1.10 Application of estuarine and coastal classifications

in marine spatial management

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SYNOPSIS

Coastal and marine classifications, both spatially explicit in the form of maps and non-spatial representations of the environment are critical to the effective implementation of management strategies such as marine spatial planning. This chapter provides a wide range of classifications and classified maps developed to simplify and communicate biological, physical, social and economic patterns in support of enhanced management decision making. Examples are provided from around the world and span a range of spatial scales from global classifications to those for individual bays and estuaries. Limitations, future challenges and priority management needs are discussed.

1.10.1 INTRODUCTION

In the coastal environment, ecological processes interact across land and sea to create complex dynamic spatial patterns in physical, chemical, biological and socio-economic attributes. The biophysical components (e.g., species, geology, climate, ocean circulation, etc.) of coastal ecosystems provide the environmental template on which human activities occur and this heterogeneity inevitably means that some places will be more productive, more diverse, more stable, more commercially valuable, more susceptible to climate change or more resilient than other areas. The widespread recognition that coastal environments are spatially heterogeneous and are being adversely impacted by multiple stressors, many of which are directly related to human activity, has reinforced the need for coordinated efforts to effectively monitor, assess and judiciously manage ecosystems within a spatial framework (Crowder and Norse 2008). Here we use the term "marine spatial management" to encompass a diverse range of management activities, some of which can be classed as ecosystem-based, but all of which rely on spatially explicit information to support decision making. For example, marine zoning and comprehensive marine spatial planning (MSP) are a subset of the broader approach of marine spatial management (Box 1).

In marine spatial planning, a fundamental first step and critical precursor to spatial decision making is to classify and map biophysical patterns, human uses and political and legal jurisdictional boundaries within geographical focal areas (Lourie and Vincent 2004, Boyes et al. 2007, Crowder and Norse 2008). Capturing the relevant information at both operationally and ecologically meaningful scales, however, is a major ongoing challenge now being addressed by advances in geospatial technologies that are rapidly revolutionizing the way we understand and manage the marine and coastal environment. Technological improvements and diversification of air-, space, and water-borne sensors combined with global positioning systems (GPS) for spatially accurate mapping are increasing data availability and diversity. Geographical information systems (GIS) and online data portals facilitate data access, storage, management, integration, analysis and visualization and are now integral components in modern marine management (Boyes et al. 2007, Gilliland and Laffoley 2008, St. Martin and Hall-Arber 2008).

In this chapter we focus on spatial representations of classification schemes, a rapidly emerging spatial management tool that translates and often simplifies raw environmental data into a more useful product for management application (Box 2). Often, synoptic information needs are urgently required to support timely implementation of management strategies and thus detailed scientific assessments are sometimes logistically unfeasible making classifications based on comprehensive best available data a practical and scientifically defensible solution. In fact, many recent classifications have been specifically created to meet the needs of particular government and non-governmental management obligations related to directives, conventions, statutes and other international, national and regional initiatives (e.g., Roff and Taylor 2000, Kendall et al. 2002, Harris et al. 2002, Hiscock et al. 2003, Madden et al. 2005, Connor et al. 2006 and other examples in this chapter).

With the rapid emergence of marine spatial planning and spatially explicit ecosystem-based management approaches, resource management agencies and conservation groups are increasingly utilizing classifications to support geographical priority setting and improving information-based decision making for state of the environment reporting that requires consistent and systematic information from which to compare and contrast ecosystem health. In this chapter, using examples from around the world, we document classifications that have been developed to support management decision making. We define marine spatial management broadly as any management activity that uses spatially explicit data to support decision making from site characterization to selecting anchorage zones to monitoring landscape and seascape change, designing networks of protected areas and integrated marine spatial planning. Most utility has been derived from spatially explicit classifications in the form of digital geographical maps, although not all coastal classifications are maps. Some classifications include features that are not easily mapped at scales operationally meaningful for management.

The possibilities for class content (or theme) within coastal classifications are extremely broad and inclusive, with limitations usually related to the availability of an appropriate sensor or logistical (i.e., high financial cost) constraints such as data availability. We include a cross-section of the data types currently being used to develop classifications, but far more examples exist than can be adequately covered here. In addition to theme, the spatial extent or geographical coverage of classifications varies greatly. This is important in terms of utility because management decisions take place at multiple levels of organization ranging from global (multinational), national, state, to an individual bay, estuary or study plot. The Large Marine Ecosystems (LME) is perhaps the best known example of a global classification and comprises ocean spaces with distinct bathymetry, hydrography, productivity and trophic relationships (Sherman and Duda 1999). LMEs have been widely used as spatial management units for which data on fisheries and other biological indicators of ecological integrity are aggregated, analyzed and assessed (Sherman and Duda 1999, Duda and Sherman 2002). A newer hierarchical classification known as the Marine Ecoregions of the World classification (Spalding et al. 2007) has more recently emerged for coastal and shelf areas shallower than 200 m and is based on biogeographical divisions. It is a nested system of 12 realms, 62 provinces and 232 ecoregions providing a broader spatial coverage and finer thematic resolution than the existing LMEs and is aimed at supporting the development of ecologically representative systems of protected areas as required by the Convention on Biological Diversity and Ramsar Convention on Wetlands. At the finest thematic resolution, the ecoregion has already been widely used by several large non-governmental conservation organizations to develop ecoregional marine classifications and assessments. Global regionalizations such as the LMEs and Marine Ecoregions are sometimes referred to as spatial frameworks or bioregional classifications, primarily because they focus on the relatively broad end of the scale using biogeographical patterns and the distribution of relatively coarse resolution physical forcing factors. As such their management utility differs from the finer scale more thematically resolved coastal classifications that focus on habitat types or communities. At the national level, Roff and Taylor (2000) developed a hierarchical geophysical approach to the classification of marine habitats for the Canadian coastline. Due to the large extent of the Canadian coastline and Economic Exclusion Zone (EEZ) and the relative paucity of species and habitat data, geophysical data were used as a surrogate for marine communities and for the identification of broad representative habitat types. The classification approach developed by Roff and Taylor (2000) and subsequently by Roff et al. (2003) has been widely applied for the classification of seascapes in marine spatial management efforts in the U.S., Europe and Australia.

Not all global classifications, however, are based on biophysical characteristics. In a simple numerical modeling approach, Halpern et al. (2007, 2008) constructed global maps of cumulative impacts from human activity to the marine environments that allowed areas to be ranked with an impact score or classified as high, medium and low impact. Using a derivative approach, a cumulative impacts model was subsequently applied and refined for the Papahānaumokuākea Marine National Monument in Hawaii to focus more on locally relevant threats including marine debris, invasive species, fishing and climate change parameters (Selkoe et al. 2009). In addition, thematic maps are increasingly being used to represent spatial patterning in ecological economics, with maps of ecosystem services being used together with spatial prioritization algorithms such as Marxan to support the decision making process (Sala et al 2002, Leslie et al. 2003; Chan et al. 2006; Geselbracht et al. 2008).

This chapter provides examples of applications of existing classifications and the development of new classifications to support a wide range of activities in marine and coastal management. The emphasis is on the use of digital maps, quantitative data and modeling combined with GIS tools since these spatial frameworks are contributing significantly to a spatial revolution in the way that we understand, utilize and manage our oceans and coasts. We focus primarily on categorical or thematic maps derived from either remotely sensed data, field surveys, expert knowledge or as often occurs an integrated combination of these information sources. The majority of our examples are focused on sub-national level classifications and associated management applications rather than global or national level, although we acknowledge the importance of nested classifications to facilitate consistency in regional, national and international assessments and management decision making.

1.10.1.1 Importance of Spatial, Temporal and Thematic resolution

In addition to spatial extent, the three attributes of a map that impinge most on the appropriateness of a spatial classification for management application are: 1) spatial resolution; 2) temporal resolution, and 3) thematic resolution; all of which can influence the application, cost-effectiveness and feasibility of map production (Fassnacht et al. 2006, Kendall and Miller 2008). Thematic resolution is influenced by the scale at which the environment is sampled and changing the number of classes can influence the patterning, be it benthic seascape or ecosystem service values, as much as changing the spatial resolution. It is often perceived that higher thematic resolution (i.e., higher number of classes) that creates highly specialized categories can potentially offer greater predictive power, but the predictive performance of categorical data really depends on what is being predicted. Spatial resolution and thematic resolution, as well as, post-classification techniques such as smoothing can greatly impact the representation of rare and fragmented ecosystems and this has considerable implications for maps directed at site prioritization in marine conservation (Thompson and Gergel 2008). Furthermore, the static nature of most classifications is an issue when applied to dynamic marine environments. Marine environments can be modified significantly by human activities, storms and swell events, disease and many sub-catastrophic disturbances at temporal scales that are markedly finer than those intervals that typically exist for the updating of maps.

1.10.1.2 Utility of Hierarchical Classification Schemes

In many cases, hierarchical classification schemes have been developed to add more flexibility for the user, particularly when manipulated in a GIS, thereby facilitating the utility for both management applications and ecological applications. For example, the British Columbia Marine Ecological Classification includes Ecozone (e.g., Pacific) as the broadest level in the hierarchy, then nested at progressively finer thematic resolution are the Ecoprovince (e.g., Pacific shelf and mountains); Ecoregion (e.g., Outer Pacific Marine Shelf); Ecosection (e.g., Queen Charlotte Sound) and finally the Ecounit, based on data for wave exposure, depth, subsurface relief, currents and substrate type (Zacharias et al. 1998). This hierarchical structure is important because ecological patterns and processes are multi-scale and management actions occur across a hierarchy of spatial scales (Wiens 2000). Roff et al. (2003) provided five important considerations for the development of a generalized hierarchical habitat classification scheme: 1.) the availability of data capable of discriminating meaningful habitat classes; 2.) redundancy in discriminating variables may occur and surrogates can be identified; 3.) discriminatory function of variables may be scale dependent (i.e., salinity may work well at one level but not another), 4.) habitat types at upper levels of the hierarchy should be more distinct from one another than those at lower levels, and 5.) the importance of discriminatory variables may vary geographically (i.e., East Pacific variables may not all be applicable to the west Atlantic) (see also Roff and Taylor 2000).

While these are useful guides for the development of classifications, the detailed architecture of the classification and resultant class distributions are also crucial to management when important decisions on management priorities and levels of action are weighted heavily on information provided in a classified map. The utility of a hierarchical classification increases further since many coastal classifications have been developed without a specific application in mind and without knowledge of future applications; many of which would be difficult to perceive given the wide range of current uses for coastal areas and types of coastal management. The recent progress in MSP has drawn heavily on existing classifications, the majority of which were not specifically designed with fully integrated MSP in mind. Significant efforts are underway to evaluate their utility and to better align and integrate local, regional, national and international classification schemes to provide interoperability across schemas and facilitate objective broader scale comparisons.

1.10.1.3 Examples of Hierarchical Classifications

The hierarchical marine habitat classification developed for EUNIS (European Nature Information System) (http://eunis.eea.europa.eu/habitats.jsp) integrates and modifies several existing schemas, including the Marine Habitat Classification for Britain and Ireland (Connor et al. 2004; http://www.jncc.gov.uk/MarineHabitatClassification) and classifications developed for the OSPAR (north-east Atlantic), Helsinki (Baltic Sea) and Barcelona (Mediterranean Sea) Conventions to create a pan-European reference set of habitat units with common descriptions. The Marine Habitat Classification for Britain and Ireland is based on multivariate analyses of more than 30,000 biological samples and is well established as a standard tool for marine conservation practitioners, industry regulators and those involved in environmental assessment, survey and management. A novel feature of the classification is the development of a key (analogous to a taxonomic key for individual species) for systematic identification of habitat types. The EUNIS classification scheme was designed to enable comparative referencing and reporting in nature conservation specifically linked to the legal obligations under EC Habitats Directive Annex I and the Bern Convention Resolution No. 4. EUNIS has been constructed to be truly hierarchical in design, with habitat units at each level aiming to be of equivalent ecological importance and with no duplication of lower level units within the higher types. The hierarchy allows mapping at different spatial scales, as demonstrated by the MESH project (Mapping European Seabed Habitats) in a web-based GIS application (http://www.searchmesh.net/) which has collated existing maps of differing levels of detail and standardized them according to the EUNIS scheme. The classification's use of physical parameters (e.g. substratum, salinity, wave and current energy), linked clearly to changes in community types, provides the basis for predicting the distribution of marine biotopes from existing data (Feral, 1999). Predictive models of EUNIS habitat types have been developed for north-west Europe (Coltman et al. 2008). The comprehensive and hierarchical structure of the EUNIS classification supports diverse management applications including: 1) provision of broad categories for the assessment of the state and trends of nature in the European Environment Agency's reporting process; 2) supporting the development of the EU NATURA 2000 conservation network and revision of Annex I of the Habitats Directive; 3) obtaining an overview of habitat distribution across Europe; to enable nations to place and assess their habitats in a European context; 4) conducting biodiversity assessments; 5) providing a practical system for the description and monitoring of habitat types for national, regional and local levels; and 6) identifying and documenting the character and distribution of the most threatened habitat types in Europe.

