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Ecosystem Services Typology in the Ocean SAMP

By

Annette R. Grilli Tania Lado and Malcolm Spaulding

Ocean Engineering Department

University of Rhode Island

Narragansett, RI

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Executive Summary

The Rhode Island Coastal Resource Management Council (CRMC) has been leading an Ocean Special Area Management Plan (SAMP) effort, that will result in zoning the state coastal waters to accommodate offshore wind farms. In earlier work, we approached offshore wind farm siting as an optimization problem considering wind resources and technological constraints (Spaulding et al, 2010). In this study, we introduce ecological constraints, within the conceptual framework of ecosystem services, and explore their effect using spatial multivariate statistical analysis (specifically, a Principal Component and Cluster Analysis; PCCA). This yields an ecological typology, or a zoning, of the coastal area based on ecological variables. The method is extended to provide a more synthetic typology of ecosystem services by integrating, besides ecological services, food provisioning and recreation. The application of PCCA to the SAMP coastal area provides a regionalization of the area into sub-ecosystems described by their: (1) dominant species, (2) biodiversity, summarized by biodiversity and richness indices, (3) resilience to wind farm impact, and (4) fishery activity. Upon analysis, the ecological sub-regions are identified and shown to be clearly driven by geomorphologic and seasonally variable oceanographic factors. The analysis clearly identifies inshore littoral and offshore deepwater sub-regions. We further find: (1) the intermediate depth area yields two to three sub-regions, depending on the season; (2) in the Fall, Block Island Sound (BIS) clearly differentiated from Rhode Island Sound (RIS), both distinct by oceanographic, geomorphologic and sedimentologic features; (3) in the Spring the RIS differentiates into two sub-regions (RIS, offshore and RIS2, near shore). Each identified sub-region is associated with a particular ecological assemblage.

The resilience of the sub-regions to wind farm impact is independently explored, for the construction and the operation phases. The sensitivity to potential wind farm impact is expressed by impact indices and assessed by weighting each species abundance introduced in the index by sensitivity coefficients to construction or operation phases of the development. These coefficients are derived from each species' estimated sensitivity to disturbing factors involved in wind farm construction and operation (i.e., noise, turbidity, electromagnetic field; French McKay et al., 2010). The methodology allows zoning the SAMP ecosystem into homogeneous functional sub-regions and identifying the most sensitive sub-regions to potential wind farm impact. Finally, combining ecosystem services typologies with technological constrains and wind resources (Spaulding et al., 2010), provides a tool to identify optimal wind farm siting areas.

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Abstract

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1. Introduction

The Rhode Island Coastal Resources Management Council (CRMC) is currently leading an Ocean Special Area Management Plan (SAMP) effort, that will result in zoning of the state coastal waters to accommodate offshore wind farm (Spaulding, et al., 2010) In earlier work, we approached the wind farm siting issue as an optimization problem considering wind resources and technological constraints (Spaulding et al, 2010). In the present study, we introduce ecological and other ecosystem services constraints and explore their effect using spatial multivariate statistical analysis, specifically, a Principal Component (PCA) and Cluster Analysis (CA), referred to as PCCA. This yields an ecosystem services typology, or zoning, of the coastal area based on ecological and other ecosystem services variables.

1.1 An Ecosystem Based Management (EBM) conceptual framework

The conceptual framework of the analysis is guided by an Ecosystem Based Management (EBM) approach, where the ecological and social domains are explicitly integrated in their dynamics (McLeod and Leslie,2009; Figure 1). The interface between these domains is defined as ecosystem services, defined as the services the ecosystem provides to the society. In this study, we adopt the terminology of services defined by McLeod and Leslie (2009), i.e. : (i) provisioning services (food, fuel, medicines); (ii) regulating services (biological regulation, climate regulation, human disease control, waste processing, flood protection, erosion control); (iii) cultural services (aesthetics, education and research); and (iv) supporting services (biodiversity, biochemical processes, nutrient cycling). This conceptual framework is the basis for the ecosystem valuation necessary to maintain the ecosystem in a healthy, productive, and resilient condition, and providing the services humans want and need (McLeod and Leslie, 2009; Arkema et al. 2006; Lester et al. 2010). The ecosystem services interface serves as an estimator of the value of the ecosystem (e.g., by quantifying those services). Within this context, we assess the value of selected ecosystem services, relevant to the proposed impact project, and implement qualitative typologies of the area, based on the natural variance of these services. Those identify homogeneous functional area or sub-ecosystem .

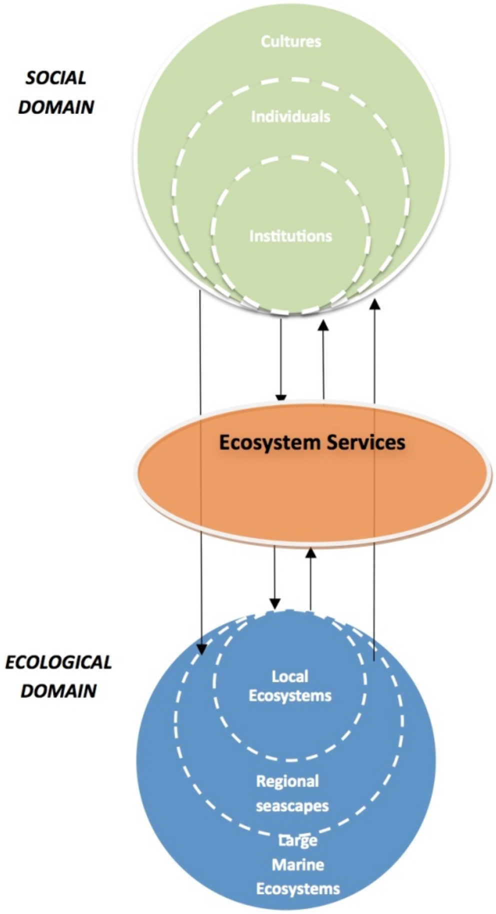

Figure 1: Ecosystem services conceptual definition. From McLeod and Leslie, 2009

1.2 Marine Ecosystem services tools

In parallel to the growing interest for an EBM approach to coastal and offshore management, marine Management Tools (MMT) have recently been developed to help with spatial planning. Many of those use econometric methodologies based on a cost-benefit approach (Barbier, and Hanley, 2009), as *InVest* (Tallis et al., 2010) or *Marxan with zones* (Watts et al., 2009; Ball and Possingham, 2000). Such MMTs feature powerful algorithms, which allow the definition of "zones" based on minimizing the cost associated with services the zoned area would provide, in the context of pre-defined *constraints.* This cost can be express in monetary units or not. Ecological constraints could include a minimum threshold of biodiversity which should be maintained, a minimal impact on specific species, as endangered species, a maximum threshold of restricted fishing area etc.

When quantitative knowledge is lacking, an alternative to using econometric methods is to perform a multivariate statistical analysis such PCCA, which provides an objective qualitative zoning or typology based on the natural gradient of the variables, and therefore a functional insight into the ecosystem. Coastal typologies are at the core of the Land-Ocean Interactions in the Coastal Zone (LOICZ) project (Bokuniewicz et al., 2003; Buddmeier et al., 2008; Maxwell and Budmeier, 2002). Initially, investigating bio- and chemico-physical changes in the coastal zone, the LOICZ project is in permanent development and it now includes socio-political and economical disciplines. LOICZ combines an extensive worldwide data base, on a 0.5 by 0.5 degree grid, and a web-based typology tool for geospatial hierarchical clustering, *DISCO* (DeLuxe Integrated System for Clustering Operation; Wessel and Smith, 1996). The NOAA Estuarine Eutrophication Program adopted *DISCO* as their preferred tool for the classification of Estuarines Systems, to update the 1999 U.S. National Estuarine Eutrophication Assessment (NEEA) (Bricker et al., 1999; NOAA). In offshore areas, Jordan (2010) and Jordan et al. (2010) recently applied a PC A to the Gulf of Maine to extract and interpret the natural geographical structure of the coastal and offshore marine biodiversity.

Despite the genuine functional value of qualitative typology, the interest for a valuation of the ecosystem remains important, for two principal reasons: (1) either we want to rank regions in terms of a particular service (e.g., is this area more valuable than the adjacent one for fisheries services ?); or (2) we want to use a complex optimization method using multiple criteria or thresholds to define the zoning and need numerical values as input (e.g., can we use that area as recreational fishing without having the biodiversity going under a certain threshold ?). In this perspective, many indices have been developed, which, by definition, summarize the complexity of the ecosystem into a single number. They are expected to be good estimators of only partial services of the ecosystem and do not pretend to reflect the value of the entire ecosystem. As an example the Marine Biotic Index, based on a multivariate approach (M-AMBI) assesses the ecological integrity of coastal and estuarine waters, following guidelines from the European Water Framework directive (2000/60/EC) (Borja et al., 2000,2008).

To approach the valuation of the entire ecosystem, some authors have used a Delphi method, where the essence of the ecosystem is tentatively captured by a finite number of pre-defined concepts, such as species rarity, species aggregation, species fitness. Then a value in terms of those concepts, derived from a scoring system based on expert opinions, is assigned to each species. Gent University (Belgium) worked towards a standardized protocol based on this methodology and successfully applied it in the North Sea (Derous et al, 2007).

In this analysis, a qualitative typology of the RI Ocean SAMP area into ecological and services "sub-regions" is combined with the development of indices, to quantify these "sub-regions" based on specific ecosystem services criteria, such as biodiversity, resilience, and fishery.

