to insufficient spatial data. Synthesized spatial distribution data were gathered from various studies performed by URI researchers as input to the EVM modeling effort.

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1 Introduction

This study supports development of the Rhode Island Ocean Special Area Management Plan (RI Ocean SAMP). The goal of the Ocean SAMP is to effectively create a plan that will serve as a baseline assessment and characterize offshore Rhode Island waters. This plan is an important milestone in Rhode Island's ongoing effort to carry out Marine Spatial Planning (MSP). The MSP approach considers the spatial distribution of all uses, resources, biological, and physical characteristics inside of a designated area. This allows managers to effectively "zone" subareas for various future uses such as renewable energy development projects. Prior to MSP, areas or locations selected for development projects were proposed and assessed by the developer. While assessment of alternative locations is required for such proposed projects, MSP is a more holistic approach. Issues such as space-use conflicts, development potential, and areas of special concern are pre-assessed before the site selection process can begin. This may also assist managers in successfully carrying out mandated Ecosystem-Based Management (EBM).

Building on the EVM model development performed under US Department of Energy (DOE) funding to the University of Rhode Island as part of the RI Ocean SAMP project, the "Developing Environmental Protocols and Modeling Tools to Support Ocean Renewable Energy and Stewardship" project, funded by the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE, contract # M10PC00097) will expand the approach to a national level and develop a framework and model to address cumulative impacts of offshore renewable energy development. The overall goals of this project are to 1) Develop methods to design and test a new conceptual framework and approach for a cumulative environmental impact evaluation of offshore renewable energy development; 2) Outline an overall Siting Evaluation Model (SEM, Figure 1) that considers both ecological values and socio-economic (human) uses; 3) Integrate various ecological data inputs into an Ecological Value Model (EVM) considering multiple levels of organization, i.e., first into ecological components (e.g., individual species) and then ecological categories (e.g., birds, fish, benthic ecosystem); 4) Quantify weighting factors and uncertainties for compositing ecological categories into an Ecological Value Index (EVI); and 5) Quantify weighting factors and uncertainties for modifying the ecological category weights in the EVI related to potential impacts of development in order to generate a Cumulative Impact Model (CIM-Eco), which would become part of the framework for an overall Siting Evaluation Model. The results of the CIM-Eco may be combined with the results of a parallel human use model CIM-HU, which addresses the impacts of development on human uses (ecological services) of the marine environment. The Human Use Index would include weighting based on relative (human use) service values. Using these tools, a decision maker could evaluate the impacts of a development, and ideally, the topology of the composite index (including uncertainties) would identify areas most suitable for alternative-energy development.

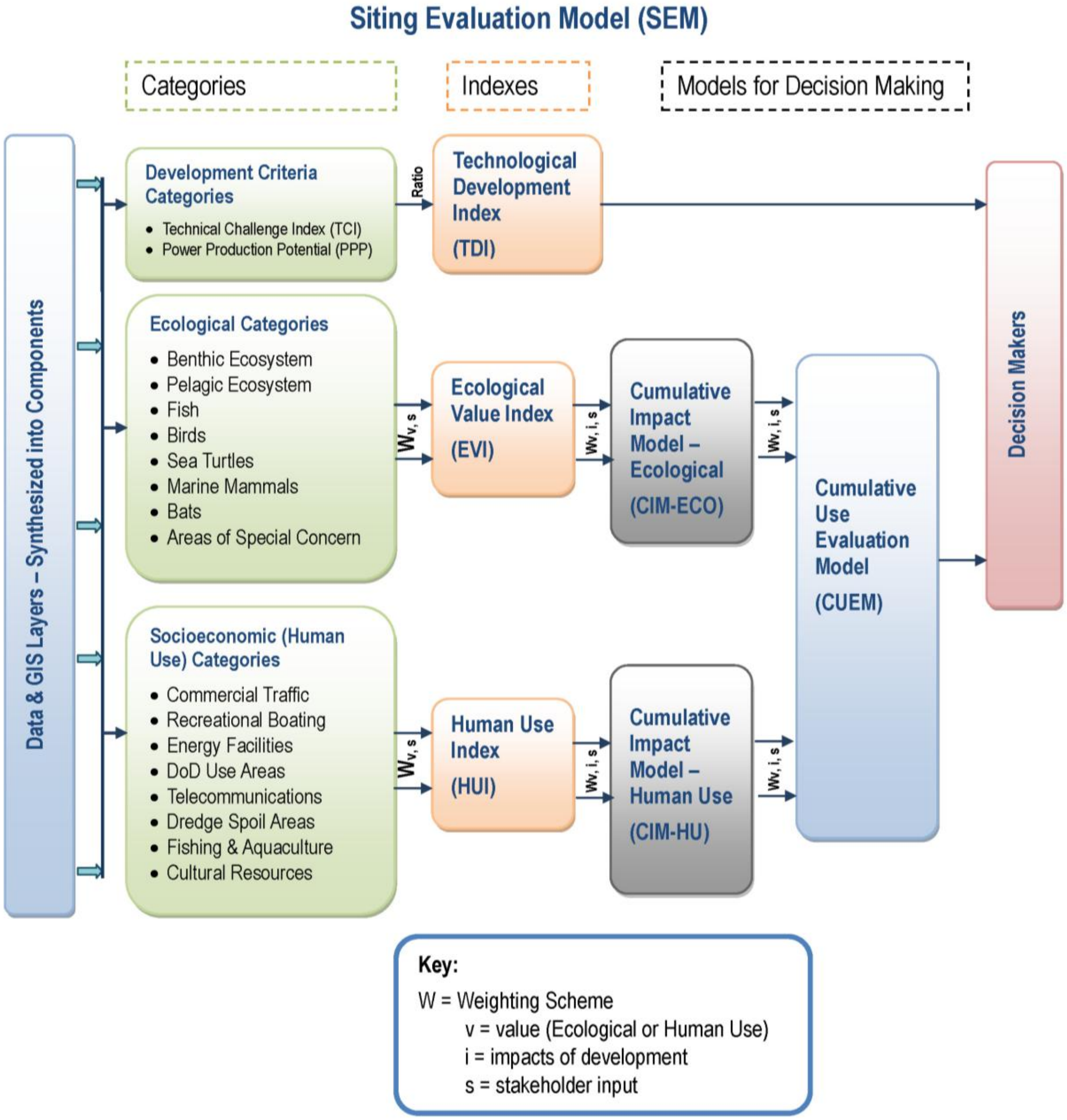


Figure 1. Framework for a Siting Evaluation Model for decision-makers, including indices of technological development potential, ecological value and human use.

Tools and models that assist in siting analysis are useful in carrying out MSP. To facilitate the application of technology constraints on siting renewable energy structures such as offshore wind farms in the Ocean SAMP area, Spaulding et al. (2010) proposed a Technology Development Index (TDI), which is ratio of the Technical Challenge Index (TCI) to the Power Production Potential (PPP) of the energy extraction device. TCI is a measure of how difficult it is to site the device at a given location plus a measure of the distance to the closest electrical grid connection point. The PPP is an estimate of the annual power production of one of the devices. The site with the lowest TDI represents the optimum. This is the location with the lowest technical challenge as compared to the power production potential. The method can be applied to any offshore renewable energy type or extraction system once the technical attributes are specified.

The Ecological Value Map (EVM) framework developed in this study models ecological values of marine biological resources for the Ocean SAMP area. The EVM framework and approach for the Ocean SAMP case study are described herein. The results of an application of the EVM can be used to compare the relative values of potential renewable energy sites of the offshore Rhode Island ocean ecosystem. This siting analysis tool provides stakeholders and managers the ability to evaluate various relative ranks for different resources. The decision maker can use the model and results to inform their evaluation of the trade-offs between the development potential (TDI) and the ecological value (EV) of the area, as well as other issues and concerns pertinent to the decision-making process (such as human uses and stakeholder concerns).

1.1 Approach

Based on our review of existing literature (see Section 2), we found the biological valuation metrics developed by Derous et al. (2007a,b,c) to be the most scientifically-based, transparent approach, with the least bias in application. This approach, where marine biological valuation is defined as the determination of value of the marine environment from a “nature conservation perspective,” represents the consensus of multiple European researchers. Their valuation methodology provides an integrated view of “the intrinsic value of marine biodiversity, without reference to anthropogenic use” and purposefully does not include the socio-economic valuation or quantification of goods and services. While monetary valuation is theoretically possible as a metric for mapping values of ecological resources, in practice the approach requires considerable site-specific research effort, is very subjective (as human perception of value is involved), and is highly uncertain. It also focuses on human perception of value (i.e., willingness-to-pay) as opposed to ecologically-based valuation approaches that are informed by scientific information and ecosystem-based resource management perspectives.

The approach for this project was to develop a model whereby input data (geospatial information describing the physical environment, ecosystems, and fish and wildlife populations) can be integrated into a composite map of biological value, with weighting factors that incorporate relative intrinsic and ecological values, as well as uncertainties in the underlying data sets. Going a step further than Derous et al.'s (2007a,b,c) approach, we also applied additional weighting factors to address the relative potential impacts of construction and operation of a hypothetical wind farm development. The weighting factors were developed by analysts based on the questions asked by decision-makers, and are subject to stakeholder input and concerns. Uncertainties measured in the underlying data were included in the hierarchy of the model, such that the more robust data would be more influential to the composite map.

To develop the approach described above, several supporting analyses and/or steps were performed to achieve a robust and comprehensive framework. The first step included a full search and review of the existing pertinent literature (see Appendix B, summarized in Section 2). Land- and marine-based biodiversity zoning models, marine protected area and MSP siting analyses and approaches, and current biological valuation and EBM literature were investigated. Several of the approaches and themes reviewed were incorporated into the EVM framework.

To apply the framework to the Ocean SAMP area, spatial data were collected from several historical Rhode Island data sets and from ongoing Ocean SAMP research projects. The collection effort involved processing (transfer, compilation, standardization, and gridding) of geospatial data on the benthic ecosystem, the pelagic ecosystem, fish, birds, sea turtles, and marine mammals.

Relative weighting schemes applied to each of the data sets were based on a review of the alternative energy impact literature, regulatory status, and approaches developed in other MPA and MSP models and tools. Other MPA and MSP case studies and tools developed for siting analysis, and/or that have an ecological valuation or sensitivity component, were reviewed and portions of these approaches, which often included socio-economic resources and space-use conflicts in addition to biodiversity, were used in developing the various weighting schemes applied to the Ocean SAMP data.

1.2 Objectives and Goals

The objectives of this research were (1) to develop an approach for quantifying ecological value of marine biological resources and the ecological services of those resources (to other ecological resources and humans); and (2) to apply the approach to the RI Ocean SAMP. The goals were to develop algorithms and methods to (1) integrate various data inputs into ecological component EVMs; (2) quantify weighting factors and uncertainties for merging component EVMs into category EVMs; and (3) quantify weighting factors and uncertainties for modifying the category EVMs into composite EVMs.

A key challenge in siting an energy facility or other commercial or industrial project is balancing the needs of the diverse interests and resources that could be affected by the project while complying with regulatory standards and meeting project objectives. The EVMs developed in this study provide a screening tool for initial renewable energy facility siting considerations in the Rhode Island ocean ecosystem, and are intended to be evaluated in conjunction with other environmental information, regulatory and management priorities, and stakeholder interests.

The approach and EVMs were developed so that they can easily be adapted as stakeholder concerns and/or data needs develop, as the analysts and managers can adjust weighting factors appropriately. The approach is purposefully open, transparent and flexible to facilitate application to a wide variety of sites and environmental conditions.

Building on the EVM model development performed as part of the RI Ocean SAMP, the “Developing Environmental Protocols and Modeling Tools to Support Ocean Renewable Energy and Stewardship” project, funded by BOEMRE, will expand the approach to a national level and develop a model to address cumulative impacts of offshore renewable energy development.

2 Background: Measure of Value Used in the EVM Model

This section provides a brief summary of the existing marine spatial planning (MSP) and ecological valuation literature that supported the development of the current EVM study and approach. An expanded literature review is provided as Appendix B to this report.

Assigning value to subareas or zones of the marine environment is not an easy task. Marine environments are intricately complex, typically multifaceted, and provide many services both to natural resources (i.e., fish and wildlife) and to humans. Past valuations have attempted to measure ecological importance, goods and services provided to humans, or both. Methods of valuation in the marine environment have evolved from land-based biodiversity and zoning assessments, natural resource management, marine protected area (MPA) siting analyses, and most recently marine spatial planning (MSP) efforts. With the onset of marine ecosystem-based management, valuation siting analysis efforts have shifted their focus towards biodiversity and ecology. Under the ecosystem-based management approach, valuation of the marine environment should be related to measures of biological and habitat importance. Because the science of valuation is rooted in both socio-economic and environmental practices, there is cross over in descriptive terminology making accurate definitions all the more important.

The socio-economic definition of the term "value" refers to the goods and services provided by the marine ecosystem, or the value of an area in terms of importance for human use (Nunes and van den Bergh, 2001; De Groot et al., 2002). This socio-economic definition or inference of the term "value" (which is often tied to a monetary unit), is more traditional and rooted in economic theory. Human uses of biological resources include consumptive uses (e.g., commercial fisheries harvest, recreational fishing), non-consumptive uses (e.g., scuba diving, wildlife viewing, aesthetics, spiritual enrichment), and non-use (e.g., option, bequest, genetic pool, existence) values (Freeman, 1993; Kopp and Smith, 1993; Unsworth and Bishop, 1994; and Smith, 1996). Many attempts have been made to measure the value of these services in economic terms, with value being defined as the aggregate "willingness-to-pay" by all individuals for all the services associated with the functioning of the ecosystem (e.g., Freeman, 1993; Smith, 1996). In practice, this approach requires considerable research and site-specific data, relying on proxy markets for ecological services that are not in fact directly traded in the marketplace. If site-specific data are not available, value transfers from other markets or locations are typically made, with a great deal of associated uncertainty. Alternatively, non-market valuation techniques such as Contingent Valuation (CV), which involves questioning samples of people regarding willingness-to-pay for ecological services, are used to estimate monetary values of services. However, these methods are difficult to apply without bias and the results, therefore, are highly variable and uncertain (NOAA, 1992). Thus, while monetary valuation is theoretically possible as a metric for mapping values of ecological resources, in practice the approach requires considerable site-specific research effort, is very subjective (as human perception of value is involved), and is highly uncertain. Thus, we do not attempt monetary valuation as part of this study.

In more recent MSP and ecological valuation efforts, the term "value" has referred to the intrinsic value of marine biodiversity, without reference to anthropogenic use (DFO, 2005; ENCORA/MARBEF, 2006; Derous et al., 2007a,b,c). Under this definition, value is measured by ecosystem processes such as food production for the food web, refuge from predators, and nesting and nursery habitat. Similarly, under the Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA"; 42 U.S.C. § 9601 et seq.), the Clean Water Act (33 U.S.C. § 1251 et seq.), the National Marine Sanctuaries Act (16 U.S.C. § 1431 et seq.), and the 1990 Oil Pollution Act ("OPA"; 33 U.S.C. § 2701 et seq.), scaling mitigation of equivalent value to lost ecological services (resulting from discharges of oil, releases of hazardous substances, physical injury, etc.) has been based on compensatory restoration rather than monetary valuation. The compensation is in the form of equivalent ecological and human services to the injuries, often measured by totaling ecologically-equivalent production of biomass or service-years of resource life (NOAA, 1995). The basis of the compensatory restoration/mitigation approach is a more objective scientific approach: ecological valuation based on biodiversity metrics related to aggregation criteria. This biodiversity metric is the basis of the EVM developed herein, as discussed further below.

Marine ecosystems are inherently complex environments having connective processes such that many aspects must be taken into consideration when measuring ecological value. In the marine environment, valuations must consider characteristics and processes of the benthic and pelagic systems, and usage of these by all species (e.g., fish, invertebrates, birds, marine mammals). Typically, ecological valuation approaches have employed multi-criteria evaluation methods while examining spatial ecosystem data, often resulting in a "hot spot" or value map of the area of interest (e.g., Villa et al., 2002; Derous et al., 2007a,b; EOEEA, 2009). Evaluation criteria have been assessed using Delphic and quantitative methods (Brody, 1998). The Delphic method of analysis relies on consensus of a group of experts in the field ranking priorities. This method is often used when time and resources are limited. Selection criteria can also be quantified or scored to minimize the influence of personal bias. Criteria specifically for evaluating the ecological importance of marine environments have evolved over the past fifteen years through small scale studies that identify significant or important marine areas to protect, as well as in larger scale MSP or marine zoning efforts (e.g., Brody, 1998; Roberts et al., 2003; Lieberknecht et al., 2004; DFO, 2005; Derous et al., 2007a,b,c). The synthesizing criteria developed in these approaches typically identify areas of low to high biodiversity.

The most notable and recent concept for marine biological valuation, representing consensus of multiple European researchers, has been developed by Derous et al. (2007a,b,c), where marine biological valuation is defined as the determination of value of the marine environment from a "nature conservation perspective." Their valuation methodology provides an integrated view of "the intrinsic value of marine biodiversity, without reference to anthropogenic use" and purposefully does not include the socio-economic valuation or quantification of goods and services. This methodology entails compilation of biological valuation maps (BVMs) using available marine ecological and biological data where intrinsic value is assessed using biological valuation criteria. BVMs can then be used as baseline data for spatial planning efforts and allow managers and planners to make objective and transparent decisions. Derous et al.'s (2007a,b,c) forms the basis of the approach used in our EVM study.

Derous et al. (2007a) present a comprehensive literature search outlining existing biological valuation approaches and assessment criteria (highlighting both terrestrial and marine case studies). The results of their literature review showed that biodiversity can be measured via three "1st order" valuation criteria: rarity, aggregation, and fitness consequence. These criteria are defined as:

- *Rarity* – The degree to which a subzone is characterized by unique, rare, or distinct features (e.g., landscapes, habitats, communities, species, ecological functions, geomorphological, or hydrological characteristics) for which no alternatives exist.
- *Aggregation* – The degree to which a subzone is a site where most individuals of a species are aggregated for some part of the year, or a site which most individuals use for some important function in their life history, or a site where some structural property or ecological process occurs with exceptionally high density.
- *Fitness consequence* – Degree to which an area is a site where the activity(ies) undertaken make(s) a vital contribution to the fitness (i.e., increased survival or reproduction) of the population or species present.

These criteria can be modified based on two other factors: naturalness and proportional importance, which are defined as:

- *Naturalness* – The degree to which an area is pristine and characterized by native species (i.e., absence of perturbation by human activities and absence of introduced or cultured species).

- *Proportional importance*:
  - Global importance – proportion of the global extent of a feature (habitat/seascape) or proportion of the global population of a species occurring in a certain subarea within the study area.
  - Regional importance – proportion of the regional (e.g., NE Atlantic region) extent of a feature (habitat/seascape) or proportion of the regional population of a species occurring in a certain subarea within the study area.
  - National importance – proportion of the national extent of a feature (habitat/ seascape) or proportion of the national population of a species occurring in a certain subarea within territorial waters.

Biological valuation methods developed by Derous et al. (2007a) do not give information on potential impacts of any activity, rather a measure of intrinsic biological value. Therefore, evaluation criteria such as “resilience” and “vulnerability,” which are based on some measure of impact, human value or judgment, are not included in their scheme. They argue that these types of criteria should be considered only after the baseline intrinsic value has been established to answer site-specific questions such as suitable placement for development projects or selection of MPAs.

Derous et al. (2007b) applied the biological valuation method to the Belgian region of the North Sea. Biological value was assessed using valuation criteria, a set of assessment questions for each criterion, and appropriate scoring systems. Derous et al. (2007b) make the point that biological valuation is transparent if assessment questions are objective, clear, and centered on the selected valuation criteria. Valuation should not be done solely using expert judgment as this can lead to subjectivity in the assessment and unrepeatable results. It is critical that any method employing subjective judgments structures these judgments in a manner that enhances replicability (Smith and Theberge, 1987). Detailed assessment questions about “structures and processes of biodiversity” will result in objective valuation whereas assessment questions straying from this theme may result in scoring from one’s own perspective, leading to incomparable results among valuations. Selection and development of assessment questions must occur on a case-by-case basis and should be appropriate for that area. Assessment questions are dependent on data availability and the presence of certain processes/structures, etc.

A workshop jointly sponsored by European Network on Coastal Research (ENCORA) and the Marine Biodiversity and Ecosystem Functioning (MARBEF) in 2006 in Ghent, Belgium brought together European researchers and managers to discuss the definition of marine biological valuation, and further developed prototype protocols for mapping and determining intrinsic biological value (valuation criteria) (as defined by Derous et al., 2007a) (ENCORA/ MARBEF, 2006). The biological valuation criteria identified in Derous et al. (2007a) were discussed at length and re-assessed for future case-study frameworks, renaming the general term “marine biological valuation” to “marine biodiversity valuation” or “marine ecological valuation.” The 1st order valuation criteria, which measure biodiversity, were refined to “rarity” (as defined above) and a combined “aggregation-fitness consequences” criterion (Derous et al., 2007c):

- *Aggregation-fitness consequences* – The degree to which a subzone is a site where most individuals of a species are aggregated for some part of the year; or a site which most individuals use for some important function in their life history; or a site where some structural property or ecological process occurs with exceptionally high density; or the degree to which a subzone is a site where the activity(ies) undertaken make a vital contribution to the fitness (i.e., increased survival or reproduction) of the population or species present (DFO, 2005; Derous et al., 2007c).

Naturalness was excluded from the framework all-together, as the natural state of most waters is unknown and it is difficult to define and apply naturalness without reference to human impact. It was decided that naturalness, or measures thereof, should be assessed after the biological valuation process is completed. Instead of keeping “proportional importance” as a modifying criterion, it was decided that the valuation should be carried out in two ways: at a local scale and at a broader (eco-regional) scale (Derous et al., 2007c).

3 Methods

3.1 EVM Model Description

3.1.1 EVM Model Approach

Building on the biological valuation approach developed by Derous et al. (2007a,b,c), a framework was developed where the ecological values of marine biological resources are modeled. The framework and approach integrate input data (geospatial information describing the geophysical environment, fish and wildlife species distributions, and ecosystems) into an Ecological Value Map (EVM), incorporating weighting schemes that reflect relative intrinsic and service values, as well as uncertainties in the underlying data sets. EVMs can be generated at various levels of detail: on the species level (component EVMs); at the group level (category EVMs); and over all resources, providing a composite EVM (Figure 2). The overall EVM index (i.e., the EVI) could be compared to similar combined index maps of human use (service values), as well as to a mapped Technological Development Index (TDI), as shown in Figure 1.

At the species level, the component EVMs are based on measures of aggregation: density, contribution to fitness, productivity, and rarity or uniqueness of attributes. Weighting schemes are applied to normalized component and category EVMs and the modified results summed to compute the next-higher EVM level (i.e., component to category to composite). Different criteria - such as the global, regional, or national importance of local species and component attributes; robustness of the data; potential for impact by a project, etc. - can change the relative importance of the component EVMs to the higher-level category and composite EVMs. The flexible weighting schemes between category EVMs are designed so that managers can integrate stakeholder input and analyze various configurations of the composite EVM.

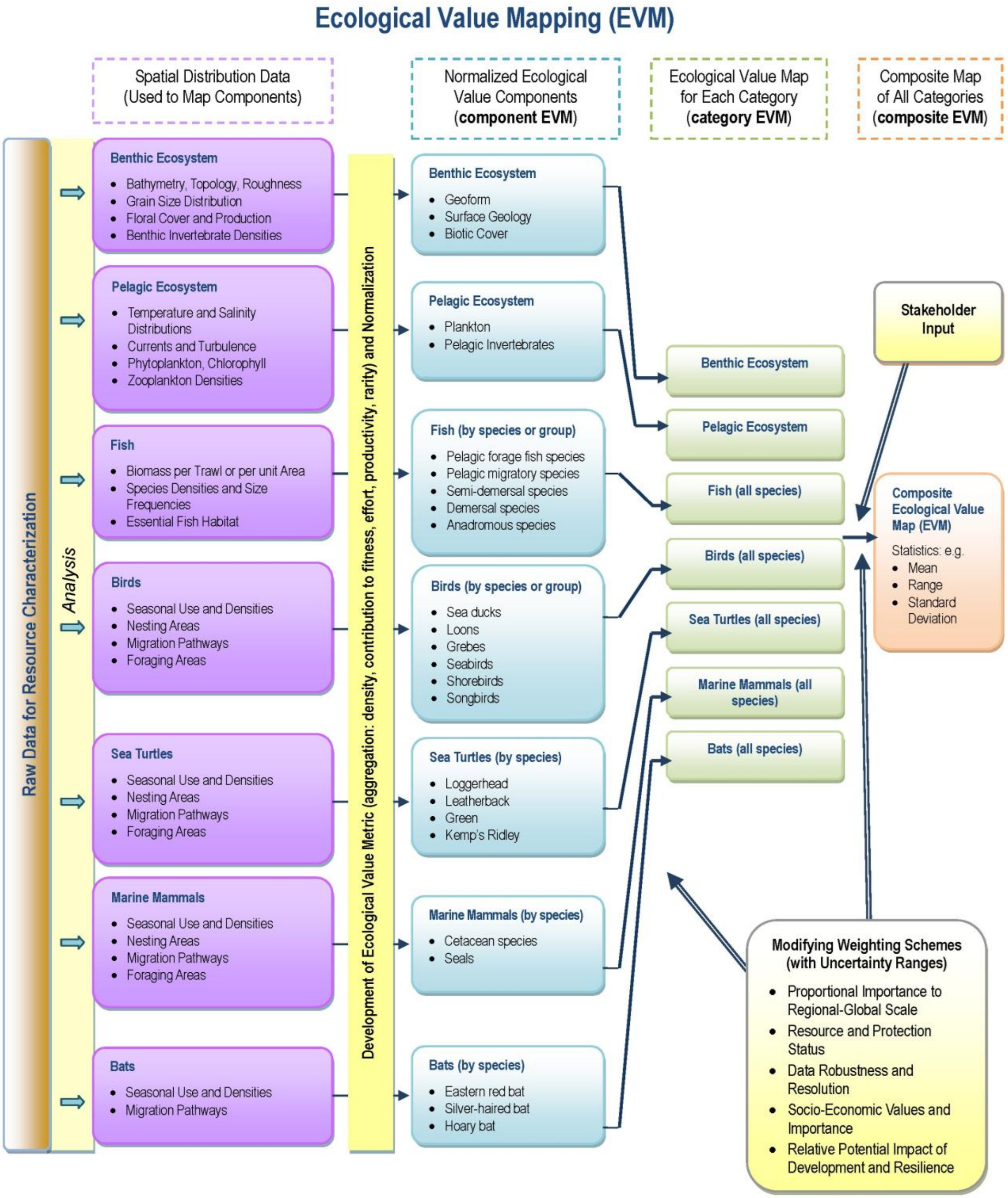


Figure 2. Flow Chart for Development of Ecological Value Maps (EVMs).

3.1.2 EVM Application to RI Ocean SAMP

The EVM framework was applied to the area of the RI Ocean SAMP. Categories considered for the Ocean SAMP application included the benthic ecosystem, the pelagic ecosystem, fish, birds, sea turtles, marine mammals, and bats (Figure 2). Synthesized spatial distribution data were gathered from various Ocean SAMP studies (as summarized in various sections of Chapter 2 Ecology of the Ocean SAMP) as inputs to the EVM modeling effort. Weighting schemes applied to the Ocean SAMP data sets are considered exploratory and provide a range of potential results. Other weighting schemes may be discussed and evaluated in the future as issues specific to the RI Ocean SAMP arise.

The first step in the EVM approach was to develop geospatial data or maps for each ecological resource to be included, gridding the data over the area of interest. Most of the basic data compilation and analysis was carried out by other Ocean SAMP researchers (see Chapter 2 of the Ocean SAMP). A *component EVM* was developed for each resource (e.g., a species or group) based on aggregation (relative density) using spatial distribution data. Individual normalized *component EVMs* were combined using relative weighting schemes to develop *category EVMs* (e.g., birds). Then, the *category EVMs* were compiled to derive a set of *composite EVMs* (Figure 2). The relative weighting schemes applied to individual resource EVMs to develop category EVMs are summarized in Table 1 and those applied at the composite level in Table 2. These weighting schemes and steps of the analysis are described below.

Table 1. Weighting Models for Developing Category EVMs.

Basis of Weighting Scheme	Description
Proportional Importance to Regional-Global Scale	Importance of RI Ocean SAMP area to the resource on a regional, national, and global scale.
Resource and Protection Status	Scarcity, such as designation as a species of concern (i.e., listed threatened and endangered species).
Relative Potential Impact of Development	Impact potential varies depending on type of project proposed (e.g., wind or other renewable energy) and other local stressors.
Data Robustness and Resolution	Those data sets with more variability and lower spatial or temporal resolution are given a lower weight.

Table 2. Weighting Models for Developing Composite EVMs.

Basis of Weighting Scheme	Description
Socio-Economic Values and Importance	Weights for different components are given based on stakeholder suggestions. (This weighting is not included here, but may be added at in some future analysis.)

3.1.3 EVM Model Calculation Methods

The following steps were used to develop the *component*, *category* and *composite* EVMs (Figure 2).

- Develop models of relative ecological values (EV) for individual resources to develop the spatial distribution data used in the EVM (as described in overview in Section 3.1.3.2, and in detail in Section 3.2):
    - Habitat – based on rugosity, sediment type, and biological communities.
    - Species of concern – based on observed or modeled relative densities.
- Develop comprehensive gridded maps of seasonal relative density, or use, for each resource (i.e., the Normalized Ecological Value Components, Figure 2; grid as described in Section 3.1.3.1).
- Combine individual indices for each resource (component) using relative weighting schemes (discussed in Section 3.1.3.3, with weighting schemes described in Section 3.3) to develop an overall index – the category EVM (Figure 2).
- Generate the composite EVM assuming equal weights for all categories. Several potential weighted combinations of ecological service values for individual categories could be further explored (in consultation with Ocean SAMP stakeholders).