In the U.S., a variety of coastal classifications have been developed to describe local or regional ecological systems and address local objectives. In response to the need for a single classification standard that is relevant to all U.S. coastal and marine environments and that can be applied on local, regional and continental scales, NOAA and NatureServe developed the Coastal Marine Ecological Classification Standard (CMECS) (Madden et al. 2005, Madden and Grossman 2008). The classification is described as an ecosystem-oriented, science-based framework developed to allow effective identification, monitoring, protection, and restoration of unique biotic assemblages, protected species, critical habitat, and important ecosystem components. The hierarchical framework contains six nested levels; each containing clearly defined classes and units as follows: *Level 1 Regime* classes are differentiated by a combination of salinity, geomorphology and depth; *Level 2 Formation* are large physical structures formed by either water or solid substrate within systems; *Level 3 Zone* classes include the water column, littoral or sea bottom; *Level 4 Macrohabitat* classes are large physical structures that contain multiple habitats; *Level 5 Habitat* classes are a specific combination of physical and energy characteristics that creates a suitable place for colonization or use by biota; *Level 6 Biotope* classes represent the characteristic biology associated with a specific habitat. The hierarchy is conceptually divided into two parts based on the kinds of data required for applying the classification. Data for the upper levels, *Regime* through *Zone* can be captured from maps, bathymetry, remote imagery and existing historical data. In contrast, the lower levels, *Macrohabitat* though *Biotope*, exist at local spatial scales and data collection is done through finer resolution remote sensing, field observation and direct measurement. Linkages between levels of the hierarchy are defined by ecosystem processes and by spatial relationships. Stated management utility includes: 1) Delineation of regions for marine protected areas and developing guidelines for their management; 2) Identification of important habitats and critical hotspots for conservation; 3) Identification of Essential Fish Habitat (EFH); and 4) Forming a scientific basis for the development, implementation and monitoring of ecosystem-based management strategies for coastal systems (Madden and Grossman 2008).

For threatened and vulnerable shallow-water coastal ecosystems such as tropical coral reefs, habitat mapping is essential for the development of effective marine management plans including MPA site selection and other conservation prioritization activities. Information gained from coral reef mapping includes identifying essential fish habitat and other ecologically sensitive areas for protection, calculating volumetric or area measurements of anthropogenic impacts, identifying reef gaps for submarine cable placement, and locating areas for artificial reef enhancement. To address multiple management and research objectives, NOAA's Benthic Habitat Classification for Puerto Rico and the U.S. Virgin Islands (Kendall 2001) was developed with a hierarchical structure that integrates four levels of classification for mapping coral reef ecosystems including: 1) *Geomorphological zone* (e.g., forereef, bank etc.); 2) *Habitat structure* (e.g., colonized hardbottom); 3) *Habitat type* (e.g., linear reef, seagrass) and 4) *Modifiers* used to show the proportion (% cover) of area coverage for macroalgae and seagrasses. A hierarchical structure means that different analyses and different levels of features can be utilized for different levels of management decision making. For example, the percentage seagrass cover was used as a variable for quantifying changes in the spatial distribution of seagrasses and the impact from hurricanes over 30 years (Kendall et al. 2004). In 2008, a new classification was developed for application to finer resolution benthic habitat maps for St John in the U.S. Virgin

Islands with a minimum mapping unit (MMU) of 1000 m^2. The fundamental difference in the St. John scheme is the deviation from coral-centric classification rules to a biological dominance scheme in which benthic habitats were classified based on the dominant biological cover type present on each mapped feature. The importance of describing the percent cover of live coral, however, was maintained by the introduction of a new map attribute *Percent Coral Cover*. This attribute describes the percent live coral cover for every feature at the scale of diver observation in the water, with no regard to dominant biological cover (Zitello et al. 2009).

Maps of habitat structure, a relatively coarse habitat classification using dominant cover types, was found to be most appropriate for predicting differences in fish assemblage composition (i.e., mangrove, seagrasses/algae, colonized hardbottom and unvegetated sediments) in SW Puerto Rico (Pittman et al. 2010) and to classify optimal seascapes for fish (Pittman et al. 2007b). When combined with information on topographic complexity of the seafloor the benthic habitat maps at the habitat type level were able to accurately predict the spatial patterns of fish species richness in the U.S. Virgin Islands and SW Puerto Rico (Pittman et al. 2007a). Furthermore, in the same region, combining geomorphological zones and habitat structure proved useful for explaining the across-shelf size dependent distributions for fish (Christensen et al. 2003).

1.10.2 SPATIAL CHARACTERIZATION USING MARINE AND COASTAL CLASSIFICATIONS

Classification schemes and associated maps are indispensible to environmental managers in providing the baseline information on the distribution of natural features, including species distributions, both within and surrounding their jurisdictions. Spatial characterizations can be species-centered, biological community centered, can represent bioregions and can be derived from geophysical or chemical variables and more recently have extended to characterize human use patterns and threats to ecosystems. The most common data types used for baseline characterizations in the marine environment are benthic habitat maps and landcover maps in terrestrial environments. Thematic habitat maps are typically developed from interpretation of remotely sensed data (space-, air- or ship-based) guided by georeferenced *in situ* samples to define classes or through spatial interpolation of georeferenced *in situ* samples. In many instances the ecological relevance of mapped classes is unclear and much work is required to determine the relationship between the spatial distributions of habitat classes and the distribution of other ecological attributes including species and biological communities.

In the Bahamas, Mumby et al. (2008) found that approximately 25-30% of benthic invertebrate species and fish were associated with a single habitat class, yet they determined that all classes (n=11) were needed if the management objective was to represent all species in the seascape. In the same region, Harborne et al. (2008) found that although each habitat class supported a distinct assemblage of fish, the efficacy of mapped habitats as surrogates for fish communities was limited by intra-habitat variability that increased with geographical scale. The relevance of mapped classes to biological communities, however, can be dependent on the mapping tools applied and the variables measured. In southern England, Eastwood et al. (2006) determined that benthic classifications of soft sediments derived from side-scan sonar were not effective at classifying biological assemblages. Similarly, Stevens and Connolly (2004) found that abiotic surrogates classified from underwater video transects in Moreton Bay, Australia, were not good surrogates for patterns of marine biodiversity. In northern Australia, however, inclusion of a wider range of physical factors including sediment composition (grain size and carbonate content), sediment mobility, water depth and organic flux were able to adequately characterize macrofaunal distributions (Post et al. 2006). The latter study highlights the importance of including process-based factors such as sediment mobility in determining patterns of diversity and individual species distributions, particularly in soft sediment dominated regions. In many areas, however, the work of assessing the utility of benthic habitat maps as surrogates of biodiversity or as predictors of species distributions is still in its infancy and is a major pursuit in the field of marine spatial ecology.

Habitat maps can also be analyzed using landscape ecology concepts and spatial tools to examine the importance of spatial heterogeneity of the environment including the significance of seascape composition (distribution, abundance and diversity of patch types) and seascape configuration or spatial arrangement (the explicit spatial geometry of patches) (Pittman et al. 2004, 2007b, Grober-Dunsmore 2007, 2008). This new approach in marine ecology represents a shift from a focus on individual habitat patches to a focus on the surrounding seascape mosaic. A classified map of functionally meaningful seascape types can provide a novel spatial template with which to frame many important management and ecological questions including the design of marine protected areas, essential fish habitat and designing optimal restoration projects. Classified maps also play an important role in forming spatial predictor variables in predictive mapping of biodiversity and explaining individual species distributions for coral reef ecosystems (Pittman et al. 2007a; Purkis et al. 2008, Pittman et al. 2009, Knudby et al. 2010) (Figure 1).

1.10.2.1 Classifying and Mapping Seascapes of the Scotian Shelf, NW Atlantic

In a hierarchical framework for the Scotian Shelf, Roff et al. (2003) classified pelagic-benthic seascapes by combining a classification of benthic seascapes (based on temperature, bottom temperature, exposure, slope and sediment types), with a classification of pelagic seascapes (based on water temperature, depth classes and stratification classes) (Figure 2A). These layers were then used to calculate a derivative map to show relative seascape heterogeneity (Figure 2B) in order to identify areas with high heterogeneity as potential focal areas for marine conservation. Further utility can be gained by quantifying the seascape composition of existing or proposed marine protected areas, for linking to key faunal populations or behavioral patterns such as migratory corridors for megafauna and addresses questions about habitat use and preferences at scales that may be more meaningful to the highly mobile organisms (Box 3). Furthermore, such information can help understand marine species distributions and characterize essential fish habitat including nursery and spawning areas.

Using similar organizational frameworks, seascapes have been classified and delineated in Australia (Harris 2007); the Gulf of Maine (CLF/WWF 2006); the Irish Sea (Vincent et al. 2004), and the Baltic Sea (Al-Hamdani et al. 2007). In the UK, four main categories of seascape types (or marine landscapes) have been defined (Connor et al. 2006). These are:

1.) Coastal (physiographic) features, such as fjords and estuaries, where the seabed and water body are closely interlinked.

2.) Topographic and bed-form features, occurring away from the coast and forming distinct raised or deepened features of the seabed at various scales;

3.) Broad-scale seabed habitats, defined through modeling and broadly equivalent to EUNIS higher level habitat classes;

4.) Water column [pelagic] features of open sea areas, such as mixed and stratified water bodies and frontal systems.

1.10.2.2 Seascapes of the Baltic Sea

Classified maps representing benthic seascapes (also referred to as benthic marine landscapes) were developed to increase the cost-efficiency of data collection and integration in the Baltic Sea and to identify essential fish habitats and other important conservation areas for the implementation of the EU Habitats Directive (Reijonen et al. 2008). Seascapes were classified using: 1.) physiographic marine features of the coast (7 classes); 2.) topographic features of the seabed (18 classes) (Figure 3), and 3.) 60 ecologically relevant benthic seascapes based on integrated data on salinity, sediments and photic depth (see Al-Hamdani and Reker 2007). These maps have provided a basemap on habitat and seascape patterns to support implementation of ecosystem-based management in the region. At the sub-regional level the maps are expected to provide a useful tool in developing integrated solutions for nature conservation and sustainable fisheries, coastal development, transport and other uses. Several regional authorities are using the maps in fisheries restoration and management plans and in the design and zonation of MPAs. To further characterize the complexity of the environment, a classified map of habitat heterogeneity (1 x 1 km^2 grid cells) was quantified from summed classes derived from variability in depth, wave exposure and shoreline complexity to provide a surrogate for biodiversity and classes were validated with in situ biological datasets (Figure 4). Although the initial efforts were focused on characterizing benthic structure, the development of pelagic seascapes similar to those developed for the Scotian Shelf are also being examined.

1.10.2.3 Australian Coastal Classifications

OzCoasts which developed from OzEstuaries was initiated by the Australian National Land and Water Resources Audit (NLWRA) from the recognized need for a more strategic data collection to ensure that information and data were accessible, collated and provided to all levels of government and the community. Consequently, the first national classification schemes pertaining to the condition and geomorphology of estuaries were created (Harris et al. 2002). Australian estuaries were classified into six sub-classes based on the wave-, tide-, and river power that shaped them: wave- and tide-dominated deltas, wave- and tide-dominated estuaries, strand plains and tidal creeks (Dalrymple et al. 1992, Harris and Heap 2003). The data indicated that tidal flats were the most common coastal depositional environment in Australia (n = 273), followed by wave-dominated estuaries (n = 145), tide-dominated estuaries (n = 99), wave-dominated deltas (n = 81), tide-dominated deltas (n = 69), strand plains (n = 43), and lagoons (n = 11). The spatial distribution of these environments around the coast exhibited a distinct zonation, such that five major coastal regions were identified: 1.) southeast coast; 2.) southwest coast; 3.) northwest coast; 4.) Gulf of Carpentaria coast; 5.) and northeast coast (Harris et al. 2002).