2. Method

The PCCA method is used to develop ecosystem services typologies or homogeneous sub-regions (section 0) based on specific selected services (section 0). Indices are developed to assess the value of the selected services in each sub-region defined by the typology (Section0), in particular, biodiversity, resilience of the ecosystem, and fisheries. (e.g, area of high biodiversity and intense recreational fishing activity; Biodiversity and Fishing indices=10 on a scale 1 to 10). The spatial scale selected is 250 by 250 m, which can be discussed, but is believed to be relevant for many ecological processes (Derous, 2007).

2.1 EBM and ecosystem services

The typologies address the following ecosystem services: (1) life supporting; (2) provisioning; and (3) cultural, services (Table 1; McLeod and Leslie, 2009). In the present study life supporting services are restricted to "ecological services" and, in particular, to two specific sub-categories: (i) the ecosystem biodiversity; and (ii) the ecosystem resilience to the impact of wind farm siting. The provisioning service is restricted to the "fisheries service", and cultural service to the "recreational fishing service".

The biodiversity service reflects both the abundance and variety of species present in the ecosystem. These are quantified by fish biomass and mammal abundance data, which were obtained from Bohaboy et al. (2010) and Kenney and Vigness-Raposa (2009). Data used is summarized in Table 2 and further discussed in the application section. A detailed description of the data sets used is given in French McKay et al (2010). The biodiversity service is first addressed through performing an ecological services typology (Section 0), and a then calculating biodiversity and richness indices (Sections 0 and 0).

The resilience service is approached by assessing the ecological sensitivity of each species to wind farm impact (Thompson, 2010). The latter was approached using a scale similar to that developed by French McKay et al (2010), based on the Programmatic Environmental Impact Statement (PEIS) criteria for alternative energy project (MMS, 20O7). We modified this scale to include a category for species with high resilience, to represent the reef effect , as observed in North sea wind farms (Linley et al. , 2007) (Table 5).

Table 1: Ecosystem and services addressed in this study (Source: McLeod and Leslie's classification, 2009, modified from UNEP 2006). WFI refers to Wind Farm Impact, with the subscript c for construction phase and o for operation phase.

Ecosystem Services	**Categories addressed**	**Valuation tools**
Provisioning services (Fishery services)	Food : Fishery	Fishery Index
Cultural services	Recreation: Recreational fishing	
Regulating services		
Supporting services (Ecological services)	Life support : Biodiversity Resilience	Biodiversity Index Richness Index Sensitivity to WFI-c Index Sensitivity to WFI-o Index

The general trend in intrinsic resilience of species groups is summarized bellow. Mammals are assumed to be the most sensitive group due to their extreme hearing sensitivity, to the point of being potentially harmed by the wind farm's construction noise. The herring group would come also high on the list of sensitivity, since these are "hearing specialists", that could potentially have their behavior impacted by the noise generated during the construction phase.

Demersal species, including flat fish, with habitat and foraging habits on, or close to the seabed, would potentially have their habitat disturbed because of the increase in turbidity during construction; scallops and lobsters would also be sensitive to turbidity. The electromagnetically sensitive skate group could potentially be disturbed when venturing close to cable routes. Game fish should be the most resilient. Demersals, however have also been shown to be extremely resilient in the sense that they re-colonize the site during operations, since underwater structures create a reef effect. The resilience service is quantified by two indices separately addressing the sensitivity to the construction and operation phases (Section 0), both representing short and long term wind farm impacts.

The fisheries service is described by an ecosystem services typology and by a fishery index calculated on the basis of three binary data sets (absence or presence), recreational fishing, mobile gear and fixed gear (Table 2: Ecological, fishing and oceanographic and geophysical data used in the analysis, source and resolution.

The recreational service is expressed by a set of recreational fishing data. Both recreational and fishery data are regrouped into a fishing index and are included in the ecological and fishing typology.

2.2 Typology

The principle of a typology, for a spatially varying multivariate data set is to regroup similar areas based on the natural variance of the data or the natural gradient in the observed spatial patterns. The challenge in such a process occurs when the number of variables becomes very large. Hence, it thus seems reasonable to first regroup variables having similar behavior into groups, to simplify the superposition of spatial patterns and make it easier to define a regionalization based on the global data set.

The Principal Component Analysis (PCA) serves this purpose, by objectively performing this regrouping without significant loss of information (Legendre and Legendre, 1998). Indeed, each principal component is a linear combination of the original variables and is orthogonal to the others. This strategy suppresses redundant information. Orthogonality implies that principal components are statistically independent and therefore each of these adds a significant new piece of information to the complex spatial pattern we aim at describing. Furthermore, in PCA analyses, most of the variance is typically explained by a number of components smaller than the number of original variables. It is generally recommended to keep a number of principal components corresponding to 80 % of the total variance (Zuur , 2009); in this study we raised this threshold to 90 %.

Hence, in this work, we first apply a PCA to the global data set, to reduce the multi-space dimension and optimize the subsequent clustering, which defines the sub-areas. The Cluster Analysis (CA) calculates distances between cells in the new reduced multivariate PCA space, and regroups similar cells into clusters, based on their proximity in the multi-space, or, in other words, based on their similarity. The *k-means* clustering method (Zuur, 2009) was selected to perform the partitioning. Each cluster in the partition is defined by its cells and their centroid. The centroid for each cluster is the point from which the sum of distances from all objects in that cluster is minimum. The method uses an iterative algorithm that minimizes the sum of distances from each object to its cluster centroid, over all clusters. This algorithm moves objects between clusters until the sum cannot be further decreased. The result is a set of clusters, which are as compact and well separated as possible. The method therefore performs an objective typology of any multivariate distribution. Hence, the CA method expresses the natural sub-zones or sub-regions in the area.

In our particular application, each cluster reflects a homogeneous *assemblage* of species. The boundary between each cluster identifies the areas of largest natural gradient in the variance of the group of species representative of that cluster. The clusters are found to vary with seasons, dependent on oceanographic factors, such as water stratification, temperature, and currents. These factors are discussed in the next section and when analyzing the specific assemblages defining each cluster.

2.3 Indices

The value of ecosystem services in each cluster is quantified by calculating ecosystem services indices, as a function of the mean values of the original variables within each cluster. Biodiversity services are represented by a biodiversity and a richness index; ecosystem resilience is represented by two indices expressing sensitivity to wind farm impact; and fishery services are represented by a fishing index. Details for each index are provided below.

2.3.1 Biodiversity Index

The biodiversity index BI expresses the relative abundance and richness of each cluster's population relative to the general population. The abundance of each species is quantified in terms of biomass, or other units of abundance, and the richness represents the variety of species. The index is formulated the following way.

For each cluster j (we will drop the subscript j for simplicity) a score S_i is assigned to each species, i, based on the relative abundance of the species within the cluster, relative to the general population. Each species' descriptive variable in the global data set is first normalized, in order for its population to follow a Gaussian distribution. Then, if the mean abundance for a given species in the cluster belongs to the first, second, third, or fourth quartile of the general population, then the species receives a score, S, of 0, 1, 2, or 3, respectively. The biodiversity, B, is expressed as the ratio of each species' score S_i to the number of species in the general population, N, summed over all n species in each cluster. This score is then standardized on a relative scale [0-10] leading to the biodiversity index, BI. Thus,

$$B = \frac{\sum_{i=1}^{n} S_i}{N} \qquad (1)$$

$$BI = \frac{\sum_{i=1}^{n} S_i}{\max(B)} * 10 \qquad (2)$$

2.3.2 Richness Index

The richness index, RI, is the ratio of the sum of the number of species in each cluster j, n_j , to the total number of species in the population, standardized on a relative scale [1-10]. Thus,

$$RI = \frac{n_j}{N} * 10 \qquad (3)$$

2.3.3 Resilience or Impact Indices

The resilience is in fact measured in terms of "no-resilience" or sensitivity to wind farm impact (WFI). Two indices are developed, expressing the species' sensitivity to the : (1) construction phase (II_c); and (2) operation phase (II_o). Both are calculated following a method similar to that defined for the biodiversity index. The abundance, however, is first scaled by an sensitivity coefficient ($c_{i\ (c,o)}$) established on a scale of 1-10, expressing the relative species sensitivity to the wind farm impact. The sensitivity coefficients are discussed in the next section, for the species groups specific to the SAMP area (Table 5). Then, the impact index is derived as a root mean square and we have,

$$I_{c,o} = \frac{\sum_n (S_i^2 * C_{i(c,o)})}{n} \qquad (4)$$

$$II_{c,o} = sign(I_{c,o}) * \frac{\sqrt{|I_{c,o}|}}{|\max(S_i^2 * I_{i(c,o)}|} * 10 \qquad (5)$$

2.3.4 *Fishing index*

The scores of the three types of fishery activities considered, mobile gear, fix gear and recreational fishing, are simply added and rescaled on a 1 to 10 scale to form the fishing index (FI). Score are binary [0 1] (section 0).

3 Application

The method is applied to the Ocean Samp area as delimited in dash (pink) on Figure 2.