3.1.3.1 Spatial Distribution Data (Map Components)

The geospatial data sets (layers) for the region of concern, typically in a Geographical Information System (GIS) format, were processed to a first level of *components* that capture and summarize the important attributes or provide a magnitude (such as species density at certain times of the year). These data were gridded (i.e., put in raster format) in an approximately 78-m by 59-m resolution grid, overlaying that used for the TDI analysis (Spaulding et al., 2010). The EVM grid has an origin at 40.88^{o}N, 71.89^{o}W, with cell sizes in degrees being 0.0007^{o} in both longitude and latitude.

3.1.3.2 Ecological Valuation and Normalization

In the second step, the component data were converted into an ecological valuation metric. Most of the ecological valuation metrics are based on standard biological metrics, such as density (number of individuals or biomass per unit area). Although not applied herein, productivity (amount of production per unit time per unit area) or resource classifications (e.g., benthic ecosystem components transformed into relative values by evaluating how frequently each classification occurs within the study area) could be used. In the present application, sea bed rugosity (roughness) was used as a proxy for the composited benthic category value, as rugosity is an approximate measure of structural complexity in the benthic environment.

In order to compare across *component EVMs*, each component EVM had to be normalized. This procedure was completed in ArcGIS 9.3 where the annual maximum raw value (e.g. abundance, sightings per unit effort, etc.) for each component was used to scale the seasonal values. This simplifies the relationship between the component EVMs by removing the order of magnitude differences that can arise between raw values while still maintaining intra-component seasonal variation. Annual component EVMs were calculated by summing the seasonal components and dividing by the total seasons sampled.

3.1.3.3 Ecological Valuation Maps (EVMs) and Weighting Schemes

When combining multiple *component EVMs*, the simplest approach is to sum all the values and generate a total for each location (grid cell), which creates a map assuming all contributing data layers are of equal weight. However, many different concerns (e.g., the importance of species, robustness of data, potential for impact by a project) can vary the relative importance of the *component EVMs*. The weighting schemes used in this analysis are described in Section 3.3. These weighting schemes are considered exploratory and other weighting schemes may be discussed and evaluated as issues specific to RI Ocean SAMP arise. The five weighting schemes utilized for this study can be represented as the following variables:

$$Data\ Robustness = W_{rob}$$
$$Protection\ Status = W_{pro}$$
$$Regional/Global\ Importance = W_{glo}$$
$$Potential\ Impact\!: Construction = W_{potc}$$
$$Potential\ Impact\!: Operation = W_{poto}$$

It should be noted that these weighting schemes, set on a relative scale from 1 (no extra weight) to 10 (highest weight), can be applied to any group of EVMs; for example, these schemes can help determine how bird species (*component EVMs*) should be weighted against each other to generate a *category EVM*; or applied to multiple *category EVMs* to depict the relative importance of fish over birds (for example) in generating a *composite EVM*. The weighting schemes may also be combined, either with equal weight (i.e., all are on a scale of 1-

10) or with criteria weights (e.g., protection status may be considered of higher importance than proportional importance to regional-global scale, and so a relative weight factor could be added to emphasize the protection status criterion).

To develop *category EVMs* corresponding to the individual weighting schemes employed in this study, the normalized input data rasters (i.e., the gridded data of value measures were divided by the maximum value in the grid and so normalized to a common scale) were multiplied by the appropriate weighting scheme, as well as a weighting scheme corresponding to data robustness. In order to prevent categories with more input data rasters from being disproportionately represented in the results, the resulting output raster was then divided by *n*, where n is the number of input data rasters in the category. This procedure is described by the following series of equations, where x is the normalized input data:

$$Regional\ Importance\ EVM = EVM_{glo} = \frac{\left(x * W_{glo} * W_{rob}\right)}{n}$$

$$Protection\ Status\ EVM = EVM_{pro} = \frac{\left(x * W_{pro} * W_{rob}\right)}{n}$$

$$Potential\ Impact\ EVM{:}\ Operation = EVM_{poto} = \frac{\left(x * W_{poto} * W_{rob}\right)}{n}$$

$$Potential\ Impact\ EVM{:}\ Construction\ EVM = EVM_{potc} = \frac{\left(x * W_{potc} * W_{rob}\right)}{n}$$

These EVMs were then averaged together in a variety of combinations to create a series of summary *category EVMs*. This procedure is described by the following series of equations:

$$Impact\ EVM = EVM_{imp} = \frac{EVM_{poto} + EVM_{potc}}{2}$$

$$Ecological\ Value\ EVM = EVM_{eco} = \frac{EVM_{glo} + EVM_{pro}}{2}$$

$$Ecological\ Impact\ EVM{:}\ Operation = EVM_{eio} = \frac{EVM_{eco} + EVM_{poto}}{2}$$

$$Ecological\ Impact\ EVM{:}\ Construction = EVM_{eic} = \frac{EVM_{eco} + EVM_{potc}}{2}$$

$$Ecological\ Impact\ EVM{:}\ Combined = EVM_{eit} = \frac{EVM_{eco} + EVM_{imp}}{2}$$

Composite EVMs were produced by summing the *category EVMs* as follows:

$$Composite\ Ecological\ Value\ EVM = \sum_i EVM_{eco,i}$$

$$Composite\ Ecological\ Impact\ EVM: Operation = \sum_i EVM_{eio,i}$$

$$Composite\ Ecological\ Impact\ EVM: Construction = \sum_i EVM_{eic,i}$$

$$Composite\ Ecological\ Impact\ EVM: Combined = \sum_i EVM_{eit,i}$$

All of these calculations were completed in ArcGIS 9.3. Weighting schemes were applied using the Weighted Sum tool in the Spatial Analyst Toolbox. Input data (rasters) were summed in each cell according to the weighting scheme outlined in each results section.

3.2 Data Used and Indexing Methods for the RI Ocean SAMP Application of the EVM

3.2.1 Benthic Ecosystem

Benthic data became available in March 2010 from Dr. John King's laboratory at URI's Graduate School of Oceanography (GSO). High-resolution benthic data for areas south and southeast of Block Island are available in the NOAA-sponsored Coastal and Marine Ecological Classification Standard (CMECS) format (Shumchenia et al., 2010). Following this format, sediment characteristics and coverages of various biota were divided into three components that define the benthic ecosystem 1.) geoform, 2.) surface geology, and 3.) biotic cover. Dr. King's group developed the framework and definitions for these CMECS components. Figure 3 is an example of the genus-defined benthic environment data developed for areas south and east of Block Island, RI. However, because these data were not available for most of the Ocean SAMP area, they were not used in the EVM analysis as part of this study. Nevertheless, this CMECS-based approach for mapping the benthic ecosystem is recommended as the preferred data input for an EVM application in future efforts.

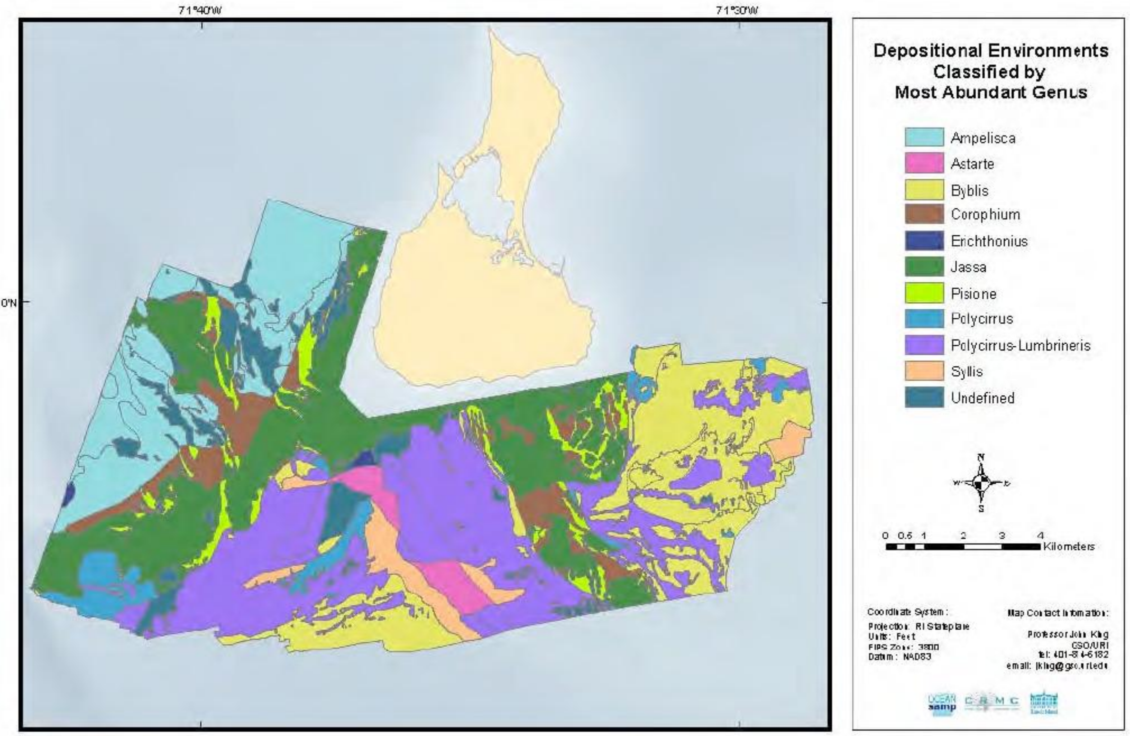
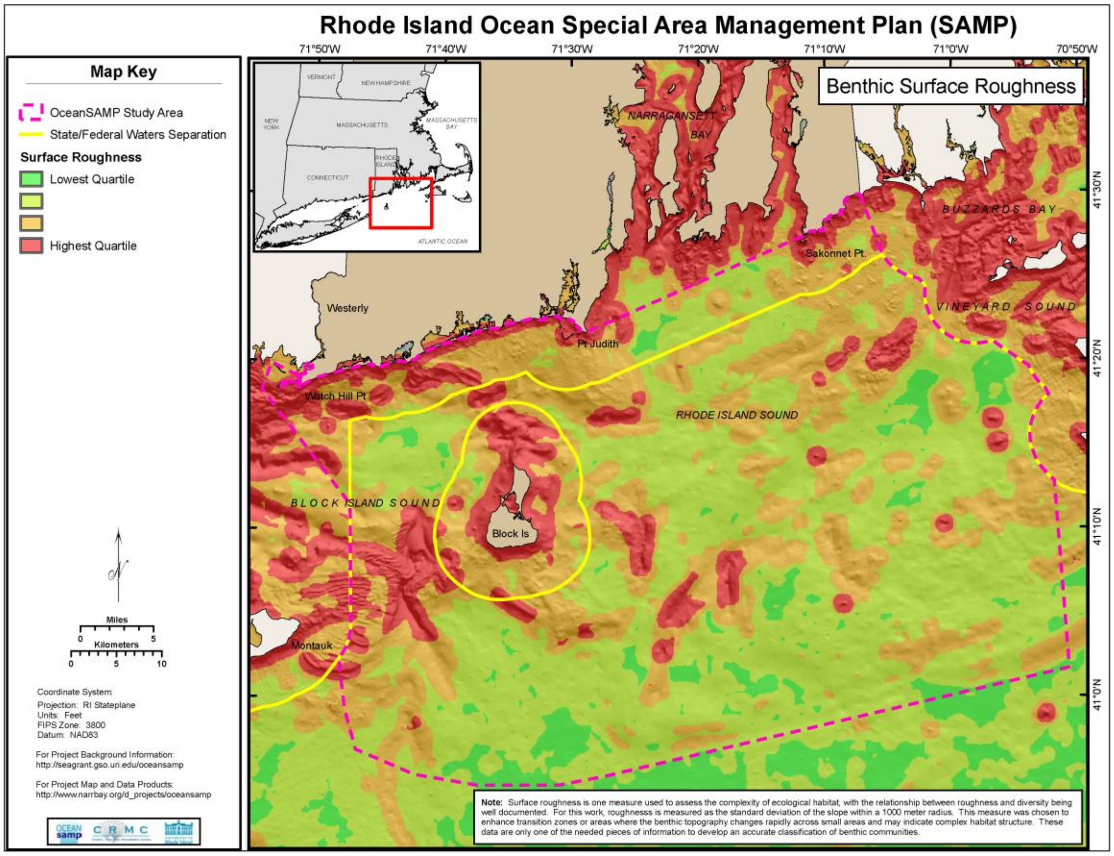


Figure 3. Genus-defined benthic geologic environment in the vicinity of Block Island, RI (LaFrance et al., 2010, Figure I-15 therein).

For benthic habitats in the entire Ocean SAMP area, a seafloor rugosity map was generated by Dr. John King and Chris Damon (URI) and provided to ASA in March, 2010 (Figure 4). Benthic surface roughness, sometimes called rugosity, can be used as an approximate measure of structural complexity in the benthic environment. Structural complexity is often used as a proxy for ecological complexity, as complex benthic habitats have been shown to support more species diversity and/or abundance. In the Ocean SAMP, benthic surface roughness was calculated using NOAA/NOS bathymetry soundings data and taking the standard deviation of the slope within a 1,000-meter radius. This procedure highlights transition zones or areas where benthic topography changes quickly, perhaps indicating complex benthic structure or large geoforms. The presumption is that the rougher the bottom, the greater the vertical complexity, which could be equated with the promotion of increased species diversity. Initial findings by LaFrance et al. (2010) suggest that the relationship between surface roughness and habitat diversity appears to vary according to the scale at which surveys are conducted and the statistical routines used to interpret the relationship. They find that a relationship does exist between surface roughness and habitat diversity, though more research is needed to determine how this relationship relates to species abundance and use of benthic habitats.

Rugosity, as a proxy for species diversity, is used in the EVM to represent the benthic ecosystem component.



Note: Surface roughness is one measure used to assess the complexity of ecological habitat, with the relationship between roughness and diversity being well documented. For this work, roughnesss is measured as the standard deviation of the slope within a 1000 meter radius. This measure was chosen to enhance transition zones or areas where the benthic topography changes rapidly across small areas and may indicate complex habitat structure. These data are only one of the needed pieces of information to develop an accurate classification of benthic communities.

Figure 4. Benthic Surface Roughness (Ocean SAMP, Figure 2.26 therein).

3.2.2 Pelagic Ecosystem

The plankton-based pelagic community is enhanced by higher phytoplankton production rates, drawing fish and wildlife predators to the area. Thus, the ecological value of pelagic ecosystem is indexed to phytoplankton productivity. The Nature Conservancy, as part of their Northwestern Atlantic Marine Eco-regional Assessment, compiled chlorophyll data from the Sea Viewing Wide Field-of-View Sensor (SeaWiFS) satellite images. Data from January 1998-December 2006 were collected and monthly data were averaged into seasonal representations (see Figure 5 for an annual average of this data). These image data have a spatial resolution on the order of 1.1 km^2. For more information on these data see: http://nature.org/namera.

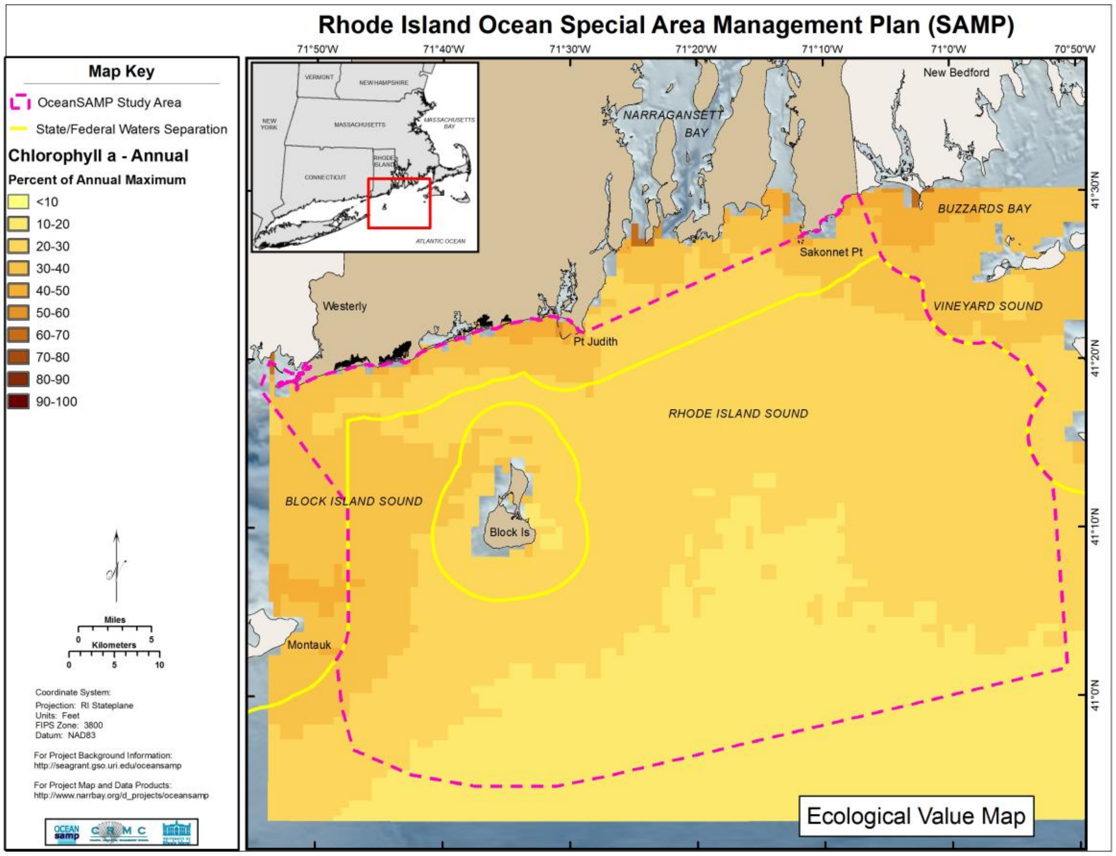
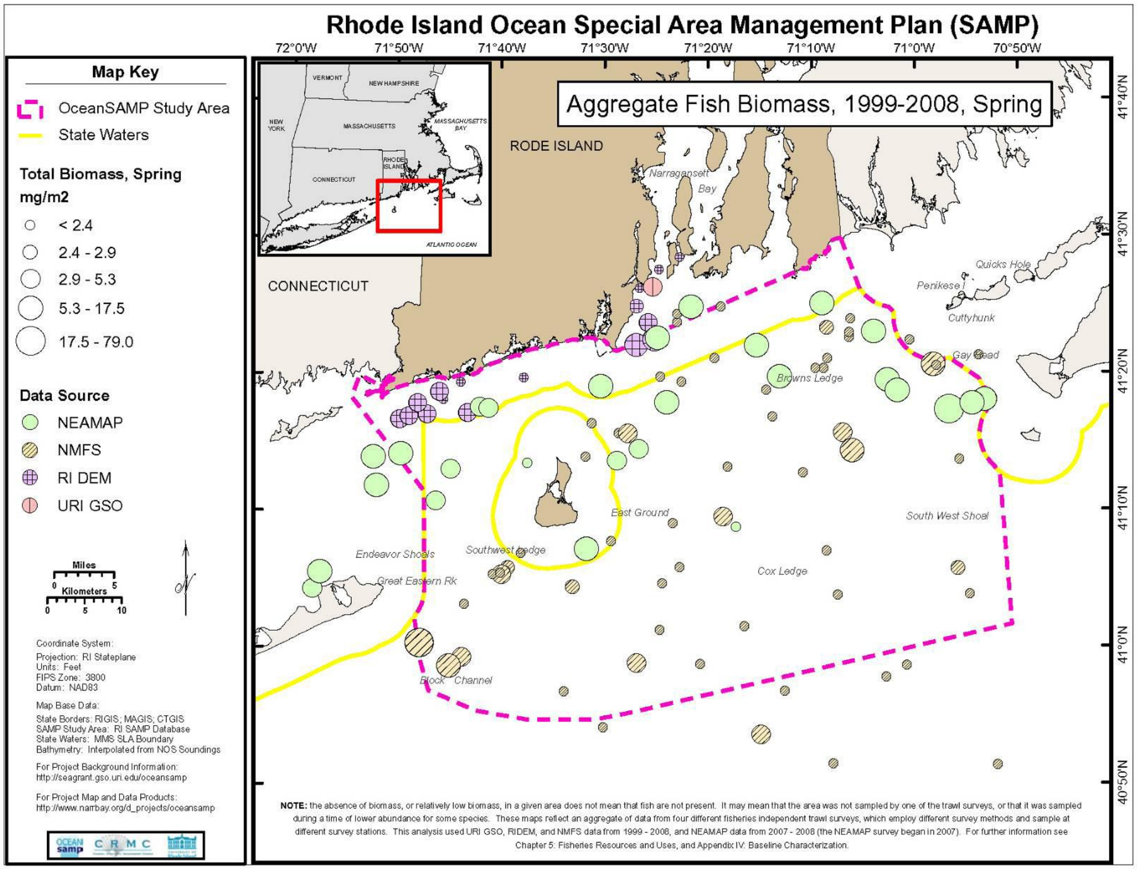


Figure 5. Component EVM of annual surface chlorophyll a concentration, represented as percent of the maximum annual value.

3.2.3 Fish (Including Fish and Large Invertebrates)

Fish resources data were compiled from several sources, as there is no one fisheries-independent survey or dataset that provides abundance and biomass information for the entire Ocean SAMP area. The data from four different fishery-independent bottom trawl surveys conducted by the Rhode Island Department of Environmental Management (RIDEM), URI Graduate School of Oceanography (GSO), Northeast Area Monitoring and Assessment Program (NEAMAP), and the National Marine Fisheries Service (NMFS) were compiled for the years 1999-2008. These data were standardized, aggregated, and analyzed by Bohaboy et al. (2010) to provide a baseline characterization of abundance and biomass for the Ocean SAMP area (Figure 6). This baseline characterization focused on 22 finfish, shellfish, and crustacean species (Table 3) and was provided to ASA in March, 2010. For a discussion on trawl types and the methods to convert data into biomass per unit area, see Section 510, Chapter 5 of the Ocean SAMP.



NOTE: the absence of biomass, or relatively low biomass, in a given area does not mean that fish are not present. It may mean that the area was not sampled by one of the trawl surveys, or that it was sampled during a time of lower abundance for some species. These maps reflect an aggregate of data from four different fisheries independent trawl surveys, which employ different survey methods and sample at different survey stations. This analysis used URI GSO, RIDEM, and NMFS data from 1999 - 2008, and NEAMAP data from 2007 - 2008 (the NEAMAP survey began in 2007). For further information see Chapter 5: Fisheries Resources and Uses, and Appendix IV: Baseline Characterization.

Figure 6. Aggregate Fish Biomass, 1999-2008, Spring (Bohaboy et al. 2010, Figure 37 therein).

Bottom trawl surveys are appropriate for sampling demersal and some pelagic species, but they may not accurately characterize the occurrence of some pelagics, shellfish, and crustaceans. As a result, although an important component of fish resources, the migration pathways and seasonal abundance trends of large pelagic teleosts (e.g., tuna) and elasmobranchs (e.g., large sharks), were not included in the baseline characterization. Moreover, bottom trawls are not able to survey certain bottom types/habitats like moraines, rocky areas, or areas with other obstructions. Therefore, the baseline characterization likely underestimates the abundance of species associated with these bottom types/habitats. The baseline characterization reflects a synthesis of data from the four different fisheries-independent trawl surveys, each with differences in the vessel types, gear types, and methods used. Analysis of the biomass data revealed that survey effects were the second most important factor in accounting for variation in total biomass. As a result, the biomass estimates for the individual surveys are not directly comparable and cannot simply be combined into a composite map. In order to correct for survey effects and compile the data, ASA obtained the results of the multi-way ANOVA conducted by

Bohaboy et al. (2010) and used the survey effect coefficients from the ANOVA to adjust the raw biomass data. This method is a simple approach to correcting for survey effects, and has inherent limitations and assumptions. For example, this approach assumes that catchability of each species was equal within a given survey. In reality, survey catchability is on a species-by-species basis. Despite the limitations, this was the most reasonable approach given the scarcity of data for certain species and our need to compile the data from the different surveys into a single composite map.

After correcting for survey effects, in order to be incorporated into the EVM, the trawl survey point data were converted into a standardized surface of relative density using the statistical modeling approach known as Kriging. Geostatistical Analyst in ArcGIS 10 was used to create surfaces for fish biomass. Data for this study were collected from 222 stations, which cover 22 fish species by 2 seasons (spring and fall). In order to increase the sample size for geostatistical analysis, the 22 fish species were combined into 10 groups based on taxonomic and functional similarities (Table 3). Then, Ordinary Kriging was used to create surfaces of fish biomass. For Kriging modeling, a histogram was drawn and a normal QQ plot was used to explore the distribution. Trend Analysis was then used to study the trends in the data, which could be related to water depths and geospatial locations. Based on those preliminary studies, Geostatistical Analyst was used to build the Kriging model. The model parameters were chosen based on the data and the trends that were discovered from preliminary studies conducted by ASA. The normality assumption for Kriging was not satisfied for some species groups (i.e., demersal fish in fall, baitfish in fall, river herring in spring and fall, large gamefish in fall, and skates in fall), and therefore Kriging failed. For those cases, Inverse Distance Weighting (IDW) was used to create the surfaces. Major outputs from Kriging and IDW include maps of prediction. The mean predicted abundances for fall and spring seasons were included as layers in the EVM (see Figures 7 and 8 for examples of the modeled surfaces).

Table 3. Taxonomic/functional groupings of species identified in fishery-independent trawl data.

Group	Common Name	Scientific Name
Lobster	American lobster	*Homarus americanus*
Sea Scallop	Atlantic sea scallop	*Placopecten magellanicus*
Squid	Longfin squid	*Loligo pealei*

Group	**Common Name**	**Scientific Name**
Demersal fish	Atlantic cod	*Gadus morhua*
	Silver hake	*Merluccius bilinearis*
	Cusk	*Brosme brosme*
	Scup	*Stenotomus chrysops*
	Goosefish	*Lophius americanus*
Flatfish	Yellowtail flounder	*Limanda ferruginea*
	Summer flounder	*Paralichthys dentatus*
	Winter flounder	*Pseudopleuronectes americanus*
Baitfish	Atlantic herring	*Clupea harengus*
	Atlantic mackerel	*Scomber scombrus*
	Butterfish	*Peprilus triacanthus*
River Herring/Smelt	Alewife	*Alosa pseudoharengus*
	American shad	*Alosa sapidissima*
	Blueback herring	*Alosa aestivalis*
	Rainbow smelt	*Osmerus mordax*
Medium Gamefish	Tautog	*Tautoga onitis*
	Black sea bass	*Centropristis striata*
Large Gamefish	Bluefish	*Pomatomus saltatrix*
	Striped bass	*Morone saxatilis*
Skates	Thorny skate	*Amblyraja radiata*
	Little skate	*Leucoraja erinacea*
	Winter skate	*Leucoraja ocellata*
	Barndoor skate	*Dipterus laevis*
Dogfish	Smooth dogfish	*Mustelus canis*
	Spiny dogfish	*Squalus acanthias*
	Dusky shark	*Carcharhinus obscurus*

A considerable amount of error is associated with creating a surface from the trawl survey point data. However, biologically reasonable trends can be seen. For example, predicted lobster abundance is high close to the mouth of Narragansett Bay in fall (Figure 7) and more dispersed in the spring (Figure 8). This trend is consistent with their annual offshore migration in the winter (Fogarty et al., 1980).

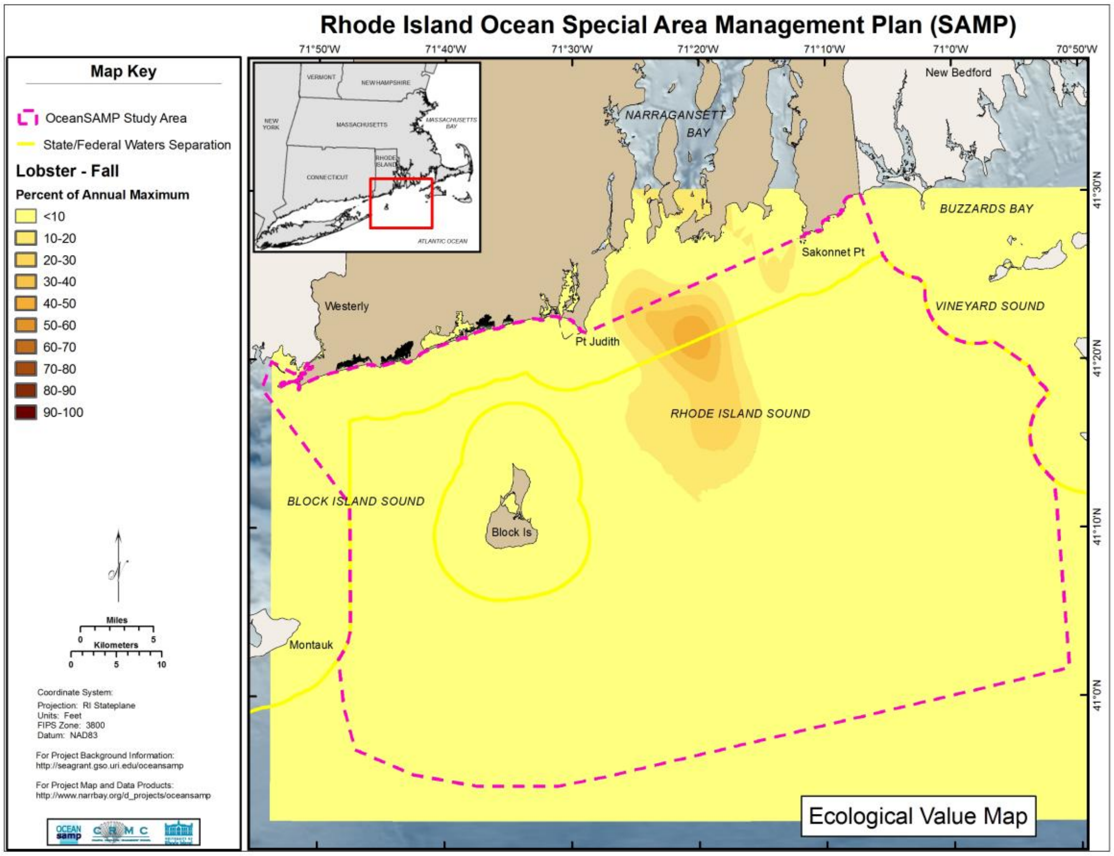


Figure 7. Component EVM (generated by Kriging) of lobster abundance during the fall season, represented as percent of the annual maximum value.