The condition and geomorphic classification schemes are a widely used source of contextual information on estuaries. Two additional classifications developed for the Australian coastal classification effort include the National Intertidal/Sub-tidal Benthic (NISB) Habitat Classification scheme (Mount et al., 2008), and a National Coastal Landform and Stability map in segmented line format (Sharples et al. 2009). The NISB Classification Scheme was developed as part of a collaborative project between the NLWRA (phase II; 2002-08) and the Federal

Government Department of Climate Change in order to support an initial vulnerability assessment for the whole of the Australian coastline, and to contribute to the development of marine ‘ecoregions’ or bioregional subregions. Before NISB, there was no consistently-classified habitat mapping of the entire Australian coastline, except at very broad scales that were not of practical use in a coastal vulnerability assessment. The NISB habitat classes include: mangroves, saltmarsh, seagrass, macroalgae, coral reef, rock-dominated, sediment-dominated and filter feeders (such as sponges). These habitats occur between the approximate position of the highest astronomical tide mark and the location of the outer limit of the photic benthic zone (usually at the 50 to 70 meter depth contour). High spatial resolution polygons with thematic attributes based on NISB are also available in Ozcoasts, together with national, state and regional summary maps for each habitat (Figure 5). The NISB Classification Scheme has been adopted as a standard by Sinclair Knight Mertz, one of Australia’s largest environmental consulting companies. In addition, it will be used by the CSIRO climate adaptation branch in the coastal version of their Impacts of Climate Change on Australian Marine Life studies (Hobday et al., 2006).

Coastal environments can also be classified according to levels of physical disturbance from extreme storm events that mobilize and transport sediments across the shelf, a characteristic feature of many shelf ecosystems. Research has shown that storms and strong currents can cause widespread sediment erosion and deposition, some of which can bury or remove seagrasses and can cause extensive physical damage to coral reefs (Puotinen 2007). Harris (unpublished manuscript) proposes the development of a framework for classifying Australia’s continental shelf relative to disturbance based on a central tenet that biodiversity will be highest at intermediate levels of disturbance following Connell’s Intermediate Disturbance Hypothesis.

Ecological theory predicts that the frequency and magnitude of disturbance can play a major role in controlling biodiversity (Connell 1978, Pickett and White 1985) and the distribution and quality of habitats, thus disturbance regime is an important spatial process of relevance to the management of marine environments. Research worldwide indicates that strategies such as MPA network design will need to consider the spatial impact and return frequencies of disturbances, as well as the biological response and recovery. Furthermore, with regard to habitat mapping, areas of high disturbance may require more frequent habitat mapping in order to maintain accuracy in the distribution of habitat types.

1.10.2.3.1 Characterization of Australia's southwest coast

In order to protect the biological diversity of marine life in Australia's Exclusive Economic Zone (EEZ) as designated by the Environmental Protection and Biodiversity Conservation Act (1999), regional marine plans and networks of representative marine protected areas were developed in both regional and commonwealth waters (Harris et al. 2007). In the absence of direct information about the distribution of biodiversity, appropriate surrogates were used instead to characterize environmental heterogeneity. To achieve this for the southwest coast EEZ (Southwest Planning Region), Geoscience Australia created maps of geomorphological features and of different seascape classes using a statistical classifier and then quantified the variety of features and seascapes to represent the spatial patterning of biophysical conditions across the region (Figure 6A). Geomorphological features were identified using a bathymetry map of 250 m spatial resolution based on features and terminology recognized by the International Hydrographic Organization (IHO). Seascapes were classified from data on water depth, slope, gravel content, mud content, seafloor temperature and surface primary productivity (carbon production per day) (Figure 6B). The derivation of classes differed from Roff et al. (2003) for the Scotian Shelf in that a statistical algorithm was used to allow the natural breaks in the data to define classes and class boundaries (Harris 2007). This approach was also used successfully for the southeastern region and for the national bioregionalization process (DEH 2005). The broad spatial coverage and complex spatial patterning of seascapes provided important complementary information to the existing localized knowledge of biodiversity in the area. Following Roff et al. (2003), diversity of geomorphological classes and the diversity of seascape classes were calculated with a sliding analytical window of 20 km radius in GIS (Figure 6C). These layers were created both individually and then summed to create a synthesis map showing combined spatial heterogeneity in the biophysical environment to identify potential biodiversity hotspots and possible sites for marine protected areas.

1.10.2.4 Marine Characterization of American Samoa

American Samoa is a small west Pacific archipelago of five islands and two coral atolls located approximately 2000 miles south-southwest of Hawaii. The main island of Tutuila hosts the Fagatele Bay National Marine Sanctuary (FBNMS) and the National Park of American Samoa. Geologically, the islands are characterized by outcrops of basalt and limestone, biogenic and volcanic silt, sand and gravel, calcareous pavements and calcareous ooze. The shallow water habitats are composed primarily of fringing reefs, a few offshore banks, and two atolls, hosting an estimated 2,705 species of fish, algae, mollusks, and corals (Fenner et al. 2008). The fringing reefs throughout the territory have been steadily recovering from crown-of-thorns starfish outbreaks in the late 1970s (Green et al., 1999), as well as from hurricanes in 1990, 1991, 2004 and 2005. A major coral bleaching event occurred in 1994, possibly due to high sea-surface temperatures from an El Niño.

The territory is currently evaluating options for increasing the amount of marine protected areas through a network of MPAs. Primary questions have been: (a) What are the significant deep-water coral reef habitats, relative to the territory's coastal ecology and current initiatives for sanctuary management? (i.e., areas of 20% or greater coral cover as mandated for protection) (b) Where are these critical habitats located, and with what major species are they associated? (c) Which habitats appear to be "biological hotspots" (e.g., areas of high biodiversity), and what are the implications for coral reef conservation and management? To support this process Oregon State University, NOAA Biogeography Branch, NOAA National Undersea Research Program and NOAA Coral Reef Ecosystem Division (CRED) have been characterizing environmental patterns and processes to assist in identifying priority areas for conservation.

Lundblad et al. (2006) used geomorphometrics such as the bathymetric position index (BPI) applied to acoustically derived bathymetry to classify the seafloor into distinct structural types. The geomorphometrics are based on the hypothesis that many physical and biological processes acting on the benthic seascape may be highly correlated with bathymetric position. In some cases a species' habitat may be partially or wholly defined by the fact it is a hilltop, valley bottom, exposed ridge, flat plain, upper or lower slope, and so forth. Hence, BPI is a measure of where a referenced location is relative to the locations surrounding it; e.g., a measure of where a point is in the overall landscape or seascape. It is derived from an input bathymetric grid and is a modification of the topographic position index (TPI) algorithm used in landscape ecology studies (e.g., Guisan et al., 1999; Jones et al. 2000; Weiss 2001). Positive BPI cell values denote features or regions that are higher than the surrounding area (e.g., ridges). Negative cell values denote features or regions that are lower than the surrounding area (e.g., valleys). BPI values near zero are either flat areas (where the slope is near zero), or areas of constant slope where the slope at the point is significantly greater than zero). The relationships between grids derived at fine and coarse scales can then be examined and mapped out as a final terrain classification map using an algorithm developed by the user through the creation of a classification dictionary (Figure 7). The integration of *in situ* diver surveys (Brainard et al., 2008), and submersible dives (Wright et al., 2005, 2006) with bathymetric characteristics is refining the development of classified benthic habitat maps for the region.

Hogrefe (2008) developed a geomorphological classification of both the terrestrial island and surrounding seafloor terrain to define marine-terrestrial units based on watershed hydrology and catchment characteristics. The approach employs analysis tools associated with the Arc Hydro data model (Maidment, 2002) to derive drainage patterns from watersheds and affiliated catchments around the island, which were then used to identify contiguous marine/terrestrial units (Figure 8). Spatiotemporal correlation analyses of population density and coral reef health indices within each of the marine/terrestrial basins revealed a decline in coral reef health associated with increased population density. The model was then used to identify marine areas with long-term monitoring sites that were most at risk from development in the watershed.

The seamless land-sea coastal terrain model provided geomorphological detail of sufficient resolution and accuracy to enhance the study of ecosystem interconnectivity and the effects of anthropogenic inputs to coral reef habitats. The American Samoa examples underscore the utility of mapping from "ridge to reef" (i.e., the connectivity between upland watersheds, intertidal zones, and shallow coastal areas including reefs), where offshore classification categories must be integrated with those for wetland and intertidal regions (e.g., Heyman and Kjerfve, 1999; Wright and Heyman, 2008; Hogrefe 2008).

1.10.3 SPATIAL CONSERVATION PRIORITIZATION AND EVALUATION

With increasing human pressure on the marine environment and a changing global climate, the efficient and effective allocation of conservation resources is both urgent and paramount. Quantitative techniques for the identification and prioritization of conservation targets are now being used widely in marine site prioritization around the world. Marine classifications are a core component of the site prioritization process and the success of these techniques is heavily dependent on the type, amount and quality of biophysical data available. The analytical approaches can involve a simple scoring, whereby each spatial unit (site, grid cell, polygon etc.) is scored relative to a set of factors (vulnerability, species richness, uniqueness, etc.) or a more analytically complex complementarity-based approach. Complementarity approaches utilize algorithms to maximize inclusion of as many components of biodiversity as possible for a given representativeness target, thus focusing more broadly on collective properties of sets of locations to provide optimal scenarios (Ferrier and Wintle 2009). Complementarity is important in situations where efficient sets of planning units are required that can both minimize the cost of conservation action and ensure that all biodiversity features receive some level of protection. The purpose of identifying priority areas for biodiversity conservation is usually to mitigate threat, therefore, incorporating information on threatening processes and the relative vulnerability of features or planning units is crucial for effective conservation.

In addition to identifying and prioritizing conservation areas, classifications in the form of marine habitat maps provide an unprecedented opportunity to evaluate both the content and the gaps in an existing conservation portfolio. Simple spatial analyses applied to habitat maps can calculate how many and how much of a seascape type, biotope or geomorphological feature is included within a system of marine protected areas and quantify that which falls outside. For example, Geoscience Australia used the seascape classification and location of existing protected areas to assess efficacy for the Marine National Park (Green Zones) of the Great Barrier Reef Marine Park through measures of CAR: Comprehensiveness (full range of ecosystems), Adequacy (viability and replication of ecosystems) and Representativeness (biotic diversity included represents each area protected). Analysis of the seascapes contained in the Green Zones revealed a good level of comprehensiveness and representativeness, with the full range of ecosystems included and high adequacy, with seven of the nine seascapes having more than 20% of their area protected (Figure 9).

In New Zealand, Shears et al. (2008) evaluated existing biogeographic classifications using systematically collected in situ marine community data and then developed a new independent biogeographic classification. The classification was then used to evaluate the existing no-take MPAs to determine the extent to which bioregions were represented within protected areas. The analysis revealed that ad hoc reserves encompassed only 0.22% of territorial waters and < 1.5% of each bioregion was represented in the Nation’s marine reserves at the time of analysis.

1.10.3.1 Identifying Priority Conservation Areas in the Northwest Atlantic

The marine waters of the Gulf of Maine and the Scotian Shelf that span the US and Canadian maritime jurisdictions are some of the most heavily utilized marine resources in the world. Management efforts are underway to identifying a network of priority areas for conservation to help balance use, restore marine ecosystems and conserve biodiversity (WWF/Conservation Law Foundation 2006). To support a comprehensive and spatially explicit approach to site prioritization, maps depicting classes of seascapes were developed for both pelagic and benthic realms building on the approach of Roff et al. (2003). This classification and mapping work was conducted as a “proof of concept” to demonstrate that sufficient data existed to implement a representative marine conservation strategy in the region. The specific goal was to identify a network of sites that would protect the full range of marine biodiversity by incorporating representation of seascapes as a design criterion. Physical seascapes were characterized based on a suite of enduring and recurrent characteristics known to influence the distribution of species and biological communities including characteristics of the seawater, composition of the seafloor, and depth. The use of abiotic surrogates was considered to add stability to the classification through time. In this classification system, each pelagic and benthic seascape was defined by a unique combination of characteristics: surface water temperature-salinity zone, depth class and degree of stratification within the pelagic realm, and bottom temperature-salinity zone, depth class, and substrate type in the benthic realm. The classes for each abiotic variable were defined through a review of the literature and analysis of the data and mapped to a grid with 5-minute (66 km^2) cells to create a separate layer for each characteristic. A multivariate cluster analysis identified zones of similar conditions in both the benthic and pelagic realms (e.g., temperature-salinity zones). Each class within a data layer was assigned a unique code and layers were combined to create unique seascape types for the benthic and pelagic realms. A total of 118 classes of benthic seascape and 47 classes of pelagic seascape were defined for the Gulf of Maine (benthic 29, pelagic 14), Scotian Shelf (22 benthic, 14 pelagic) and Georges Bank (57 benthic, 19 pelagic). A spatial prioritization analysis was conducted using MARXAN (Ball and Possingham 2000) applied to benthic seascapes, pelagic seascapes and the combined benthic-pelagic seascapes. The best representative network for benthic seascapes consisted of 29 areas distributed throughout the analysis region covering approximately 20% of each of the biogeographic areas. Substrate type had an important influence on the nature of the benthic seascape layer and on the configuration of the networks selected by MARXAN. Without substrate data, the number of seascape conservation features decreased from 108 to only 32. Site prioritization based on both benthic and pelagic seascapes was performed to obtain a network that was fully representative of marine habitats. The representative network developed from seascapes alone was similar to the best network of priority areas for conservation based on a far broader range of features including existing conservation priorities, highlighting the value of the abiotic variables as surrogates for biodiversity and a cost-effective tool for marine spatial management.