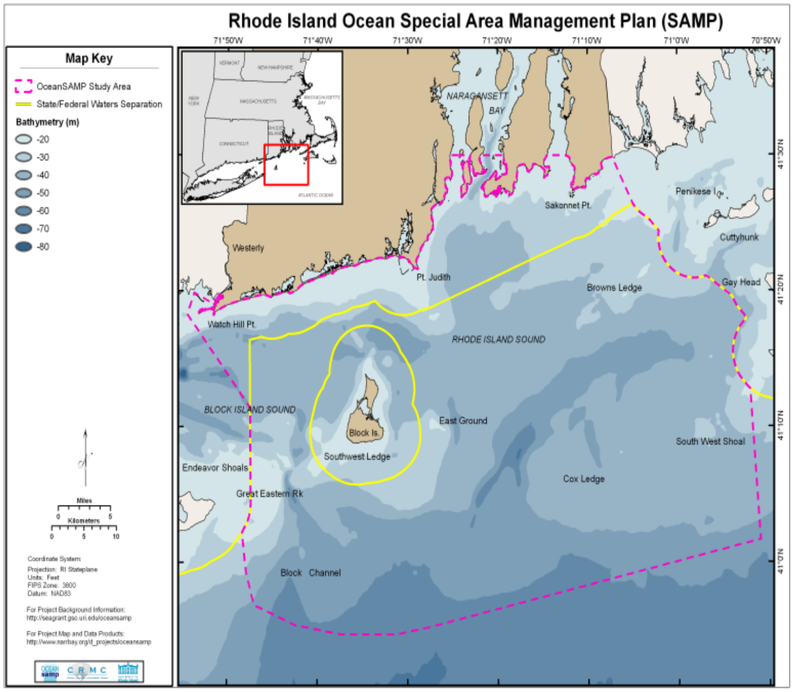

Figure 2 : SAMP area (Spaulding et al., 2010)

The study is done in five steps: (1) seasonal typologies are established for geophysical variables, to develop an understanding of the geophysical structure of the area; (2) seasonal typologies are established for ecological services, based strictly on ecological variables, fish and mammals abundance; (3) the impact of the wind farm (construction and operation) on ecological services is assessed; (4) fisheries data are added to the ecological data base and a second set of seasonal typologies is established, reflecting ecological and fisheries services; and finally (5) the ecosystem services are combined with the Technological Development Index (TDI), to identify optimal wind farm siting areas (Spaulding et al., 2010; Section 0).

Seasonal typologies are restricted to Fall and Spring since fish data were not available for Summer and Winter.

3.1 Data

Data characteristics and sources are summarized in Table 2.

The fall season ecological typology is based on 12 fish species and 2 mammal groups, whales and dolphins, and the spring season ecological typology is based on 16 fish species and 3 mammals groups, whale, dolphin, and porpoise. The fish typical lognormal distributions was normalized. The sampled sites (a minimum of 30 sites were required for the species to be included in the typology) were re-interpolated on the 250 by 250 m grid using a krigging algorithm. It was verified that the distributions re-created on the grid after interpolation were similar to the original lognormal distributions.

Fish data were obtained from three survey sources, as listed in Table 2: Ecological, fishing and oceanographic and geophysical data used in the analysis, source and resolution. The aggregation of data from three different sources, obtained using different survey methods, and for different years, was investigated by comparing their respective probability distribution. Although a slight difference was observed among them, it is not statistically significant. In this specific application, there is not enough data to meaningfully extract the portion of the variance due to sampling from that due to oceanographic, ecological, or time factors. This issue could be addressed using a larger spatial sample, in this work, it is assumed reasonable to aggregate the available data into a single population. This yields a larger data set for performing the spatial interpolation and reduces the error due to under-sampling.

Fisheries data are binary data reflecting the usage or non-usage of that space, to fish for a given species, as obtained by polling fishermen. Data are categorized into mobile and fix gear and recreational fishing.

Geophysical and oceanographic data considered for the typology are: water depth, sea floor slope and its standard deviation (on 1000 m radius), sediment median grain size, sea surface temperature and density stratification.

The water depth is extracted from the NOAA coastal Relief model and the slope and the standard deviation of the slope are derived from those data; the Slope is the maximum slope in each 250x250 m grid cell; the standard deviation is the standard deviation of the slope in a 1000 m radius; the sea surface temperature is obtained from satellite data (1 km resolution), the density stratification is obtained from modeled data (0.25 to 2.5 km resolution) and quantified using the buoyancy frequency squared, N^2 (S^{-2}),

$$N^2 = \frac{g}{\rho_0}\frac{d\sigma_t}{dz} \qquad (6)$$

where g is gravitational acceleration, σ_t, the density anomaly (kg/m^3), ρ_0 ,a constant reference density, and z is the vertical coordinate, positive upward. The sediment median grain size is obtained from the U.S. Geophysical Survey as point data and is interpolated on the 250-250 m grid (phi units: negative value of the base 2 logarithm of the grain median diameter, expressed in mm) .

Table 2: Ecological, fishing and oceanographic and geophysical data used in the analysis, source and resolution

	Type or Sampling Agency	Units and resolution	Period	Source
Ecological				
Fish American lobster, *Homarus americanus* Alewife, Alosa Pseudoharengus Atlantic sea scallop, *Placopectin magellanicus*	North East Area Monitoring and Assessment Program (NEAMAP)	Biomass per unit area(mg/m2) Point data	Fall 2007 Spring 2008	Bohaboy et al., (2010)
	National Marine Fisheries		Fall and spring	

Atlantic cod, *Gadus morhua* Atlantic herring, Clupea harengus Atlantic mackerel, Scomber Scombrus Black sea bass, *Centropristis striata* Bluefish, *Pomatomus saltatrix* Blueback herring, *Alosa aestivalis* Butterfish, *Peprilus triacanthus* Little skate, *Leucoraja erinacea* Longfin squid, *Loligo peali* Scup, *Stenotomus chrysops* Silver hake, *Merluccius bilinearis* Striped bass, *Morone saxatilis* Summer flounder, *Paralichthys dentatus* Winter flounder, *Pseudopleuronectes americanus* Winter skate, *Leucoraja ocellata* Sea scallops, Atlantic sea scallops	Services (NMFS)		1999-2008	
	RI Department of Environmental Management (DEM)		Monthly 1999-2008	
Mammals Whales Dolphin Mammals	Observations	Sighting per Unit effort (SPUE) Interpolated on a 0.5 minute grid.		Kenney and Vigness-Raposa, (2009)
Fishery Recreational use Mobil gear Fix gear	Fisherman interview	Binary data 0.5 minute grid		Beutel (2009)
Oceanographic and Geophysical data				
Bathymetry	NOAA Coastal	m		

Bathymetry	relief Model	Kriging on 250 m X250 m grid		
Bottom roughness		Standard deviation slope (1000 m radius)		LaFrance et al. (2010)
Bottom slope		Deg. Max slope on a 250 m X 250 m cell		
Sea surface temperature	Satellite data NASA Terra and Aqua (MODIS sensors)	Deg. Celcius 1 km	2002-2007	Codiga and Ullman (2010)
Stratification	Modeled data: FVCOM simulation	Buoyancy frequency squared (s^{-2}) 0.25 to 2.5 km resolution	2006	Codiga and Ullman (2010) Chen et al. (2006)
Sediments	SEABED: Atlantic coast offshore surficial sediment data. US Geological Survey	Phi median Point data		Reid et al. (2005)

3.2 Geophysical typology

The application of PCA and CA to geophysical and oceanographic data identifies sub-regions, which allow isolating the Rhode Island Sound (RIS) from the Block Island Sound (BIS) and differentiating littoral and deep water areas, as well as rough morainic seafloor, from smooth sandy or clayish seafloor. The RIS is characterized by slight stratification and relatively warm water versus colder surface water in well mixed BIS. The shallow water, sandy bottom of South West Shoal is also identified from the RIS (Figure 3, Figure 3 and Figure 4).

Codiga et Ullmann have described in detail the oceanography of the area and the specific identity of the BIS and RIS, on the western and eastern sides of Block Island, respectively. The BIS is dominated by the estuarine fresh water system flowing from Long Island in a westward direction. The RIS is dominated by a slight upwelling in Fall, while in Summer the New England current, flowing E-W , weakens and temporally separates to create a counter-clockwise loop entering Rhode Island waters exiting at the SE of BI, to rejoin the main New England current.

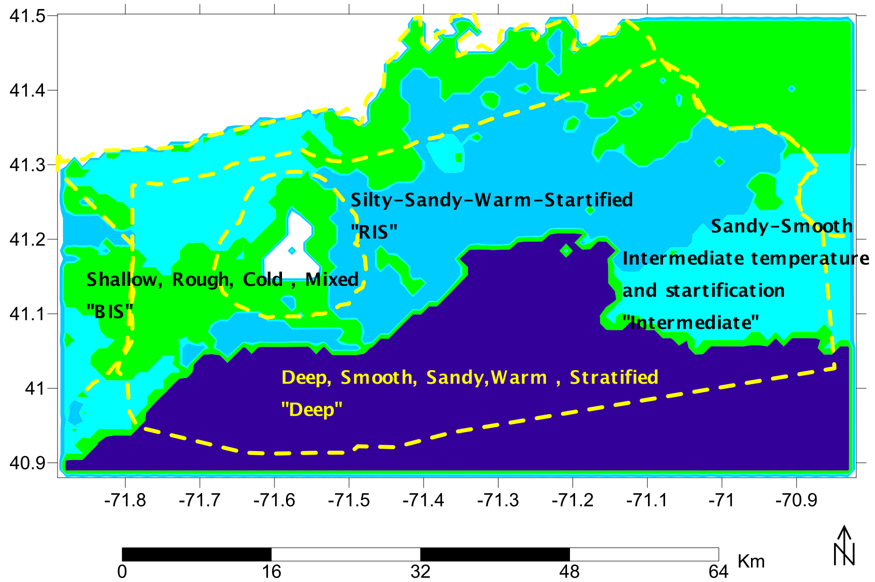

Figure 3: Fall season geophysical sub-regionalization resulting from cluster analysis