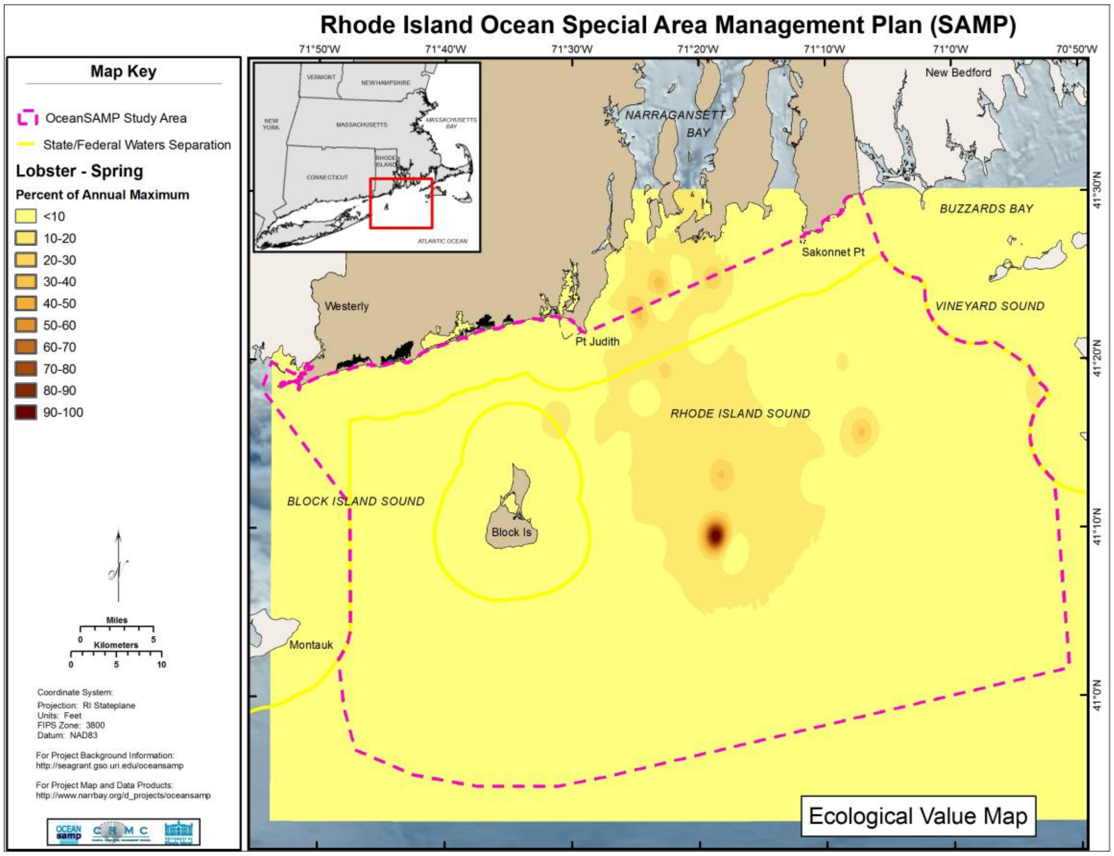


Figure 8. Component EVM (generated by Kriging) of lobster abundance during the spring season, represented as percent of the annual maximum value.

Additionally, Essential Fish Habitat (EFH) has been designated for many species in the waters off southern New England. EFH is designated as 10' by 10' latitude/longitude squares, and all areas of the Ocean SAMP have designated EFH for at least 20 species/life stages. As a result, the resolution of these presence/absence data cannot be appropriately combined with the rest of the data incorporated in the EVM process. See Figure 9 for a depiction of the number of species/life stages in each 10' square in the Ocean SAMP area. This figure was developed using EFH designation information from the NMFS Northeast Regional Office *Guide to Essential Fish Habitat Designations in the Northeastern United States* website (http://www.nero.noaa.gov/hcd/index2a.htm).

EFH designation requires NMFS and federal agencies to work to protect these areas from actions which may have an adverse effect on EFH. This is accomplished by reviewing proposed federal actions (including authorization of projects) through the National Environmental Policy Act (NEPA) process to avoid, minimize, or mitigate potential impacts. Thus, EFH mapping could be used as an additional tool to evaluate potential development locations; however, we did not include it in the EVM at this time because of the nature of the data set (presence-absence only).

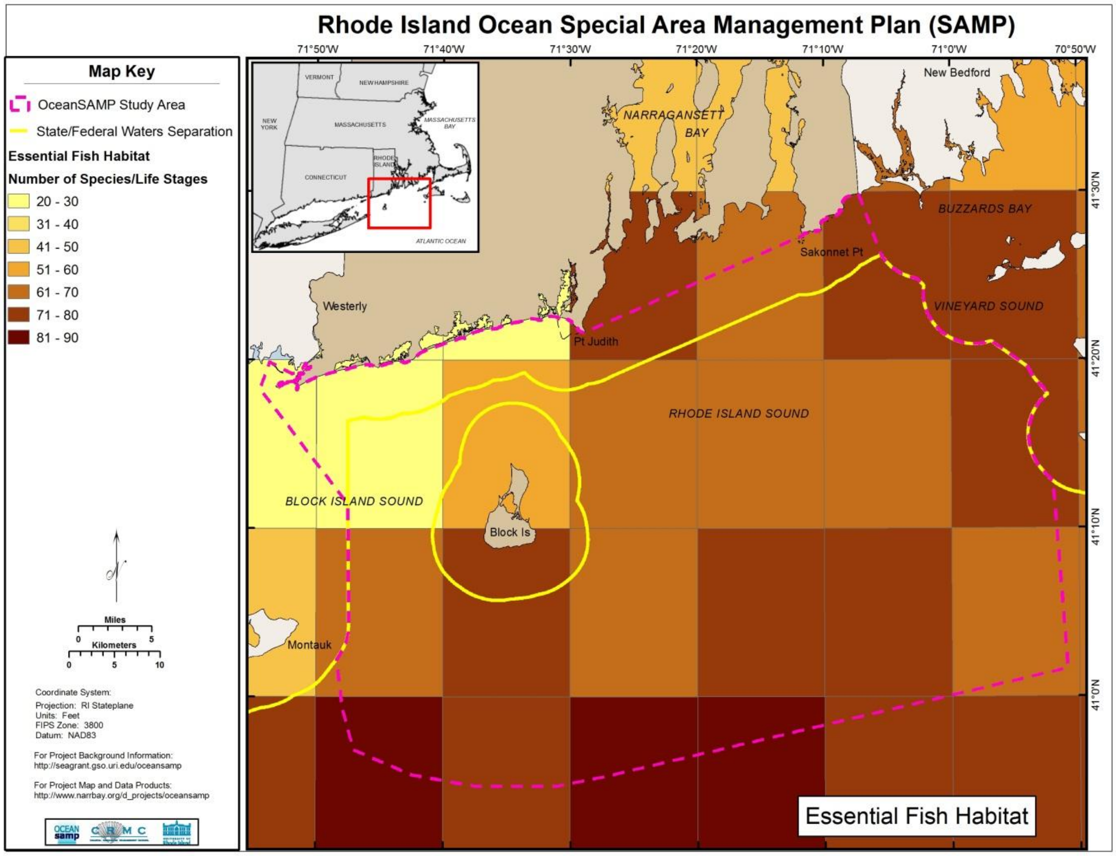


Figure 9. Essential Fish Habitat, depicted as total number of species and life stages with EFH in each 10’ latitude/longitude square.

3.2.4 Birds

To assess current spatial and temporal patterns of avian abundance and movement within the Ocean SAMP study area, as well as to identify the most common bird species using Ocean SAMP waters, aerial, ship-based, and land-based surveys were conducted by the URI’s Department of Natural Resources Science. For a detailed discussion of survey methodologies and preliminary results, refer to Paton et al. (2010). The data summarized in that report were provided to ASA in June 2010 and updated in December 2010. These surveys continued and another updated report, with more complete bird data, will be released in mid-2011.

Nearshore and offshore ship-based line-transect surveys were conducted approximately once per month from February to May 2009 on two 7.4 by 9.26 km grids and then approximately four times per month from June 2009 until March 2010 on eight 7.4 by 9.26 km grids (Figure 10). These surveys were designed to quantify the density and abundance of all species of waterbirds within each survey grid. Using a chartered vessel operating at constant speed, all individuals observed within a moving "box" 300 m ahead of and 300 m perpendicular to the vessel were recorded. Environmental data were also recorded, as well as anthropogenic influences that may have attracted birds to the transect, such as fishing boats or floating debris, etc.

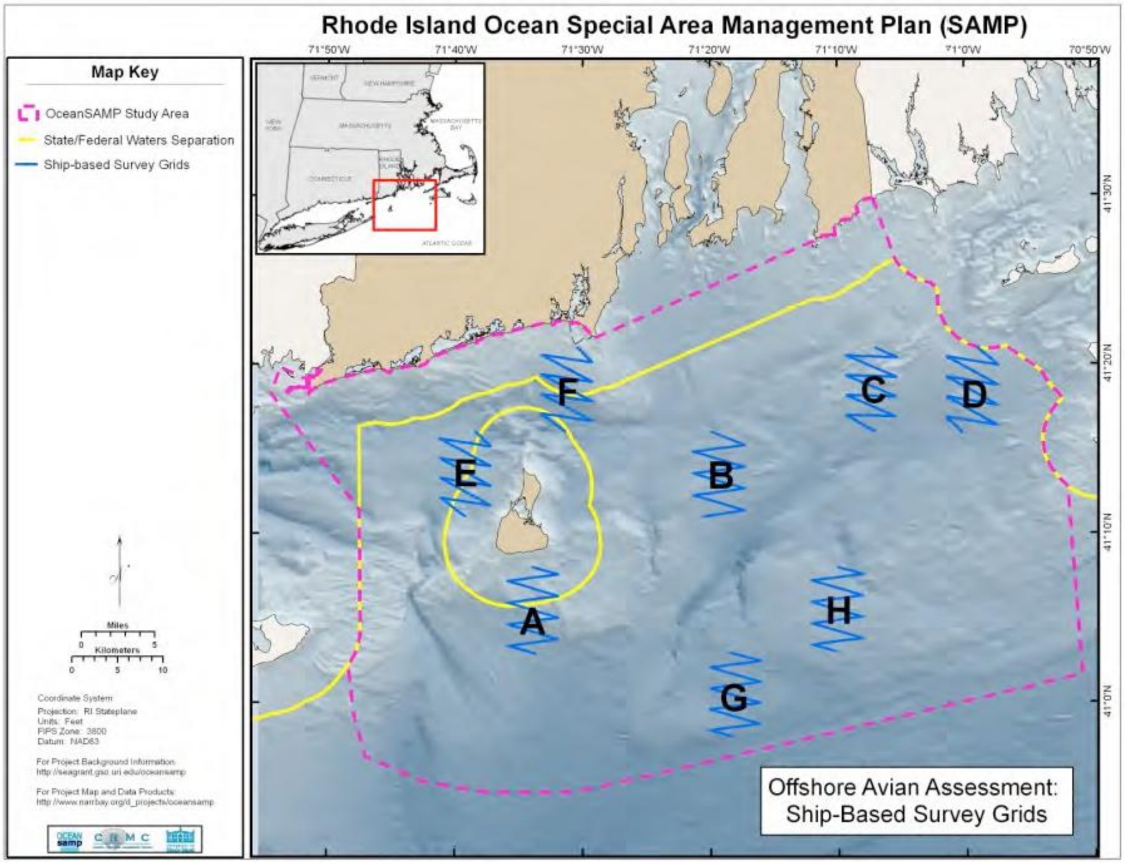


Figure 10. Locations of nearshore and offshore ship-based survey grids (Paton et al, 2010, Figure 24 therein).

The ship-based survey data were used to create surface density models to visually depict the abundance distribution of species common to the Ocean SAMP study area. The surface density models relate survey observations with depth and distance to land to predict densities across sampled and un-sampled areas. A grid made up of 2 km by 2 km cells was overlaid over the study area and populated with predicted abundance for each cell. Based on the predictions for each of the grid cells, abundance distribution maps were generated for eight species groups by season (Table 4). These abundance maps represent foraging areas for the species evaluated, and do not include movement corridors (see Figure 11 for an example abundance distribution map). A variance component was also calculated for each model. Because the abundance maps are based on a predictive model based on behavior (rather than a spreading model such as Kriging) and patchy observational data, some artifacts of the model are apparent in the maps, namely the light and dark "contours" of abundance at varying distances from shore that result from the distance-from-land-based model used for the surfaces (Figure 11). For a more detailed discussion of the development and application of the surface density models, refer to Paton et al. (2010). Improvements to this modeling approach are currently being developed by Paton et al., which will be described in an updated report expected to become public in mid-2011.

Table 4. Bird groups included in the EVM.

Bird Group	**Species Included in the Surface Density Model**	**Survey Data included in the Surface Density Model**
Loons	Common loon (*Gavia immer*)	Aerial survey (winter, spring)*
Alcids	Razorbill (*Alca torda*) Common murre (*Uria aalge*) Dovekie (*Alle alle*)	Ship survey (winter), Aerial survey (spring)
Gulls	Great black-backed gull (*Larus marinus*) Herring gull (*Larus argentatus*) Laughing gull (*Leucophaeus atricilla*)	Ship survey (winter, spring, summer, fall)
Gannets	Northern gannet (*Morus bassanus*)	Ship survey (winter, spring, fall)
Sea Ducks	Common eider (*Somateria mollissima dresseri*) Surf scoter (*Melanitta perspicillata*) Black scoter (*Melanitta nigra americana*)	Aerial survey (winter, spring)*
Shearwaters	Cory's shearwater (*Calonectris diomedea*) Greater shearwater (*Puffinus gravis)*	Ship survey (summer)
Terns	Common tern (*Sterna hirundo*) Roseate tern (*Sterna dougallii*)	Aerial survey (summer)
Petrels	Wilson's storm-petrel (*Oceanites oceanicus*)	Ship survey (summer)

*Survey data was unavailable for the fall season for loons and sea ducks, but these groups are both abundant in the fall in the Ocean SAMP area. As a result, spring surface density models were used as a proxy for fall surface density models for these two species groups in the EVMs.

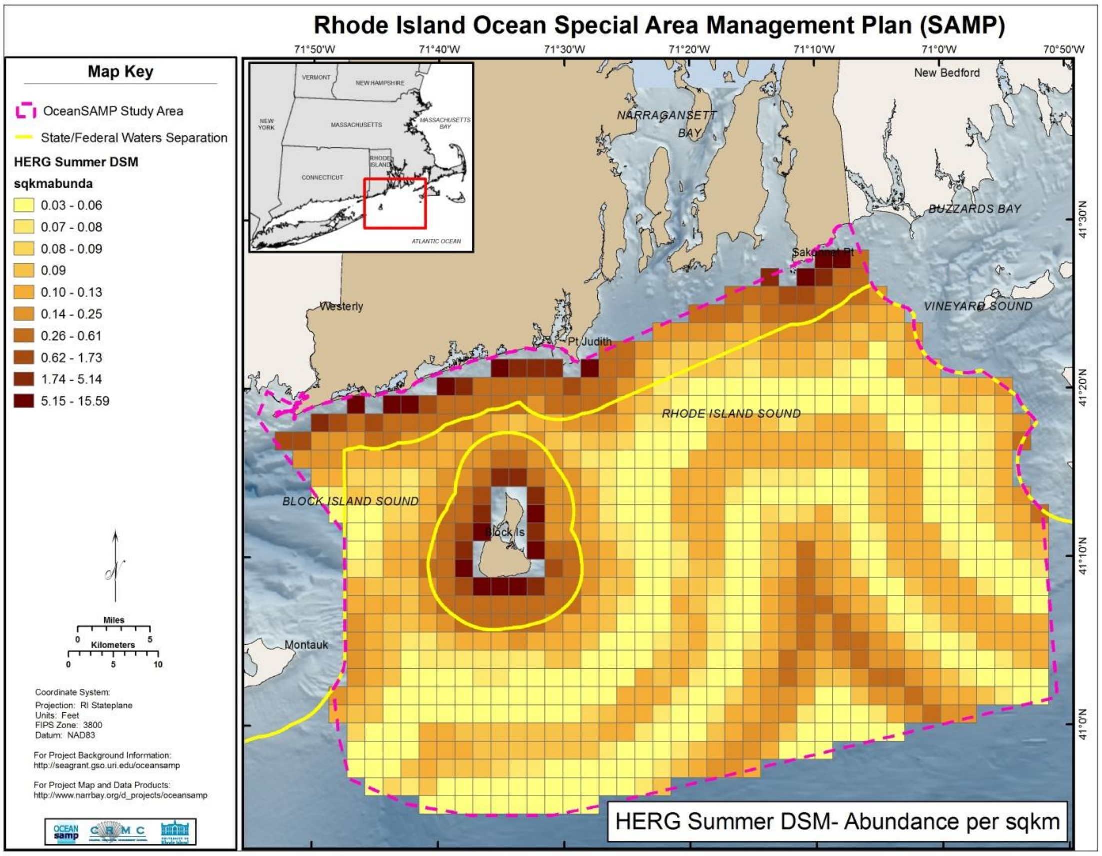


Figure 11. Example abundance distribution map (predicted summer herring gull abundance per square kilometer) (Paton et al. 2010).

Based on both land-based and ship-based survey counts, Paton et al. (2010) have identified 25 waterbird species that commonly inhabit and/or use the waters of the Ocean SAMP area. Common eider are the most abundant user of nearshore waters (≤ 3 km from shore), followed by the herring gull and surf scoter. Offshore waters (> 3 km from shore) are utilized most heavily by northern gannets, followed by Wilson's storm-petrels, and herring gulls. Gulls appear to be one of the major users of Ocean SAMP waters, both inshore and offshore, and throughout the seasons. In general, bird life is most diverse and abundant during fall and spring migration periods, and during winter (Paton et al., 2010).

3.2.5 Marine Mammals

Data for cetaceans and pinnipeds were provided by Robert Kenney (URI). The procedure for data collection and analysis is described in Kenney and Vigness-Raposa (2009). All data described below and used in the ecological value analysis were normalized sightings per unit effort (SPUE) values. Figure 12 is an example of the modeled SPUE surfaces incorporated into the EVM for marine mammals. Similarly, Kenney and Vigness-Raposa (2009) classified all species into five priority categories for the Ocean SAMP area. All species with sufficient data records were included in this ecosystem analysis regardless of priority ranking.

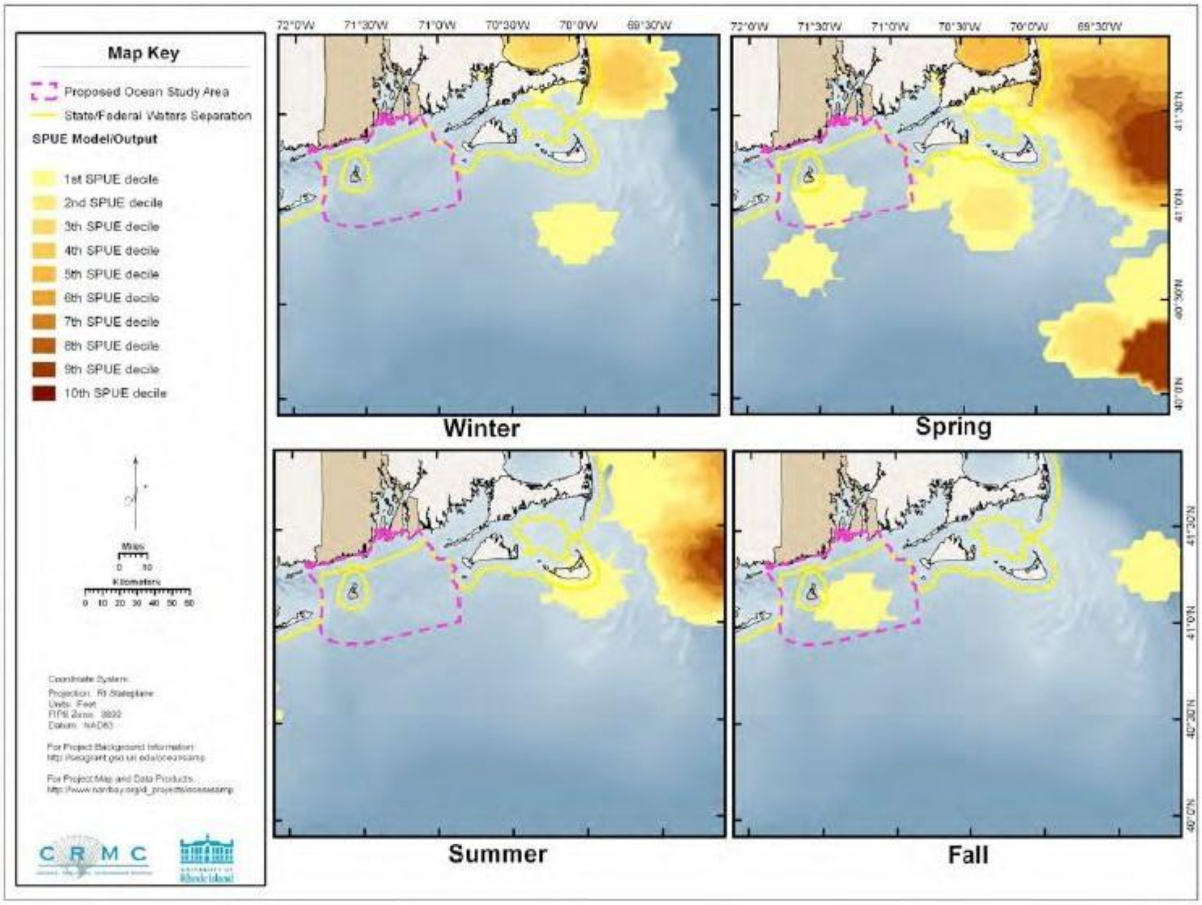


Figure 12. Example modeled-predicted surface of seasonal relative abundance (North Atlantic right whale) (Ocean SAMP, Figure 2.32(a) therein).

3.2.5.1 Distributions of Cetaceans in RI Ocean SAMP Area

Thirty species of cetaceans (whales, dolphins, and porpoises) have been observed in the offshore waters of Rhode Island. Many of these have been observed only occasionally due to many factors including widely dispersed populations and preferred habitat in other locations. A full account of all species observed can be found in Kenney and Vigness-Raposa (2009).

Cetaceans that were observed frequently enough to allow statistical interpretation and are included in the analysis are: North Atlantic right whale (*Eubalaena glacialis*), humpback whale (*Megaptera novaeangliae*), fin whale (*Balaenoptera physalus*), sperm whale (*Physeter macrocephalus*), harbor porpoise (*Phocoena phocoena*), Atlantic white-sided dolphin

(*Lagenorhynchus acutus*), short-beaked common dolphin (*Delphinus delphis*), common minke whale (*Balaenoptera acutorostrata*), pilot whales (long-finned, *Globicephala melas*, and short-finned, *G. macrorhynchus*), and common bottlenose dolphin (*Tursiops truncatus*).

Many of these species have higher relative abundances east of Cape Cod and in offshore waters south of the Ocean SAMP area. Of all the species analyzed, North Atlantic right whales are the species of greatest concern. Right whales are currently protected in a large portion of the Ocean SAMP waters November through April by requiring large ships to maintain speeds of 10 knots or less through the Block Island Seasonal Management Area (SMA, Figure 13). Right whales can be found in Rhode Island waters during any season, though the modeled abundance shows presence only in spring and fall (Kenney and Vigness-Raposa, 2009; Figure 12). Like EFH, the SMA is area is not included in the EVM procedure but rather should be utilized as an interpretation tool when evaluating potential projects.

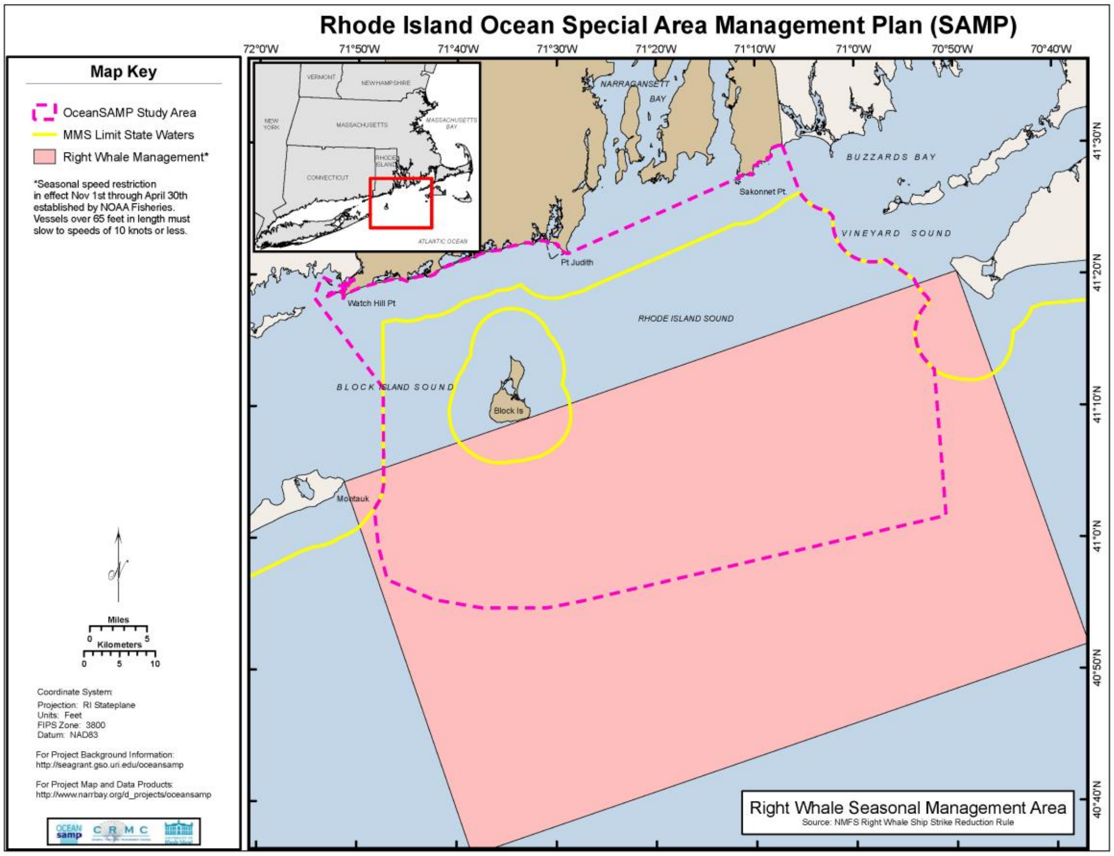


Figure 13. NMFS right whale seasonal management area. Seasonal speed restrictions are in effect November 1st through April 30th. Vessels over 65 feet (19.8 meters) in length must slow to speeds of 10 knots (5.1 m/sec) or less (Ocean SAMP Figure 7.3 therein).

3.2.5.2 Distributions of Pinnipeds in RI Ocean SAMP Area

Pinnipeds found in the Ocean SAMP area include five species of seals: harbor seal (*Phoca vitulina*), gray seal (*Halichoerus grypus*), harp seal (*Pagophilus groenlandicus*), hooded seal (*Cystophora cristata*), and ringed seal (*Pusa hispida*) (Kenney and Vigness-Raposa, 2009). Of these species, harbor seals are common in the Ocean SAMP area, particularly along Block Island, and are considered seasonal residents of Rhode Island. Harp, hooded, and gray seals are also all common in the Ocean SAMP area, while the ringed seal is rare.

Unlike cetaceans, pinnipeds also use the terrestrial environment, mainly as "haul-out" sites for activities such as resting. When out of the water they are usually easily startled by natural and anthropogenic activities (Richardson, 1995b). Narragansett Bay has many haul-out sites, as does Block Island, used primarily by harbor seals (Schroeder, 2000). These locations are important to these species and should be considered in the siting of offshore projects. Like the right whale SMA, their haul-out locations are not included in the EVM but should be used as an additional tool to evaluate potential projects.

Distinguishing between species of seals at sea is difficult during a survey, and some aerial surveys (e.g., those targeting right whales) may not spend the time to differentiate harbor and gray seals in large, mixed-species haul-outs. Therefore, the data analyzed contained a large number of seal sightings that were not identified to species. Because of this, the modeled relative abundance of seals was calculated by combining all records of seals. Abundance is highest in Narragansett Bay and between the south shore of Cape Cod and the islands during fall, winter, and spring (Kenney and Vigness-Raposa, 2009).