1.10.3.2 Ecological Valuation Index for the Massachusetts Ocean Plan, USA

Members of the Habitat and Fisheries Work Groups of the Massachussets Ocean Management Plan developed the concept, methodology, and data for an ecological valuation index (EVI) to assist in identifying and protecting special, sensitive, or unique areas as directed by the Massachusetts Oceans Act (2008). The Ecological Valuation Index (EVI) is a numerical and spatial representation of the intrinsic ecological value of a particular area, excluding social and economic interests. It was envisioned that the EVI would highlight ecosystem components that have a particularly high ecological or biological significance and play a particular role in the marine environment, thereby facilitating comparison between sub-areas and provision of a greater-than-usual degree of risk aversion in spatial planning activities. Data for four marine mammal species, five bird species, five crustacean species, eight mollusk species, and 22 fish species were incorporated into the EVI (http://www.env.state.ma.us/eea/mop/draft-v2/draft-v2-evi.pdf). Individual datasets were then rated according to a standard set of ecological criteria (major contribution to survival/health of population, spatial rarity, and global and regional importance) (Figure 10). The EVI work group used a score based on a simple scale, creating a semi-quantitative scoring system that can be used when data are incomplete and expert judgment is used. Scoring was binary with a 1 given if the criterion was met and a zero if not and all criteria received equal weight. A data set for each species was given a score for each criterion and the sum of the scores was then attributed to the appropriate 250 by 250 m grid cells. Using fish and invertebrates as an example the following species are scored according to the ecological criteria (http://www.env.state.ma.us/eea/mop/draft-v2/draft-v2-evi.pdf):

1.) *Species abundant within the planning area for which the planning area plays a significant role in supporting the regional population.* Atlantic cod populations have decreased in many areas, but they are abundant in Massachusetts waters (spatial distribution = "0"). Waters are vital habitat that support breeding and juvenile stages (major contribution to fitness = "1").

2.) *Species with limited spatial distribution, including both numerically rare and abundant species.* Octopus are at the edge of their critical habitat (spatial distribution criterion =

"1"), but the planning area is not considered of vital importance to population viability and the planning area does not support a major proportion of the global or regional population (major contribution to fitness = "0").

3.) *State listed species of concern*. Atlantic wolffish is a candidate for the Endangered Species List. It prefers hard bottom substrata where it guards its nest and occurs mostly along the northern shores of Massachusetts. Due to its vulnerability and rarity, this species scored positively for all criteria.

1.10.4 OCEAN ZONING AND MARINE SPATIAL PLANNING

Zoning is an important process within marine spatial planning (MSP) that has been greatly facilitated through application of a wide range of spatial classifications. Day (2002) defined zoning as "*a spatial planning tool that acts like a town planning scheme*" that "*allows certain activities to occur in specified areas but recognises that other incompatible activities should only occur in other specially designated areas and in this way zoning provides area-based controls and separates conflicting uses*". Thus, a zoning plan facilitates the marine spatial planning process by providing an easily comprehensible way to manage human activities in marine areas. The overarching goal for both MSP and zoning is to ensure that the objectives of marine areas, resources, ecosystem services and nature conservation are met. The Great Barrier Reef Marine Park (GBRMP) Zoning represents the largest and most complex application of systematic conservation planning principles (Fernandes et al. 2005) and has a bioregions classification at its core. In fact, the GBRMP zoning plan itself is a spatial classification using eight color coded zones to provide multiple levels of protection and conservation ranging from a general use zone to a no-take preservation zone (Figure 9).

In the Baltic Sea region of northern Europe, the BALANCE project (Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning) for the Baltic Sea MSP initiative states that coherent ecological information is included as a basic layer along with human use and activities, and thus helps to minimize the impact on the environment (BALANCE, 2008). The BALANCE project recognizes that no marine zoning or spatial planning should be done on a "blue background" or with a simple navigational chart for guidance. Instead, bathymetry and biotope maps should be considered as the "aerial photographs of the sea".

1.10.4.1 Marine Spatial Planning in the Baltic

The Baltic Sea supports many human uses including commercial and leisure activities such as dredging, fisheries, tourism, coastal development placing increasing pressures on vulnerable marine habitats and resources. To resolve resource conflicts and address the lack of integrated management planning, an ecosystem-based approach to management, based on transnational spatial planning is being implemented. An EC funded project BALANCE (Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning) developed a pilot zoning plan for the densely populated coastal areas near Stockholm in Sweden. The area is important for navigational and recreational activities, near shore fishing, sand extraction activities and offshore wind-farms. The objective of the draft zoning map was primarily to document present uses and regulations in a spatially explicit format, including important shipping channels, restricted military zones and exclusive uses (e.g., wind farms) and nature conservation areas (Natura 2000 sites, national parks, seal sanctuaries etc.). Potential sites for future fish farms, offshore wind-farms and nature conservation areas were selected using the decision support tool Marxan and incorporated into the zoning plan. The selected sites were complementary to the already designated Natura 2000 SACs ("locked in" planning units), and together formed a representative sample of all the marine landscape types and important habitats. Sites that were found unsuitable for MPA designation, such as areas with a high level of threat or several conflicting interests, were avoided when equal conservation values could be found elsewhere. Combining classified maps with a decision support tool such as Marxan in the selection of candidate sites for conservation will increase the likelihood that the selected sites fulfill the whole range of predefined ecological and socio-economic targets in the most suitable locations while simultaneously securing a spatially efficient design of the network (Ekebom et al. 2008). The original zoning map was improved by including some of the Marxan suggestions to the map, leading to a more efficient and consistent zoning scheme (Figure 11). As a result, some *targeted management zone* areas were expanded by including new "selected planning unit" sites. Also, a potential fish spawning area, initially defined as a *targeted management zone*, was relocated to an area which also was selected as a potential candidate for protection by Marxan.

1.10.4.2 Multiple-Use Zoning in the Irish Sea, UK

In 1999, the Irish Sea Pilot was initiated to examine the feasibility of beginning systematic and coordinated marine spatial planning in the UK. The Irish Sea was selected as an appropriate place to investigate feasibility of MSP as it experiences a wide range of human uses that compete for space and exhibits a very complex mosaic of management activities, jurisdictions and legal mechanisms (Boyes et al. 2007). Uses included aggregate extraction, archaeology, dredging and dredge disposal, military activities, nature conservation, oil and gas exploration, ports and harbors, recreation, sea fisheries, shipping, submarine cables and pipelines, and wind farm developments.

Based on the jurisdictional area, a zoning map of the Irish Sea was proposed which defined zones where types of multiple-use, exclusive use or partial use policies applied. As a feasibility study, the zoning scheme was not intended to be an objective-based comprehensive multiple-use zoning scheme for this regional sea. The proposed zones (Figure 12) from the least to highest protection were: Zone 1. General use zone with two subzones: Zone 1A. Minimal Management (MM) and Zone 1B. Targeted Management (TM); Zone 2. Conservation Priority Zone (CPZ); Zone 3. Exclusion Zone (EZ) with sub-zones of Zone 3A. Limited Exclusion (LE) and Zone 3B. Significant Exclusion (SE) and Zone 4. Protected Zone (PZ) (defined in Boyes et al. 2007). The proposed zoning scheme was then tested against the Irish Sea Pilot's collated data on protected areas, seascapes and features (habitats and species) of national importance. The extent of existing protected areas designated in the UK under the Habitats and Species Directive (SACs) and Wild Birds Directive (SPAs) and Marine Nature Reserves (mostly nearshore sites) have been used to identify the location of important natural resources that are priorities for protection. The marine mapping project is a partnership initiative of the Joint Nature Conservation Committee (JNCC) to provide seascape maps for the UK Sea area (Connor *et al.* 2006), including all waters out to 200 nm. Seascapes included benthic and pelagic classes and the five rarest seascapes were used to evaluate the proposed zoning scheme. These included gas structures, photic reefs, aphotic reefs, sea mounds and deep-water channels. The study demonstrated that existing legal mechanisms on which the proposed zoning scheme was based do not provide adequate protection to important nature conservation features, particularly the rare seascapes within the Irish Sea. In fact, most nature conservation sites actually function as multi-use areas and the highest levels of protection occur in sites designated for sectoral use, but with stringent regulatory measures (e.g., Military areas). Using the seascape maps, the analysis highlighted visually and descriptively the extent to which the existing planning and governance framework is able, or unable, to meet the increasing pressures of activities and developments within the marine environment. The study recommended, a network of areas be designed that include representation of all seascape types, and in which the conservation requirements of the important features inform the decision making. This study highlighted the need for information-based delineation of conservation priority areas needs to be an integral component of marine spatial planning.

Marine Spatial Planning will be introduced nationally across UK waters under the Marine and Coastal Access Act which came into force in 2009. The Act (and similar legislation in Scotland) additionally requires the development of a network of marine protected areas. To support both of these initiatives, the marine maps prepared in 2006 for UKSeaMap (Connor et al. 2006) have been updated, using improved data sets and modeling techniques creating two maps covering all UK waters:

- A modeled map of EUNIS habitats (at EUNIS level 3 or 4), based on substratum, bathymetry, light penetration, wave and current energy, temperature data layers
- A seascapes map (*sensu stricto*), encompassing coastal features, offshore topographic features and plains.

1.10.4.3 Massachusetts Ocean Plan

The State of Massachusetts directed by The Massachusetts Oceans Act of 2008 has developed a comprehensive marine spatial management plan to serve as the basis for the protection and sustainable use of the State's ocean and coastal waters (Massachusetts Ocean Management Plan, 2009). The ocean plan addresses four goals: 1.) balance and protect the natural, social, cultural, historic, and economic interests of the marine ecosystem through integrated management; 2.) recognize and protect biodiversity, ecosystem health, and the interdependence of ecosystems; 3.) support wise use of marine resources, including renewable energy, sustainable uses, and infrastructure; and 4.) incorporate new knowledge as the basis for management that adapts over time to address changing social, technological, and environmental conditions (Massachusetts Ocean Management Plan, 2009). The ocean plan established three categories of management area: 1.) *Prohibited*, 2.) *Regional Energy*, and 3.) *Multi-Use*. The *Prohibited* Area is a specific area where most uses, activities and facilities are expressly prohibited by the Ocean Sanctuaries Act, as amended by the Oceans Act. *Renewable Energy* Areas are places specifically designated for commercial wind energy facilities, in recognition of the need to provide opportunity for renewable energy generation at a meaningful scale, but to do so with careful regard for potential environmental impacts. The *Multi-use* Area is the remainder (and majority) of the ocean planning area, where uses, activities and facilities allowed by the Ocean Sanctuaries Act are managed based on siting and performance standards (associated with specific mapped resources and uses) that direct development away from high value resources and concentrations of existing water-dependent uses.

To support plan development, best available spatial data were reviewed and compiled by working groups under six major themes including habitat; fisheries; transportation, navigation and infrastructure; sediment; recreation and cultural services and renewable energy. The data layers used are catalogued in MORIS, the Massachusetts Ocean Resource Information System (available at www.mass.gov/czm/mapping/index.htm). The working groups compiled a baseline assessment to inventory and spatially describe the physical characteristics, natural communities, and human interactions within the planning area. Special, sensitive or unique areas (SSU) were delineated based on endangered species of cetacean and seabirds, areas of topographically complex seafloor, important areas for commercial and recreational fisheries, intertidal flats and seagrass beds. For large cetaceans, core habitat was classified for North Atlantic right whale, fin whale and humpback whale. Areas of core whale habitat were represented as concentrations in abundance based on sightings datasets compiled and analyzed by NOAA's National Centers for Coastal Ocean Science report for the years 1970-2005 in the southern Gulf of Maine (NCCOS 2006, Pittman and Costa 2010). Bias from uneven allocation of survey effort (temporally or spatially) was corrected using a sighting-per-unit-effort (SPUE) algorithm. SPUE values for each 5 x 5 minute grid cell were then interpolated spatially and classified into five relative abundance classes, and the top two classes were extracted by the Massachusetts Ocean Management Plan team to represent "core" habitat for each of these three species. The core areas where then used to determine potential conflicts (via spatial overlap) with other uses such as pipelines, cables, renewable energy, sand and gravel extraction, boating and shipping and recreational and commercial fisheries.