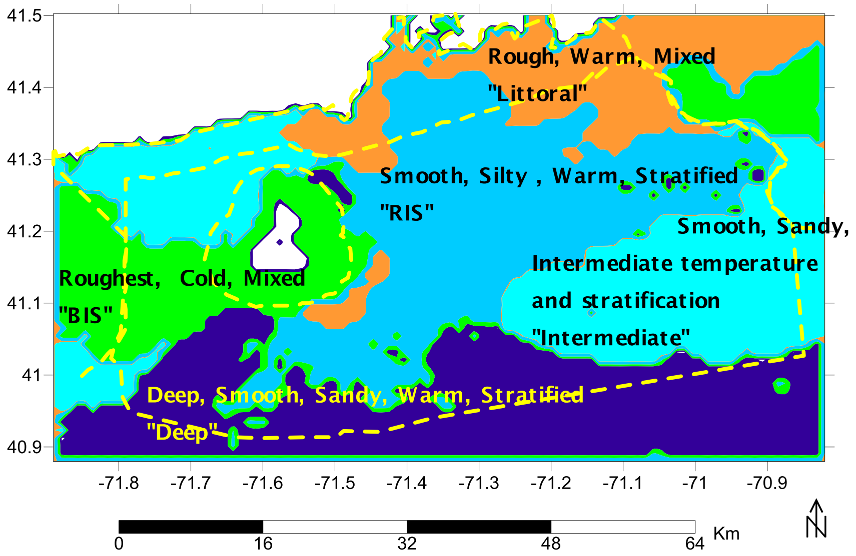

Figure 4: Spring season sub-regionalization resulting from cluster analysis

The analysis shows that year round there are relatively stable oceanographic sub-regions, in particular in the well mixed BIS (Figure 3, Figure 4). In both seasons, the heart of RIS appears as a homogeneous sub-region,with warm and relatively stratified water over a relatively smooth silty to sandy sea floor (blue region, "RIS"). "RIS" is adjacent to the deep water sub-region in the south (dark blue, "Deep") and the boundary between both varies significantly between seasons, with a seasonally significant warming-up of the RIS sub-region causing its southerly expansion. The intermediate cluster (light blue, "intermediate") reflects relatively colder temperature, weak stratification, smooth flat seafloor with slightly coarser sediments than the "RIS" cluster. It regroups the South West Shoal area and the Northern part of BIS. A littoral sub-region (in orange on the map, "littoral"), however, appears in Spring. It regroups well mixed warm water, with terminal moraine seafloor, and separates itself from the well mixed cold water with terminal moraine sea floor of BIS (green area, "BIS"). A parallel 3D modeling study in the SAMP area, coupling wind, ocean circulation, wind wave, and sediment transport models (Harris et al., 2010), confirms the dichotomy between BIS and RIS with a strong tidal current pattern dominating BIS, leading to significant transport of coarse grain sediment, versus a weak current pattern in RIS, limiting transport to fine silty sediment. This pattern is supported by backscattering measurements (Codiga and Ullman 2010; Harris et al., 2010).

This geophysical typology provides a background to better understand the significance of the ecological services geographical pattern, presented in the next section.

3.3 Seasonal Ecological services Typology

The seasonal typologies for Fall and Spring in the SAMP area identifies 5 and 6 sub-regions respectively (Figure 6, Figure 8), each being defined by a specific ecological assemblage (Figure 5, Figure 10). In addition, biodiversity and richness indices are calculated for each sub-region (Figure 7 and Figure 9). A summary of the characteristics of each sub-regions is presented in Table 3 and Table 4. Both maps show a pattern strikingly similar to the geophysical pattern, showing RIS isolated from BIS and the onshore/offshore gradient differentiating littoral and deep water areas. In the Fall, we observe a clear increase in biodiversity and richness from deep to shallow water, although there is a sharp departure from RIS to BIS, with a lower biodiversity and richness in the BIS. The indices, however, are only partial indicators of the dissemblance or resemblance of the clusters and the full meaning of the sub-regions must be found in the composition of their assemblages or in their dominant species. Thus, the Deep water assemblage reflects a dominance of mammals and medium sized game fish; RIS is primarily dominated by demersal fish and secondarily by mammals; BIS is also similarly dominated by demersals and secondarily by mammals, but both groups are less abundant than in RIS; the littoral cluster is the richest in species with dominance of demersals, skates and lobsters. The highly biodiverse Sakonnet cluster is at the northern boundary of the SAMP area and is actually out of the area of interest for wind farm siting; hence, it will be omitted in the following.

Table 3: Assemblage, biodiversity and richness indices for Fall sub-regions.

Cluster Fall	Biodiversity Index	Richness Index	Dominant group
Sakonnet	10	7.1	Demersal Skate Squid
Deep	5.7	5.7	Medium game Mammal
Rocky	7.5	7.1	Demersal Mammal
RIS	9.5	8.6	Demersal Mammal
Littoral	9.5	10	Demersal Skate Lobster