3.2.6 Sea Turtles

There are four sea turtle species found in the waters of the north Atlantic off Rhode Island and southern Massachusetts. In the Ocean SAMP area, leatherback sea turtles (*Dermochelys coriacea*) are common, and loggerhead sea turtles (*Caretta caretta*) are the most common. The Kemp's ridley (*Lepidochelys kempii*) sea turtle has been documented in significant numbers in Cape Cod Bay in the summer, but data are lacking on the migration path these turtles follow and where they occur in the Ocean SAMP area. However, because the Kemp's ridley inhabits coastal waters and embayments, it should be considered when assessing ecological value of the area. The green (*Chelonia mydas*) sea turtle is also a coastal species, feeding on eelgrass and other aquatic grasses, and has rarely been sighted in the Northeast in the last several decades. It is possible that restoration of eelgrass beds in the Northeast and warming water temperatures may lead to range expansion of the green sea turtle into the Ocean SAMP region in the future.

Of the four turtle species, to date only leatherbacks and loggerheads have been sighted with enough frequency in the Ocean SAMP region for abundance patterns to be analyzed, although incomplete and/or unavailable datasets may ultimately tell a different story. See Kenney and Vigness-Raposa (2009) for methods and procedures regarding the relative abundance analysis. Figure 14 is an example of the model-predicted SPUE surfaces incorporated into the EVM for sea turtles.

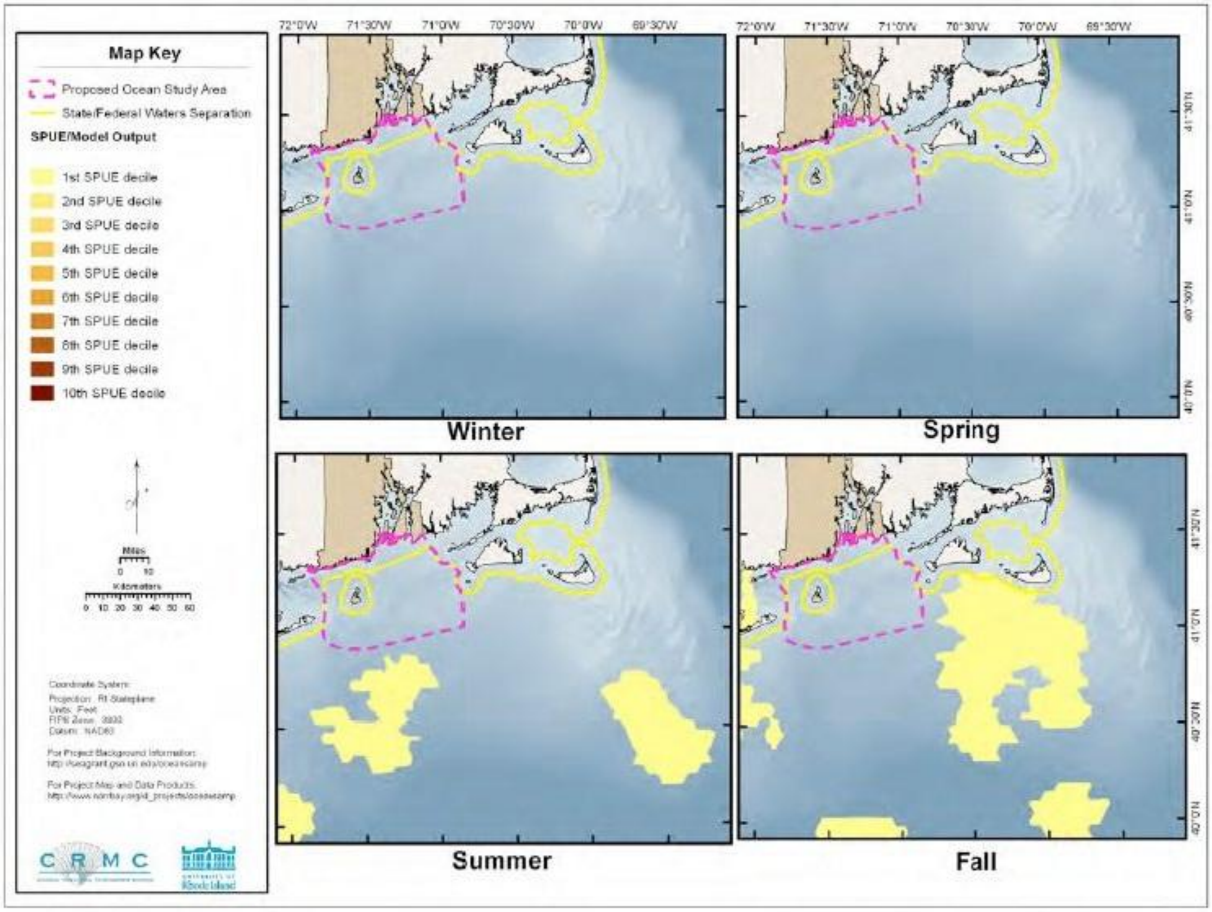


Figure 14. Example model-predicted surface of seasonal relative abundance (leatherback sea turtle) (Ocean SAMP, Figure 2.35 therein).

While combining the turtle data is not advised because of the differences in life histories between the species, it is likely that conservation methods made for one species of sea turtle will benefit the others (Kenney and Vigness-Raposa, 2009). Therefore, even though only the leatherback and loggerhead are represented in the EVM for the Ocean SAMP area, all four species would likely benefit from mitigation or conservation methods directed at individual sea turtle species.

3.2.7 Bats

Bat mortality at land-based wind farms has become an increasing concern that is not well understood (Cryan and Brown, 2007), but serious enough to halt the continued development of a wind farm in West Virginia (Glod, 2009). This landmark case demonstrated that the ecology of proposed locations warrants careful consideration, especially with regards to potential impacts on endangered species.

The majority of bats killed by land-based wind turbines are migratory tree bats that roost in trees throughout the year and migrate seasonally (Cryan and Brown, 2007). Migratory tree bats that occur within the Ocean SAMP area include the eastern red (*Lasiurus borealis*), hoary (*L. cinereus*), and silver haired bats (*Lasionycteris noctivagans*). Bat behavior during migration is still largely undescribed, with little more than hypotheses as to why bats are at such a high risk for mortality (Cryan and Barclay, 2009). At land-based wind farms scientists are researching whether bats are attracted to turbines, and if mating and/or feeding behaviors play a role in fatalities.

Bats are commonly considered terrestrial mammals but migratory species have been found to migrate over open oceans; many sightings, both confirmed and anecdotal, of flocks flying over open water have been recorded over the past century (Cryan pers. comm., 2009). Cryan and Brown (2007) investigated the occurrence of horay bats on one of the Farallon Islands, an island off the coast of California used as a stopover point. This study confirms the migration of bats over open water and suggests that occurrences could be predictable based on weather and other environmental conditions.

To date the migration patterns of bats along the east coast are not well documented, therefore it is difficult to determine if the coastal and offshore areas of Rhode Island are part of bat flyways. In the Northeast, bat observations include:

- Periodic sightings in the spring and fall at the lighthouse on Mount Desert Rock, thirty miles (48.2 km) off the coast of Maine;
- Oceanic sighting around the islands of coastal Maine and the Gulf of Maine, off Nova Scotia, and off Montauk Point New York; and

- Observation closer to shore over Long Island Sound, off Sandy Hook New Jersey, across Cape Cod and Cape Cod Bay, and Nantucket Sound (Cryan, pers. comm.).

Bats have also been observed seasonally on Bermuda, indicating that they are likely migrating over a large expanse of open water (Van Gelder and Wingate, 1961). As part of their pre-project research, Deepwater Wind is using radar to monitor for bats on Block Island. There are no other published reports on the occurrence, or lack thereof, of seasonal or resident bats on the island. Because there is only anecdotal evidence of bats over open waters around the Ocean SAMP area, they were not included in the EVM.

3.3 Relative Weighting Schemes

The weighting schemes used in this analysis are described below. These weighting schemes are considered exploratory and other weighting schemes may be discussed and evaluated as issues specific to the RI Ocean SAMP arise. It should be noted that these weighting schemes, set on a relative scale from 1 (no extra weight) to 10 (highest weight), can be applied to any group of EVMs; for example, these criteria can help determine how bird species (*component EVMs*) should be weighed against each other to generate a *category EVM*; or applied to multiple *category EVMs* to depict the relative importance of fish over birds (for example) in generating a *composite EVM*. The weighting schemes may also be combined, either with equal weight (i.e., all are on a scale of 1-10) or with criteria weights (e.g., protection status may be considered of higher importance than proportional importance to regional-global scale).

3.3.1 Proportional Importance to Regional-Global Scale

The national, regional, and global distributions of resources may be used to put resource occurrences in the study area into various contexts. If a resource is confined within the study area, it should potentially be handled differently than one that has a global distribution. In order to determine the proportional importance of the study area to each resource, questions regarding their distribution can be evaluated, including:

- Is the Rhode Island population of this species a major proportion of the national/regional/global population?
- Is the Rhode Island population of the species otherwise important to the national/regional/global population? (E.g., does the Rhode Island subpopulation provide important genetic diversity to the larger population?)

This weighting scheme, scaled from 1 = not important to 10 = highest importance at the global scale, will mostly be applied to generate category EVMs, but may be used to depict importance of local components (e.g., certain benthic habitats) over more globally distributed components (e.g., sea turtles) in a composite EVM. Below is the scheme utilized in this study:

- 10 – Distribution indigenous, found only in the Rhode Island study area
- 8 – Distributed in northeastern North America (Mid-Atlantic U.S. to Newfoundland)
- 6 – Distributed in the Northwest Atlantic or eastern North America
- 4 – Distributed in the northern Atlantic or in North America and Europe
- 2 – Distributed in the Atlantic or in multiple continents around the Atlantic
- 1 – Global distribution, RI study area a very small fraction of distribution

3.3.2 Resource and Protection Status

Some species have been designated by governments and international organizations as at higher risk for extinction than others. These designations are usually a result of declining population numbers. However, just because a population on the whole is declining in numbers does not necessarily mean that all subsets of the population face the same problem. Likewise, a population on the whole could be stable while a subpopulation is currently declining. Because of this distinction several questions need to be considered when evaluating how to weigh population status, including:

- Is the population listed as a species of special concern, threatened, endangered, or not listed?
- How prevalent is the population in the study area?
- Is the segment of the population found in the study area unique to the whole population?

A weighting scale that reflects protection and population status, as applied here, is:

- 10 – Listed as endangered at the federal level
- 9 – Listed as endangered at the state level
- 8 – Listed as threatened at the federal level
- 7 – Listed as threatened at the state level

- 6 – Listed as a species of concern at the federal level, a candidate species for listing, or afforded special protection under regulations other than the Endangered Species Act (e.g., Marine Mammal Protection Act, Migratory Bird Treaty Act)
- 5 – Listed as a species of species concern at the state level or a candidate species for listing
- 4 - Not listed, but at low population size relative to historical levels
- 3 - Not listed, but decreased or decreasing population size
- 2 - Not listed, at approximately historical population size
- 1 - Not listed, highly abundant compared to historical levels.

In addition to weighting the entire data layer according to protection status, portions of the gridded data layer could be weighed differently to highlight the importance of certain protected areas, such as MPAs or areas designated as critical habitat. In this way both spatially-discriminated protection (MPAs) and species-specific protection could be incorporated into the weighting scheme and EVM. However, there are no MPAs in the Ocean SAMP area, and there are EFH designations in all areas of the Ocean SAMP. Thus, this type of weighting is not included in this application.

3.3.3 Relative Potential Impact of Development

Offshore alternative energy development may adversely impact the marine environment as the result of activities causing habitat alteration, noise, vibration, collisions, and electromagnetic fields (EMF). To date there are a handful of documents that assess the potential direct, indirect, and cumulative impacts of alternative energy projects. These include reports from the United Kingdom's Collaborative Offshore Wind Research Into the Environment (COWRIE) (Gill et al., 2005; Thomsen et al., 2006; SMRU Ltd, 2007; Gill et al., 2009; and King et al., 2009), a MMS synthesis document by Michel et al. (2007), and the MMS Programmatic Environmental Impact Statement (PEIS) for alternative energy projects (MMS, 2007). A majority of the operational and construction impact studies for offshore alternative energy come from wind development projects in Europe (e.g., Horns Rev, Nysted, and various projects in the United Kingdom). Many of the construction, and some operational, activities are similar in nature to those involved in offshore oil and gas exploration. Therefore some of the oil and gas environmental impact literature has been leveraged for alternative energy (e.g., benthic habitat alteration during construction, introduction of artificial reef and increased structure during operations).

Relative impact potential is generally project- and site-specific. That is, impact type and degree of effects are often dependent on location (physical and biological conditions), the energy project type (e.g., wind, wave, tidal current), and the construction methodologies employed. For example, adverse avian impacts associated with wind energy projects can range from high to low and depend heavily on location. Conversely, with tidal energy projects entrainment and impingement of fish are major concerns, while bird collisions may not be as important. Different resources also vary in their sensitivity to potential impacts.

There are numerous methods and approaches whereby impacts to the marine environment are measured. These methods have been developed through federal, state, and global initiatives, as well as by non-governmental stakeholder and academic organizations. Examples of different approaches for assessing impacts on the marine environment are described below.

Horns Rev Criteria-Based Scheme

In Europe, there have been a few impact analyses conducted on wind farms in Denmark and the United Kingdom. Skov et al. (2006) investigated the impacts on marine mammals from the Horns Rev 2 wind farm in Denmark. Table 5 outlines the assessment criteria used including importance of the issue, magnitude, persistence, and likelihood of occurring (Skov et al., 2006).

Table 5. Criteria for assessing impacts for the Horns Rev 2 offshore wind park Environmental Impact Assessment (Skov et al., 2006).

Criteria	Factor	Notes
Importance of the Issue	1. International interests 2. National interests 3. Regional interests 4. Local areas and areas immediately outside the condition 5. Only to the local area 6. Negligible to no importance	In physical and biological environment, local area is defined as wind park area
Magnitude of the impact or change	1. Major 2. Moderate 3. Minor 4. Negligible or no change	Levels of magnitude may apply to both beneficial/positive and adverse/negative impacts
Persistence	1. Permanent—for the lifetime of the project or longer 2. Temporary (long term)—more than 5 yrs 3. Temporary (medium term)—1 to 5 yrs 4. Temporary (short term)—less than 1 yr	
Likelihood of occurring	1. High (>75%) 2. Medium (25–75%) 3. Low (<25%)	

Criteria	Factor	Notes
Other	Direct/indirect impact—caused directly by the activity or indirectly by affecting other issues as an effect of the direct impact	

US MMS PEIS-Based Scheme

The United States National Environmental Policy Act (NEPA) requires federal agencies to integrate environmental values into their decision-making processes by considering the environmental impacts of their proposed actions. There are various NEPA standards and definitions for assessing impacts that are used in Environmental Impact Assessments (EIA) and Environmental Impact Statements (EIS). These criteria are reflected in the Programmatic Environmental Impact Statement (PEIS) for alternative energy projects (MMS, 2007). The PEIS is the U.S. government's published expected relative impact document (MMS, 2007) that is general to all alternative energy development for the outer continental shelf (OCS).

Table 6 is a summary of the impact magnitude by ecological component as specified by the PEIS. The impact levels in the table are defined as follows:

- *Negligible* – means there is no measurable impact.
- *Minor* – means that most impacts to the affected resource could be avoided with proper mitigation. If impacts occur, the affected resource will recover completely without any mitigation once the impacting agent is eliminated.
- *Moderate* – means that impacts to affected resources are unavoidable. The viability of the affected resource is not threatened although some impacts may be reversible. The affected resource would recover completely if proper mitigation is applied during the life of the project or proper remedial action is taken once the impacting agent is eliminated.
- *Major* – means that impact to the affected resource is unavoidable. The viability of the affected resource may be threatened and would likely not fully recover even if proper mitigation is applied during the life of the project or remedial action is taken once the impacting agent is eliminated.

Table 6. Magnitude of impacts from OCS wind development activities by ecological component as stated in the Programmatic Environmental Impact Statement (PEIS) (MMS, 2007).

Ecological Component	Project Phase/ Activity Type	Impact Level			
		Negligible	Minor	Moderate	Major
Marine Mammals	**Construction**				
	Geological and Geophysical Surveys	X (most species)	X (T&E species)		
	Noise		X (most species, and T&E species)	X (some species, and T&E species)	
	Vessel Traffic		X (most species,	X (T&E species)	X (T&E species)
	Waste Discharge and Accidental Fuel Releases	X			
	Operation				
	Turbine Noise			X	
	Service Vessel Collision		X (most species)	X (T&E species)	X (T&E species)
	Service Vessel Traffic Noise	X			
	Accidental Releases of Fuels (service vessels)	X			
	Accidental Releases of Fuels (wind facility)	X (dependent on size of spill)	X (dependent on size of spill)	X (dependent on size of spill)	X (dependent on size of spill)
	Entanglement		X (gray whale)	X (gray whale)	
Marine and Coastal Birds	**Construction**				

Ecological Component	**Project Phase/ Activity Type**	**Impact Level**			
		Negligible	**Minor**	**Moderate**	**Major**
	Cable Trenching	X	X (dependent on proximity to shore, amount of habitat loss)	X (dependent on proximity to shore, amount of habitat loss)	
	Waste Discharge and Accidental Fuel Releases	X			
	Onshore Construction		X (dependent on long-term, short-term disturbance)	X (dependent on long-term, short-term disturbance)	
	Offshore Construction	X (dependent on habitat type and species present)	X (dependent on habitat type and species present)	X (dependent on habitat type and species present)	
	Operation				
	Turbine Collisions		X (dependent on species and number affected)	X (dependent on species and number affected)	X (dependent on species and number affected)
	Turbine Site Avoidance	Unknown	Unknown	Unknown	Unknown
	Service Vessel Traffic	X			
	Accidental Releases of Fuels (service vessels)	X			
	Accidental Releases of Fuels (wind facility)	X (dependent on size of spill)	X (dependent on size of spill)	X (dependent on size of spill)	X (dependent on size of spill)
Fish Resources and EFH	**Construction**				
	Sediment Disturbance	X (dependent on species mobility)	X (dependent on species mobility)		

Ecological Component	**Project Phase/ Activity Type**	**Impact Level**			
		Negligible	**Minor**	**Moderate**	**Major**
	Crushing of Benthic Organisms	X (dependent on foraging species mobility)	X (dependent on foraging species mobility)		
	Turbidity	X			
	Noise	X (dependent on species and persistence of noise)	X (dependent on species and persistence of noise		
	Vessel Traffic	X			
	Waste Discharge and Accidental Fuel Releases	X			
	Operation				
	Scouring Around Piles		X		
	Habitat Alteration	X (dependent on prevalence of habitat type, species, and project magnitude)	X (dependent on prevalence of habitat type, species, and project magnitude)	X (dependent on prevalence of habitat type, species, and project magnitude)	X (dependent on prevalence of habitat type, species, and project magnitude)
	Lighting	Unknown	Unknown	Unknown	Unknown
	Service Vessel Traffic	X			
	Turbine Noise and Vibration	X (dependent on intensity of noise and species)	X (dependent on intensity of noise and species)		
	Electromagnetic Fields	X (more study needed)	X (more study needed)		
	Accidental Releases of Fuels (service vessels)	X (dependent on size of spill)	X (dependent on size of spill)		

Ecological Component	**Project Phase/ Activity Type**	**Impact Level**			
		Negligible	**Minor**	**Moderate**	**Major**
	Accidental Releases of Fuels (wind facility)	X (dependent on size of spill)	X (dependent on size of spill)	X (dependent on size of spill)	X (dependent on size of spill)
Sea Turtles	**Construction**				
	Geological and Geophysical Surveys	X (most species)	X (T&E species)		
	Noise		X		
	Cable Trenching		X (dependent on location)	X (dependent on location)	
	Vessel Traffic		X (juveniles and adults)	X (hatchlings)	
	Waste Discharge and Accidental Fuel Releases	X	X		
	Onshore Construction	X (dependent on proximity to nesting site)	X (dependent on proximity to nesting site)	X (dependent on proximity to nesting site)	
	Operation				
	Turbine Noise	Unknown	Unknown	Unknown	Unknown
	Service Vessel Traffic		X	X	
	Accidental Releases of Fuels (service vessels)	X (juveniles and adults)	X (hatchlings, dependent on location)		
	Accidental Releases of Fuels (wind facility)	X (dependent on size of spill and proximity to nesting habitats)	X (dependent on size of spill and proximity to nesting habitats)	X (dependent on size of spill and proximity to nesting habitats)	X (dependent on size of spill and proximity to nesting habitats)
Seafloor Habitat	**Construction**				
	Disturbing Sediments	X	X		
	Crushing of Benthic Organisms	X	X		
	Turbidity	X	X		
	Habitat Alteration	X	X		

Ecological Component	**Project Phase/ Activity Type**	**Impact Level**			
		Negligible	**Minor**	**Moderate**	**Major**
	Operation				
	Habitat Alteration	X	X		
	Turbine Noise	X	X		
	Electromagnetic Fields	X	X		
Fisheries	**Construction**				
	Habitat Alteration	X			
	Noise	X			
	Space-use Conflicts	X			
	Vessel Traffic	X			
	Waste Discharge and Accidental Fuel Releases	X			
	Operation				
	Space-use Conflicts	X (dependent on location)	X (dependent on location)	X (dependent on location)	
	Service Vessel Traffic	X			
	Turbine Noise	X			
	Electromagnetic Fields	X			
	Habitat Alteration	X			
	Navigation Hazards	X			
	Waste Discharge and Accidental Fuel Releases	X			
	Gear Entanglement	Unknown	Unknown	Unknown	Unknown

EVM: Modified MMS-PEIS Scheme Based on Noise, EMF and Other Research

To incorporate the relative impact of development on resources in the RI Ocean SAMP area into the EVM, we developed a weighting scheme to reflect how individual resources could potentially be affected by actions or environmental consequences associated with offshore wind farm development:

- 10 – Potential to be killed
- 8 – Potential to be injured
- 6 – Potential for habitat loss or degradation

- 4 – Potential to be harassed (e.g., annoyance, disruption of behavioral patterns such as migration, breeding, feeding, or sheltering)
- 3 – Potential for indirect adverse impacts (e.g., reduced prey availability)
- 2 – Insignificant or discountable (i.e., extremely unlikely) impact
- 1 – Beneficial effect or no potential adverse effect

Using this scheme, we evaluated the potential impact of a hypothetical wind farm development project on each species individually. Construction activities were assumed to include the installation of a subsea cable with a shore landfall. For this evaluation, construction and operations activities were considered separately using the same weighting scale, and all activities were assumed to be unmitigated. In reality, state and federal regulatory agencies would require various mitigations to minimize adverse impacts on resources of concern. If mitigation was considered in the EVMs, the resulting maps are likely to show substantially different results. Future versions of the EVM could be modified to include mitigation measures, either by adding a weighting scheme with negative values, or by simply assigning lower potential impact weights to each resource (as appropriate given the type of mitigation).

To assign weights to each species, we considered their life history, behavioral characteristics, and overall sensitivity to the suite of potential impacts associated with offshore wind farm construction and operation. For example, for the North Atlantic right whale, the main potential impacts of offshore wind farm construction were assumed to be noise, increased turbidity, and vessel collisions. Considering these potential impacts overall, this species was assigned an 8 for construction (i.e., potential to be injured) because unmitigated noise and vessel collisions could result in injury. In addition to the potential impacts listed in the MMS-PEIS table (Table 6), we also considered the research and information discussed below in assigning weights to individual species.

Noise

Research in Europe provides additional information on the impacts of noise associated with wind farm construction and operations (Thomsen et al., 2006). Reviews have shown that the noise from construction-related pile driving has the most potential to cause adverse impacts (Thomsen et al., 2006; Michel et al., 2007). Generally, marine mammals have been found to be most sensitive to sounds within their range of vocalizations (Richardson, 1995a). Because baleen whales utilize frequencies in the same range as pile-driving noise, they would be most sensitive. Dolphins and porpoises use higher frequencies for vocalizations (OSPAR, 2009). Harbor seals do not appear to be sensitive to construction activities and accompanying noise, returning quickly to preferred haulouts (MMS, 2007).

Electromagnetic Fields

Research in Europe also provides additional information on the impacts of electromagnetic fields (EMF) associated with wind farm operations (Gill et al. 2005; Gill et al., 2009). EMF is thought to have the highest effects on fish that sense both electric and magnetic fields: the elasmobranchs (sharks, skates and rays), eels and sturgeons. These groups use EMF to detect prey and for migratory cues. Eels and sharks detect or are attracted to electric transmission cables. The concern is that EMF from cables might disrupt migration or foraging. Most teleost (bony) fish do not sense electric fields, only magnetic fields (Gill et al. 2005; Gill et al., 2009). Presumably they would be less sensitive to EMF generated by buried cables interconnecting the turbines and carrying power to shore. Pelagic species would be less affected than benthic species, as the EMF would only influence organisms near the sea floor. Large migratory species could be more sensitive than small species because the large body size would be able to detect a magnetic field (Gill et al. 2005; Gill et al., 2009). Crustaceans could be attracted to EMF as well, as shrimp have been observed to be attracted to EMF emitters. The effects of EMF on wildlife (mammals, birds, sea turtles) are not well known. In general, however, EMF is thought to have at most a minor adverse impact (MMS, 2007).

Interactions between Wildlife and Wind Turbines

The impacts of wind turbines on birds and bats will depend on species-specific activities, such as flight height and the ability of individuals to avoid turbines or wind farms. Attractors such as lights, perching locations, and availability of prey may also affect their behavior around the wind farms. Certain wildlife species may prefer to avoid the turbines, and would thereby be excluded from the wind farm area.

Seabed Disturbance

Construction activities will disturb the benthos in the cable jet-plowing footprint and other areas disturbed by anchors, etc. Soft-bottom communities typically recover from such disturbance in 2-3 years, whereas hard bottoms require longer recovery times. This soft bottom recovery rate is a conservative estimate resulting from a review of benthic studies performed in the Narragansett Bay, Rhode Island and Long Island Sound regions (Rhoades et al., 1978;

Germano et al., 1994; U.S. Army Corps of Engineers [USACE], 1997; Newell et al., 1998; Murray and Saffert, 1999; USACE, 2001). Additionally, resuspension of sediments disturbed by construction activities can cause increased turbidity and may result in adverse impacts on fishery and other marine resources.

Habitat Alteration

Habitat alterations will be in the form of artificial reef creation, which may benefit hard-bottom communities and their predators. Displaced soft-bottom communities would be somewhat adversely impacted.

Relative impact weighting schemes can be applied at either the category EVM or composite EVM level. These results can be modified and weighting schemes can be adapted as new information regarding impacts of alternative energy development becomes available. In addition, cumulative impacts of multiple activities can be addressed by developing relative impact weighting results for each project or stressor, along with results from other weighting schemes such as proportional importance and resource protection status (Sections 3.3.1 and 3.3.2). Cumulative impacts are defined as the result of the incremental impact of the proposed action when added to other past, present, and reasonably foreseeable future actions (MMS, 2007). Thus, this EVM approach can be an Ecosystem-Based Management (EBM) tool (McLeod and Leslie, 2009) in that the entire ecosystem is considered, as well as the impact of human activity (i.e., offshore development).

3.3.4 Data Robustness and Resolution

The evaluation of resource values in an EVM is only as reliable as the input data; and different resources require varying degrees of effort for data collection. Thus, uncertainty associated with collected data and EVM layers needs to be evaluated. Data sets with more spatial accuracy should be distinguished from data sets requiring a lot of interpolation to generate a complete EVM layer. Questions that define data robustness include:

- What is the sampling resolution (spatially and temporally)?
- How many years of data are included?
- How frequently were the data collected?

Data layers with higher resolution in space and time are given relatively higher weights, whereas sparse data sets needing interpolation are weighted lower. Having multiple years of data collections would warrant a higher weighting than data for a single year or season. This data robustness weighting scheme can be applied at either the category or composite level.

3.3.5 Socio-Economic Values and Importance

Ecological values could be modified by factors related to stakeholder concerns, and so reflect human service values to some degree, while retaining the underlying scientific analysis and objectivity. We envision this stakeholder-value weighting would occur at the category level when developing an overall composite EVM, as stakeholders relate more to "fish", "birds" or "marine mammals" (for example) as opposed to individual species (Figure 2). However, no attempt was made to obtain such input or include this socioeconomic-based weighting in the present project.

4 Results of EVM Application and Discussion

4.1 Category EVMs

This section contains a selection of category EVMs generated for each ecological category, namely the annual average for Ecological Value, depicted with color bins based on quartiles. These maps represent only a small subset of the category EVMs produced for this study. Additional category EVMs (annual and seasonal), as well as the input component EVMs (annual and seasonal) are provided are provided as digital maps (see Appendix A for a description of the folder structure and naming convention).

4.1.1 Benthic Ecosystem

Benthic ecosystem category EVMs were created using the weighting scheme in Table 7.

Table 7. Weighting scheme for benthic ecosystem in the category EVM.

Weighting Criteria:	Regional-Global Importance	Protection Status	Impact Potential - Construction	Impact Potential - Operation	Data Robustness
Benthic Roughness	1	1	8	1	3

The benthic roughness of the RI Ocean SAMP area is fairly uniform throughout. The areas of highest roughness are located within Narragansett Bay (and therefore not in the Ocean SAMP area) and to the southwest of Block Island (Figure 15). Benthic roughness was used as a proxy for benthic community analyses which are labor intensive, especially over such a large area. As more detailed descriptions of the benthic communities are completed this category EVM can be modified.