1.10.5 ECOSYSTEM-BASED FISHERIES MANAGEMENT

One of the foundational concepts underlying the ecosystem approach to fisheries management is that different geographic areas have different biological production capacities and these are interlinked with the spatial heterogeneity of ecological patterns and processes including human activity. This requires management strategies that can incorporate the ecological dynamics in a spatially explicit framework. One of the first steps following the establishment of ecosystem-based management (EBM) goals is to characterize the biophysical habitat features of the management area (Cogan et al. 2009). In fisheries management, habitat mapping is increasingly utilized to inform management with regard to assessing the relative sensitivity of seabed features to the impacts of fishing (e.g., bottom trawling), identifying, mapping and modeling Essential Fish Habitat (EFH) and species distributions. In the United States, the importance of classified maps in sustainable fisheries management was emphasized by the implementation of the National Fish Habitat Action Plan (Association of Fish and Wildlife Agencies, 2006) which requested habitat mapping and classification as a primary priority in its research plan. In addition, the classification of complex spatio-temporal behavioral patterns in fishing activity are required to support a wide range of spatial management activities including impact assessment, fleet management, enforcement, spatial characterizations and monitoring that are crucial for implementation of ecosystem-based fisheries management, MPA site selection and marine spatial planning.

1.10.5.1 Mapping Essential Fish Habitat (EFH)

In 1996, the U.S. Magnuson-Stevens Act (reauthorized 2006) mandated the identification of essential fish habitat (EFH) for ‘quota’ species. The U.S. Congress defined EFH as ‘those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity’, a definition that includes the physical, chemical and biological properties of marine areas and the associated sediment and biological assemblages that sustain fish populations throughout their full life cycle (DOC, 1997). Habitat Areas of Particular Concern (HAPC) are discrete subsets of EFH that provide extremely important ecological functions or are especially vulnerable to degradation and HAPCs can be designated based on: 1) importance of the ecological function provided by the habitat; 2) extent to which the habitat is sensitive to human-induced environmental degradation; 3) whether, and to what extent, development activities are, or will be, stressing the habitat type, and 4) rarity of the habitat type. The HAPC and EFH designations are classes of habitat required to help prioritize conservation efforts and more effectively target management activities. The identification and mapping of ecologically meaningful EFH and HAPC provides important spatial information to support ecosystem-based fisheries management and marine spatial planning. Fisheries Management Councils are mandated to include maps showing the geographical location and extent of EFH and HAPC in management plans and identify the different habitat types designated as EFH. Most mapping data is unlikely to be able to fully capture the spatial complexity of EFH for most species, particularly for the highly mobile species typical of the commercial fisheries. The conventional approach has been to determine habitat associations and then to assign equal value to all such habitat types in the region. While this implements a precautionary approach, it does not, however, represent the actual faunal distribution since much of the functionally important spatial heterogeneity is rarely incorporated in broad scale mapping used to delineate EFH. Recent work for fish associated with coral reef ecosystems has shown that considerable variability exists within an individual habitat class (Harborne et al. 2008). Another approach to mapping EFH involves quantitative spatial predictive modeling using the statistical relationship between species and a suite of environmental variables to extrapolate distributions across space. Benthic habitat data and suitability indices of relative abundance across environmental gradients are commonly used within GIS in order to develop Habitat Suitability Index (HSI) models (e.g., Rubec et al., 1998a,b; Brown et al., 2000). HSI models may help predict optimal habitat and abundance zones for various species, therefore aiding managers in designating EFH. Recent advances in the field of predictive modeling including application of machine-learning algorithms, combined with an increase in mapped environmental data and GIS has facilitated a boom in the development of accurate spatial predictions that offer great utility in filing data gaps and providing fundamental ecological information to support management (Elith et al. 2006, Leathwick et al. 2008). Although spatial predictive techniques are more frequently applied to terrestrial ecosystems, examples have recently emerged for marine ecosystems primarily focused on species distributions (Valavanis et al. 2008, Maxwell et al. 2009, Pittman et al. 2009) and biodiversity (Pittman et al. 2007a, Purkis et al. 2008), although they can also equally be used to predict the distribution of abiotic variables and biological habitat types.

1.10.5.2 Mapping and Classifying Fishing Effort in the UK

Fishing is widely considered as one of the highest impact industries on the UK marine environment in terms of its magnitude and spatial extent (Jennings et al. 2001, Dinmore et al., 2003; Eastwood et al., 2007). In addition to the removal of target-species biomass, ecosystem effects of fishing may include bycatch and discarding of nontarget fish species, bycatch of marine mammals and seabirds, and particularly with bottom trawling, mechanical disturbance and damage to benthic communities. Broad scale assessment of fishing impacts requires a detailed understanding of the spatial and temporal variability in fishing pressure across multiple spatial scales (Jennings and Cotter 1999, Stelzenmüller et al. 2008, Pederson et al 2009) (Figure 13). Spatial data representing fishing pressure and impacts play a critical role when objectives are to minimizing conflict with competing sectors and reducing the overall economic cost to fishers of any MPA network configuration (Lynch, 2006, Leathwick et al. 2008).

Rarely are the spatial patterns of fishing pressure quantitatively mapped and analyzed in relation to marine benthic habitats, yet the newly available marine classifications now facilitate such an approach. For example, Stelzenmüller et al. (2008) calculated the proportion of each seascape class fished, using a classified seascape map together with fishing vessel locations over time acquired with a long-term vessel monitoring system (VMS). The results revealed that seascapes with coarse or mixed sediments and weak or moderate tide stress were heavily fished. Seascapes experienced different intensities of fishing pressure depending on their spatial location in UK offshore waters and the regional heterogeneity of seascape types (Figure 14). Descriptions of the spatial distribution of fishing pressures can also be linked to the sensitivity of the benthic environments. The patchiness of fishing activity, and the consistency with which fishing occurred in the same regions year on year provides valuable information for the selection of the spatial extent of marine planning units.

1.10.5.3 Examining Conflicts between Fishing and Conservation in the German North Sea

In May 2004, Germany was the first EU Member State to nominate a comprehensive set of 10 Natura 2000 marine sites to the European Commission, covering 31.5% of its offshore EEZs in the Baltic and North Sea (Kraus et al. 2006) (Figure 15). The principal objective of sites selected as part of Natura 2000 is to protect biodiversity and achieve or maintain a 'favourable conservation status' of habitats and species named in the EU Birds and Habitats directives and to contribute to the implementation of the 1992 UN Convention on Biological Diversity. Several of the conservation areas overlapped with commercial fishing interests. To examine the extent of potential conflicts between fishing activities and nature conservation objectives, Pedersen et al. (2008) integrated habitat classifications, vessel monitoring data classified by gear type and existing MPA boundaries to support development of fishery-management plans for each Natura 2000 (Figure 15). In the German EEZ, only two benthic habitat types, sandbanks and reefs, have been relevant to the designation process of Natura 2000 marine sites. Sandbanks and reefs perform several important ecological functions, such as offering protection for rare and threatened species, supporting unique communities and providing breeding, nursery, feeding, and resting habitats for marine organism (listed in Pedersen et al. 2008). In addition to benthic habitat information, fishers behavior was classified and mapped using data from a vessel monitoring system (VMS). Within European seas, fishing vessels >15 m length are required to operate a satellite-based VMS providing detailed information on where fishing vessels operate (every 1-2 hours) and effort and gear used that can then be linked to reported catch data. Effort was classified by boat and gear type for registered vessels from Belgium, Denmark, Estonia, Germany, Latvia, the Netherlands, Poland, Sweden, and the United Kingdom. Trawlers with trawling speeds of 5-7 knots (engine power > 221 kW) were classified as large beam trawlers, mostly targeting sole and plaice. Small beam trawlers (≤ 221 kW) known as "Eurocutters", mainly targeting shrimp, but also sole and plaice in offshore areas. A third class of vessel were the extra-heavy beam trawlers, documented as vessels that operated on stony ground with heavy gear and an average trawling speed of 4-5 knots. Spatial effort is determined largely by gear type and therefore the intensity of impacts to Natura 2000 sites and associated habitat types are affected differently by different fishing techniques. For example, integrating the habitat map with VMS data revealed that large beam trawlers avoid operating in reef areas, small beam trawlers utilize all bottom types (Figure 15), while reefs are targeted by beam trawlers with heavy gear along with potters and whelkers. The fine-scale, spatio-temporal distribution data for the international fishing effort together with spatial information on the distribution of conservation features and MPA boundaries provided a spatially explicit understanding of potential conflicts between the fishery industry and conservation. Such information offered a cost-effective and fisheries independent approach to assess threats and design measures to reduce any negative impacts that could reduce the efficacy of conservation strategies.

1.10.6 OPTIMIZING ENVIRONMENTAL MONITORING

Classifications and associated thematic maps provide a spatial framework with which to collect, organize, analyze and report on changing environmental conditions. There are several practical difficulties in comparing variables such as biodiversity across different habitats and species in ecosystems, and therefore many ecological studies are confined to a limited group of species, in a restricted habitat, using a single sampling method. Such narrow approaches are not satisfactory for environmental management, particularly where there is a need to monitor and assess conditions across a broad heterogeneous region. Identification of sampling strata can improve the design and interpretation of surveys and experimental studies. A coastal classification in the form of a map facilitates sampling across multiple classes, regardless of whether classes are habitat types, socio-economic categories or management strata. One of the greatest benefits of using a consistent classification is that the results from surveys of one or more sites can be directly compared with other studies. A classification can thus be an important standard in environmental assessment, for instance, where an evaluation of the nature conservation status or long-term monitoring of sites is required.

The main goal of sample surveys is to obtain accurate, high-precision estimates of population and community metrics at a minimum of cost. Maps of environmental covariates, such as benthic habitat, at the appropriate spatial scales and spatial extent can be used to effectively divide the sampled population into strata. Stratified and stratified-random designs can use marine habitat classifications to optimize sampling and to target priority areas and design comparative monitoring protocols. A stratified-random design may divide the survey domain into regions of relatively homogenous variance called strata and then allocate sampling more intensively in the highly-variable to achieve better estimates than a simple random design using the same sample size. Better estimates of a target variable derived from stratified sampling can improve model results considerably when survey data are applied in species distribution modeling (Hirzel and Guisan 2002).

GIS-based tools for allocating samples can provide a statistically robust, ecologically meaningful and cost-effective approach to designing a sampling strategy. For example, NOAA’s Sampling Design Tool for ArcGIS (Menza and Finnen 2007) provides a user-friendly process to develop sampling strategies with three ways to generate point samples: simple random, stratified random and multi-stage random (Figure 16). Ultimately, the choice of which method to use depends on survey objectives and the types of data available.

1.10.7 SPATIAL CHANGE ANALYSIS

The analysis of spatial and thematic changes based on a comparison of classified maps over time is a logical and efficient part of ecosystem-based management. A wide range of remote sensing technologies are applied to quantify environmental change, with many applications using satellite data due to a high frequency of repetitive coverage and consistency in image characteristics and processing techniques. Coastal change detection studies have involved the use of time series data from a wide range of sensors including Advanced Very High Resolution Radiometer (AVHRR), Landsat Thematic Mapper (TM), Multispectral Scanner (MSS), SPOT data, aerial photography and airborne laser altimetry. At finer spatial scales, subaquatic change detection has also been performed using underwater photography and video mosaicking. In addition to remote sensing techniques, a suite of pattern metrics and spatial statistics commonly applied in landscape ecology provide techniques to quantify the change in landscape or seascape composition and spatial configuration. Whatever the technique used for image acquisition, it is important that a standardized classification schema is applied in comparative analyses to maintain consistency in the types of classes discriminated.