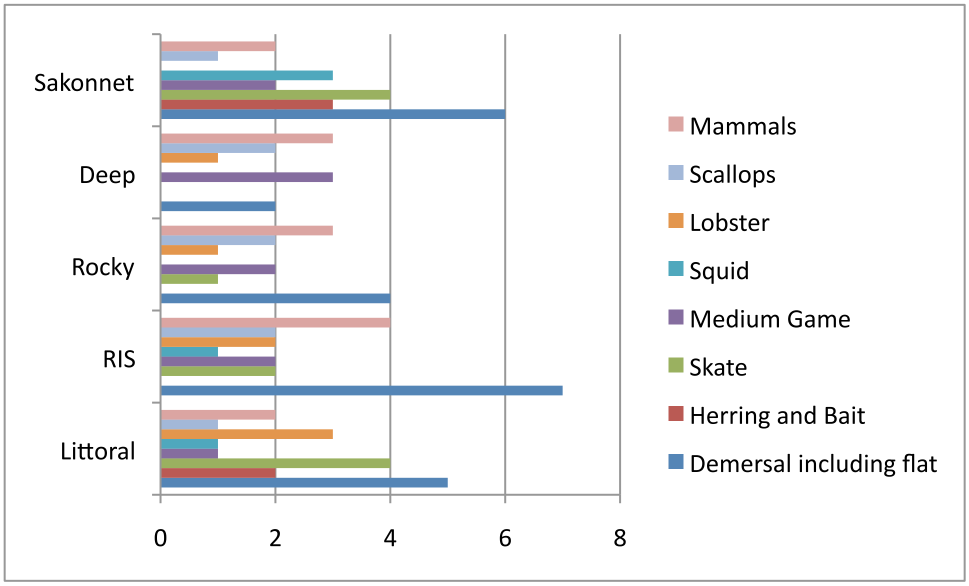

Figure 5: Ecological assemblages for Fall ecological sub-regions

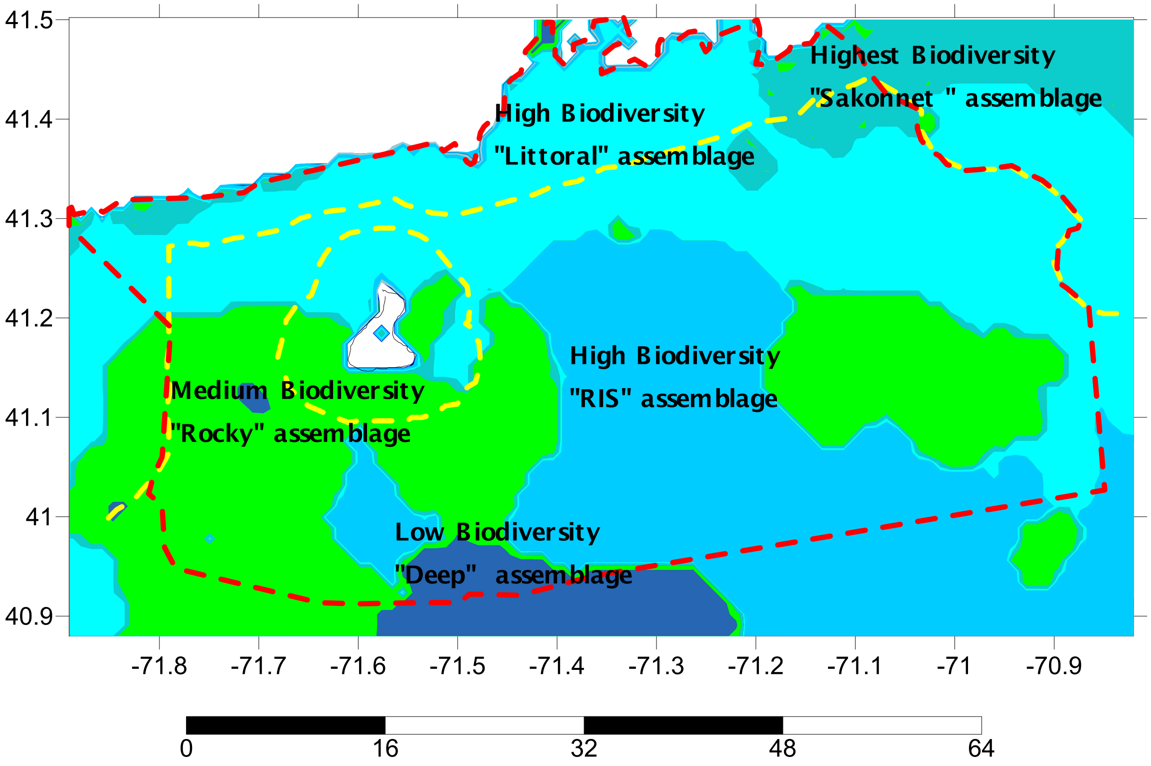

Figure 6: Fall ecological typology based on cluster analysis

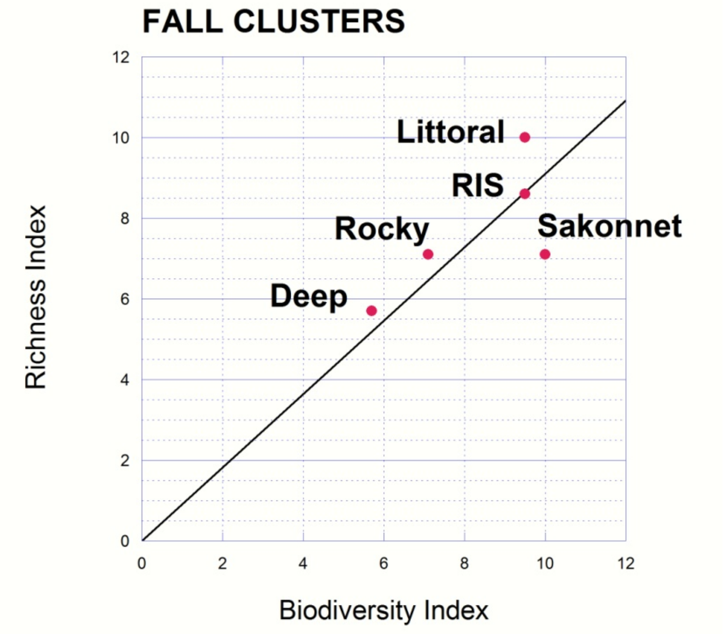

Figure 7: Biodiversity and richness indices for SAMP Fall ecological sub-regions

Spring clusters show a similar general onshore/offshore, BIS/RIS, dissociation, but also isolate the northern part of RIS, adjacent to the "littoral" cluster. This additional sub-region, referred to as "RIS2", is characterized by the highest biodiversity and richness in species, and the dominance of demersal and herring. Although whales, dolphins and porpoises are present in "RIS2", these are not dominant species, as in "RIS" and "Deep" clusters. Whales, dolphins and porpoises are significantly more abundant in Spring than in Fall and therefore their distribution affects the clustering by increasing the variance related to mammals, and therefore the discrepancy between the mammal-dominant and non-mammal-dominant clusters. The "littoral" cluster, dominated by demersal fish, does not include a significant presence of whales, dolphins or porpoises, and consequently shows less biodiversity than in Fall, when the presence of mammals is not as dominant. As in Fall, the "rocky" well- mixed BIS consistently shows less biodiversity and less richness in species.

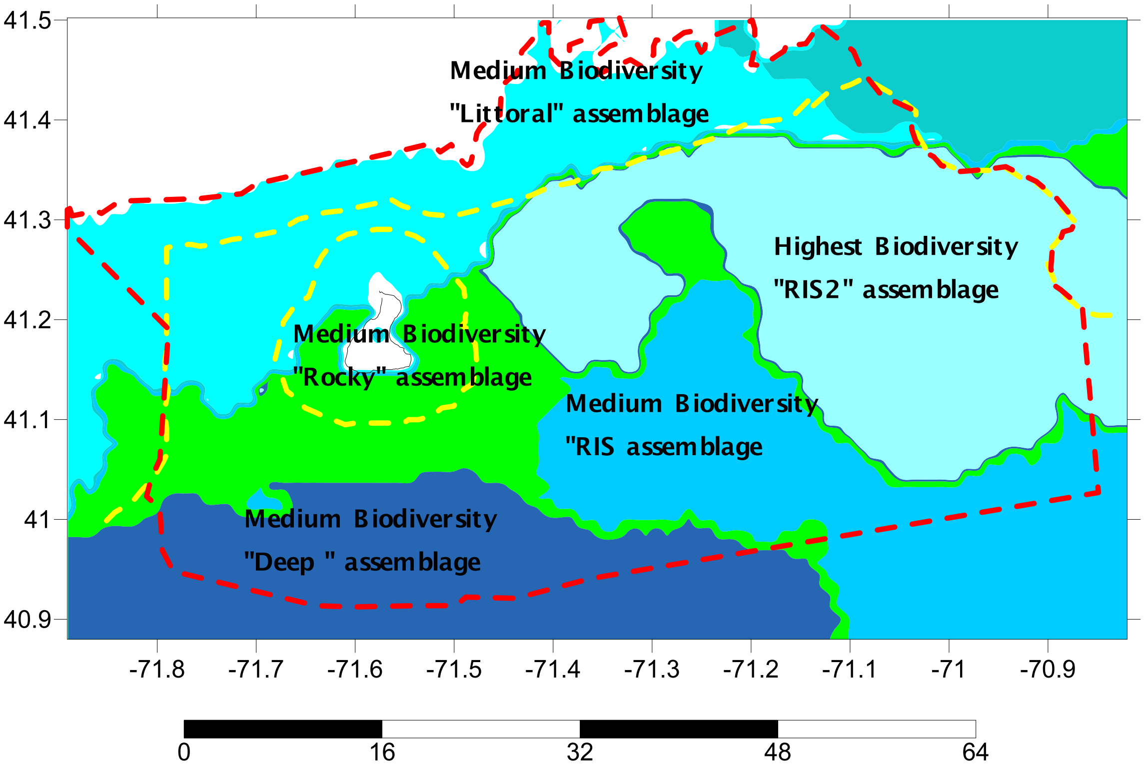

Figure 8: Spring ecological typology based on cluster analysis.

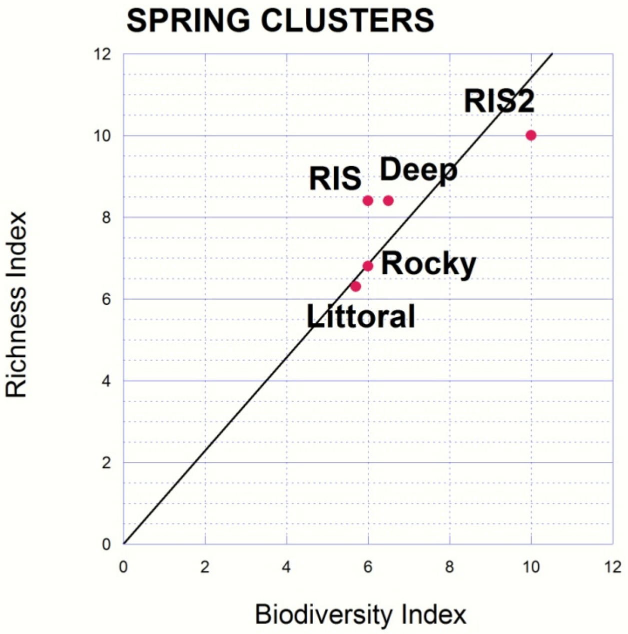

Figure 9: Biodiversity and richness indices for SAMP Spring ecological sub-regions

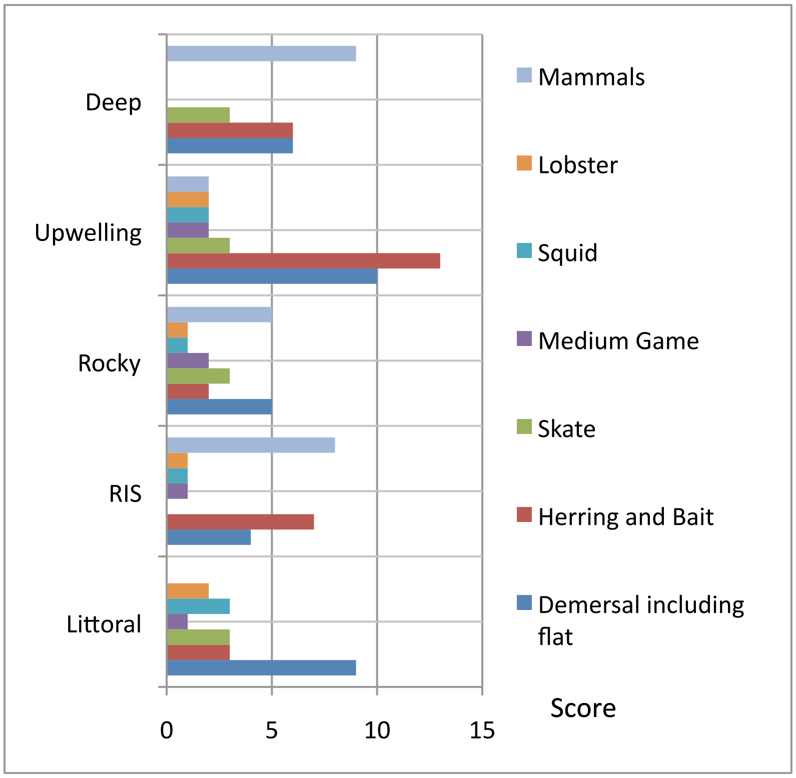

Figure 10 : Ecological assemblages for Spring ecological sub-regions

Table 4: Assemblage, biodiversity and richness indices for Spring sub-regions

Cluster	Biodiversity Index	Richness Index	Dominant groups
Deep	6.5	8.4	Mammals (Demersal & Herring)
RIS2	10	10	Demersal Herring
Rocky/BIS	6	8.4	Demersal Mammals
RIS	6	6.8	Herring Mammals
Littoral	5.7	6.3	Demersal Lobster

3.4 Potential wind farm impact on ecological services

In an attempt to assess the potential impact of wind farms on ecological services, a sensitivity index is developed for each cluster, based on the intrinsic species' sensitivity to potential disturbances resulting from a wind farm project. Disturbances considered here are noise, turbidity, and electromagnetic field (EMF). Each species is characterized by a sensitivity coefficient on a scale of disturbance from -2 to 10, with -2 reflecting a positive effect or attraction, 0 no effect, 3, a potentially indirect impact, 4, a behavior modification, 6, an habitat modification, 8, health issues, and 10, the species death. The sensitivity coefficients for each group of species are presented in Table 5. This scale of sensitivity and the scoring attributed to each species' functional group was developed by French McKay et al (2010), based on PEIS criteria (MMS, 2007) and an extensive literature review (Skow, 2006; Thomsen et al., 2006; Gill et al., 2005, 2009). The scale was slightly modified in this work to include the reef effect (Linley et al., 2008), i.e., causing a potential attraction for demersal fish with a -2 sensitivity coefficient, during the operation phase. As shown on Table 5, the species sensitivity is independently assessed for construction and operation phase.