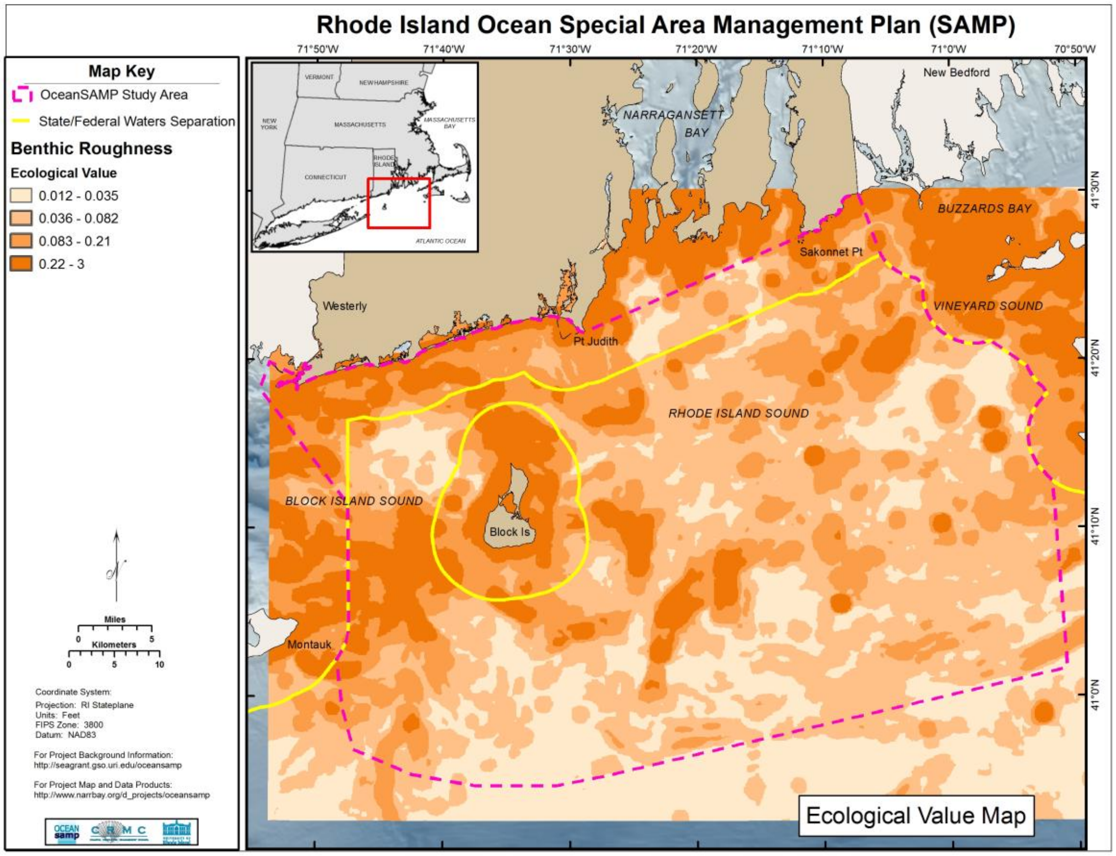


Figure 15. Category EVM of combined global importance *and* protection status for benthic ecosystems.

4.1.2 Pelagic Ecosystem

Pelagic ecosystem category EVMs were created using the weighting scheme in Table 8.

Table 8. Weighting scheme for pelagic ecosystem in the category EVM.

Weighting Criteria:	Regional-Global Importance	Protection Status	Impact Potential - Construction	Impact Potential - Operation	Data Robustness
Chlorophyll a	1	1	2	2	5

Remotely sensed surface chlorophyll *a* data shows that the highest concentrations occur during the summer, close to shore. During the fall and winter there is a more even distribution of chlorophyll concentrations throughout the Ocean SAMP area. In the spring, most of the Ocean SAMP has lower concentrations, with the areas to the west of Block Island showing the highest concentrations (see Appendix A for seasonal EVMs). When averaged over the year, the ecological value of chlorophyll (as a proxy for the pelagic environment) is generally higher closer to shore and lower in the offshore environment (Figure 16).

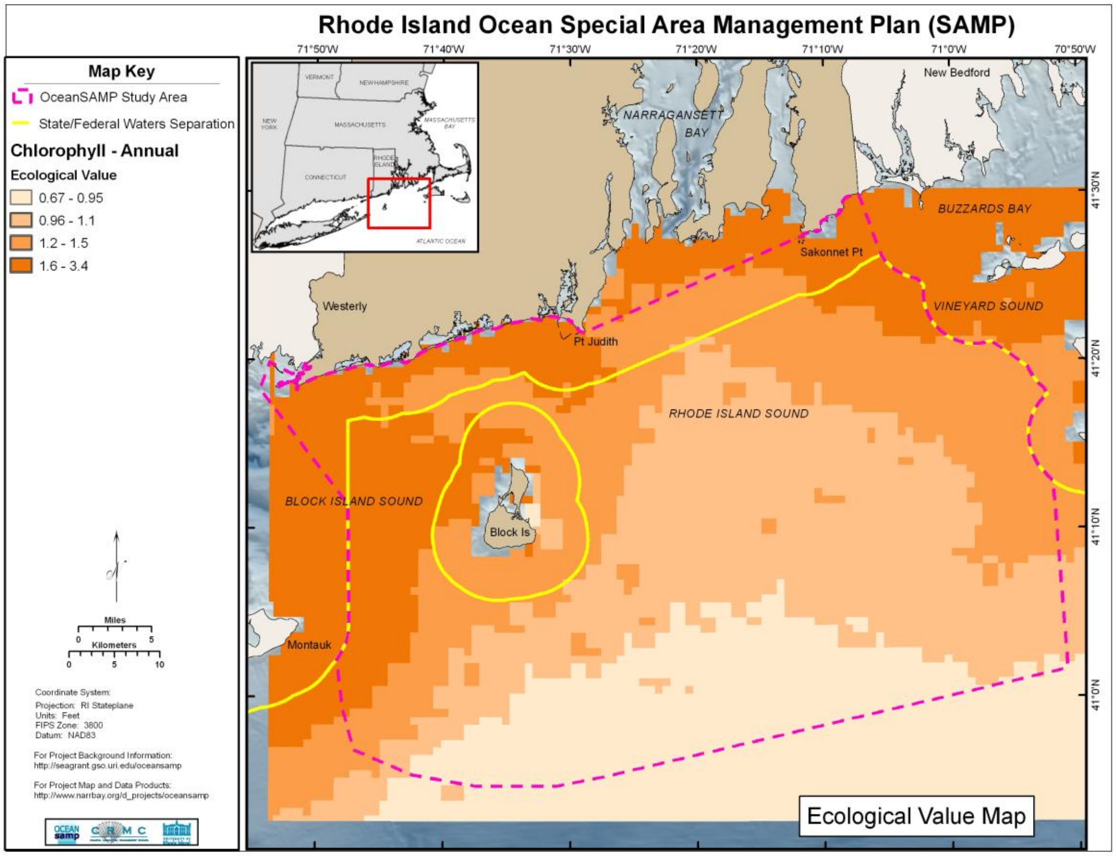


Figure 16. Category EVM of combined global importance *and* protection status for surface chlorophyll *a*, averaged over the seasons for an annual perspective.

4.1.3 Fish

The ten groups of fish and invertebrate species were combined into category EVMs using the weighting scheme in Table 9. The spread of values is similar across regional importance, protection status, and impact potential due to construction. Impact potential due to operation reflects that species that are associated with hard bottoms may actually benefit from the installation of a wind farm as they could find the piles and scour protection to be suitable habitat.

Table 9. Weighting schemes for fish and invertebrate groups included in the category EVM.

Weighting Criteria:	Regional-Global Importance	Protection Status	Impact Potential - Construction	Impact Potential - Operation	Data Robustness
Lobster	6	4	6	1	3
Sea Scallop	6	2	8	6	3
Squid	6	2	4	2	3
Demersal fish	6	4	6	6	3
Flatfish	8	4	6	6	3
Baitfish	4	2	4	2	3
River Herring/Smelt	8	6	4	2	3
Medium Gamefish	8	4	4	1	3
Large Gamefish	6	3	4	1	3
Skates	8	3	6	4	3

In the annual ecological value map of fishes and large invertebrates (see Appendix A for seasonal EVMs), areas of high relative ecological value fall into three general regions: south of the mouth of Narragansett Bay, in intermediate depths in the eastern portion of the Ocean SAMP study area, and southeast of Montauk, New York (Figure 17). Because this map is made up of ten species groups with varying habitat preferences, one would not expect to see a clear trend associated with a particular sediment/habitat type. However, there is a general trend of higher ecological value closer to shore than in the offshore environment.

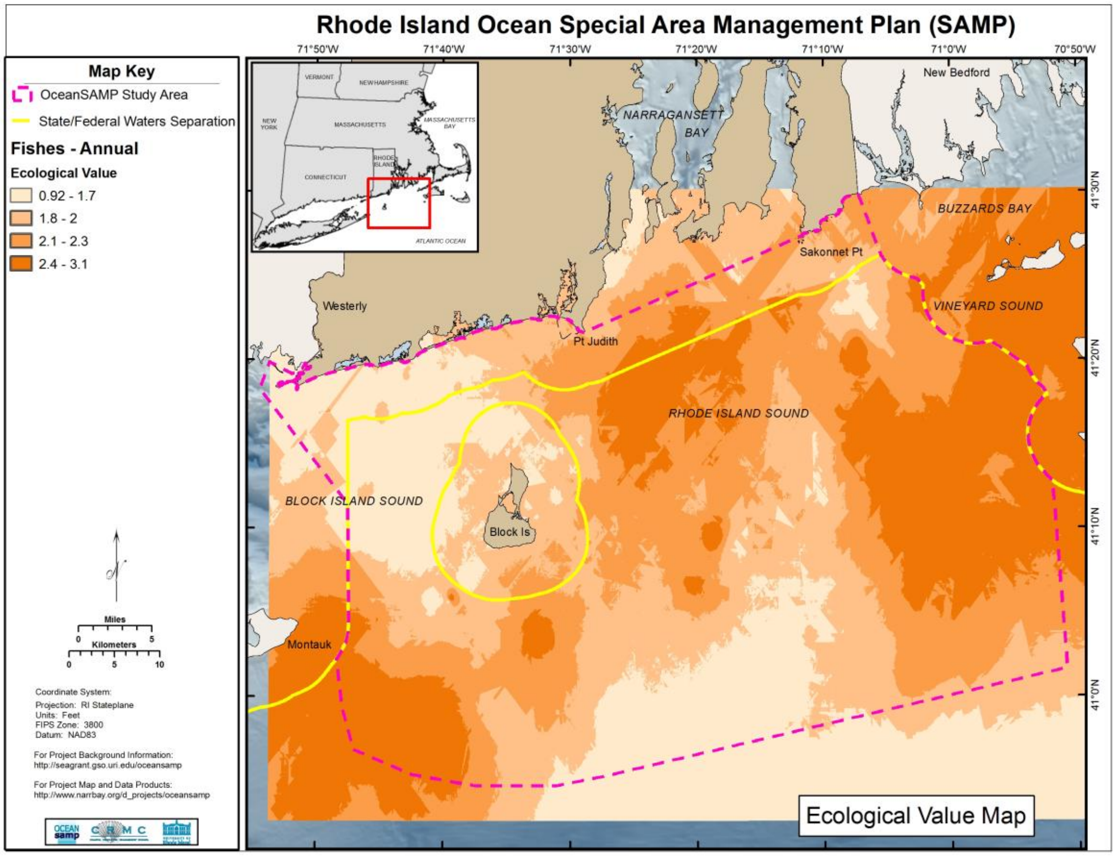


Figure 17. Category EVM of combined global importance *and* protection status for all fish and invertebrate species, averaged over the seasons for an annual perspective.

4.1.4 Birds

Observational data collected by Peter Paton's group was modeled into surfaces for eight species groups. The bird groups were combined into category EVMs using the weightings in Table 10. Data robustness for loons and sea ducks was assigned a lower weight than for other species groups because survey data was unavailable for the fall season for loons and seaducks, but these groups are both abundant in the fall in the Ocean SAMP area. As a result, spring surface density models were used as a proxy for fall surface density models for these two species groups in the EVMs. It is important to note that the modeled surfaces only represent foraging areas for the species evaluated, and do not include movement corridors.

Table 10. Weighting schemes for bird groups included in the category EVM.

Weighting Criteria:	Regional-Global Importance	Protection Status	Impact Potential - Construction	Impact Potential - Operation	Data Robustness
Loons	4	4	6	6	5
Alcids	4	4	6	6	7
Gulls	4	2	2	2	7

Weighting Criteria:	**Regional-Global Importance**	**Protection Status**	**Impact Potential - Construction**	**Impact Potential - Operation**	**Data Robustness**
Gannets	4	2	6	6	7
Sea Ducks	1	3	6	6	5
Shearwaters	2	3	4	4	7
Terns	4	6	4	10	7
Petrels	1	2	4	4	7

In the annual ecological value map for birds (Figure 18), areas of high relative ecological value are distributed throughout the Ocean SAMP area, with no obvious overall pattern (see Appendix A for seasonal EVMs). This lack of a strong overall trend is not surprising given that the eight bird groups included in the EVM analysis represent species with a variety of habitat preferences. For example, based on Paton et al.'s (2010) literature review, most sea ducks typically forage in waters that are 5 to 20 m deep where bivalves and other forage is available; gannets and loons are piscivorous specialists and tend to occur in areas where water depths are 30 to 45 m deep and <35 m deep, respectively; and within the alcid group, razorbills were consistently found in shallower waters closer to the mainland, common murre primarily occur in the central regions of the Ocean SAMP area, and dovekies occur offshore over deeper depths out to the continental shelf.

It is important to note that the large, inverted V-shaped area of high ecological value that appears in the southern portion of Rhode Island Sound (Figure 18) can be attributed to the modeling approach that was used to generate a continuous topology for the bird group input layers. As discussed in section 3.2.4, this pattern is likely being driven by the predictive model based on depth and distance from shore, rather than a true underlying pattern in bird abundance. The modeled bird-density topologies are presently being updated by Paton et al., and these new results are expected to improve the EVMs that result from this input data.

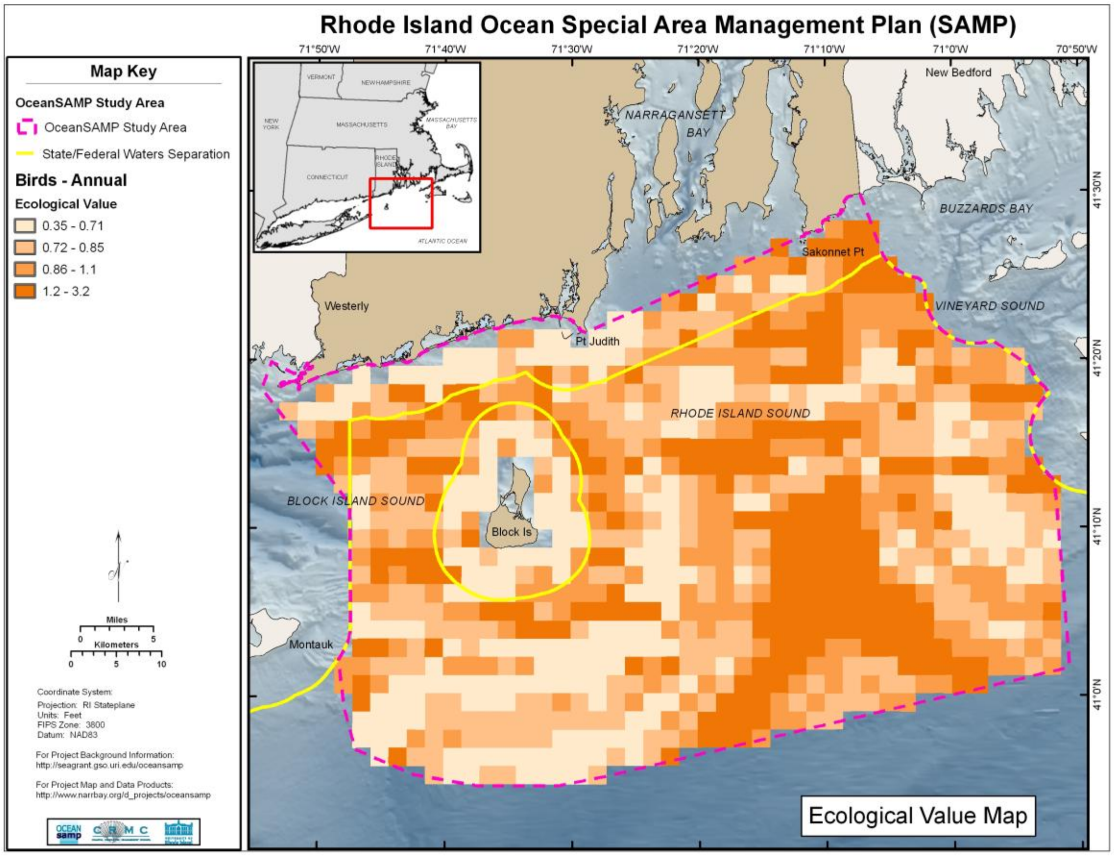


Figure 18. Category EVM of combined global importance *and* protection status for all bird groups, averaged over the seasons for an annual perspective.

4.1.5 Marine Mammals

Eleven species of marine mammals were included in this analysis. The weighting schemes used for creating the category EVMs are listed in Table 11. All mammals were given equal weight for impact potential due to the construction and operation of a wind farm. The North Atlantic right whale, which is found in the RI Ocean SAMP area during its spring and fall migration, has a higher influence on EVMs than other marine mammals because of its smaller geographic range.

Table 11. Weighting schemes for marine mammal species included in the category EVM.

Weighting Criteria:	Regional-Global Importance	Protection Status	Impact Potential - Construction	Impact Potential - Operation	Data Robustness
Bottlenose Dolphin	1	6	8	4	5
Fin Whale	1	10	8	4	5
Harbor Porpoise	2	6	8	4	5
Humpback Whale	1	10	8	4	5

Weighting Criteria:	**Regional-Global Importance**	**Protection Status**	**Impact Potential - Construction**	**Impact Potential - Operation**	**Data Robustness**
Minke Whale	1	6	8	4	5
Pilot Whales	2	6	8	4	5
North Atlantic Right Whale	8	10	8	4	5
Short-beaked Common Dolphin	1	6	8	4	5
Seals	2	6	8	4	5
Sperm Whale	1	10	8	4	5
Atlantic White-sided Dolphin	4	6	8	4	5

The annual ecological value map for marine mammals (see Appendix A for seasonal EVMs) shows a strong offshore/nearshore trend, with higher relative ecological value with increasing distance from shore (Figure 19). This pattern is primarily influenced by federally-listed endangered species (i.e., fin, humpback, North Atlantic right, and sperm whales). In the nearshore, the waters surrounding Sakonnet Point have slightly higher relative ecological value than other areas along the Rhode Island mainland coast. This is mainly driven by the presence of seals and harbor porpoise.

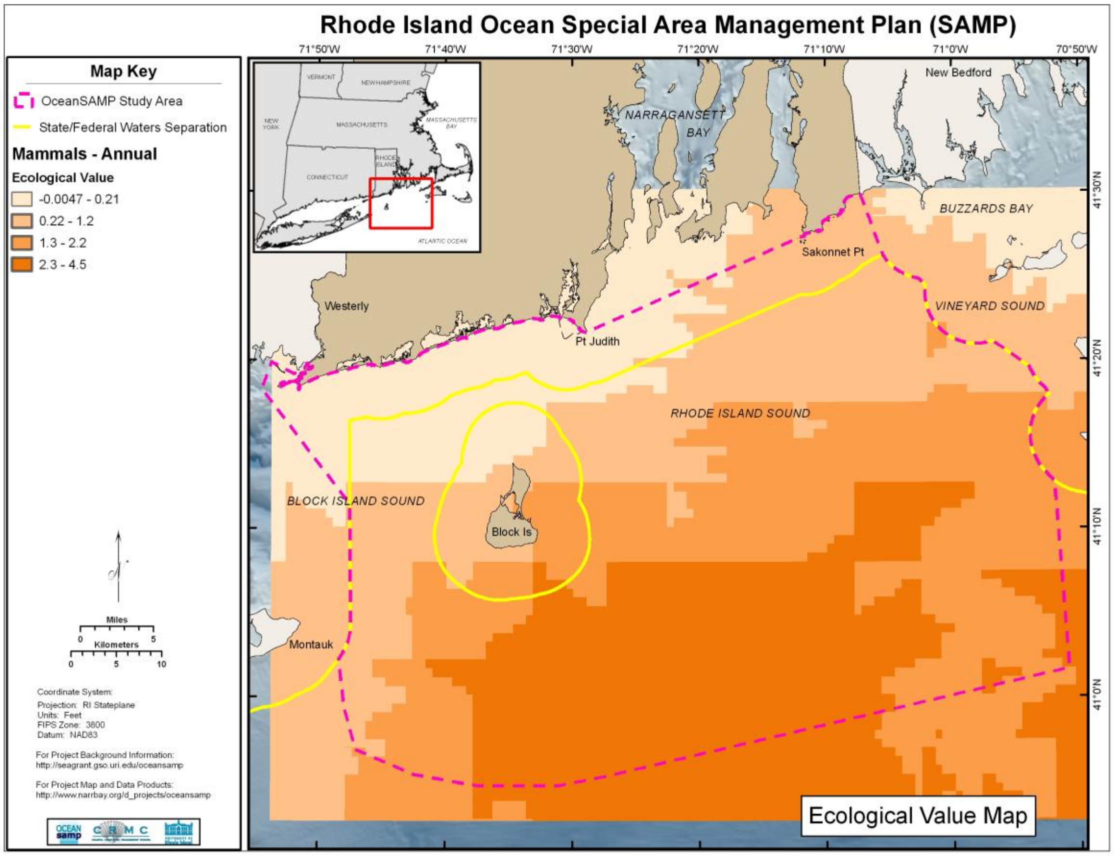


Figure 19. Category EVM of combined global importance *and* protection status for marine mammals, averaged over the seasons for an annual perspective.

4.1.6 Sea Turtles

As described in Section 3.2.6, data on turtle species in the Ocean SAMP region are rare. Leatherback and loggerhead turtles use the RI Ocean SAMP area similarly and are weighted similarly on most scales (Table 12). The one difference arises in the Protection Status category as leatherbacks are federally endangered and loggerheads are federally threatened[1].

Table 12. Weighting schemes for sea turtle species included in the category EVM.

Weighting Criteria:	Regional-Global Importance	Protection Status	Impact Potential - Construction	Impact Potential - Operation	Data Robustness
Loggerhead	1	8	8	4	5
Leatherback	1	10	8	4	5

The annual ecological value map (see Appendix A for seasonal EVMs) reinforces the trend that loggerhead and leatherback sea turtles are generally found further offshore, with highest

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[1] Though currently listed as threatened, the Northwest Atlantic population segment of loggerhead sea turtles has been proposed for listing as endangered.

relative ecological value in the offshore portion of the Ocean SAMP (Figure 20). Leatherback turtles are a stronger driver of the ecological value distribution than loggerhead turtles due to their status as a federally-listed endangered species. Kemp's ridley and green sea turtles were not included in this analysis because of a lack of sufficient data. They are both coastal species, and inclusion of these species in the EVM would likely alter the apparent spatial trends.

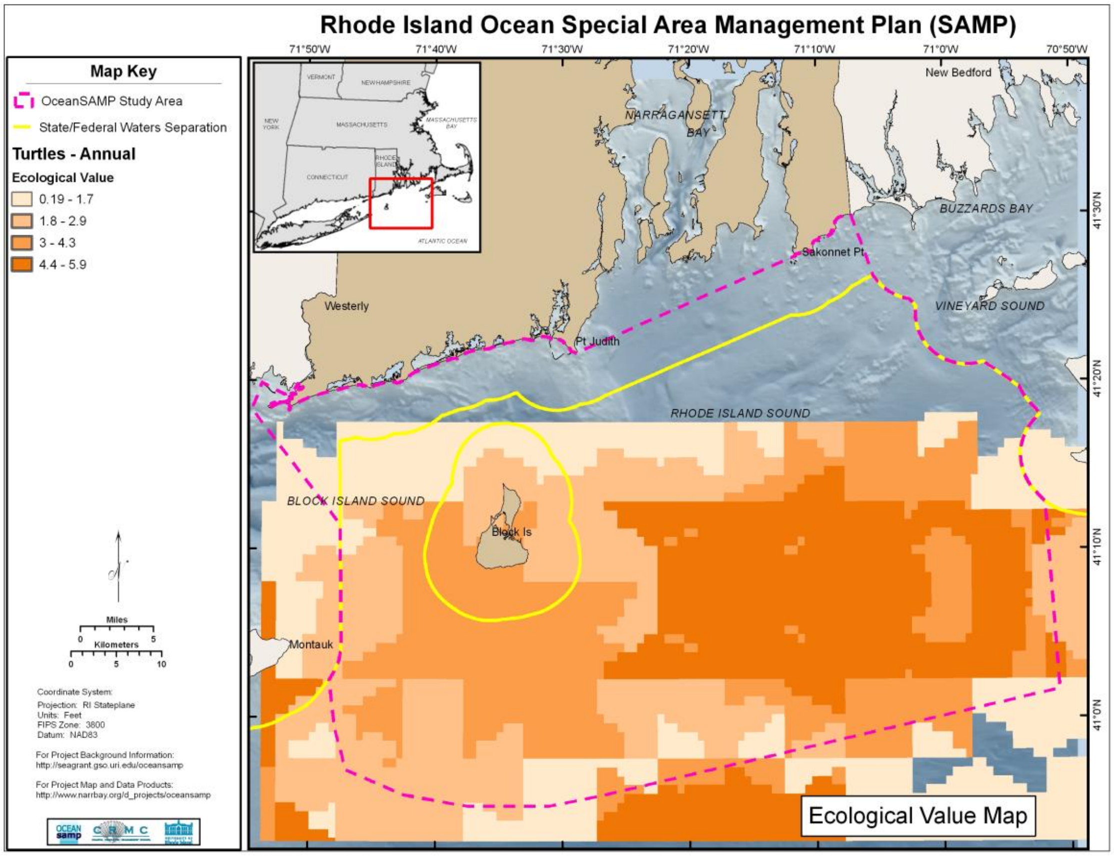

Figure 20. Category EVM of combined global importance *and* protection status for sea turtles, averaged over the seasons for an annual perspective.

4.2 Composite EVM

This section contains a selection of composite EVMs, depicted with color bins based on quartiles. These maps represent only a small subset of the composite EVMs produced for this study. Additional composite EVMs (annual and seasonal) are provided as digital maps (see Appendix A for a description of the folder structure and naming convention).

4.2.1 Ecological Value

Figure 21 depicts the composite EVM for all of the resources included in this study, on an annual basis (see Appendix A for seasonal EVMs). In general, this EVM demonstrates a pattern of lower relative ecological value in the nearshore environment and higher relative ecological value in the offshore environment, with the areas of highest relative ecological value located to the southeast of Block Island and in a large area in the southeast of the Ocean SAMP area. This pattern is primarily being driven by the presence of marine mammals and turtles and their status as federally-protected species.

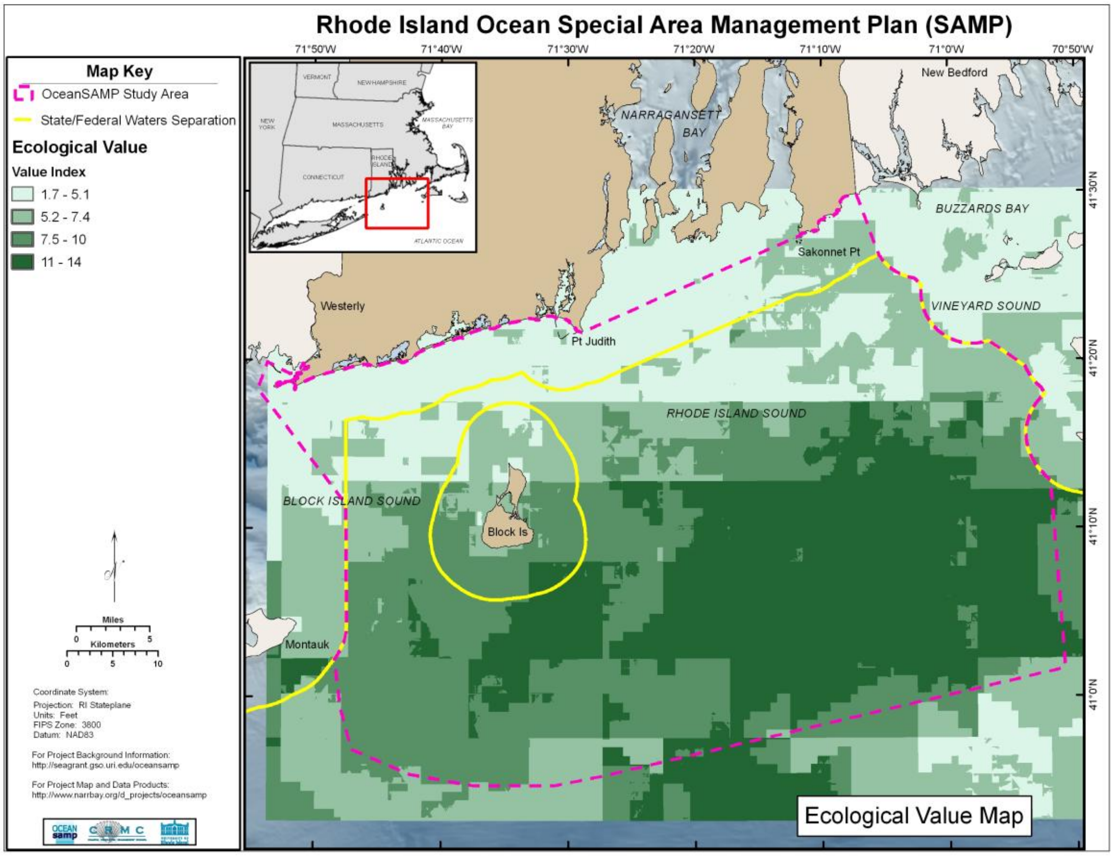

Figure 21. Annual Composite EVM of ecological value (global importance + protection status) for all resources (see Appendix A for seasonal EVMs).