1.10.7.1 NOAA C-CAP Change Detection

NOAA's CoastWatch Change Analysis Program (C-CAP) uses digital remote sensing data from LandsatTM and aerial photography together with georeferenced *in situ* measurements to monitor change in coastal intertidal areas, wetlands, and adjacent uplands at five year intervals. C-CAP has developed a relatively coarse thematic resolution hierarchical classification scheme with 15 upland classes and 14 wetland classes, primarily to include key classes that can be accurately discriminated from multispectral satellite data (Dobson et al. 1995; http://www.csc.noaa.gov/crs/lca/tech_cls.html). The coastal classification system is a component of the National Land Cover Database (NLCD) and was designed to be compatible with the U.S. Geological Survey "Land Use and Land Cover Classification for use with remote sensing data"; 2) the U.S. Fish and Wildlife Service "Classification of Wetlands and Deepwater Habitats of the United States and 3) the U.S. Environmental Protection Agency Environmental Monitoring and Assessment Program (EMAP) classification system. In addition to depicting the land cover status for a given point in time, comparing maps from various years documents how land cover changes over time. With these maps users can examine how the land cover has changed (e.g., from forests to shrubs) and the amount of change can be easily quantified, as well as the change in spatial patterning (e.g., fragmentation) of individual land cover classes or entire landscape units. This information can be used to better understand the cumulative effects of environmental change, including the impacts of urban development and agriculture on the losses, gains and quality of wildlife habitat and indicators that link land cover change with ecosystem health can be developed and evaluated.

1.10.7.2 Tracking Coastal Habitat Change in New Jersey, USA

During the last 50 years, development has increased dramatically along Barnegat Bay, a shallow, lagoon-type estuary located on the coast of central New Jersey. The bay and its 42 miles of shoreline offer many recreational activities such as boating, fishing, and swimming. In addition, the estuary is ecologically important as a breeding ground for oysters, clams, blue crabs, and many other commercially important fish. Increased nutrient loading due to surface water runoff in the watershed has occurred as a consequence of dramatic landuse alteration and has impacted the coastal ecosystem structure and function (Kennish et al. 2007). Change detection applied to a satellite derived land cover classification from 1972 and 1995 (Figure 17) and from 1995 to 2006 quantified the recent rapid conversion of forested and wetland habitats to urban land cover 'developed land', with riparian zones altered by an average of 16% (min 4% and max. 50%) by 2006 (Figure 17) (Lathrop and Bognar 2001). Landsat Thematic Mapper data were classified using an adaptation of the NOAA C-CAP protocol (Dobson et al. 1995). The classification incorporated 38 different land cover classes which were integrated with U.S. Fish and Wildlife Service National Wetland Inventory maps, submerged aquatic vegetation (SAV) maps, and bathymetry derived from the NOAA nautical chart of Barnegat Bay to produce a seamless land-sea habitat map. The resulting comprehensive synthesis map combined upland, wetland, and the benthic habitats of the Barnegat Bay watershed (Lathrop et al. 1999).

1.10.7.3 Tracking Coastal Habitat Change in Louisiana, USA

Change detection for the Louisiana coast using Landsat TM data was conducted for the Louisiana Coastal Area Comprehensive Coastwide Ecosystem Restoration Study (Barras et al. 2003). Each Landsat TM scene covered approximately 185 km by 180 km and had a minimum ground resolution of 30 m. Each classified pixel in the source land and water data sets were compared on a pixel-by-pixel basis to identify the spatial trend in the changes. A change pixel was classified as: (1) land to land = no change, (2) water to water = no change, (3) land to water = change (loss), or (4) water to land = change (gain) (Barras et al. 2003). The final classification showed a net loss of wetland and significant shoreline erosion between 1990 and 2000. Figure 18 shows that the Gulf of Mexico shoreline experienced significant loss (150 to 200 m) south of Rockefeller Wildlife Refuge due to erosion, but some gains were detected west of Freshwater Bayou. Analysis of a Landsat TM scene acquired on October 16, 2002, after the central Louisiana coast was struck by Hurricane Lili on October 3, 2002, revealed creation of over 256.6 ha of new ponds in a formerly dense healthy marsh that had shown no significant loss since the late 1970s (Barras et al. 2003).

1.10.7.4 Mangrove Change Detection in Southeast Asia

Mangrove forests are a unique tropical and subtropical plant community growing at the interface between land and sea. Mangrove forests and their associated ecosystems are an important natural resource for people (Barbier et al. 2008) and provide critical habitat for a wide diversity of organisms both above and below the water (Nagelkerken et al. 2008). The wide range of goods and services provided by mangrove forests has been valued at USD 200,000-900,000 ha^{-1} annually (Wells et al. 2006). Nevertheless, in the two decades between 1980 and 2000 an estimated 35% of the world’s mangroves were lost due to human and non-human processes. The rates of loss continue to rise more rapidly in developing countries, where the majority (>90%) of the world’s mangroves are located (Duke et al. 2007). The primary causes of loss are through urbanization, conversion to agriculture and mariculture, human modifications to coastal hydrology, pollution, landfill, salt production and direct use of trees for timber, fuel and medicines (Valiela et al. 2001, Walters et al. 2008). Mangroves have also been destroyed and degraded by hurricanes and tsunamis (Alongi 2008, Giri et al. 2008) and now sea-level rise has been identified as a substantial cause of recent and predicted future reductions in the area and health of mangroves (Gilman et al. 2008).

Classified remote sensing imagery such as generated from spectral interpretation of Landsat TM data provides a time series appropriate for a quantitative synoptic change detection to assess the distribution of mangroves and to document quantitatively how the spatial patterning of mangroves (losses, gains, contiguity/fragmentation) have changed. Combining map products with spatial analyses and data from investigation of the causal mechanisms that have led to changes and characterization of areas that have experienced most change will provide valuable information to support resource management decision-making, policy formulation and public education. Giri et al. (2008) interpreted a Landsat time series to estimate the extent of tsunami-affected mangrove forests in SE Asia and to determine the rates and causes of deforestation from 1975 to 2005. Using a post classification change detection approach for coastal areas of Indonesia, Malaysia, Thailand, Burma (Myanmar), Bangladesh, India and Sri Lanka, the analyses determined that the region had lost 12% of its mangrove forests from 1975 to 2005 (Figure 19). Rates and causes of deforestation varied both spatially and temporally. Annual deforestation was highest in Burma (*c*. 1%) and lowest in Sri Lanka (0.1%). In contrast, mangrove forests in India and Bangladesh remained unchanged or gained a small percentage. Change detection revealed that the major causes of deforestation were agricultural expansion (81%), aquaculture (12%) and urban development (2%) (Figure 19). This type of application can also be used to assess the role of mangroves in protecting the coastline from tsunamis and to identify possible areas for conservation, restoration and rehabilitation.

1.10.8 ENVIRONMENTAL RISK ASSESSMENT AND HUMAN IMPACTS

Knowledge of the distribution of habitats, communities, and species and how they respond to the effects of human and non-human processes is fundamental to effective management of the marine environment. Spatially explicit risk assessments that link information on the sensitivity of the environment to the occurrence of a pressure are fundamental to the implementation of spatial management (Hope, 2006). In fact, the spatial distribution of habitats and the spatial distribution of human activities are in many cases interrelated. Many directives and strategies such as the EC Water Framework Directive and the EC Marine Strategy Framework Directive state that efficient management must identify anthropogenic pressures on the marine environment and assess their potential effects. Methods for assessing habitat sensitivity to human impacts are now urgently needed to measure impact sustainability, develop spatial management plans, and support sound environmental impact assessments. These procedures should be quantitative, validated, repeatable, and applicable at multiple spatial scales relevant to both the impact and management (Hiddink et al., 2007, Fraschetti et al. 2008).

Marine species and habitats vary in their response to stressors (both anthropogenic and non-anthropogenic) and delineating and classifying areas or habitat classes based on their relative sensitivity and vulnerability to stressors is a valuable tool in managing and predicting disturbances to the marine environment. Zacharias and Gregr (2005) define “sensitivity” as the degree to which marine features respond to stresses, which are considered as deviations of environmental conditions beyond the expected range, and “vulnerability” as the probability that a feature will be exposed to a stress to which it is sensitive. Another related term is “recoverability”, defined as the ability of a habitat, community or species to return to a state close to that which existed before the activity or event caused change.

With appropriate spatial information these definitions can be represented spatially as classes within a thematic map. The identification and classification of areas based on the sensitivity of species and habitats for use in management planning requires access to extensive biophysical and socio-economic data usually for both land and sea together with interpretation of data in a comprehensive, consistent and structured way (Tyler-Walters and Jackson 1999, Hiscock and Tyler-Walters 2006). Thus, the process of classifying risk is continually evolving to incorporate best available information on the biological responses to disturbance. In Europe, work is underway to determine the most suitable indicator species to represent community level sensitivity to specific types of human activities occurring in specific marine biotopes (Tyler-Walters et al. 2009). Sensitivity analysis has been implemented with various qualitative, semi-quantitative and quantitative approaches. Here we show examples of a selection of both qualitative and quantitative models that also integrate expert opinion in the development of sensitivity maps.

1.10.8.1 Environmental Sensitivity Index Mapping

NOAA’s Environmental Sensitivity Index (ESI) Mapping, first developed in the 1970’s is an inter-agency map product coordinated by the Office of Response and Restoration that has become the most widely used approach to mapping environmental sensitivity in the United

States (Gundlach and Hayes 1978). The approach systematically compiles best-available information on: 1.) Shoreline type (substrate, grain size, tidal elevation, origin); 2.) Exposure to wave and tidal energy; 3.) Biological productivity and sensitivity; 4.) Human uses; and 5.) Ease of cleanup in the event of a chemical spill. The classified maps are provided as atlases for each state and jurisdiction in hard copy and digital form to be used by federal and state agencies as a starting point for prevention, planning and response actions and are considered to provide the essential information needed for effective site-specific planning, particularly in the event of a chemical spill (NOAA 1996 – ESI guidelines). Electronic versions of the ESI maps and associated descriptive information are utilized by the U.S. Coast Guard as a first phase in assessing the course of action relative to priority areas when an oil spill occurs.

Some of the first ESI maps were produced for The State of Alabama in 1996 and then updated in 2007 (Figure 20). The maps incorporated dynamic characteristics of the coastal system in the prediction of the behavior and persistence of oil since the intensity of energy expended upon a shoreline by wave action, tidal currents, and river currents directly affect the persistence of stranded oil in addition to substrate type and grain size. The potential for biological injury and ease of cleanup of spilled oil are also important factors in the ESI ranking. In general, areas exposed to high levels of physical energy, such as wave action and tidal currents, and low biological activity rank low on the scale, whereas sheltered areas with associated high biological activity have the highest ranking.

The “shoreline,” representing the boundary between land and water, is color-coded with the ESI classification. The distribution of biological resources is shown using many different conventions (Figure 20). The major convention is an icon associated with a point, line, or polygon that shows the species’ areal distribution. The icon’s reference number corresponds to a data table with details on species and life history. Biological resource data are organized into six major groups, each with a reference color: birds (green), mammals (brown), fish (blue), shellfish (orange), reptiles (red), and rare/endangered plants and special habitats (purple). Most of the human-use resources are point features indicated by a black-and-white icon. Managed lands, such as refuges and sanctuaries, have their boundaries shown as a dot-dash line with an icon and name placed inside. Where the feature is a known point location (e.g., a drinking water intake, boat ramp, marina) the exact location is shown as a small black dot and a line is drawn from it to the icon. Activities such as commercial and recreational fishing and areas such as recreational beaches are also indicated by an icon placed in the general area without any lines to points or polygons since the boundaries are not readily defined. Some features, like historic and archaeological sites, are location-sensitive: the agency managing the resource believes the exact location should not be shown in order to protect the site. In these cases, the icon is placed in the general area of the resource, but the exact location is not shown (Text adapted from Sample ESI Map 21 http://response.restoration.noaa.gov/).

1.10.8.2 Marine Sensitivity Mapping in the UK

In the UK, the European Union Nature Information System (EUNIS) (Davies and Moss 2004) based on a modified seabed biotope classification first developed for the UK has been integrated with a database on species and biotope sensitivities to human activity using a GIS to provide sensitivity maps (Hiscock and Tyler-Walters 2006). This assessment developed by the Marine Life Information Network (MarLIN) estimates the sensitivity of a marine biotope, based on the response of some component species to disturbance, thus requiring relatively detailed information at the species level. It was first commissioned in 1999 to support implementation of the EC Habitats Directive and the UK Biodiversity Action Plan in the seas around England and Scotland. The MarLIN definition recognizes that sensitivity is dependent on the intolerance of a species or habitat to damage from an external factor and the time taken for its subsequent recovery. For example, a very sensitive species or habitat is one that is very adversely affected by an external factor arising from human activities or natural events (killed/destroyed, 'high' intolerance) and is expected to recover over a very long period of time, i.e. >10 or up to 25 years ('low'; recoverability) (Figure 21). MarLIN have developed standard benchmarks to enable comparative assessment of sensitivity relative to a specified change in the environment based on best available information from scientific studies (http://www.marlin.ac.uk/sensitivityrationale.php). Where there is insufficient information to assess the recoverability of a habitat or species the ‘precautionary principle’ is adopted and the recovery will be assumed to take a very long time i.e. ‘low’ recoverability in the derivation of a sensitivity rank.