The impact index is developed as a weighted root-mean-square of the score of abundance of each species, where the weight is the sensitivity coefficient. The detailed formulation of the impact index is given in Section 0, equations **Error! Reference source not found.** and **Error! Reference source not found.** . This analysis is exploratory and should still be viewed as "work in progress", but preliminary results are given to show the application of the method. The sensitivity to a potential reef effect is assessed by comparing the potential impact with and without the reef effect assumption. Results are provided for both seasons. Results during the operation phase include two values, with or without reef effects.

Table 5: Species sensitivity coefficients to wind farm construction and operation, from French McKay et al (2010), adjusted to include the reef effect on demersal species (0 to 10 or -2 to 10, low to high impact).

Species Group	Sensitivity coefficient during construction	Sensitivity coefficient during operation
Lobster	6	1
Sea Scallops	8	6
Demersal Fish including flat	4	[2,-2]
Baitfish	4	2
Herring	4	2
Medium and large Gamefish	4	1
Skates	6	4
Mammal	8	4

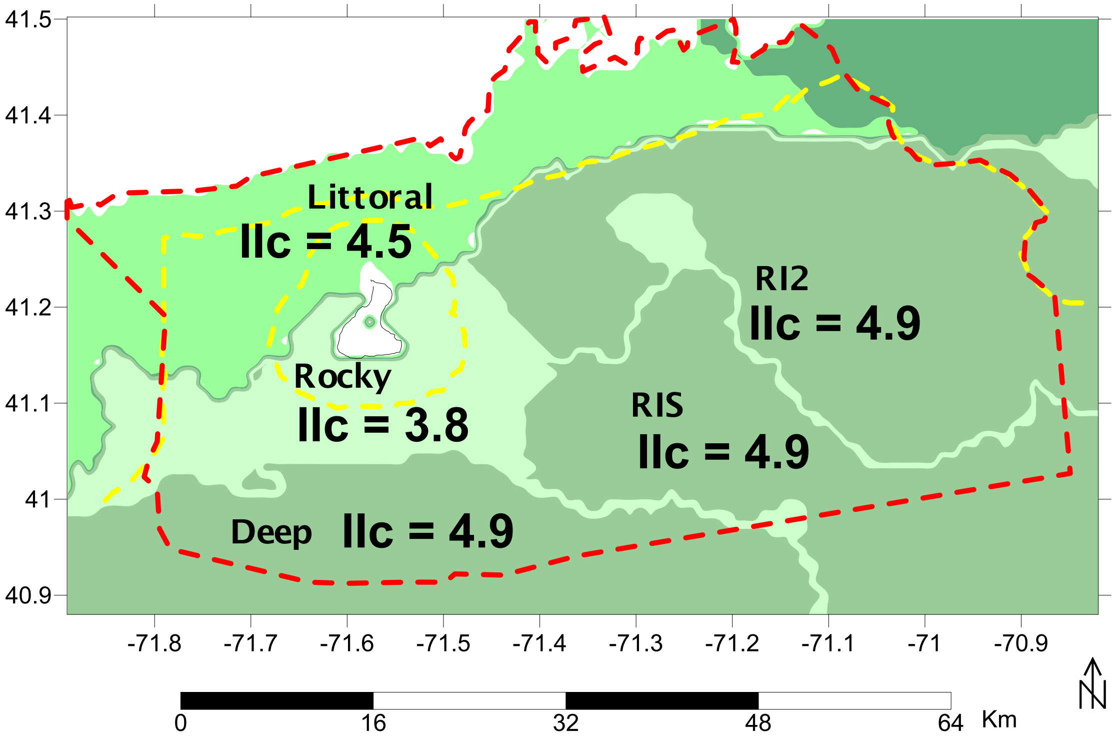

Figure 11: Spring Impact Index, II_c , during construction phase

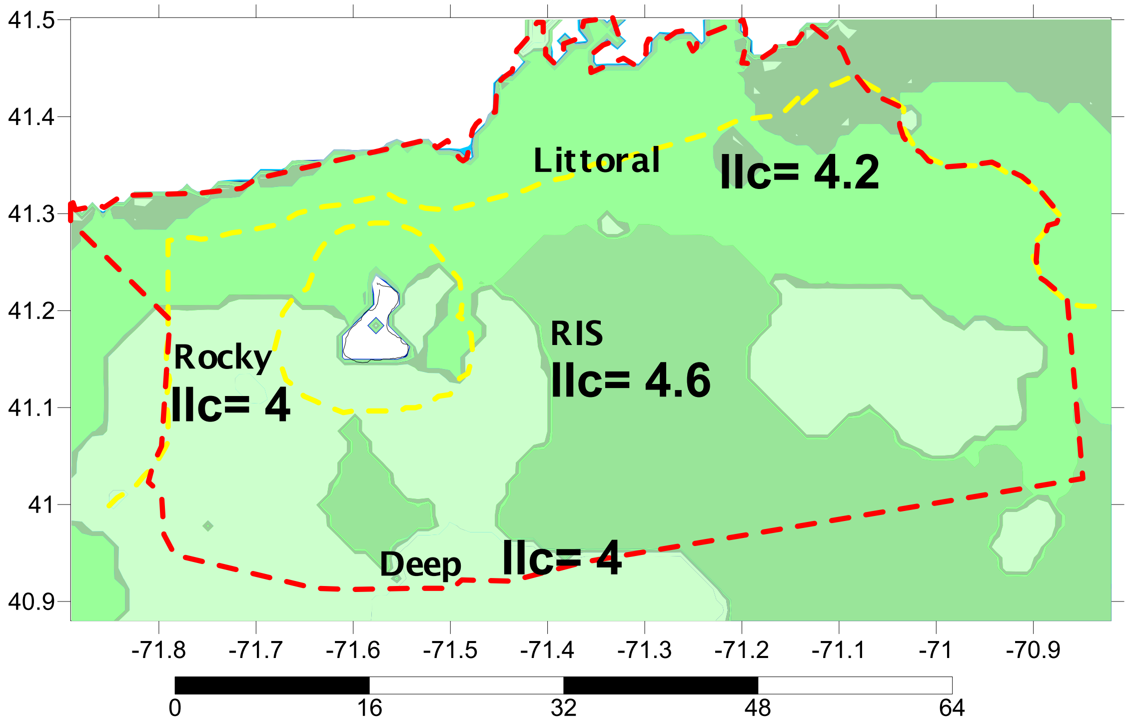

Figure 12:Fall Impact Index, II_c ,during construction phase

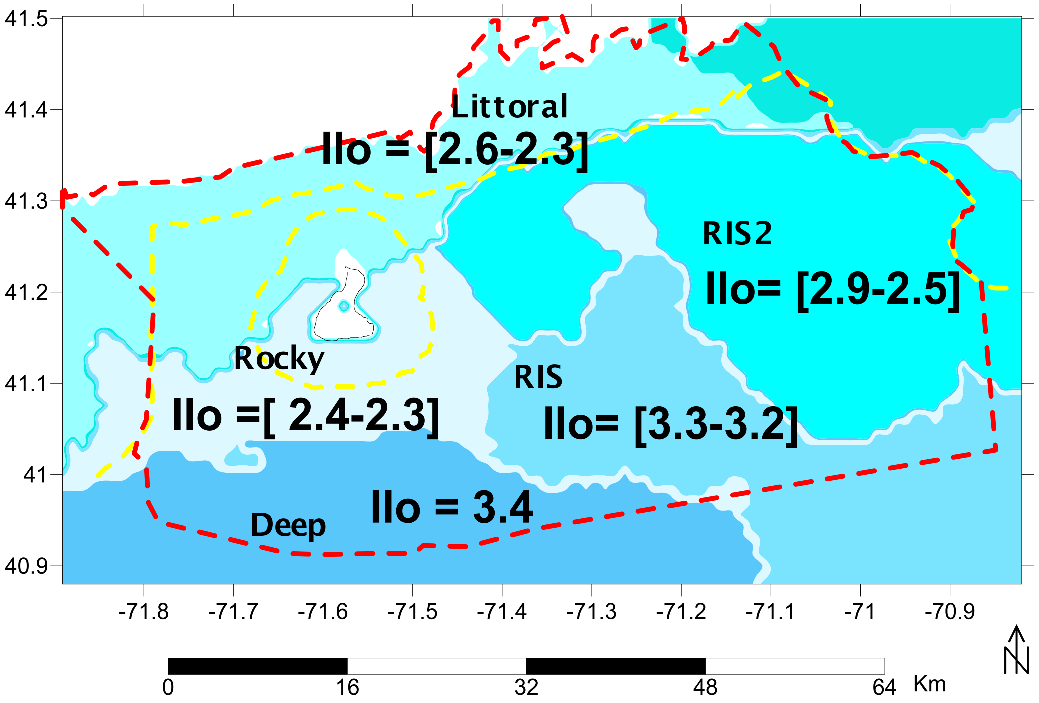

Figure 13 : Spring Impact Index, II_o, during operation phase without or with reef effect, first and second index respectively.