While protected species are likely to be an important factor in the regulatory review of a proposed offshore project, the marine mammal and turtle species found in the Ocean SAMP area have large geographic ranges and do not have critical habitat within the study area. Assessing these migratory species at a local scale (i.e., within the relatively small Ocean SAMP area) may lead to overestimation of the importance of the local area to that species. For example, North Atlantic right whales are known to pass through the Ocean SAMP area, but their most important habitat areas in the region occur further north. In our EVM modeling approach, the North Atlantic right whale data set was normalized only within the Ocean SAMP, rather than within the full geographic extent of the data set. As a result, areas within the Ocean SAMP boundaries with known occurrences of North Atlantic right whales were modeled as having higher ecological value than areas where the whales are not known to occur, even though the Ocean SAMP area may be of little importance to the species overall. During model development, we felt this was an appropriate approach, given that we were attempting to assess the *relative* ecological value of areas within the Ocean SAMP boundaries. However, the issue of determining the appropriate scale on which to analyze input data sets is an important matter that warrants additional consideration in future ecological valuation efforts.

As an exercise, we also produced an annual composite EVM for all of the resources included in this study except marine mammals and turtles (Figure 22). When marine mammals and turtles are excluded from the analysis, their influence on the annual composite EVM (Figure 21) is clear. The strong offshore/nearshore trend in ecological value is no longer present, and areas of high ecological value are now primarily influenced by the presence of bird species.

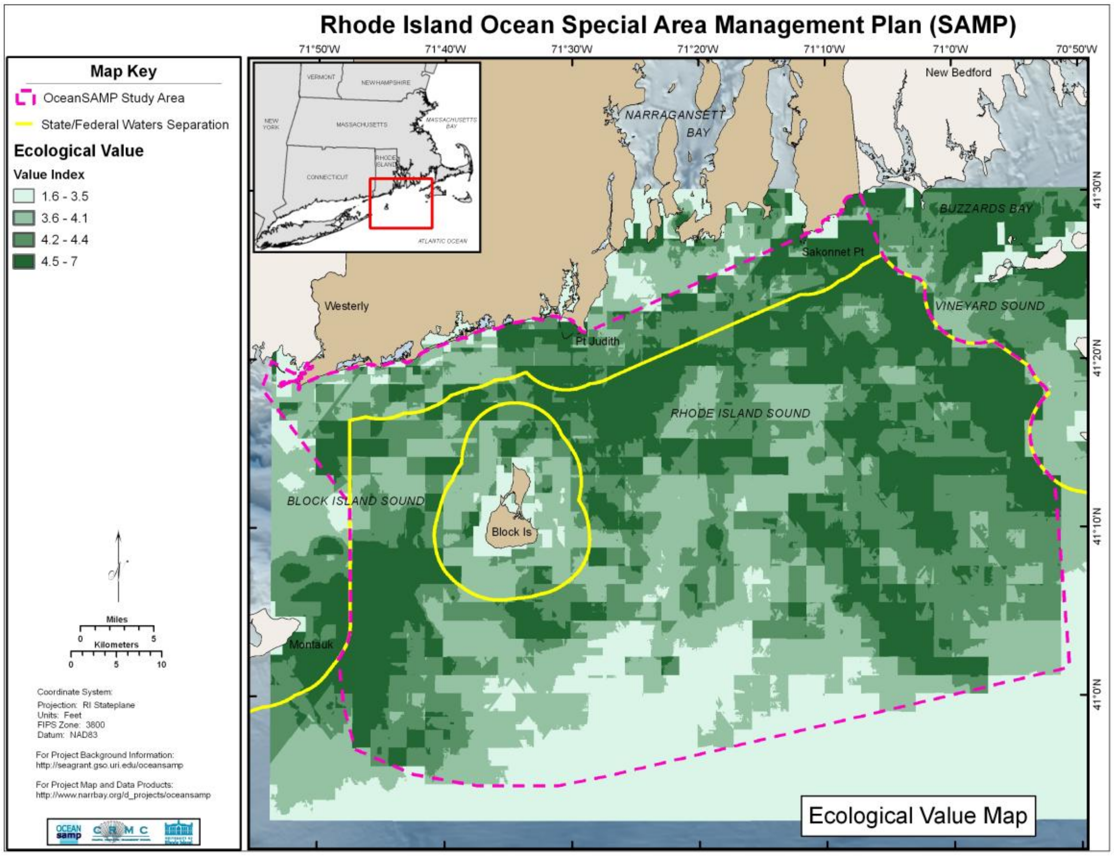

Figure 22. Annual Composite EVM of ecological value (global importance + protection status) for all resources except marine mammals and sea turtles.

As part of the Ocean SAMP, a principal component (PCA) and cluster analysis (CA) statistical analysis was conducted by Grilli et al. (2010) to identify homogenous ecological and socio-ecological sub-regions in the Ocean SAMP study area. The PCA-CA examines the mapped ecological information to provide objective analyses of the variability indicated by the data, without assigning values, scores, or weights. This results in a quantitative organization of the data in terms of principal components, ultimately leading to a clustering or a grouping of similar areas into homogeneous zones.

The PCA-CA approach could be a useful complement to our EVM valuation analysis because it provides two independent objective analyses: (1) a quantitative description of the spatial variability of biodiversity and ecological structure; and (2) the definition of limits between zoned areas of similar ecological value, based on the gradients of observed variables. However, the opportunity for comparison with Grilli et al.'s (2010) analysis is limited because the PCA-CA analysis did not use the same set of input data employed in the EVM. For example, bird abundance data were not incorporated into the PCA-CA and only the fall and spring seasons were analyzed. The PCA-CA also included fisheries use data, which was not included in the EVM analysis.

4.2.2 Ecological Value and Potential Impact from Construction

When the potential impact from construction of an offshore wind farm is considered along with ecological value (Figure 23), the offshore/nearshore pattern is still apparent, and is still strongly driven by the presence of marine mammals and sea turtles. This result is consistent with reviews that have shown that the noise from construction-related pile driving has the most potential to cause adverse impacts (Thomsen et al., 2006; Michel et al., 2007), and marine mammals are likely to be the ecological group most sensitive to these impacts. Sea turtles are assumed to be less sensitive to potential noise impacts, but are at risk of entanglement with lines/gear and collisions with construction vessels.

It should be noted that in our application of potential impact weightings to the EVM, we assumed that construction and operation impacts were unmitigated. In reality, state and federal regulatory agencies would require various mitigations to minimize adverse impacts on resources of concern. If we were to consider mitigation in the EVMs, the resulting maps would show different patterns of sensitivity. For example, a common mitigation measure for reducing the potential adverse impacts of construction noise on marine mammals is to use observers to visually monitor for marine mammals within the construction area prior to and during construction activities, suspending activities when a marine mammal is present. Another mitigation measure is to power-up noise-generating equipment slowly (i.e., soft start, ramp up) to give any marine mammals present in the area the opportunity to leave before construction activities commence. If these mitigation measures were included in our application of potential impact weightings to the EVM, marine mammals would have received a lower weighting for potential construction impact, and this likely would have reduced the prominence of the offshore/nearshore trend.

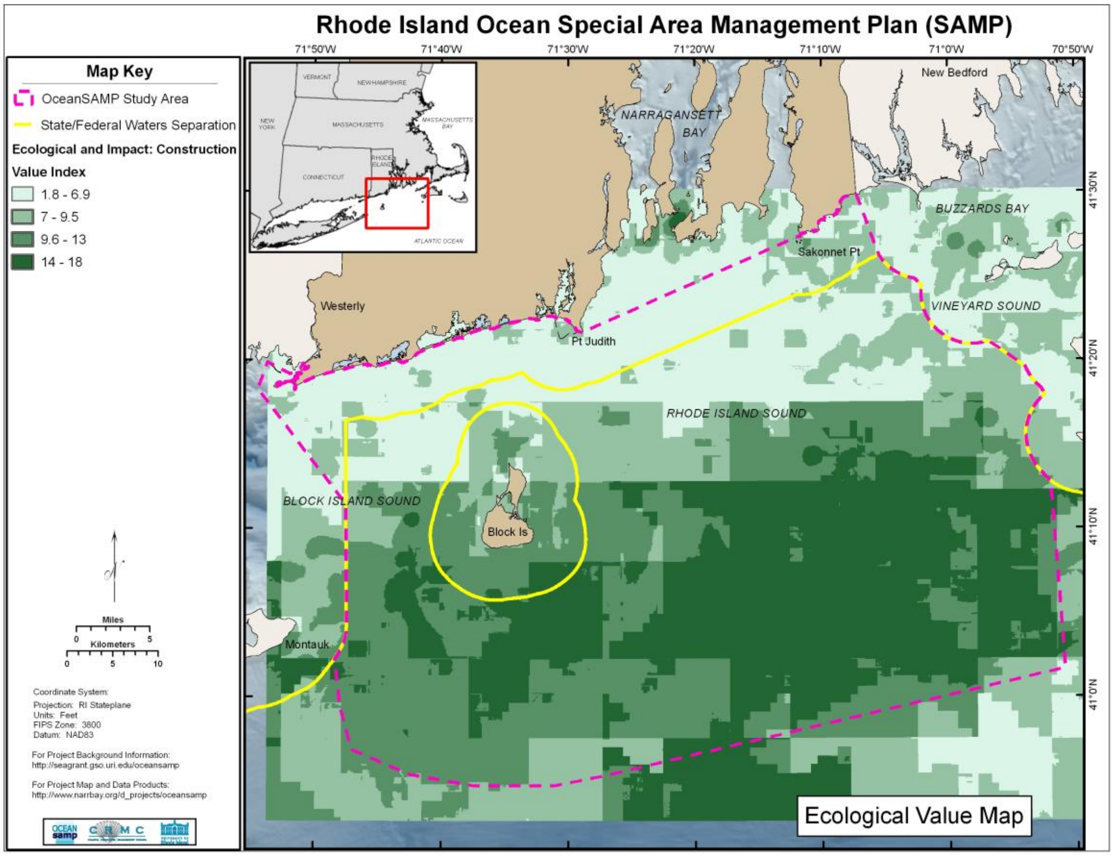

Figure 23. Annual Composite EVM of ecological value and potential impact (construction only) for all resources (see Appendix A for seasonal EVMs).

4.2.3 Ecological Value and Potential Impact from Operation

When the potential impact from operation of an offshore wind farm is considered along with ecological value (Figure 24), the pattern of relative value/sensitivity to operational impacts is very similar to that of construction impacts (Figure 23), but of lesser magnitude. This is expected, since operational impacts of wind farms, though longer term, are generally assumed to be less acute than temporary construction impacts.

As discussed in Section 4.2.2, we did not consider potential mitigation when applying impact weightings to the EVM. If we were to consider mitigation in the EVMs, the resulting maps would likely show different patterns of sensitivity.

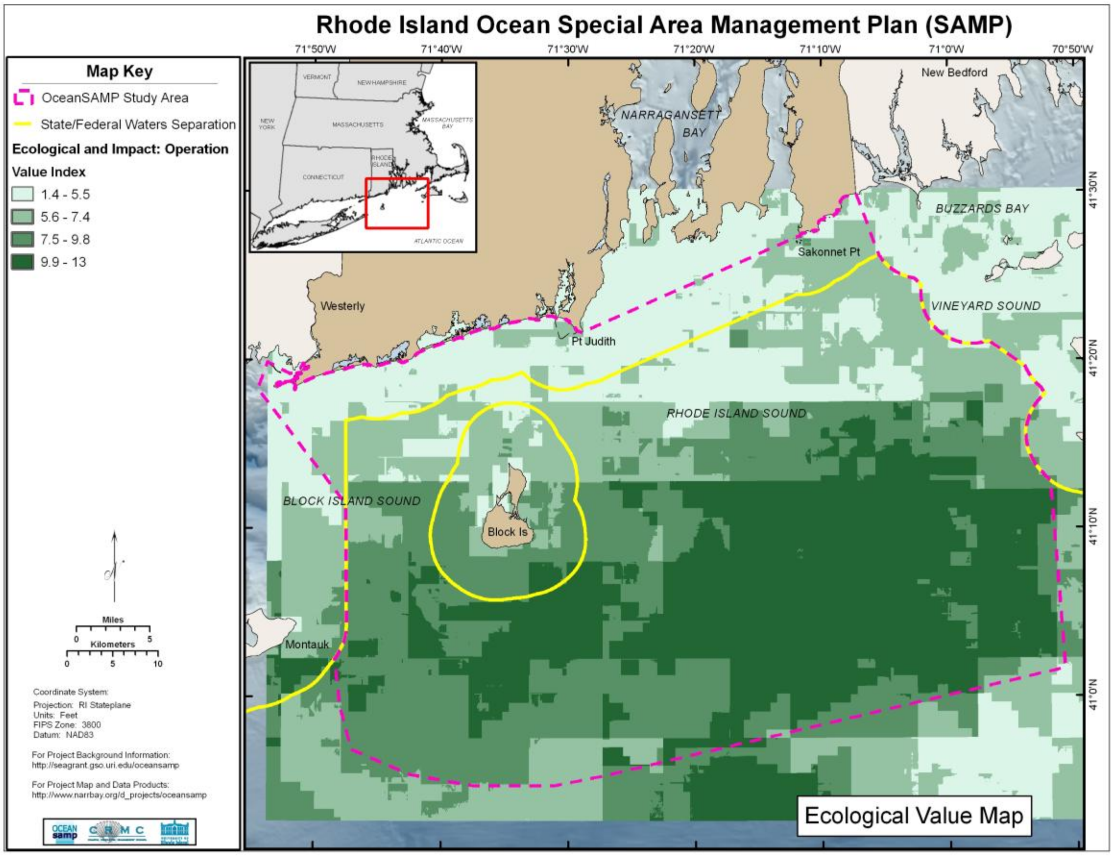

Figure 24. Annual Composite EVM of ecological value and potential impact (operation only) for all resources (see Appendix A for seasonal EVMs).

4.2.4 Ecological Value and Potential Impact from Construction and Operation

Combining potential impact from construction and operation of an offshore wind farm with ecological value (Figure 25) yields many of the same patterns discussed in Sections 4.2.2 and 4.2.3 above. We have included this map for the sake of completeness, however, the separate EVMs for construction (Figure 23) and operation (Figure 24) are likely be more informative for screening potential offshore wind farm sites. Since construction impacts are temporary, stakeholders and regulators may consider them to be less important in siting considerations relative to operational impacts, which are more permanent. Future versions of this combined impact EVM could be modified to weight construction and operational impacts accordingly.

As discussed in Section 4.2.2, we did not consider potential mitigation when applying impact weightings to the EVM. If we were to consider mitigation in the EVMs, the resulting maps would likely show different patterns of sensitivity.

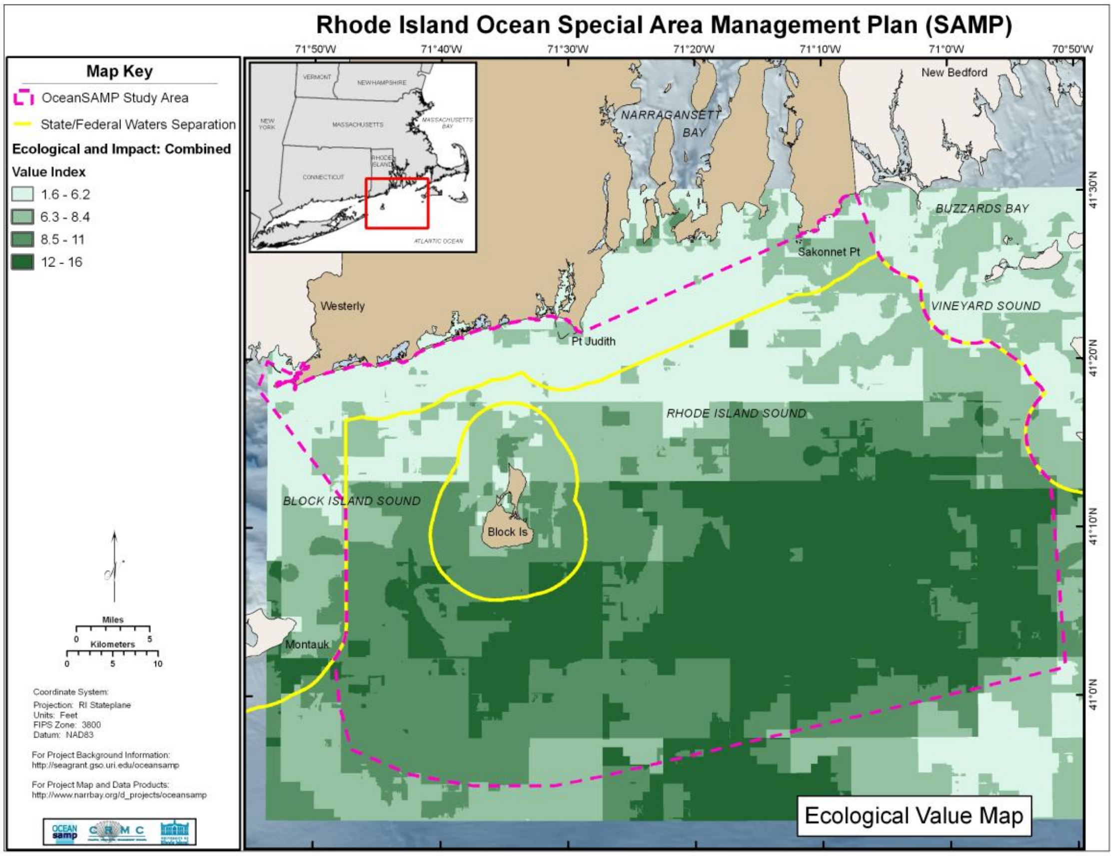

Figure 25. Annual Composite EVM of ecological value and potential impact (construction + operation) for all resources (see Appendix A for seasonal EVMs).

5 Conclusions

The EVM framework developed in this study models ecological values of marine biological resources for the Ocean SAMP area. EVMs were generated at various levels of detail: on the species level (component EVMs); at the group level (category EVMs); and over all resources, providing a composite EVM. The results of this application of the EVM can be used to compare the relative values of potential renewable energy sites, or of sites in general, within the offshore Rhode Island ocean ecosystem (i.e., the Ocean SAMP area).

Building on the biological valuation approach developed by Derous et al. (2007a,b,c), the approach for this project was to develop a model whereby input data (geospatial information describing the physical environment, ecosystems, and wildlife populations) could be integrated into a composite map, utilizing weighting factors that incorporate relative intrinsic and ecological values, as well as the robustness of the underlying data sets. Going a step further than our inclusion of weighting with the Derous et al. (2007a,b,c) approach, we also applied weighting factors to address the relative potential impacts of construction and operation of a hypothetical wind farm development.

Based on our experience in developing the EVM approach, as well as reviewing other MSP approaches, there are several challenges in applying ecological valuation as a useable tool for MSP efforts. Difficulties include the following: (1) a lack of standardized input data; (2) patchy or inconsistent data availability/coverage necessitating application of interpolation models or spreading algorithms with uncertain underlying input data; (3) defining the appropriate scale for the valuation effort; and (4) representing habitat components. These challenges are discussed in more detail in the following paragraphs.

Attaining comprehensive data with ample spatial coverage for ecological valuations can be difficult. MSP efforts generally require ecological valuation of broad scale coastal zones, but in many cases, biological data are patchy and/or focused on a particular area of concern. Data inputs are typically pulled from a variety of sources, and therefore include multiple studies, each with varying scopes, methodologies, and objectives. As a result, it can be challenging to standardize these data sets so that they can be combined in a meaningful way. Furthermore, data may simply not exist for particular ecosystem components, or may not have adequate spatial coverage. For example, for the benthic ecosystem only a subset of the Ocean SAMP area has been sampled for biological cover and densities, whereas rugosity was available for the entire area of interest. In addition, we did not have sufficient spatial data to include bats in the present EVM analysis, but bats could be a sensitive component in the Ocean SAMP area. The sampling coverage needed to truly represent broad scale study areas is often unavailable and costly to obtain. Modeling data layers based on spatial interpolations between points (as we did for the fish data in this study), or extrapolating a surface as a function of a variable with ample spatial coverage has been used as one way to address this data gap problem (Degraer et al., 2008; EOEEA, 2009; Greene et al., 2010). However, as demonstrated by the bird surface density models used in this study, the modeling method employed to generate a continuous topology can heavily influence the final results, and therefore warrants careful consideration. In view of the reality that data coverage and quality will vary by region and resource, we recommend a hierarchy of approaches be developed for generating topologies, dependent on the nature, comprehensiveness, and uncertainties of the available data. The approaches may include various spatial statistical techniques (e.g., Kriging, Inverse-Distance Weighted Interpolation), empirical models, and behavioral models, depending on data availability and quality. Uncertainties may also be addressed via proportional weightings or sensitivity analysis.

Determining the appropriate scale on which to analyze input data sets is an important element in ecological valuation efforts. As discussed in section 4.2.1, the scale at which the data are analyzed will heavily influence the results, and therefore inappropriate scales can lead to skewed interpretation and poor decision making. For example, a non-migratory benthic fish species could most likely be assessed appropriately at a local scale, while some migratory species (e.g. great whales) should be assessed at a regional or coastal scale. Assessing a migratory species with a large geographic range at a local scale may lead to overestimation of the importance of the local area to that species.

Finally, better representation of habitat components in ecological valuations would provide a more robust representation of ecosystem dynamics. For example, our EVM approach was based on mapping of species' density/abundance, and habitat components were only included at a very basic level (i.e., benthic rugosity as a proxy for benthic habitat, and primary production as a proxy for the pelagic ecosystem). Including more detail on habitat features/dynamics, such as employing the CMECS approach, would significantly strengthen the EVM approach. However, obtaining broad scale habitat data can be costly and labor intensive. If it is not feasible to obtain detailed habitat data, valuation approaches should at least attempt to include known biogeographic qualities, particularly any unique or unusual biological, chemical, physical, or geological features.

Another limitation, but also a strength, of the EVM approach is the assignment of the weighting factors (i.e., valuation) to the input data, since alternative weighting schemes or relative rankings of individual layers could affect the final EVM products considerably. The weighting schemes employed in this study are considered exploratory, and could be modified to integrate stakeholder input or other factors. Other weighting schemes may be discussed and evaluated in the future as issues and concerns arise. We envision the weightings to be used as a measure of the relative importance decision-makers might place on the various resources, and the views of various stakeholders, along with uncertainties, may be explored by varying the weightings. Thus, the weightings implicitly made in any trade-off decision-making process are explicitly stated using this framework, with a criteria-related basis, making the decision-making process transparent and documented.

In conclusion, a key challenge in siting an energy facility or other commercial or industrial project is balancing the needs of the diverse interests and resources that could be affected by the project while complying with regulatory standards and meeting project objectives. Despite the limitations and challenges discussed above, the EVM model developed in this study provides a screening tool for initial renewable energy facility siting considerations in the Rhode Island ocean ecosystem. The EVMs are intended to be evaluated in conjunction with other environmental information, regulatory and management priorities, and stakeholder interests. The EVM approach developed in the DOE study, as well as the lessons learned, are being leveraged for the BOEMRE project and developed further to expand the approach to a national perspective and develop a model to address cumulative impacts of offshore renewable energy development.

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Appendix A: Guide to the Digital Ecological Value Maps

A large number of Ecological Value Maps (EVMs) were created as part of the Rhode Island Ocean Special Area Management Plan (SAMP). Not all of these maps were included in the Appendix to the main report but are available to readers as digital files (*.jpg).

This document is a list of the figures available in the "Digital Maps" folder, and the figure captions that describe the EVM.

Table of Contents

Component EVMs

Component EVMs are seasonal (where available) and annual representations of each individual resource mapped as part of this analysis.

Seasons:

- Ann = Annual (average of all seasons available)
- Fal = Fall (October – December)
- Spr = Spring (April – June)
- Sum = Summer (July – September)
- Win = Winter (January – March)

Component EVMs → Benthic Roughness

BenRough.jpg: Component EVM of benthic roughness, represented as percent of the maximum value.

Component EVMs → Chlorophyll

Chl_ann.jpg: Component EVM of annual surface chlorophyll a concentration, represented as percent of the maximum value.

Chl_fal.jpg: Component EVM of fall surface chlorophyll a concentration, represented as percent of the annual maximum value.

Chl_spr.jpg: Component EVM of spring surface chlorophyll a concentration, represented as percent of the annual maximum value.

Chl_sum.jpg: Component EVM of summer surface chlorophyll a concentration, represented as percent of the annual maximum value.

Chl_win.jpg: Component EVM of winter surface chlorophyll a concentration, represented as percent of the annual maximum value.

Component EVMs → Fish

Bait_ann.jpg: Component EVM (generated by Kriging) of annual baitfish abundance, represented as percent of the maximum value.

Bait_fal.jpg: Component EVM (generated by Kriging) of baitfish abundance during the fall season, represented as percent of the annual maximum value.

Bait_spr.jpg: Component EVM (generated by Kriging) of baitfish abundance during the spring season, represented as percent of the annual maximum value.

Dems_ann.jpg: Component EVM (generated by Kriging) of annual demersal fish abundance, represented as percent of the maximum value.

Dems_fal.jpg: Component EVM (generated by Kriging) of demersal fish abundance during the fall season, represented as percent of the annual maximum value.

Dems_spr.jpg: Component EVM (generated by Kriging) of demersal fish abundance during the spring season, represented as percent of the annual maximum value.

Flat_ann.jpg: Component EVM (generated by Kriging) of annual flatfish abundance, represented as percent of the maximum value.

Flat_fal.jpg: Component EVM (generated by Kriging) of flatfish abundance during the fall season, represented as percent of the annual maximum value.

Flat_spr.jpg: Component EVM (generated by Kriging) of flatfish abundance during the spring season, represented as percent of the annual maximum value.

Herr_ann.jpg: Component EVM (generated by Kriging) of annual river herring and smelt abundance, represented as percent of the maximum value.

Herr_fal.jpg: Component EVM (generated by Kriging) of river herring and smelt abundance during the fall season, represented as percent of the annual maximum value.

Herr_spr.jpg: Component EVM (generated by Kriging) of river herring and smelt abundance during the spring season, represented as percent of the annual maximum value.

Lagm_ann.jpg: Component EVM (generated by Kriging) of annual large gamefish abundance, represented as percent of the maximum value.

Lagm_fal.jpg: Component EVM (generated by Kriging) of large gamefish abundance during the fall season, represented as percent of the annual maximum value.

Lagm_spr.jpg: Component EVM (generated by Kriging) of large gamefish abundance during the spring season, represented as percent of the annual maximum value.

Lbst_ann.jpg: Component EVM (generated by Kriging) of annual lobster abundance, represented as percent of the maximum value.

Lbst_fal.jpg: Component EVM (generated by Kriging) of lobster abundance during the fall season, represented as percent of the annual maximum value.

Lbst_spr.jpg: Component EVM (generated by Kriging) of lobster abundance during the spring season, represented as percent of the annual maximum value.

Megm_ann.jpg: Component EVM (generated by Kriging) of annual medium gamefish abundance, represented as percent of the maximum value.

Megm_fal.jpg: Component EVM (generated by Kriging) of medium gamefish abundance during the fall season, represented as percent of the annual maximum value.

Megm_spr.jpg: Component EVM (generated by Kriging) of medium gamefish abundance during the spring season, represented as percent of the annual maximum value.

Scal_ann.jpg: Component EVM (generated by Kriging) of annual sea scallop abundance, represented as percent of the maximum value.

Scal_fal.jpg: Component EVM (generated by Kriging) of sea scallop abundance during the fall season, represented as percent of the annual maximum value.

Scal_spr.jpg: Component EVM (generated by Kriging) of sea scallop abundance during the spring season, represented as percent of the annual maximum value.

Skat_ann.jpg: Component EVM (generated by Kriging) of annual skate abundance, represented as percent of the maximum value.

Skat_fal.jpg: Component EVM (generated by Kriging) of skate abundance during the fall season, represented as percent of the annual maximum value.

Skat_spr.jpg: Component EVM (generated by Kriging) of skate abundance during the spring season, represented as percent of the annual maximum value.

Sqid_ann.jpg: Component EVM (generated by Kriging) of annual squid abundance, represented as percent of the maximum value.

Sqid_fal.jpg: Component EVM (generated by Kriging) of squid abundance during the fall season, represented as percent of the annual maximum value.

Sqid_spr.jpg: Component EVM (generated by Kriging) of squid abundance during the spring season, represented as percent of the annual maximum value.

Component EVMs → Birds

Alcd_ann.jpg: Component EVM for annual presence of alcid species.

Alcd_spr.jpg: Component EVM for spring presence of alcid species.

Alcd_win.jpg: Component EVM for winter presence of alcid species.

Cdck_ann.jpg: Component EVM for annual presence of seaduck species.

Cdck_fal.jpg: Component EVM for estimated fall presence of seaduck species, based on spring data.

Cdck_spr.jpg: Component EVM for spring presence of seaduck species.

Cdck_win.jpg: Component EVM for winter presence of seaduck species.

Gull_ann.jpg: Component EVM for annual presence of gull species.

Gull_fal.jpg: Component EVM for fall presence of gull species.

Gull_spr.jpg: Component EVM for spring presence of gull species.

Gull_sum.jpg: Component EVM for summer presence of gull species.

Gull_win.jpg: Component EVM for winter presence of gull species.

Loon_ann.jpg: Component EVM for annual presence of loon species.

Loon_fal.jpg: Component EVM for estimated fall presence of loon species, based on spring data.

Loon_spr.jpg: Component EVM for spring presence of loon species.

Loon_win.jpg: Component EVM for winter presence of loon species.