There are a number of other approaches to sensitivity assessment, such as that developed for fishing activities by Hall et al. (2008). Stelzenmüller et al. (2010) developed a marine spatial risk assessment framework for the UK continental shelf assessing the vulnerability of 11 fish and shellfish species to aggregate extraction. The authors calculated a sensitivity index (SI) using species life-history characteristics and modeled the spatial distributions of species using geostatistical techniques applied to long-term monitoring data. Sensitivity maps were produced by merging sensitivity indices and predicted species distributions which were then overlayed with the occurrence of aggregate extraction activity in inshore waters, including sediment plume estimations, to describe species vulnerability to dredging (Figure 22).

1.10.8.3 USGS Coastal Hazards Maps

The rapidly growing population of coastal residents and their demand for reliable information regarding the vulnerability of coastal regions to storm impacts have created a need for classifying coastal lands and evaluating storm hazard vulnerability. Government officials and resource managers responsible for dealing with natural hazards also need accurate assessments of potential storm impacts in order to make informed decisions before, during, and after major storm events. Mitigating damage to natural coastal resources and economic development depend on integrating models of storm parameters, hazard vulnerability, and expected coastal responses. Thus, storm hazard vulnerability assessments constitute one of the fundamental components of forecasting storm impacts. The primary purpose of the USGS National Assessment of Coastal Change Project is to provide accurate representations of pre-storm ground conditions for areas that are designated high-priority because they have dense populations or valuable resources that are at risk from storm waves. Another purpose of the project is to develop a geomorphic (land feature) coastal classification that, with only minor modification, can be applied to most coastal regions in the United States. A coastal classification map (Figure 23) describing local geomorphic features is the first step toward determining the hazard vulnerability of an area. The National Assessment of Coastal Change Project's Coastal Classification Maps present ground conditions such as beach width, dune elevations, overwash potential, and density of development. In order to complete a hazard vulnerability assessment, that information must be integrated with other information, such as prior storm impacts and beach stability. The coastal classification maps provide much of the basic information for such an assessment and represent a critical component of a storm-impact forecasting capability.

1.10.8.4 Classifying and Mapping Human Impacts in Hawaii

Conventional approaches to evaluating the distribution and ecological impacts of human activities to the marine environment have used expert opinion to evaluate or rank impacts, for example, the Reefs at Risk (Bryant et al. 1998) used expert opinion to classify the world's coral reefs into low, medium and high threat categories. Although widely used, these techniques are sometimes considered lacking in objectivity due to bias in perceived threats and are usually not spatially articulated in a consistent framework. More recently, Halpern et al. (2007, 2008) developed an analytical grid-based framework for calculating and mapping the cumulative impact of human activities at a spatial resolution of 1 km^2 based on individually weighted stressor layers. The cumulative impact mapping framework has great versatility and can be conducted at a range of scales and is now being applied at finer resolution to map smaller geographical areas around the world. A cumulative impacts approach was applied and locally refined for the Papahãnaumokuãkea Marine National Monument in Hawaii to focus more on locally relevant threats including marine debris, ship strike risk, invasive species, fishing and several climate change parameters (Selkoe et al. 2009). These data were combined with habitat maps and expert judgment on the vulnerability of different habitat types in the Monument to estimate spatial patterns of current cumulative impact at 1 ha (0.01 km^2) resolution (Figure 24). Halpern et al. (2007) developed a suite of five criteria related to vulnerability to make basic characterizations of how activities impact ecosystems or ecozones differently: (1) the spatial scale at which the threat acts, (2) the frequency with which it acts, (3) the number of trophic levels impacted, (4) the resistance of the ecosystem to impact, and (5) the recovery time needed to return to an un-impacted state. Quantitative values for the five criteria were estimated from the mean of survey responses by 25 scientific experts on the NWHI and combined into a single ‘‘vulnerability score’’ for every ecozone-threat combination. Ecozones were classified from the existing digital benthic habitat maps created by the Biogeography Branch of the U.S. National Oceanic and Atmospheric Administration (http://ccma.nos.noaa.gov/ecosystems/coralreef/nwhi_mapping.html).

In contrast to the global impacts model, the local model revealed that cumulative impact was greater for shallow reef areas than deeper offshore areas, which corroborated expert opinion. One specific location experienced 13 of the total 14 threats used in the model. Ocean temperature variation associated with disease outbreaks was found to have the highest predicted impact overall, however, ship traffic was identified as a high threat that could be more easily mitigated via management action. Managers can make use of these maps to prioritize management actions, guide permitting decisions and to design targeted monitoring programs.

1.10.8.5 Classifying and Mapping Coastal Vulnerability to Climate Change in Australia

The Department of Climate Change and the Department of Environment, Water, Heritage and the Arts (DEWHA) are working with the states and territories through the Intergovernmental Coastal Advisory Group to assess Australia’s coastal vulnerability to climate change, including impacts on coastal habitats and infrastructure. The Coastal Vulnerability Assessment Project (Sharples 2009) will provide fundamental datasets to support decision makers in identifying those areas in Australia’s coastal zone where potential climate change impacts may be rated as high, medium and low. This assessment is based on data from a nationally consistent geomorphic map of the entire Australian shoreline in a GIS-based segmented line format (Figure 25). Each line segment contains multiple attribute fields that describe important aspects of the shoreline geomorphology and potential impacts of climate change and sea level rise, including shoreline erosion. This data format has been termed a ‘Smartline’ (Sharples 2006). The Smartline maps are also linked to a comprehensive database called ABSAMP (Australian Beach Safety & Management Program) which contains information on every beach in Australia.

1.10.9 CLASSIFYING WATER QUALITY

1.10.9.1 Australian Environmental Condition Assessment Framework

The National Land and Water Resources Audit of the Department of Water is developing an assessment of the condition of Australian estuaries through an estuarine condition statement that summarizes all available information and a report card that identifies pressures, vulnerabilities and management objectives. A national condition assessment framework provides a practical and logical structure for regional and national reporting, directing research, enhancing communication, facilitating coordination between jurisdictions and guiding identification of indicators (Arundel and Mount 2007). The condition classifications of 971 estuaries (i.e., near-pristine, largely unmodified, modified and extensively modified) relied mainly on qualitative information and expert opinion on a range of criteria (Heap et al. 2001). Subsequent studies have demonstrated systematic changes in geomorphic indicators with diminishing condition status (i.e. from near-pristine, through modified to severely modified) pointing to changes in the surface area of sediment facies (habitats) between modified and pristine estuaries (Heap et al., 2004) and larger sediment loads and higher levels of maturity in the more modified systems (Radke et al., 2006). This was evident in larger areas of tidal sand banks, intertidal flats and mangroves in tide-dominated estuaries, and larger intertidal flats in wave-dominated systems. Metal concentrations also have been found to continue to increase above background concentrations in correspondence with diminishing condition status in the NLWRA framework (Birch and Olmos, 2008; Olmos and Birch, 2008).

OzCoasts online database provides classified maps to assist in delivering national level assessments on the broad ecological integrity of estuaries based on the National Monitoring and Evaluation Framework (Figure 26). The Report Card Reporting tool of the national Estuary Coastal and Marine (ECM) indicator protocols initiative allows users to view aggregated report scores and trends on an annual basis at a range of different spatial scales including national, state/territory, regional and bioregional. The online map interface shows the reporting regions (estuaries) as dots, with a color coding that matches that of the condition assessment in an accompanying pie chart.

1.10.9.2 European Community Marine Strategy Framework Directive

In Europe, the EC Marine Strategy Framework Directive, adopted in 2008, requires EU Member States to achieve 'Good Environmental Status' in all their marine waters out to 200 nm (and on extended Continental Shelf areas up to 350 nm, where claimed under UNCLOS), by 2020. To develop biodiversity assessments suitable for such large sea areas, new integrated assessment techniques have been trialled for the first time in the UK and by OSPAR (Connor 2009). For UK waters, the extent of impact on habitats from a set of 22 pressures was assessed within 11 regions, leading to an overall assessment of status of each habitat in each region. Due to the large sea areas being assessed, modeled EUNIS habitat maps (from MESH; www.seachMESH.net) were aggregated into six broad habitat types and spatial data on the distribution of human activities and their pressures were compiled. As monitoring data on impacts is spatially restricted (mostly coastal), the trial relied on the expert judgment of about 40 scientists to follow a systematic methodology for making the assessments (Connor 2009). Figure 27 illustrates the broad habitat categories assessed, and the accompanying table (Figure 28) provides a summary of the impacts by pressure for each of the 11 regions (regional seas). The results of the UK assessment contribute to the UK's second state of the seas report (Charting Progress 2). Similarly, the results of the OSPAR assessment are published in the OSPAR Quality Status Report 2010.

1.10.10 DESIGN OF RESTORATION STRATEGIES

Deciding which restoration project to undertake can often be a daunting task for resource managers. The decision process, however, can be simplified into three steps: 1.) assessment and characterization of the study area; 2.) development of site selection criteria, and 3.) prioritization of potential sites. A wide range of mapped information can be used at all stages including monitoring and assessment of restoration effectiveness.

Classifications can support restoration activities through site selection (i.e., finding the optimal or most suitable sites for restoration) based on biophysical features and socioeconomic factors. In addition, application of landscape ecology concepts and tools can support both site selection and design of the restoration activity. Consideration of the site context or surroundings can be achieved cost-effectively using thematic map products to describe the elements of the landscape, such as the type and impact of land uses adjacent to the site and if historical maps or a time series is available then an understanding of the historical ecology of the site can be immensely useful. From a design point of view, landscape ecology can provide insight into important ecological relationships at scales relevant to restoration decision making. For example, if restoring mangroves as fish habitat then an optimal location for restoration may include mangroves that are in close proximity to seagrasses that combine to offer complementary and supplementary resources thus capable of supporting elevated fish diversity and abundance in the region (Dunning et al. 1992, Pittman et al. 2007b). Furthermore, restoration site planning that increases connectivity between degraded fragmented habitats may result in greater benefits in terms of the persistence and resiliency of restored habitats. Given the uncertainty of climate change effects, greater attention on ecological processes in site selection will become increasingly important.

The best methods appear to be those that rely on a scientific understanding of the requirements (e.g., elevation, hydrology) of species and communities, and what must be done to a site to make these conditions correct for the intended purpose.

1.10.10.1 Targeting Wetlands for Restoration in North Carolina, USA

Approximately 50 percent of the original wetlands of coastal North Carolina have been drained and converted primarily to agriculture and other land uses (Hefner and Brown, 1985, Dahl and Johnson 1991). Continued alteration of wetlands typically results in compensatory mitigation that usually involves the restoration of former wetlands, creation of new wetlands, enhancement of certain functions in degraded wetlands, or preservation of highly functional wetlands and rare or endangered wetland types. Success rates in mitigatory restoration are relatively low due largely to inappropriate site selection. Sites have been guided by convenience, cost, and time rather than by the consideration of wetland functions and watershed conditions and this can result in the selection of a mitigation site lacking the potential to support the wetland functions that it is designed to replace.

To improve decision making in site selection, the North Carolina Department of Environment and Natural Resources, Division of Coastal Management (DCM) developed a method for identifying and ranking potential restoration and enhancement sites using spatial data on wetland type, soils, hydrography, land use, and land cover. (http://dcm2.enr.state.nc.us/Wetlands/wetlands.htm) The watershed-based data is used by restoration project teams as a planning tool to assess potential site conditions and to evaluate the potential for success. The four GIS-based mapping procedures developed by North Carolina are: 1.) wetland type mapping, 2.) wetland functional assessment mapping, 3.) potential wetland restoration and enhancement mapping, and 4.) the restoration functional assessment, which estimates the levels and types of functions a wetland restoration site could perform if restored. These procedures are based on function, therefore they help to locate potential restoration sites that replace a wetland's function in its watershed, not just lost wetland area. The identification and mapping of potential wetland restoration and enhancement sites begins with the identification of areas with hydric soils that were once wetlands and are potential restoration sites and secondly areas that have been degraded or converted to a different wetland type that are classified as enhancement sites (Williams 2002).