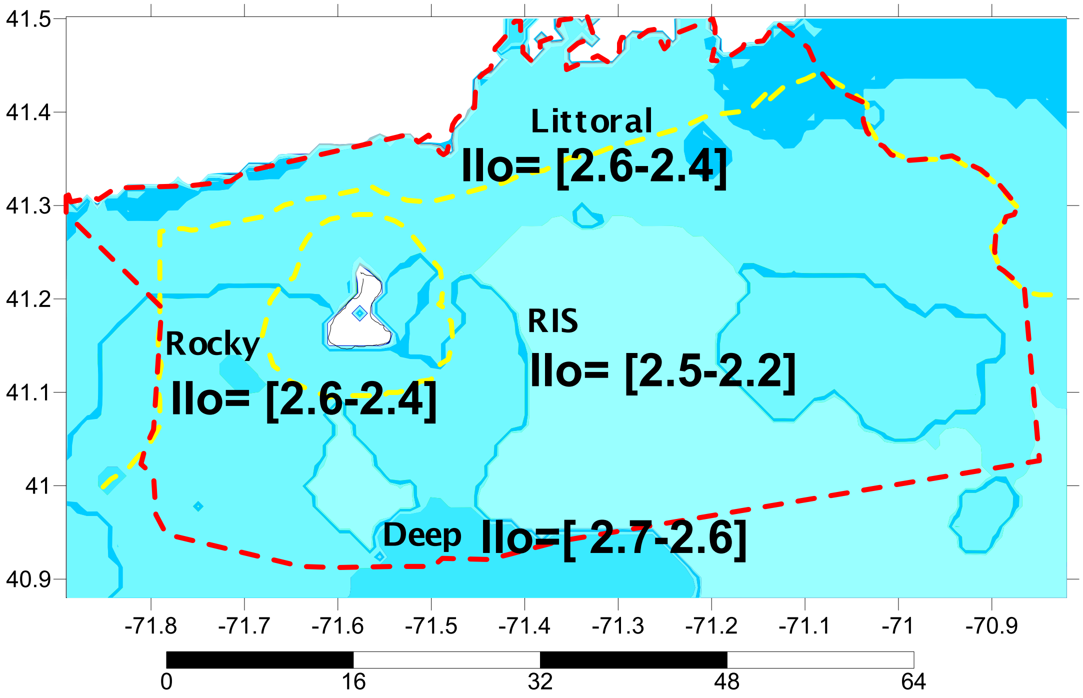

Figure 14: Fall Impact Index, II_0during operation phase without or with reef effect, first and second index respectively

The sensitivity study to wind farm potential impact shows a potentially significant impact, mostly during the construction phase, primarily due to noise effects on mammals and herring; a secondary impact is also related to the increased turbidity primarily affecting demersal fish. The rocky cluster, with lower biodiversity, would potentially be the most resilient. In Spring, the deep water and RIS assemblages, largely dominated by mammals, would potentially be the most sensitive. During the operation phase, however, the direct impact of the wind farm would be minor, but the positive reef effect would attract demersal fish; therefore, the RIS2 cluster would potentially be the most resilient area.

This sensitivity analysis needs to be validated with in situ data; in particular, the scale of the sensitivity coefficient needs to be calibrated against measurements. Complex feedback effects should be considered, and a modeling approach of disturbance effects, such as noise effects on mammals as well as reef effects, should be the basis for the values of the sensitivity coefficient.

3.5 Seasonal Ecological and Fishery services Typology

A typology similar to the ecological typology was established for ecological and fisheries services, in which the fisheries usage was added to the multivariate data set describing the area.

This second typology yields homogeneous regions based both on ecological and fisheries services. Sub-regions are shown on Figures. 14 and 15, and their characteristics in terms of indices and assemblage are summarized in Tables 6 and 7.

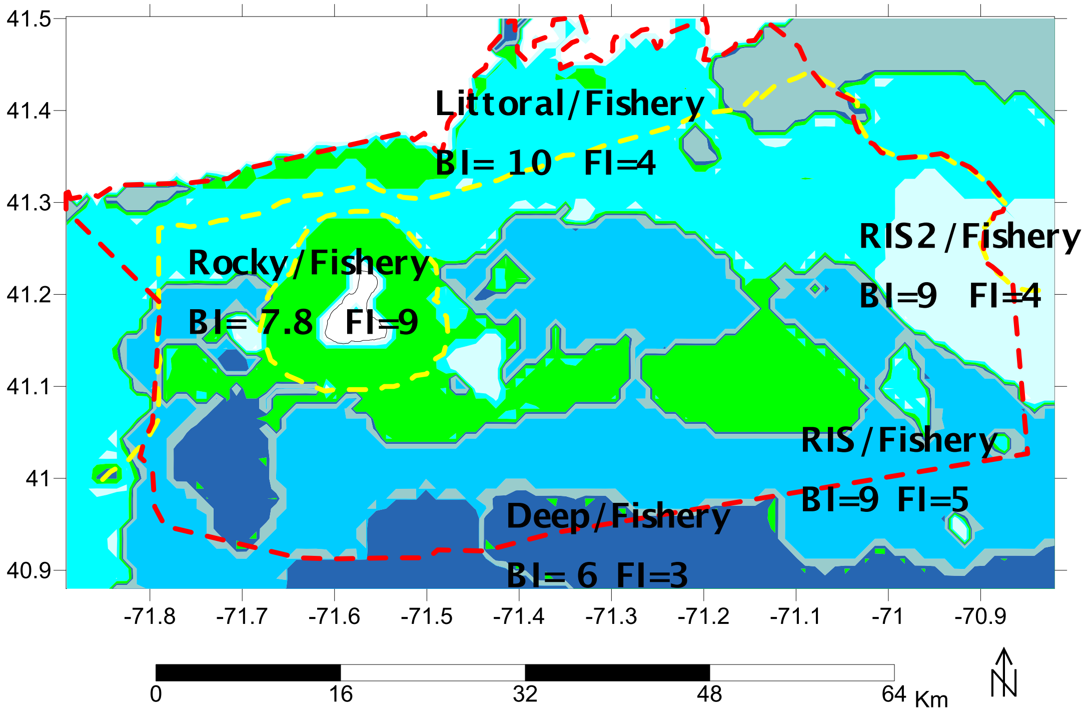

Figure 15: Fall ecological and fisheries services typology, BI-Biodiversity index and, FI-Fishery index.

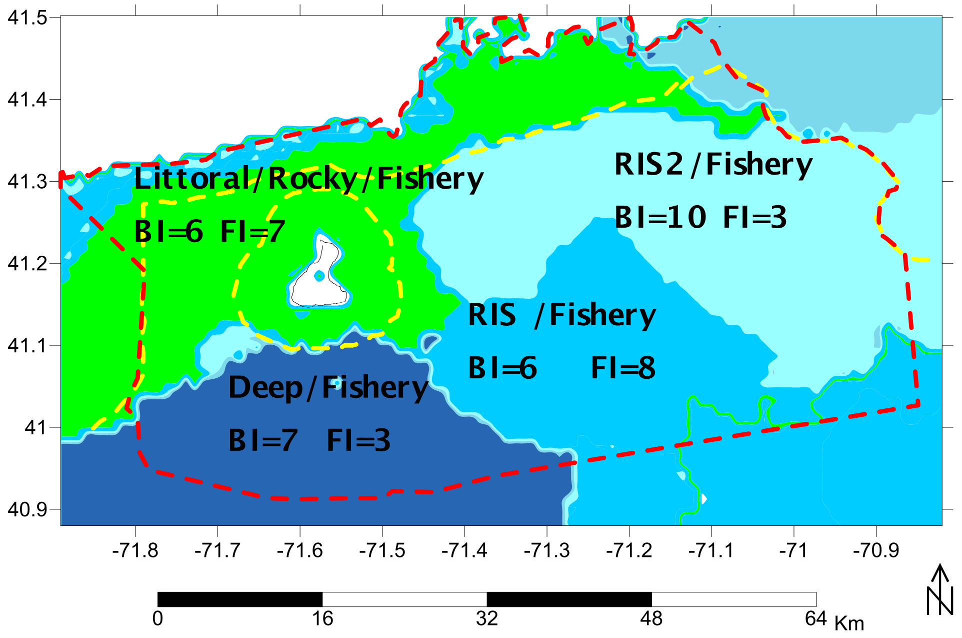

Figure 16: Spring ecological and fisheries typology, BI-Biodiversity index and, FI-Fishery index.

Table 6: Fall clusters' ecological and fisheries services' characteristics: Biodiversity, richness, fisheries indices and dominant group in ecological assemblages (see Figure 15: Fall ecological and fisheries services typology for cluster location).

Fall all services Clusters	Biodiversity Index	Richness Index	Fishery Index	Impact Construction	Impact Operation	Dominant group
Deep-Fishery	**6.1**	**5.7**	**3**	**5.2**	**3.6**	**Mammals**
Rocky-Fishery	**7.8**	**8.6**	**9**	**4**	**2.5**	**Demersal Mammals**
RIS - Fishery	**9.1**	**9.3**	**5**	**4.3**	**2.7**	**Demersal Mammals**
Littoral - Fishery	**10**	**10**	**4**	**4.5**	**2.8**	**Demersal Skate**
RIS2	**9.1**	**7.1**	**4**	**5.4**	**3.3**	**Demersal Skate**

A clear seasonal discrepancy appears, showing the dominance of fisheries services in very shallow water, around Block Island and in the vicinity of Cox Ledge in Fall, whereas the fisheries services are definitely dominant in RIS in Spring. This results from the dominance of recreational fishing in the Fall. In Spring , the fisheries and ecology services combine to create two major areas of intense fishing activity and average biodiversity, differentiated by their assemblage; the "RIS-Fishery" cluster is dominated by herring, demersal and mammals, whereas the "Rocky-fishery" cluster (which actually has absorbed the littoral cluster) is dominated by demersal. The "RIS2-fishery" cluster is relatively more isolated from fishing activity.

Table 7: Spring clusters' ecological and services characteristics: biodiversity, richness. Fisheries indices and dominant group in ecological assemblage (see Figure 16 for cluster locations).