Noga_ann.jpg: Component EVM for annual presence of gannet species.

Noga_fal.jpg: Component EVM for fall presence of gannet species.

Noga_spr.jpg: Component EVM for spring presence of gannet species.

Noga_win.jpg: Component EVM for winter presence of gannet species.

Shwt_ann.jpg: Component EVM for annual presence of shearwater species.

Shwt_sum.jpg: Component EVM for summer presence of shearwater species.

Tern_ann.jpg: Component EVM for annual presence of tern species.

Tern_sum.jpg: Component EVM for summer presence of tern species.

Wisp_ann.jpg: Component EVM for annual presence of petrel species.

Wisp_sum.jpg: Component EVM for summer presence of petrel species.

Component EVMs → Turtles

Letu_ann.jpg: Component EVM of annual leatherback sea turtle SPUE, represented as percent of the maximum value.

Letu_fal.jpg: Component EVM of leatherback sea turtle SPUE during the fall season, represented as percent of the annual maximum value.

Letu_sum.jpg: Component EVM of leatherback sea turtle SPUE during the summer season, represented as percent of the annual maximum value.

Lotu_ann.jpg: Component EVM of annual loggerhead sea turtle SPUE, represented as percent of the maximum value.

Lotu_fal.jpg: Component EVM of loggerhead sea turtle SPUE during the fall season, represented as percent of the annual maximum value.

Lotu_sum.jpg: Component EVM of loggerhead sea turtle SPUE during the summer season, represented as percent of the annual maximum value.

Component EVMs → Mammals

Bodo_ann.jpg: Component EVM of annual common bottlenose dolphin SPUE, represented as percent of the maximum value.

Bodo_sum.jpg: Component EVM of common bottlenose dolphin SPUE during the summer season, represented as percent of the annual maximum value.

Fiwh_ann.jpg: Component EVM of annual fin whale SPUE, represented as percent of the maximum value.

Fiwh_fal.jpg: Component EVM of fin whale SPUE during the fall season, represented as percent of the annual maximum value.

Fiwh_spr.jpg: Component EVM of fin whale SPUE during the spring season, represented as percent of the annual maximum value.

Fiwh_sum.jpg: Component EVM of fin whale SPUE during the summer season, represented as percent of the annual maximum value.

Fiwh_win.jpg: Component EVM of fin whale SPUE during the winter season, represented as percent of the annual maximum value.

Hapo_ann.jpg: Component EVM of annual harbor porpoise SPUE, represented as percent of the maximum value.

Hapo_spr.jpg: Component EVM of harbor porpoise SPUE during the spring season, represented as percent of the annual maximum value.

Hapo_sum.jpg: Component EVM of harbor porpoise SPUE during the summer season, represented as percent of the annual maximum value.

Hapo_win.jpg: Component EVM of harbor porpoise SPUE during the winter season, represented as percent of the annual maximum value.

Huwh_ann.jpg: Component EVM of annual humpback whale SPUE, represented as percent of the maximum value.

Huwh_spr.jpg: Component EVM of humpback whale SPUE during the spring season, represented as percent of the annual maximum value.

Huwh_sum.jpg: Component EVM of humpback whale SPUE during the summer season, represented as percent of the annual maximum value.

Miwh_ann.jpg: Component EVM of annual minke whale SPUE, represented as percent of the maximum value.

Miwh_fal.jpg: Component EVM of minke whale SPUE during the fall season, represented as percent of the annual maximum value.

Miwh_spr.jpg: Component EVM of minke whale SPUE during the spring season, represented as percent of the annual maximum value.

Miwh_sum.jpg: Component EVM of minke whale SPUE during the summer season, represented as percent of the annual maximum value.

Piwh_ann.jpg: Component EVM of annual pilot whales SPUE, represented as percent of the maximum value.

Piwh_spr.jpg: Component EVM of pilot whales SPUE during the spring season, represented as percent of the annual maximum value.

Piwh_win.jpg: Component EVM of pilot whales SPUE during the winter season, represented as percent of the annual maximum value.

Riwh_ann.jpg: Component EVM of annual North Atlantic right whale SPUE, represented as percent of the maximum value.

Riwh_fal.jpg: Component EVM of North Atlantic right whale SPUE during the fall season, represented as percent of the annual maximum value.

Riwh_spr.jpg: Component EVM of North Atlantic right whale SPUE during the spring season, represented as percent of the annual maximum value.

Sado_ann.jpg: Component EVM of annual short-beaked common dolphin SPUE, represented as percent of the maximum value.

Sado_fal.jpg: Component EVM of short-beaked common dolphin SPUE during the fall season, represented as percent of the annual maximum value.

Sado_spr.jpg: Component EVM of short-beaked common dolphin SPUE during the spring season, represented as percent of the annual maximum value.

Sado_sum.jpg: Component EVM of short-beaked common dolphin SPUE during the summer season, represented as percent of the annual maximum value.

Sado_win.jpg: Component EVM of short-beaked common dolphin SPUE during the winter season, represented as percent of the annual maximum value.

Seal_ann.jpg: Component EVM of seal SPUE, represented as percent of the maximum value.

Seal_fal.jpg: Component EVM of seal SPUE during the fall season, represented as percent of the annual maximum value.

Seal_spr.jpg: Component EVM of seal SPUE during the spring season, represented as percent of the annual maximum value.

Seal_sum.jpg: Component EVM of seal SPUE during the summer season, represented as percent of the annual maximum value.

Seal_win.jpg: Component EVM of seal SPUE during the winter season, represented as percent of the annual maximum value.

Spwh_ann.jpg: Component EVM of annual sperm whale SPUE, represented as percent of the maximum value.

Spwh_spr.jpg: Component EVM of sperm whale SPUE during the spring season, represented as percent of the annual maximum value.

Spwh_sum.jpg: Component EVM of sperm whale SPUE during the summer season, represented as percent of the annual maximum value.

Wsdo_ann.jpg: Component EVM of annual Atlantic white-sided dolphin SPUE, represented as percent of the maximum value.

Wsdo_fal.jpg: Component EVM of Atlantic white-sided dolphin SPUE during the fall season, represented as percent of the annual maximum value.

Wsdo_spr.jpg: Component EVM of Atlantic white-sided dolphin SPUE during the spring season, represented as percent of the annual maximum value.

Wsdo_sum.jpg: Component EVM of Atlantic white-sided dolphin SPUE during the summer season, represented as percent of the annual maximum value.

Wsdo_win.jpg: Component EVM of Atlantic white-sided dolphin SPUE during the winter season, represented as percent of the annual maximum value.

Category EVMs

Category EVMs are seasonal (where available) and annual representations of grouped resources mapped as part of this analysis.

EVMs:

- Eco = Ecological Value
- Eic = Ecological Impact: Construction
- Eio = Ecological Impact: Operation
- Eit = Ecological Impact: Combined
- Glo = Global Importance
- Imp = Impact Value
- Potc = Potential Impact: Construction
- Poto = Potential Impact: Operation
- Pro = Protection Status

Listed below are the file names and descriptions for the annual maps. Seasonal maps can be found in appropriately labeled folders and have the same set of suffixes (see above).

Seasons:

- Ann = Annual (average of all seasons available)
- Fal = Fall (October – December)
- Spr = Spring (April – June)
- Sum = Summer (July – September)
- Win = Winter (January – March)

Category EVMs → Benthic Roughness

Benr_ann_eco.jpg: Category EVM of combined global importance *and* protection status for benthic ecosystems.

Benr_ann_eic.jpg: Category EVM of combined potential impact due to construction *and* ecological value (global importance + protection status) for benthic ecosystems.

Benr_ann_eio.jpg: Category EVM of combined potential impact due to operation *and* ecological value (global importance + protection status) for benthic ecosystems.

Benr_ann_eit.jpg: Category EVM of combined potential impact (construction + operation) *and* ecological value (global importance + protection status) for benthic ecosystems.

Benr_ann_glo.jpg: Category EVM of weighted global importance of each species for benthic ecosystems.

Benr_ann_imp.jpg: Category EVM of combined potential impact due to operation *and* construction activities for benthic ecosystems.

Benr_ann_potc.jpg: Category EVM of weighted potential impact due to construction activities for benthic ecosystems.

Benr_ann_poto.jpg: Category EVM of weighted potential impact due to operation activities for benthic ecosystems.

Benr_ann_pro.jpg: Category EVM of weighted protection status for benthic ecosystems.

Category EVMs → Chlorophyll

Chl_ann_eco.jpg: Category EVM of combined global importance *and* protection status for surface chlorophyll *a*, averaged over the seasons for an annual perspective.

Chl_ann_eic.jpg: Category EVM of combined potential impact due to construction *and* ecological value (global importance + protection status) for surface chlorophyll *a*, averaged over the seasons for an annual perspective.

Chl_ann_eio.jpg: Category EVM of combined potential impact due to operation *and* ecological value (global importance + protection status) for surface chlorophyll *a*, averaged over the seasons for an annual perspective.

Chl_ann_eit.jpg: Category EVM of combined potential impact (construction + operation) *and* ecological value (global importance + protection status) for surface chlorophyll *a*, averaged over the seasons for an annual perspective.

Chl_ann_glo.jpg: Category EVM of weighted global importance of each species for surface chlorophyll *a*, averaged over the seasons for an annual perspective.

Chl_ann_imp.jpg: Category EVM of combined potential impact due to operation *and* construction activities for surface chlorophyll *a*, averaged over the seasons for an annual perspective.

Chl_ann_potc.jpg: Category EVM of weighted potential impact due to construction activities for surface chlorophyll *a*, averaged over the seasons for an annual perspective.

Chl_ann_poto.jpg: Category EVM of weighted potential impact due to operation activities for surface chlorophyll *a*, averaged over the seasons for an annual perspective.

Chl_ann_pro.jpg: Category EVM of weighted protection status for surface chlorophyll *a*, averaged over the seasons for an annual perspective.

Category EVMs → Fish

Fish_ann_eco.jpg: Category EVM of combined global importance *and* protection status for all fish and invertebrate species, averaged over the seasons for an annual perspective.

Fish_ann_eic.jpg: Category EVM of combined potential impact due to construction *and* ecological value (global importance + protection status) for all fish and invertebrate species, averaged over the seasons for an annual perspective.

Fish_ann_eio.jpg: Category EVM of combined potential impact due to operation *and* ecological value (global importance + protection status) for all fish and invertebrate species, averaged over the seasons for an annual perspective.

Fish_ann_eit.jpg: Category EVM of combined potential impact (construction + operation) *and* ecological value (global importance + protection status) for all fish and invertebrate species, averaged over the seasons for an annual perspective.

Fish_ann_glo.jpg: Category EVM of weighted global importance of each species for all fish and invertebrate species, averaged over the seasons for an annual perspective.

Fish_ann_imp.jpg: Category EVM of combined potential impact due to operation *and* construction activities for all fish and invertebrate species, averaged over the seasons for an annual perspective.

Fish_ann_potc.jpg: Category EVM of weighted potential impact due to construction activities for all fish and invertebrate species, averaged over the seasons for an annual perspective.

Fish_ann_poto.jpg: Category EVM of weighted potential impact due to operation activities for all fish and invertebrate species, averaged over the seasons for an annual perspective.

Fish_ann_pro.jpg: Category EVM of weighted protection status for all fish and invertebrate species, averaged over the seasons for an annual perspective.

Category EVMs → Birds

Bird_ann_eco.jpg: Category EVM of combined global importance *and* protection status for all bird groups, averaged over the seasons for an annual perspective.

Bird_ann_eic.jpg: Category EVM of combined potential impact due to construction *and* ecological value (global importance + protection status) for all bird groups, averaged over the seasons for an annual perspective.

Bird _ann_eio.jpg: Category EVM of combined potential impact due to operation *and* ecological value (global importance + protection status) for all bird groups, averaged over the seasons for an annual perspective.

Bird _ann_eit.jpg: Category EVM of combined potential impact (construction + operation) *and* ecological value (global importance + protection status) for all bird groups, averaged over the seasons for an annual perspective.

Bird _ann_glo.jpg: Category EVM of weighted global importance of each species for all bird groups, averaged over the seasons for an annual perspective.

Bird _ann_imp.jpg: Category EVM of combined potential impact due to operation *and* construction activities for all bird groups, averaged over the seasons for an annual perspective.

Bird _ann_potc.jpg: Category EVM of weighted potential impact due to construction activities for all bird groups, averaged over the seasons for an annual perspective.

Bird _ann_poto.jpg: Category EVM of weighted potential impact due to operation activities for all bird groups, averaged over the seasons for an annual perspective.

Bird _ann_pro.jpg: Category EVM of weighted protection status for all bird groups, averaged over the seasons for an annual perspective.

Category EVMs → Turtles

Turt_ann_eco.jpg: Category EVM of combined global importance *and* protection status for sea turtles, averaged over the seasons for an annual perspective.

Turt_ann_eic.jpg: Category EVM of combined potential impact due to construction *and* ecological value (global importance + protection status) for sea turtles, averaged over the seasons for an annual perspective.

Turt_ann_eio.jpg: Category EVM of combined potential impact due to operation *and* ecological value (global importance + protection status) for sea turtles, averaged over the seasons for an annual perspective.

Turt_ann_eit.jpg: Category EVM of combined potential impact (construction + operation) *and* ecological value (global importance + protection status) for sea turtles, averaged over the seasons for an annual perspective.

Turt_ann_glo.jpg: Category EVM of weighted global importance of each species for sea turtles, averaged over the seasons for an annual perspective.

Turt_ann_imp.jpg: Category EVM of combined potential impact due to operation *and* construction activities for sea turtles, averaged over the seasons for an annual perspective.

Turt_ann_potc.jpg: Category EVM of weighted potential impact due to construction activities for sea turtles, averaged over the seasons for an annual perspective.

Turt_ann_poto.jpg: Category EVM of weighted potential impact due to operation activities for sea turtles, averaged over the seasons for an annual perspective.

Turt_ann_pro.jpg: Category EVM of weighted protection status for sea turtles, averaged over the seasons for an annual perspective.

Category EVMs → Mammals
Mamm_ann_eco.jpg: Category EVM of combined global importance *and* protection status for marine mammals, averaged over the seasons for an annual perspective.

Mamm_ann_eic.jpg: Category EVM of combined potential impact due to construction *and* ecological value (global importance + protection status) for marine mammals, averaged over the seasons for an annual perspective.

Mamm_ann_eio.jpg: Category EVM of combined potential impact due to operation *and* ecological value (global importance + protection status) for marine mammals, averaged over the seasons for an annual perspective.

Mamm_ann_eit.jpg: Category EVM of combined potential impact (construction + operation) *and* ecological value (global importance + protection status) for marine mammals, averaged over the seasons for an annual perspective.

Mamm_ann_glo.jpg: Category EVM of weighted global importance for marine mammals, averaged over the seasons for an annual perspective.

Mamm_ann_imp.jpg: Category EVM of combined potential impact due to operation *and* construction activities for marine mammals, averaged over the seasons for an annual perspective.

Mamm_ann_potc.jpg: Category EVM of weighted potential impact due to construction activities for marine mammals, averaged over the seasons for an annual perspective.

Mamm_ann_poto.jpg: Category EVM of weighted potential impact due to operation activities for marine mammals, averaged over the seasons for an annual perspective.

Mamm_ann_pro.jpg: Category EVM of weighted protection status for marine mammals, averaged over the seasons for an annual perspective.

Composite EVMs

Composite EVMs are seasonal and annual representations of all resources mapped as part of this analysis.

EVMs:

- EVMe = Ecological Value
- EVMc = Ecological and Impact: Construction
- EVMo = Ecological and Impact: Operation
- EVMt = Ecological and Impact: Combined

Listed below are the file names and descriptions for the annual maps. Seasonal maps can be found in appropriately labeled folders and have the same set of suffixes (see above).

Seasons:

- Ann = Annual (average of all seasons available)
- Fal = Fall (October – December)
- Spr = Spring (April – June)
- Sum = Summer (July – September)
- Win = Winter (January – March)

Composite EVMs → Annual

Evmc_ann.jpg: Annual Composite EVM of ecological value and potential impact (construction only) for all resources.

Evme_ann.jpg: Annual Composite EVM of ecological value (global importance + protection status) for all resources.

Evmo_ann.jpg: Annual Composite EVM of ecological value and potential impact (operation only) for all resources.

Evmt_ann.jpg: Annual Composite EVM of ecological value and potential impact (construction + operation) for all resources.

Composite EVMs → Annual → Mar. Mam. and Turtles Excluded

Evme_ann_partial.jpg: Annual Composite EVM of ecological value (global importance + protection status) for all resources except marine mammals and sea turtles.

Ecological Value Map (EVM)
for the Rhode Island Ocean Special Area Management Plan –
May 2011 Update

Appendix B

Literature Review of Ecological Valuation Approaches for Marine Ecosystems

by

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Introduction

Assigning value to subareas or zones of the marine environment is not an easy task. Marine environments are intricately complex, typically multifaceted, and provide many services both to natural resources (i.e., fish and wildlife) and to humans. Past valuations have attempted to measure ecological importance, goods and services provided to humans, or both. The outcome of a valuation of a selected area can vary greatly depending on what is being examined. As with any scientific study, clear definitions of the descriptive terms used and what is being measured are pertinent. Methods of valuation in the marine environment have evolved from land-based biodiversity and zoning assessments, natural resource management, marine protected area (MPA) siting analyses, and most recently marine spatial planning (MSP) efforts. Because this science is rooted in both socio-economic and environmental practices, there is cross over in descriptive terminology making accurate definitions all the more important.

The socio-economic definition of the term "value" refers to the goods and services provided by the marine ecosystem, or the value of an area in terms of importance for human use (Nunes and van den Bergh, 2001; De Groot et al., 2002). Human uses of biological resources include consumptive uses (e.g., commercial fisheries harvest, recreational fishing), non-consumptive uses (e.g., scuba diving, wildlife viewing), and non-use (e.g., intrinsic, bequest) values (Freeman, 1993; Kopp and Smith, 1993; Unsworth and Bishop, 1994; and Smith, 1996). This socio-economic definition or inference of the term "value" (which is often tied to a monetary unit), is more traditional and rooted in economic theory.

Ecosystem-based management is an "integrated approach to management that considers the entire ecosystem, including humans" (McLeod and Leslie, 2009). Ecosystem-based management is place- or area-based, as it focuses on a specific ecosystem and the activities affecting it (Douvere, 2008). The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive, and resilient condition so that it can provide the services humans want and need. The emphasis on managing places is a key characteristic of ecosystem-based management and differs from past management approaches in that it considers the cumulative impacts of different sectors, as opposed to focusing on a single species, sector, or activity (Douvere, 2008; McLeod and Leslie, 2009). Several ecosystem-based management practices and tools have developed over the past two decades that assess the marine environment from a holistic, ecological standpoint. However, there is a recognized need for more concrete guidance and operational tools to move the implementation of ecosystem-based management forward (Douvere, 2008). Recently, MSP has emerged as a powerful tool for making ecosystem-based management a reality (Douvere, 2008). MSP is a spatial management practice that considers usage of an area by all sectors (e.g. fisheries, oil and gas industry, renewable energy development). To successfully carry out MSP, baseline scientific and socio-economic data must be mapped to support comprehensive decision making and siting analysis.

With the onset of marine ecosystem-based management, valuation siting analysis efforts have shifted their focus towards biodiversity and ecology. Under the ecosystem-based management approach, valuation of the marine environment should be related to measures of biological and habitat importance. In more recent MSP and ecological valuation efforts, the term "value" has referred to the intrinsic value of marine biodiversity, without reference to anthropogenic use (DFO, 2005; ENCORA/MARBEF, 2006; Derous et al., 2007a,b,c). Under this definition, value is measured by ecosystem processes such as food production for the food web, refuge from predators, and nesting and nursery habitat.

Marine ecosystems are inherently complex environments having connective processes such that many aspects must be taken into consideration when measuring ecological value. In the marine environment, valuations must consider characteristics and processes of the benthic and pelagic systems, and usage of these by all species (e.g., fish, invertebrates, birds, marine mammals). Typically, ecological valuation approaches have employed multi-criteria evaluation methods while examining spatial ecosystem data, often resulting in a "hot spot" or value map of the area of interest (e.g., Villa et al., 2002; Derous et al., 2007a,b; EOEEA, 2009). Evaluation criteria have been assessed using Delphic and quantitative methods (Brody, 1998). The Delphic method of analysis relies on consensus of a group of experts in the field ranking priorities. This method is often used when time and resources are limited. Selection criteria can also be quantified or scored to minimize the influence of personal bias. Criteria specifically for evaluating the ecological importance of marine environments have evolved over the past fifteen years through small scale studies that identify significant or important marine areas to protect, as well as in larger scale MSP or marine zoning efforts (e.g., Brody, 1998; Roberts et al., 2003a;

Lieberknecht et al., 2004; DFO, 2005; Derous et al., 2007a,b,c). The synthesizing criteria developed in these approaches typically identify areas of low to high biodiversity.

The following review summarizes several studies in which methods and criteria for marine ecological valuation were developed.

Overview of Socio-economic Valuation

As discussed above, ecological resources provide services to humans, in addition to their intrinsic ecological value (which may be related to biodiversity [Wilson, 1988; Derous et al., 2007a,b,c]) and services to the ecosystem (e.g., nesting and foraging habitat, refuge from predators, food production, nutrient cycling). Human services include consumptive uses (e.g., commercial harvest, recreational fishing), non-consumptive uses (e.g., scuba diving, wildlife viewing, aesthetics, spiritual enrichment), and non-use (e.g., option, bequest, genetic pool, existence) values (Freeman, 1993; Kopp and Smith, 1993; Unsworth and Bishop, 1994; Smith, 1996). Many attempts have been made to measure the value of these services in economic terms, with value being defined as the aggregate "willingness-to-pay" by all individuals for all the services associated with the functioning of the ecosystem (e.g., Freeman, 1993; Smith, 1996). In practice, this approach requires considerable research and site-specific data, relying on proxy markets for ecological services that are not in fact directly traded in the marketplace. If site-specific data are not available, value transfers from other markets or locations are typically made, with a great deal of associated uncertainty. Alternatively, non-market valuation techniques such as Contingent Valuation (CV), which involves questioning samples of people regarding willingness-to-pay for ecological services, are used to estimate monetary values of services. However, these methods are difficult to apply without bias and the results, therefore, are highly variable and uncertain (NOAA, 1992). Arrow et al. (2001) outline the potential biases and errors associated with CV, as well as criteria for reliable CV studies. Of the potential biases and errors associates with CV studies, Arrow et al. (2001) list the following as the most concerning: (1) the CV method can produce results that appear to be internally inconsistent; (2) responses to CV surveys can seem implausibly large in view of the many programs for which individuals might be asked to contribute and the existence of both public and private goods that might be substitutes for the resource(s) in question; (3) most applications of the CV method fail to remind respondents of the budget constraints under which willingness-to-pay spending decisions must be made; (4) respondents may not be provided adequate information about the program they are being asked to value, or may not fully absorb and accept detailed program information as the basis for their responses; (5) in generating aggregate estimates using the CV technique, it is sometimes difficult to determine the extent of the population that is appropriate for determining values; and (6) respondents in CV surveys may actually be expressing feelings about the "warm glow" of donating to a worthy cause, rather than actual willingness to pay for the program in question.

Given these difficulties and data constraints, more recent attempts at ecological valuation have focused on approaches based on biodiversity; and scaling mitigation of equivalent value to lost ecological services has been based on compensatory restoration rather than monetary valuation. Under the Comprehensive Environmental Response, Compensation, and Liability Act (“CERCLA”; 42 U.S.C. § 9601 *et seq*.), the Clean Water Act (33 U.S.C. § 1251 *et seq*.), the National Marine Sanctuaries Act (16 U.S.C. § 1431 *et seq*.), and the 1990 Oil Pollution Act (“OPA”; 33 U.S.C. § 2701 *et seq*.), natural resource trustees (i.e., designated government agencies) act on behalf of the public to protect natural resources and make damage claims against parties responsible for injuries to natural resources resulting from discharges of oil, releases of hazardous substances, or physical injury. The compensation is in the form of equivalent ecological and human services to the injuries, often measured by totaling ecologically-equivalent production of biomass or service-years of resource life (NOAA, 1995).

Thus, while monetary valuation is theoretically possible as a metric for mapping values of ecological resources, in practice the approach requires considerable site-specific research effort, is very subjective (as human perception of value is involved), and is highly uncertain.

Relevant MPA Efforts and Valuation Criteria

To efficiently execute MSP management, ecological valuation of broad scale coastal zones and subareas is necessary. Ecological valuation of the marine environment for MSP is a relatively new science, and despite the current global push to implement MSP practices, little guidance exists. There is increasing awareness that rigorous procedures are needed for assessing the value of marine areas; these procedures should be based on objectively chosen criteria and sound scientific monitoring data (Agardy, 2010). Currently, approaches, methods, and protocols for ecological valuation are being developed and tested.

To date, most of the development and refinement of ecological valuation criteria and methods has arisen out of initiatives to identify and designate MPAs. Many different selection approaches have been used for MPAs, from using criteria as general guidelines to more complex methods of scoring and ranking (Brody, 1998). Historically, the selection of MPAs was largely opportunistic or arbitrary; recently, a more Delphic or judgmental approach has been advocated (Agardy, 2010), and many important ecological concepts and valuation methods have evolved and been examined during MPA siting analyses. Ecological valuation for MPA siting differs from valuation for MSP, as MSP valuation is not a process to select areas for conservation according to an objective; rather it should be an overview of baseline ecological value of the study area (Derous et al., 2007a). However, the criteria and methods used for selection of MPAs have greatly informed or helped the development of MSP approaches. The underlying theme of many MPA selection criteria is reflected in the recent MSP studies, tools, case studies, and models. Several relevant assessments and studies from the MPA literature are discussed below.

Habitat-level Approaches

Attaining comprehensive data with ample spatial coverage for ecological valuations can be challenging. In many cases, biological data are patchy and/or focused on a particular area of concern. The sampling coverage needed to truly represent broad scale study areas is often unavailable and costly to obtain (e.g. characterization of the benthic habitat). Amalgamation of data sets from studies performed at various locations and by various researchers may lead to standardization and effort issues inherent to the sampling approaches, although these amalgamation efforts are still useful if standardization is handled properly and limitations are well defined. Modeling data layers based on spatial interpolations between points, or extrapolating a surface as a function of a variable with ample spatial coverage has been used to address the data gap problem (Degraer et al., 2008; EOEEA, 2009; Greene et al., 2010). For example, in the Belgian part of the North Sea, Degraer et al. (2008) constructed a habitat suitability model for soft sediment communities. It was determined through statistical analysis of benthic samples that median grain size and sediment mud content were the two most important environmental variables determining the macrobenthic community. Because sediment spatial distribution was well known, model-based predictions could be made regarding the biological communities for the unsampled areas.

To further investigate the data insufficiency problem, Ward et al. (1999) evaluated the use of four different ecosystem-level (i.e., “coarse-filter”) surrogates as the basis for identifying marine reserves in Jervis Bay, Australia: (1) habitat categories, and species-level assemblages of (2) fish, (3) invertebrates, and (4) plants (e.g., algae, seagrasses). The performance of these surrogates was evaluated based on the total number of taxa (i.e., species richness) contained in marine reserves generated by a number of selection simulations. This approach allowed for an assessment of, for example, the extent to which reserves chosen solely on the presence of fish assemblages would also coincidentally include taxa of invertebrates or plants. Ward et al.’s (1999) findings suggest that habitat-level surrogates may be appropriate for initially identifying areas of high priority, without the need for extensive species-level survey data. In addition, site selection based on habitat categories would have a lower risk of failing to coincidentally include certain taxonomic groups.

Computer-based Approaches

In regional conservation planning situations with multiple conservation targets and thousands of potential sites, computer-based siting algorithms can be useful in reducing the enormous number of potential reserve systems to a more manageable set of scenarios (Leslie et al., 2003). The various siting algorithms available can be grouped into three main types: iterative, optimizing, and simulated annealing.

Iterative algorithms use a set of criteria to order each planning unit and then choose the highest ranking site. Some of the most popular iterative or heuristic algorithms aim to achieve representation of rare species or maximize species richness. While useful, these approaches generate only one solution and it is unlikely to be the optimal one (Leslie et al., 2003).

Using standard mathematical programming methods, optimizing algorithms, such as an Integer Linear Program (ILP) can be used to find the optimal reserve-selection solution. ILPs determine how to maximize or minimize a particular function, subject to several constraints (represented as linear relationships). ILPs can be used to find the optimal reserve-selection solution; however, they also produce only one solution. In a conservation planning situation, multiple solutions are often more desirable. Furthermore, if a conservation planner prefers a spatially-clustered reserve system, optimal solutions cannot be guaranteed with this method (as it is a Non-linear Integer Programming problem) (Leslie et al., 2003). Another limitation is that because of the computing time required, the optimization method fails in situations where there are more than a few hundred potential planning units (Possingham et al., 2000).

Simulated annealing is a flexible optimization algorithm that starts with a random reserve system and then iteratively explores trial solutions by making sequential random changes to the set of planning units. In each iteration, the previous set of units is compared with the new set, and the best one is accepted (Possingham et al. 2000). The strength of this approach is its avoidance of local optima and more opportunities to reach the global minimum. This approach has been shown to outperform simpler iterative or heuristic algorithms (Possingham et al., 2000).

Using benthic habitat data from the Florida Keys, Leslie et al. (2003) demonstrated the use of simulated annealing to identify marine reserve systems that met specified levels of habitat representation. To apply this approach, they used the reserve design software package SPEXAN[1] (an acronym for SPatially EXplicit ANnealing). Using the reserve scenarios generated by simulated annealing, the authors also conducted an irreplaceability analysis to determine how many times each site was chosen during 100 runs. This analysis identified sites that were consistently selected in the reserve network scenarios, as well as sites that were never or infrequently chosen. Identifying consistently chosen (i.e., "irreplaceable") sites is a useful output of siting algorithms that could be used to indicate priority areas for conservation.

Although Leslie et al.'s (2003) analysis focused on using habitat representation to select reserve sites, the authors note that many other types of data could be incorporated into the algorithms, such as occurrences of species of concern, protected sites, recreational and fishing pressure, land-based activities, etc. They also stated that information regarding currents and other oceanographic features could be incorporated into the siting algorithm through the formulation of an additional constraint.

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[1] A modified version of SPEXAN was later developed into the software product now known as Marxan.

Villa et al. (2002) used spatial multiple criteria analysis (SMCA) to integrate objective data with stakeholder priorities in the development of a proposed zoning plan for the Asinara Island National Marine Reserve in Italy. SMCA is one method among a diverse set of techniques known as multicriteria evaluation. These techniques are widely used in both economic analyses and environmental impact assessments and are rooted in land-based urban and regional zoning and management (Voogd, 1983; Nijkamp et al., 1990; Agardy, 2010). By coupling geographic information system-based land assessment with a formal analysis of design priorities, SMCA can be used to objectively evaluate the suitability of various marine areas for different uses and levels of protection. In addition to planning, techniques based on SMCA can also be used to monitor the effectiveness of MPA management and evaluate whether objectives are being met according to expected time frames (Villa et al., 2002). One of the strengths of SMCA is that both quantitative and semi-quantitative information/ranks can be combined in the analyses without the need for special data processing (Villa et al., 2002).

Concordance/discordance analysis is a fundamental technique in SMCA in which a set of attributes is ranked according to a concordance (or discordance) score computed based on “priority weights” that reflect the importance of each attribute within a particular scenario (Villa et al., 2002). These concordance scores are then used to create a map for each land- or marine-use scenario depicting the agreement between the specified priorities and the features of the area of interest. The maps from several different scenarios can then be aggregated and analyzed using GIS (Agardy, 2010). To inform the proposed zoning plan for the Asinara Island reserve, Villa et al. (2002) aggregated the available data into five higher-level variables, as described below:

- Natural Value of the Marine environment (NVM). This map aggregated values related to (1) the diversity and size distribution in the benthic and aquatic communities, (2) the presence of endemic or rare species, and (3) the presence and status of conservation habitats that have crucial roles in maintaining ecosystem function (e.g., nursery areas).
- Natural Value of the Coastal environmental (NVC). This map was obtained by aggregating information relative to important coastal endemic species, the suitability of habitats for return or reintroduction of key species, and the ability of the coastal habitat to support key species that nest on the mainland. The aggregation was performed by applying SMCA to the raw information.

- Value of Area for Recreational Activities (RAV). This map was also obtained by assigning relative importance values to each variable included and performing a SMCA to characterize the value as concordance of the area characteristics with the suitability for each feature. The final value map was obtained from the results of the SMCA after weighting with the accessibility of the area.
- Values of the area for Commercial exploitation of Resources (CRV). This map was prepared based on maps identifying areas of traditional and artisan fishing activity and the general suitability of areas for such practices.
- Degree of accessibility of area (Ease of Access, EAC). This was map prepared based on distance buffering of maps identifying marine access routes and existing harbors. The EAC map was used both as a "benefit" value for scenarios where access is allowed and encouraged, and as a "cost" factor in high protection scenarios, being a proxy for potential disturbance.

These various GIS layers were then combined into one surface of evaluation units. Evaluation units were derived by processing the data contained in the initial set of variable layers to identify all areas where unique combinations of variable values exist. Then various priority weights were applied to the evaluation unit layer to produce a final concordance map. These priority weights were developed through consultation with various stakeholders for four different protection levels.

There have been several MPA siting studies conducted using a decision support software program called Marxan (Stewart et al., 2003; Richardson et al., 2006; Klein et al., 2008; Smith et al., 2009). Marxan (Ball and Possingham, 2000; Possingham et al., 2000) is used to identify potential reserves or reserve networks that meet explicit conservation objectives. Essentially, Marxan software includes or excludes a planning unit from being reserved, implicitly assuming two zones: reserved or not reserved. The biological criterion that Marxan uses to discriminate between marine areas is the number of species or communities contained within a designated level of representation. The Marxan method has been applied to marine reserve case studies in California, the United Kingdom, Australia, and elsewhere.

The recently-developed Marxan with Zones (Watts et al., 2009) is an analytic tool that expands on the basic marine reserve design problem to incorporate new functionality and broaden its utility for practical application. This newer version of the Marxan tool shifts away from the binary decision framework towards a multi-use seascape planning paradigm supporting allocation of planning units to a range of different management actions. Marxan with Zones is designed to improve planning for marine protected area (MPA) systems, but also for application to a wider range of natural resource management and spatial planning problems.

Valuation Criteria

Roberts et al. (2003a,b) identified criteria for objectively assessing the biological value of areas being considered for marine reserves. The overall goal of the evaluation scheme was to promote the development of reserve networks that would maintain biodiversity and ecosystem functioning at large scales. In certain past cases, socio-economic evaluation criteria for an area had been given equal or greater weight than the ecological considerations. This can lead to selection of areas with little biological value that fail to meet many of the management and conservation objectives (Roberts et al., 2003a,b). Roberts et al. (2003a) argue that in general, biological evaluation should precede and inform social and economic evaluation of potential reserve sites.

The criteria developed in Roberts et al. (2003a,b) concentrate on the assessment of sites according to their biodiversity, the processes that support that biodiversity, and processes that aid fisheries management and provide other human benefits. Valuation criteria representing the biodiversity of sites included: biogeographic representation, habitat heterogeneity, endemism, and presence of species or populations of special interest (e.g., threatened species). Valuation criteria used to assess sustainability of biodiversity and fishery values included: size of reserves necessary to protect viable habitats, presence of exploitable species, vulnerable life stages, connectivity between reserves, links among habitats, and provision of ecosystem “services” for people. Human threats and natural catastrophes were also accounted for and enabled candidate sites to be eliminated from consideration if risks were too great, but also helped prioritize among sites where threats could be mitigated by protection.

The International Maritime Organization (IMO) has put forth guidelines for the identification and designation of Particularly Sensitive Sea Areas (PSSAs) (IMO, 2006). A PSSA is defined by the IMO as an area in need of special protection due to its significance for recognized ecological, socio-economic, or scientific attributes, where such attributes may be vulnerable to damage by international shipping activities. The guidelines state that in order to be identified as a PSSA, the area should meet at least one of the criteria defined below. Additional factors are also considered in order to assess the vulnerability of the area to impacts from international shipping; these factors are beyond the scope of this review, and are therefore not discussed further.

- *Ecological criteria*
    - *Uniqueness or rarity* – An area or ecosystem is considered unique if it is the only one of its kind (e.g., habitats of rare, threatened, or endangered species that occur only in one area). An area or ecosystem is considered rare if it only occurs in a few locations or has been seriously depleted across its range. Nurseries or certain feeding, breeding, or spawning areas may also be considered rare or unique.
    - *Critical habitat* – An area that may be essential for the survival, function, or recovery of fish stocks or rare or endangered marine species, or for the support of large marine ecosystems.
    - *Dependency* – An area where ecological processes are highly dependent on biotically structured systems (e.g., coral reefs, kelp forests, mangrove forests, seagrass beds). Dependency also embraces the migratory routes of fish, reptiles, birds, mammals, and invertebrates.
    - *Representativeness* – An area that is an outstanding and illustrative example of specific biodiversity, ecosystems, ecological or physiographic processes, or community or habitat types or other natural characteristics.
    - *Diversity* – An area that may have an exceptional variety of species or genetic diversity or includes highly varied ecosystems, habitats, and communities.
    - *Productivity* – An area that has a particularly high rate of natural biological production.

  - *Spawning or breeding grounds* – An area that may be a critical spawning or breeding ground or nursery area for marine species which may spend the rest of their life-cycle elsewhere, or is recognized as migratory routes for fish, reptiles, birds, mammals, or invertebrates.
  - *Naturalness* – An area that has experienced a relative lack of human-induced disturbance or degradation.
  - *Integrity* – An area that is a biologically functional unit; an effective, self-sustaining ecological entity.
  - *Fragility* – An area that is highly susceptible to degradation by natural events or by the activities of people.
  - *Bio-geographic importance* – An area that either contains rare biogeographic qualities or is representative of a biogeographic "type" or types, or contains unique or unusual biological, chemical, physical, or geological features.
- *Social, cultural and economic criteria*
  - *Social or economic dependency* – An area where the environmental quality and the use of living marine resources are of particular social or economic importance, including fishing, recreation, tourism, and the livelihoods of people who depend on access to the area.
  - *Human dependency* – An area that is of particular importance for the support of traditional subsistence or food production activities or for the protection of the cultural resources of the local human populations.
  - *Cultural heritage* – An area that is of particular importance because of the presence of significant historical and archaeological sites.
- *Scientific and educational criteria*
  - *Research* – An area that has high scientific interest.
  - *Baseline for monitoring studies* – An area that provides suitable baseline conditions with regard to biota or environmental characteristics, because it has not had substantial perturbations or has been in such a state for a long period of time such that it is considered to be in a natural or near-natural condition.

  - *Education* – An area that offers an exceptional opportunity to demonstrate particular natural phenomena.

In 2007, the Convention on Biological Diversity (CBD) organized a workshop in the Azores to develop a consolidated set of scientific criteria for identifying ecologically or biologically significant marine areas in need of protection, as well as to compile biogeographical and ecological classification systems for delineating ocean regions and ecosystems (CBD, 2008). The adopted criteria (summarized below) share many similarities with the IMO criteria.

- *Uniqueness or rarity* – Areas that contains unique, rare, or endemic species, populations, or communities; unique, rare, or distinct habitats or ecosystems; and/or unique or unusual geomorphological or oceanographic features.
- *Special importance for life history stages of species* – Areas that are required for a population to survive and thrive, such as breeding grounds, spawning areas, nursery areas, juvenile habitat, and habitats of migratory species (e.g., feeding, breeding, moulting, wintering, or resting areas, migratory routes).
- *Importance for threatened, endangered, or declining species and/or habitats* – Areas containing habitat for the survival and recovery of endangered, threatened, or declining species, or areas with significant assemblages of such species. Includes breeding grounds, spawning areas, nursery areas, juvenile habitat, and habitats of migratory species (e.g., feeding, breeding, moulting, wintering, or resting areas, migratory routes).
- *Vulnerability, fragility, sensitivity, or slow recovery* – Areas that contain a relatively high proportion of sensitive habitats, biotopes, or species that are functionally fragile (i.e., highly susceptible to degradation or depletion by human activity or by natural events) or with slow recovery.
- *Biological productivity* – Areas containing species, populations, or communities with comparatively higher natural productivity (e.g., frontal areas, upwellings, hydrothermal vents).
- *Biological diversity* – Areas containing comparatively higher diversity of ecosystems, habitats, communities, or species, or having higher genetic diversity (e.g., seamounts, fronts and convergence zones, cold coral communities, deep-water sponge communities).

- *Naturalness* – Areas with a comparatively higher degree of naturalness as a result of the lack of or low level of human-induced disturbance or degradation.

Notabartolo di Sciara and Agardy (2009) describe the first phase in the process of developing a network of representative marine protected areas in areas beyond national jurisdictions in the Mediterranean Sea. As part of the this effort, the authors developed a set of region-specific criteria by adapting other existing criteria, including the Specially Protected Area of Mediterranean Importance (SPAMI) criteria ("Common criteria for the choice of protected marine and coastal areas that could be included in the SPAMI List") listed in Annex I of the Protocol to the Barcelona Convention concerning Specially Protected Areas and Biological Diversity in the Mediterranean (also known as the SPA/BD Protocol). The Annex lists the following criteria for use in assessing the regional value of an area:

- *Uniqueness* – The area contains unique or rare ecosystems, or rare or endemic species.
- *Natural representativeness* – The area has highly representative ecological processes, or community or habitat types or other natural characteristics. Representativeness is defined as the degree to which an area represents a habitat type, ecological process, biological community, physiographic feature, or other natural characteristic.
- *Diversity* – The area has a high diversity of species, communities, habitats, or ecosystems.
- *Naturalness* – The area has a high degree of naturalness as a result of the lack or low level of human induced disturbance and degradation.
- *Presence of habitats that are critical to endangered, threatened or endemic species.*
- *Cultural representativeness* – The area has a high representative value with respect to cultural heritage, due to the existence of environmentally sound traditional activities integrated with nature which support the well-being of local populations.

Notabartolo di Sciara and Agardy (2009) contend that these criteria alone are insufficient to guide the development of a representative network of MPAs in the Mediterranean Sea and suggest integrating the SPAMI selection criteria with other existing criteria used in the development of MPA networks. The authors proposed the following eight criteria for the selection of priority regions in the Mediterranean Sea, based on the SPA/BD Protocol criteria for

SPAMIs, and incorporating additional information from other criteria, most notably those adopted by the CBD. The proposed criteria are listed below:

- *Uniqueness or rarity* – Areas that contain unique, rare, or endemic species, populations or communities; unique, rare or distinct, habitats or ecosystems; and/or unique or unusual geomorphological or oceanographic features.
- *Special importance for life history stages of species* – Areas that are required for a population to survive and thrive.
- *Importance for threatened, endangered or declining species and/or habitats* - Areas containing habitat for the survival and recovery of endangered, threatened, declining species or area with significant assemblages of such species.
- *Vulnerability, fragility, sensitivity, or slow recovery* – Areas containing a relatively high proportion of sensitive habitats, biotopes or species that are functionally fragile (highly susceptible to degradation or depletion by human activity or by natural events) or with slow recovery.
- *Biological productivity* – Areas containing species, populations, or communities with comparatively higher natural biological productivity.
- *Biological diversity* – Areas containing comparatively higher diversity of ecosystems, habitats, communities, or species, or having higher genetic diversity.
- *Naturalness* – Areas with a comparatively higher degree of naturalness as a result of the lack of or low level of human-induced disturbance or degradation.
- *Cultural representativeness* – Areas with a high representative value with respect to the cultural heritage, due to the existence of environmentally sound traditional activities integrated with nature which support the well-being of local populations.

Considering the various sets of criteria discussed above, it is clear that despite slightly different definitions, there are several common themes in criteria currently used for ecological valuation. Smith and Theberge (1986) conducted a review of criteria used in the evaluation of natural areas, including wetland, freshwater, and marine environments. Their review identified a number of criteria that have been used to identify and evaluate the significance of natural areas. Of the 22 evaluation systems they reviewed, the most common criteria used consisted of the following: rarity, uniqueness (used in 91 percent of the studies); diversity (91 percent); size (50 percent); naturalness (45 percent); representativeness, typicalness (36 percent); and fragility (32 percent).

Brody (1998) reviewed and compared existing selection criteria frameworks for six MPA-related programs in the Gulf of Maine. Ecological characteristics (e.g., representativeness, ecological importance, uniqueness) were the criteria most heavily emphasized in the programs reviewed. Social criteria (e.g., education, recreation, and culture) were the least used criteria among the identified programs. Overall, management objectives that aim to protect natural processes or threatened species place a high priority on criteria that value ecological components of the marine environment, such as representativeness, naturalness, diversity, and ecological sensitivity. Management objectives for MPAs that encourage human use tend to rely more on pragmatic/feasibility criteria, such as accessibility, compatibility, financial resources, and cooperative management. Management objectives that focus on more intensive human use and aim to maintain species/habitats for sustainable human use rely more on economic criteria, such as importance to fisheries, importance to species, and biological productivity. Management objectives that focus on passive human use tend to emphasize criteria such as tourism/recreation, education/interpretation, and uniqueness (e.g., unique features that attract the interest of visitors).

Relevant MSP Efforts

In the last decade or so, several countries have begun implementing (or developing) MSP, including Australia, New Zealand, the United Kingdom, the Netherlands, Belgium, Germany, Denmark, Italy, China, West Africa, the United States, Canada and others (Douvere, 2008; Agardy, 2010). Several of these efforts are discussed in the following paragraphs. Most of these international efforts (with the exception of China), have focused on establishing marine reserves and MPAs. However, in Europe (particularly the North Sea area), MSP has become much broader and is more focused on establishing ecosystem-based management, including enhancing efficient use of the marine environment, identifying opportunities for shared use, and resolving use conflicts (both between different sea uses and between users and the environment) (Douvere, 2008).

Under Canada's Oceans Act, the Department of Fisheries and Oceans (DFO) developed a tool or framework to identify ecologically and biologically significant areas to aid in providing these areas a heightened degree of risk aversion in the management of activities (DFO, 2005). In this framework, significant areas are identified based on characteristics of a particular area, and the process-based understanding of important characteristics in terms of ecosystem structure and function. On the conceptual level, the framework uses three main criteria, against which specific areas can be evaluated with regards to their ecological and biological significance, including uniqueness, aggregation, and fitness consequences. For specific cases, in addition to these three criteria, they suggest that resilience and naturalness should also be considered. DFO (2005) suggested that areas should be comparatively evaluated using a probabilistic view for all five criteria. Those areas that rank highly on one or more of the three main criteria for a single species or habitat feature may be considered significant.

DFO (2005) provided some caveats in applying their framework. It needs to be taken into consideration that some of the information sources from well-sampled areas may be "clustered in space," and may provide a biased view of uniqueness; further consideration and review of qualitative and semi-quantitative methods to help reduce this bias were suggested. Vulnerability of the area (i.e., relative vulnerability of species or structural habitat features to disturbance and relative exposure of sites to likelihood of perturbations) should be considered during the evaluation. Spatial scale on all levels (i.e., for structural habitat, life history function, community structure, and connectivity between sites) should always be taken into account during the area evaluation for all five dimensions. Spatial scale needs to be recognized as a constant source of uncertainty. Temporal scale also needs to be considered during the comparative evaluation between areas.

DFO (2005) provides illustrations of how various ecological functions, including spawning/breeding, nursery/rearing, feeding, migration, and seasonal refugia, would be judged under each of the five ranking criteria considered. Similarly, they provided illustrations of how biodiversity (presence of endangered or threatened species and presence of highly diverse or productive communities) and various structural features, including physical oceanographic features (e.g., tidal mixing zones, convergence zones, polynyas, upwelling zones), strong topography, sponge reefs, deepwater corals, and macrophyte beds would be judged under the five ranking criteria.

As described in Agardy (2010), in 2002 the UK government began a regional planning effort to identify marine areas of conservation interest, as well as areas with development potential for maritime industries. As a pilot project, a partnership of several agencies collected geophysical, hydrographical, nature conservation, ecological, and human-use data and analyzed various planning options for the Irish Sea using GIS and Marxan. As part of the Irish Sea Pilot, areas of national importance for marine conservation were identified with the objective of eventually developing a network of protected sites consisting of representative examples of each habitat type, areas of exceptional biodiversity, and important areas for aggregations of highly mobile species. Criteria used to assess national importance included typicalness, naturalness, size, biological diversity, critical areas for certain stages in the life cycles of key species, and nationally-recognized important marine features (Connor et al., 2002; Lieberknecht et al., 2004). Two approaches for applying criteria were tested. The first approach applied criteria directly at the landscape scale. Previous studies identified the "best examples" of each marine landscape at the regional sea scale. The approach operated under the assumption that marine landscapes would act as surrogates for smaller levels of scale (species, habitats) which would ensure the full representation of biodiversity within the final set of areas. The second approach utilized the reserve selection software Marxan (Ball and Possingham, 2000; Possingham et al., 2000), which aided in the process of identifying nationally import marine areas at a regional scale, especially in data-poor offshore regions. This approach tested how the criteria can be incorporated into Marxan using real data from the Irish Sea. One of the main outcomes of this case study was that the various criteria definitions were found to be too restrictive and only effective in areas with good data coverage. The authors concluded that refined definitions were necessary to make the criteria more applicable.

In 2002, China's "Law on the Management of Sea Use" came into effect and established a management framework and initial regional planning system for development and conservation in the marine environment (Li, 2006; Douvere, 2008). The Law establishes that any individual or entity that plans to use the marine environment must apply in advance and obtain authorization from both the provincial and national government. The Law also imposes a userfee system. Furthermore, the legislation stipulated that the State Oceanic Administration work with the governments of coastal provinces, autonomous regions, and municipalities to formulate a marine functional zoning plan, under which the marine environment is divided into different functional zones based on criteria related to ecological functions and priority use. The formulation of the marine functional zoning plan was required to follow the basic principles listed below:

- Scientifically defining the functions of the sea area according to such natural attributes as its geographic location, natural resources, and natural environment;
- Making overall arrangements for sea area use among various related sectors according to economic and social development needs;
- Protecting and improving the ecological environment, ensuring the sustainable utilization of the sea area, and promoting the development of the marine economy;
- Ensuring maritime traffic safety; and
- Safeguarding the security of national defense and meeting the needs of the military's use of the sea.

After extensive studies and data collection, the National Marine Functional Zoning Scheme was submitted and approved by the State Council. Any use of the sea must comply with this scheme (Li, 2006).

The most notable and recent concept for marine biological valuation, representing consensus of multiple European researchers, has been developed by Derous et al. (2007a,b,c), where marine biological valuation is defined as the determination of value of the marine environment from a "nature conservation perspective." Their valuation methodology provides an integrated view of "the intrinsic value of marine biodiversity, without reference to anthropogenic use" and purposefully does not include the socio-economic valuation or quantification of goods and services. This methodology entails compilation of biological valuation maps (BVMs) using available marine ecological and biological data where intrinsic value is assessed using biological valuation criteria. BVMs can then be used as baseline data for spatial planning efforts and allow managers and planners to make objective and transparent decisions.

Derous et al. (2007a) present a comprehensive literature search outlining existing biological valuation approaches and assessment criteria (highlighting both terrestrial and marine case studies). The results of their literature review showed that biodiversity can be measured via three "1st order" valuation criteria: rarity, aggregation, and fitness consequence. These criteria are defined as:

- *Rarity* – The degree to which a subzone is characterized by unique, rare, or distinct features (e.g., landscapes, habitats, communities, species, ecological functions, geomorphological, or hydrological characteristics) for which no alternatives exist.
- *Aggregation* – The degree to which a subzone is a site where most individuals of a species are aggregated for some part of the year, or a site which most individuals use for some important function in their life history, or a site where some structural property or ecological process occurs with exceptionally high density.
- *Fitness consequence* – Degree to which an area is a site where the activity(ies) undertaken make(s) a vital contribution to the fitness (i.e., increased survival or reproduction) of the population or species present.

These criteria can be modified based on two other factors: naturalness and proportional importance, which are defined as:

- *Naturalness* – The degree to which an area is pristine and characterized by native species (i.e., absence of perturbation by human activities and absence of introduced or cultured species).
- *Proportional importance*:
    - *Global importance* – proportion of the global extent of a feature (habitat/seascape) or proportion of the global population of a species occurring in a certain subarea within the study area.
    - *Regional importance* – proportion of the regional (e.g., NE Atlantic region) extent of a feature (habitat/seascape) or proportion of the regional population of a species occurring in a certain subarea within the study area.

  - *National importance* – proportion of the national extent of a feature (habitat/ seascape) or proportion of the national population of a species occurring in a certain subarea within territorial waters.

Biological valuation methods developed by Derous et al. (2007a) do not give information on potential impacts of any activity, rather a measure of intrinsic biological value. Therefore, evaluation criteria such as "resilience" and "vulnerability," which are based on some measure of impact, human value or judgment, are not included in their scheme. They argue that these types of criteria should be considered only after the baseline intrinsic value has been established to answer site-specific questions such as suitable placement for development projects or selection of MPAs.

Derous et al. (2007b) applied the biological valuation method to the Belgian region of the North Sea. Biological value was assessed using valuation criteria, a set of assessment questions for each criterion, and appropriate scoring systems. Examples of assessment questions included:

- Is the subzone characterized by high counts of many species?
- Is the subzone characterized by the presence of many rare species?
- Is the abundance of rare species high in the subzone?
- Is the abundance of habitat-forming species high in the subzone?
- Is the abundance of ecologically significant species high in the subzone?
- Is the species richness in the subzone high?
- Are there distinctive/unique communities present in the subzone?

Derous et al. (2007b) make the point that biological valuation is transparent if assessment questions are objective, clear, and centered on the selected valuation criteria. Valuation should not be done solely using expert judgment as this can lead to subjectivity in the assessment and unrepeatable results. It is critical that any method employing subjective judgments structures these judgments in a manner that enhances replicability (Smith and Theberge, 1987). Detailed assessment questions about "structures and processes of biodiversity" will result in objective valuation whereas assessment questions straying from this theme may result in scoring from one's own perspective, leading to incomparable results among valuations. Selection and development of assessment questions must occur on a case-by-case basis and should be appropriate for that area. Assessment questions are dependent on data availability and the presence of certain processes/structures, etc.

A workshop jointly sponsored by European Network on Coastal Research (ENCORA) and the Marine Biodiversity and Ecosystem Functioning (MARBEF) in 2006 in Ghent, Belgium brought together European researchers and managers to discuss the definition of marine biological valuation, and further developed prototype protocols (i.e., valuation criteria) for mapping and determining intrinsic biological value (as defined by Derous et al., 2007a) (ENCORA/ MARBEF, 2006). The biological valuation criteria identified in Derous et al. (2007a) were discussed at length and re-assessed for future case-study frameworks, renaming the general term "marine biological valuation" to "marine biodiversity valuation" or "marine ecological valuation." The 1st order valuation criteria, which measure biodiversity, were refined to "rarity" (as defined above) and a combined "aggregation-fitness consequences" criterion (Derous et al., 2007c):

- *Aggregation-fitness consequences* – The degree to which a subzone is a site where most individuals of a species are aggregated for some part of the year; or a site which most individuals use for some important function in their life history; or a site where some structural property or ecological process occurs with exceptionally high density; or the degree to which a subzone is a site where the activity(ies) undertaken make a vital contribution to the fitness (i.e., increased survival or reproduction) of the population or species present (DFO, 2005; Derous et al., 2007c).

Naturalness was excluded from the framework all-together, as the natural state of most waters is unknown and it is difficult to define and apply naturalness without reference to human impact. It was decided that naturalness, or measures thereof, should be assessed after the biological valuation process is completed. Instead of keeping "proportional importance" as a modifying criterion, it was decided that the valuation should be carried out in two ways: at a local scale and at a broader (eco-regional) scale (Derous et al., 2007c).

The Massachusetts Ocean Management Plan (MOP) developed the Ecological Valuation Index (EVI) for Massachusetts state waters (EOEEA, 2009). The EVI was defined as the "numerical representation of the intrinsic ecological value of a particular area, excluding social and economic interests" (EOEEA, 2009). This approach employed spatial analysis techniques where ecological data were gridded into 250 by 250 meter cells. Spatial interpolation was used to fill gaps where data did not exist, resulting in representative surfaces for each ecological entity. Ecological data assessed included presence/absence of species, habitat areas, critical habitats, seafloor characteristics, and fisheries. In this approach, spatial ecological data were evaluated under four criteria adapted from Derous et al. (2007a,b,c,): major contribution to fitness, spatial rarity, population of global importance, and population of regional importance. A set of assessment questions was developed under each of these criteria (i.e., for major contribution to fitness: Does this area make a major contribution to the survival and/or reproduction of the species or population?). A simple binary scoring technique was applied to the data for each of the four criteria. Once data layers were compiled, scores were summed in each grid cell to calculate an overall mapped spatial index, which ranged from low value to high value. However, one of the main limitations of this approach was that the simple binary scoring and summing was insufficiently discriminating of the relative values of the spatial domain, leading to ambiguous results.

A marine ecosystem-based management model was applied to spatially-explicit planning for wind farm development in the sounds and off the coast of North Carolina (Peterson, 2009). The factors involved in this modeling included analysis of 1) spatial distribution of available wind power; 2) ecological risks and synergies, especially for birds and bats; 3) conflicts affecting site selection, such as military uses, ocean shipping lanes, fishing grounds, oyster reef sanctuaries, seagrass beds, and live bottom reef habitats; 4) foundation systems that would be used; 5) geological framework of the area; 6) utility transmission infrastructure; 7) utility-related statutory and regulatory barriers; 8) legal framework, issues and policy concerns; 9) carbon reduction potential, and 10) economics. For the analysis of ecological risks and synergies, birds and bats were assumed to be at greatest risk from wind turbines over water; however, marine mammals, sea turtles, fish, and bottom-dwelling invertebrates were considered due to the potential of harm by noise and other factors. The model also highlighted positive environmental outcomes in some areas from the placement of wind turbines, including oyster reef establishment in saline sounds, rocky-hard bottom creation in coastal ocean, aiding mariculture offshore, and enhancing local upwelling in the coastal ocean.

As the synthesis component of the model, the data from the individual groups were integrated into a geographic information system. While synthesizing the data, the identification of severe constraints that could preclude wind energy development was emphasized. Those areas that were considered "no-build" (e.g., too shallow or reserved for other uses) and those areas with high ecological impact or low suitability for foundation construction were eliminated. For this model, the researcher equally weighed each constraint and assumed an equal degree of certainty to the extents of each component (Peterson, 2009).

Conclusions

Based on the existing literature discussed above, we found the biological valuation metrics developed by Derous et al. (2007a,b,c) to be the most scientifically-based, transparent approach, which the least bias in application. Their valuation methodology provides an integrated view of "the intrinsic value of marine biodiversity, without reference to anthropogenic use" and purposefully does not include the socio-economic valuation or quantification of goods and services. Additionally, biological valuation methods developed by Derous et al. (2007a) do not give information on potential impacts of any activity, rather a measure of intrinsic biological value. They argue that criteria such as "resilience" and "vulnerability" should be considered only after the baseline intrinsic value has been established to answer site-specific questions such as suitable placement for development projects or selection of MPAs.

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