Spring services Clusters	Biodiversity Index	Richness Index	Fishery Index	Impact Index Construction	Impact Index Operation	Dominant group
Deep-Fishery	7.2	7.9	3	5.1	3.5	Mammals Demersal
RIS2-Fishery	10	10	3	4.8	2.1	Demersal Herring
Rocky-Fishery	6.1	7.4	7	4.1	2.3	Demersal
RIS - Fishery	6.4	7.4	8	4.5	2.8	Herring Demersal Mammals

The sensitivity to wind farm impact is assessed through the Impact Index. When combining ecological and fisheries ecosystem services, the ecosystem seems be the most resilient in the "RIS2 –Fishery" cluster . This cluster seasonally varies in shape and its most conservative Fall shape should define the most resilient zone.

3.6 Ecosystem services, technological constrains and wind resources

The "optimal siting" map combines the ecosystem services, integrating ecological and fisheries services, with the technological constrains and the wind resources. Technological constrains and wind resources are expressed in the form of an index, the Technological Development Index (TDI), proposed by Spaulding et al. (2010). The index is an integer value larger or equal to 1, with a value of 1 representing an optimal siting area, an area with potential wind power dominating largely over technological constraints. Superimposing the ecosystem services sub-regions allows one to relate each sub-region to its potential appeal in terms of the balance of wind resources and technological constraints. Figures 17 and 18 show the ecological clusters superimposed on the TDI, for fall and spring respectively, where, in terms of appeal for wind farm siting, the bluer, the better. From this preliminary study, it seems therefore that the SE part of the RIS2-fishery cluster, which is characterized by a relatively low fishing index, a high resilience to potential wind farm impact, and sitting in a favorable TDI area, would be a good candidate for the sitting of a wind farm.

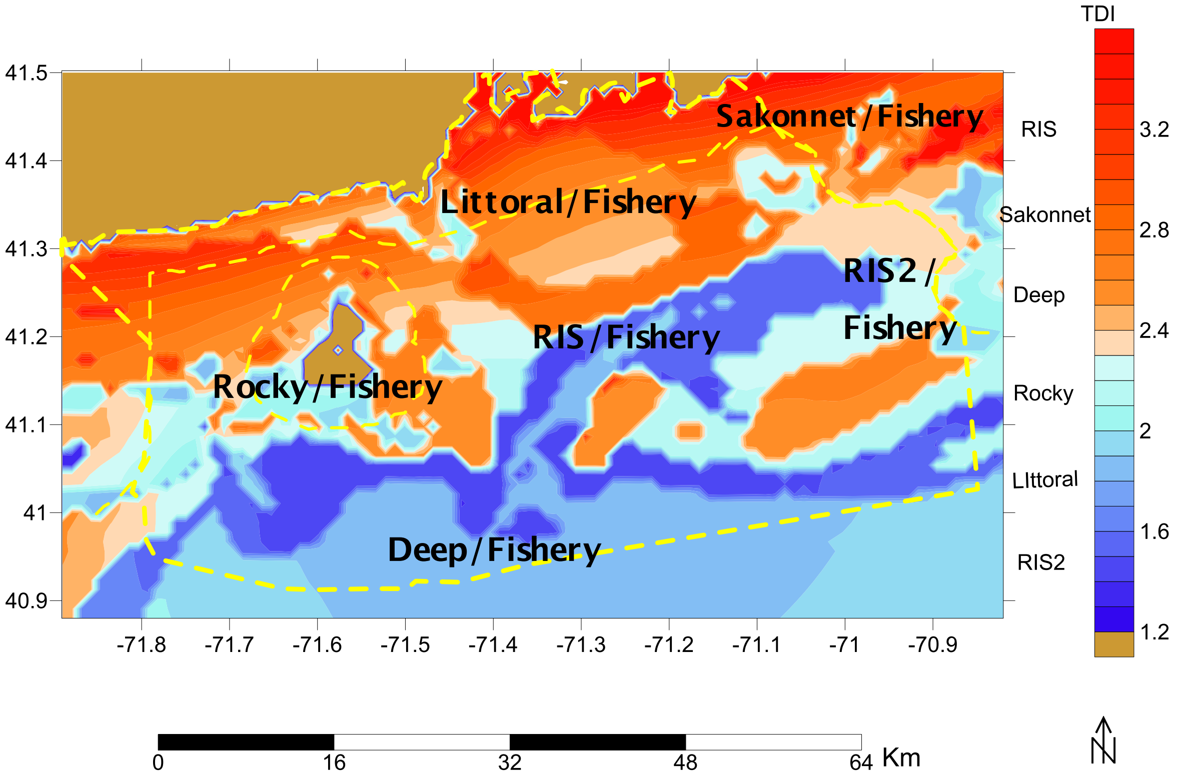

Figure 17 :Fall Optimal Siting Map: TDI and ecosystem services sub-regions.

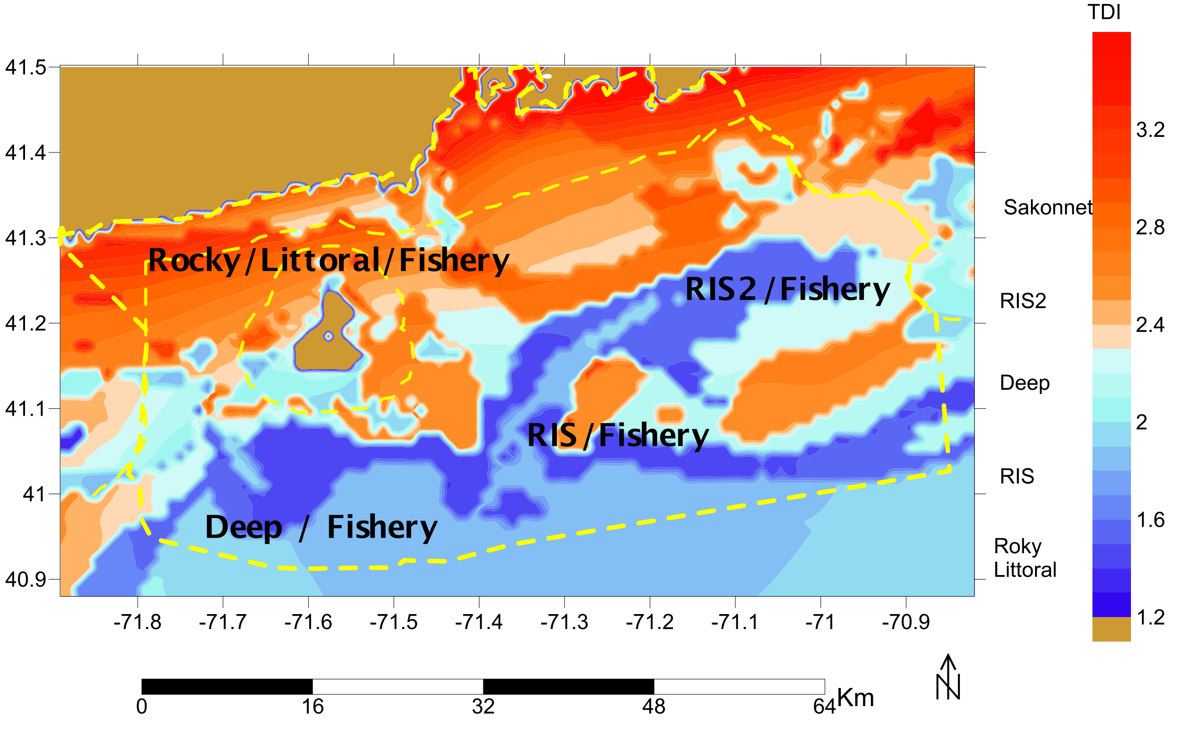

Figure 18: Spring Optimal Siting Map: TDI and ecosystem services sub-regions

4 Conclusion

We proposed and detailed the implementation of a rigorous and objective methodology to establish a typology or a functional zoning of ecosystem services. This typology is based on the natural gradient of the variables describing the ecosystem and yields a qualitative zoning of the area. Each identified ecological services sub-regions is defined by a specific assemblage of dominant species, and is shown to reflect a specific geophysical environment and oceanographic processes. We find that the method isolates onshore and offshore sub-ecosystems and, in medium depth, differentiates the well mixed, colder water and rough seafloor of BIS, from the warmer and stratified water over mostly smooth seafloor of RIS. We are currently working on the quantitative evaluation of these geophysical factors to help explain the ecological variance, but this aspect was out of the scope of this preliminary study. Within this functional framework and in the perspective of optimizing wind farm siting, a set of indices describing the intrinsic value of each cluster was developed: biodiversity, richness, fisheries and sensitivity to wind farm impact. Biodiversity and richness indices clearly identify the RIS as the most ecologically diverse area, in contrast with the BIS, in particular, its northern part in Spring. The deep water area is the least ecologically diverse one (lower biodiversity and richness indices), but it includes the heart of the area for mammals passage through Rhode Island waters, in the southern part of the RIS.

The sensitivity study to wind farm impact, approached through the Impact Index, isolates the deep water and southern RIS sub-regions as the most sensitive to construction impact, since they host the transect of more mammals than at any other place. The northern part of the RIS (RIS2), a priori sensitive since characterized by high biodiversity and richness in species, would however be the most resilient during the operation phase since it mostly hosts demersal species, shown to be attracted by wind support structures which act as a an artificial reef.

Combining ecosystem services with technological constrains and wind resources, provides a tool to identify optimal wind farm siting areas.

Future work should address the issues of fuzzy borders and uncertainty, including the question of uncertainty associated to the survey sampling. In addition, the species resilience and the reef effect should be particularly addressed.

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