Sites are first classified into one of nine wetland disturbance classes according to a set of criteria based on site conditions and disturbance types. Based on the soil type, each site is then classified as one of six restoration types that refer to the wetland type that could be restored or enhanced. DCM classifies potential wetland restoration and enhancement sites according to the wetland plant community types that they are likely to support once they are restored or enhanced (Figure 29). The development of the classification scheme for potential wetland restoration and enhancement sites is based on soil taxonomy, a frequency analysis of DCM's wetland type mapping results (wetland type vs. soil mapping unit), landscape position, and best professional judgment from wetland scientists and soil scientists.

1.10.10.2 Identifying and Prioritizing Restoration Sites in Puget Sound, Oregon USA

The sub-estuaries of Puget Sound have lost more than 80% of tidal marsh habitats in the past 150 years and efforts are underway to restore priority areas. Dean et al. (2000) used spatial data and GIS techniques to calculate the extent of loss in the Skagit River estuary and to identify and rank areas that would be appropriate for restoring estuarine habitat for the benefit of chinook salmon (*Oncorhynchus tshawytscha*) and other threatened or endangered species. Selection criteria were based on ecologically meaningful characteristics of the landscape (following Shreffler and Thom 1993), balanced with criteria ranking ease of restoration. Landscape variables included areas of tidal and seasonal flooding, hydrological connectivity and ecological sustainability with the final site prioritization classification developed with a tally of scores from each criterion (i.e., 0= outside flood corridor; 4= inside flood corridor). Hydrology was the basis for classifying connectivity and this was achieved by identifying barriers to the flow of water (i.e. major roads, levees or dikes) relative to known salmon movement corridors such as barriers to juvenile-bearing fresh water (Skagit River), salt water (Skagit Bay, Padilla Bay, Swinomish Channel) or adjacent to both. For sustainability, a higher score was assigned to larger areas of wetland with the assumption that a larger area is more sustainable than a smaller area. For ease of restoration, public land was scored more highly than private and natural vegetation (forest, marsh) scored more highly than agriculture and impervious surfaces and plots with fewer owners received higher scores than many owners. To define the priority ranking classes, scores were summed for every quarter-acre cell, and the scores were divided into four priority ranges with Priority 1 being the highest priority and 4 the lowest (Figure 30).

1.10.11 CLASSIFYING AND MAPPING SOCIO-ECONOMIC PATTERNS

Human use patterns, anthropogenic stressors/pressures and economic evaluations of goods and services are some of the human dimensions data that are increasingly being represented by classifications that play an important role in marine spatial planning and the evaluation of potential threats. Not only do these data help in planning, but also provide an effective way to evaluate the likely economic impact of marine spatial planning decisions. Human dimensions data are complex to depict spatially and very diverse, but significant advances have been made to map social data including ecosystem valuations that can help prioritize management activities.

Economic value can be shown in various ways, Figure 31 shows a section of the Baltic Sea that has been classified according to its tourism value represented by recreational boating and cottages, and tourism related companies. This information is useful in assessing the impact of different zoning scenarios on the marine and coastal tourism associated economy. For example, if a zoning regulation prohibits development of docks, hotels or boating then the cost can be calculated for specific regions. Furthermore, the information can be combined to show the overall picture of the economy geographically

1.10.11.1 Classifying and Mapping Ecosystem Services

Ecosystem services are the benefits people obtain either directly or indirectly from ecological systems (Millenium Ecosystem Assessment 2003) and are a critical component of comprehensive marine spatial planning. An ecosystems services approach to valuing marine biodiversity is recognized as a framework by which economic, ecological and social values can be incorporated into the decision making process (Rees et al. 2010) and inclusion can help to promote efficient strategies for biodiversity conservation and anticipate stakeholder conflicts (Beaumont et al. 2007). Naidoo et al. (2008) argued that to understand the interaction between biodiversity and ecosystem services, values must be quantified and their areas of production mapped. An increasing amount of spatially-explicit information is being collected on the ecological and socio-economic value of goods and services associated with coastal ecosystems (Chan et al. 2006). De Groot et al. (2002) defined 23 ecosystem functions with a wide range of examples of goods and services provided by these functions that can be classified into three groups: 1.) ecological, 2.) socio-cultural, and 3.) economic value. Troy and Wilson (2006) developed a spatial framework for the analysis of ecosystem service values (ESVs) through integration of biophysical land use units classified from remotely sensed data with estimates of ecosystem service values extracted from existing studies. Each mapping unit in the study areas was assigned a land cover class and an ESV multiplier, allowing values to be summed and cross-tabulated by service type and land cover type. Total ESV flow of a given cover type can be summed by adding up the individual, non-substitutable ESV associated with a cover type and multiplying by area. Scenarios can be modeled by changing the inputs and carrying out a change detection analysis to investigate the effect of a proposed planning decision or alternatively by recreating historical conditions for comparison with present day and future anticipated change. In 2004, Fisheries and Oceans Canada (DFO) developed an approach to identify Ecologically and Biologically Significant Areas (EBSAs) based on five criteria: uniqueness, aggregation, fitness consequences, resilience and naturalness (Jamieson and Levings 2001). The DFO approach was adapted for application to the Belgian part of the North Sea (BPNS) and resulted in the development of biological valuation maps (BVMs). BVMs serve as a tool to identify areas of particular high biological significance and facilitate management of human activities, making best use of available data sets using criteria for biological valuation: rarity, aggregation/fitness consequences, naturalness and proportional importance (Derous et al. 2007).

1.10.11.1.1 Mapping ecosystem services for systematic planning, California, USA

For the Central Coast ecoregion of California, Chan et al. (2006) developed a systematic planning framework of site prioritization using Marxan (Ball and Possingham 2001) that integrated biodiversity and ecosystem services. Six ecosystem services were chosen based on the availability of spatial data and knowledge of ecosystem functions including carbon storage, crop pollination, flood control, forage production, outdoor recreation and freshwater provision (Figure

32). Results show that sites selected using ecosystem services alone did not protect sufficient proportions of biodiversity, but biodiversity alone did protect substantial amounts of ecosystem services. The authors found that strategically targeting biodiversity and only four of the ecosystem services that were positively correlated with biodiversity offered an acceptable overall result with several areas identified where both high biodiversity and high ecosystem services coincide. Areas of concordance also were identified in a global analysis (Naidoo et al. 2008), but better assessment of synergies and trade-offs in conserving biodiversity and ecosystem services are needed to support optimal strategies in an ecosystem-based approach to management.

1.10.11.1.2 Mapping change in ecosystem service values, Puget Sound, Washington State, USA

For Maury Island, a small island located in Puget Sound, Washington State, USA, changes in ecosystem service value flows were estimated under two alternative development scenarios: 1) enlargement of a gravel mine and associated dock and 2) fully building in the allowable residential zone over 20 years (Figure 33) (Troy and Wilson 2006). The unique land cover classification included disturbed land (urban, barren, unvalued); saltwater wetland; freshwater wetland; nearshore habitat (intertidal salt estuaries, estuarine intertidal aquatic beds, stream mouths, sea cucumber habitat, geoduck habitat and herring and salmon spawning grounds); coastal open water; grassland; stream buffers (50ft); coastal riparian; beach; beach near dwelling and forest). The Maury Island scenario analyses estimated that the mine development would result in loss of $703,000 in yearly ecosystem services the following year and the residential development scenario would result in a loss of $548,000.

1.10.12 FUTURE DIRECTIONS AND PRIORITY MANAGEMENT NEEDS

Increasing demand for spatial representations of ecosystem attributes (both human and non-human characteristics) to support environmental characterizations, assessment and management planning including marine spatial planning are expected to lead to more comprehensive mapping programs. In Europe, the European Commission is developing broad-scale maps for the Baltic, North, Celtic and western Mediterranean Seas. This project (EUSeaMap) builds upon the outputs of previous mapping efforts as presented in this chapter to produce harmonized EUNIS maps across the four regions. In the U.S., President Obama's Ocean Policy Task Force released its Interim Framework for Effective Coastal and Marine Spatial Planning in 2009. The framework recommends a comprehensive, integrated approach to planning and managing uses and activities using the Large Marine Ecosystem or sub-divisions of LME's as management units. This major initiative will require significant spatial data gathering, integration and analyses to support the work of regional planning teams to provide information on:

1.) important physical and ecological patterns and processes (e.g., basic habitat distributions and critical habitat functions) that occur in the planning area, including their response to changing conditions;
2.) the ecological condition and relative ecological importance or values of areas within the planning area, using regionally-developed evaluation and prioritization schemes;
3.) the relationships and linkages within and among regional ecosystems and the impacts of anticipated human uses on those connections;

4.) the spatial distribution of, and conflicts and compatibilities among, current and emerging ocean uses in the area and:

5.) important ecosystem services in the area, and their vulnerability or resilience to the effects of human uses, natural hazards, and global climate change;

Examples of many of these themes are documented here in this chapter, yet new spatial data acquisitions will also be required to support effective decision making in CMSP. Furthermore, in the U.S. the Ecosystem Services Research Program of the Environmental Protection Agency (EPA) is developing a national atlas of ecosystem services for the United States to enable decision makers to consider ecosystem services in the planning process (Neale and Lopez 2009). The focus is primarily terrestrial due to the availability of satellite data, but will include estuarine and coastal regions with ecosystem services classified into broad categories of water quality, quantity, and timing; climate regulation; food, fiber, and fuel; storm surge and wave/tidal energy protection; aquatic and terrestrial habitat; and human health, cultural values, and recreation. The atlas will be an internet-based product that provides data at multiple spatial scales and will include historical data, as well as future scenarios.

NOAA’s Coastal Services Center (CSC) and the U.S. Minerals Management Service have recently developed an online Multipurpose Marine Cadastre (MMC) to allow users to visually analyze and explore geospatial data for marine spatial planning activities. CSC has also developed an online legislative atlas “georegulation” which depicts the spatial "footprint" of the state and federal legislation. In Australia and other countries around the world too, marine cadastres are being developed.

1.10.12.1 Linking Patterns and Processes in Ecological Classifications

Although considerable progress has been made to develop harmonized hierarchical and practical classifications at national and multi-national levels, our understanding of the relationship between the classes delineated and the physical environment, especially in offshore and deep waters, is still often limited. A key challenge in support of EBM is to develop marine and coastal classifications that incorporate functional characteristics of the environment that can be used to assess the health of the ecosystem and its response to disturbance. This can be challenging, for example, classifying and mapping dynamic water circulation patterns presents certain problems when representing spatial dynamics unless spatially persistent features exist at discrete locations. Likewise, the direct spatial characterization of ecological processes such as predator-prey dynamics can also be challenging unless more structurally obvious surrogates can be identified.

In the mapping of seascape types, further research is needed to guide the integration of biotic and abiotic data and the combining of pelagic and benthic seascapes, since often very little is known about pelagic-benthic coupling and the relative importance of the measured variables that are included in the classification. Often variable inclusion is based on data availability rather than the ecological significance in describing the system. It is crucial to characterize seascapes in an ecologically meaningful way that will increase the efficacy of decision making and better understand the environmental drivers of change, identify rare and special interest areas, predict the distribution of biodiversity and establish appropriate levels of protection. Clearly, the data needs for effective MSP are extensive, the Massachusetts Ocean Management Planning process identified key information needs for development of classifications that included the continuation of high resolution seafloor bathymetric mapping and benthic habitat mapping to ensure that special, sensitive, or unique estuarine and marine life and habitats could be identified and protected, habitat evaluation methodology can be refined and ecosystem values and services can be evaluated and mapped. Where data is available increased data sharing and development of data portals with detailed metadata will facilitate the effective application of spatial data in marine spatial management. In addition, more information is needed to better understand the temporal variability of seascape characteristics and to assess their vulnerability to perturbations, resilience and recovery times.

Where spatial data gaps exist, spatial predictive modeling is emerging as an accurate and cost-effective tool to fill spatial information gaps and help elucidate on macroecological drivers in support of decision making in marine and coastal management (Leathwick et al. 2008, Pittman et al. 2009, Valavanis et al. 2008). Landscape ecology concepts and tools offer great promise in determining the ecological relevance of the spatial patterning depicted in seascape maps including functional connectivity, synergistic interactions among adjacent seascape types such as complementation effects and other functions of multiple seascape types. Landscape ecology has developed analytical techniques such as pattern metrics specifically for quantifying the spatial complexity in landscape or seascape composition, spatial configuration (Robbins and Bell 1994, Wedding et al. in press). Furthermore, a new generation of surface metrics can be applied to examine the three-dimensional spatial gradients in surface morphology of the environment (Pittman et al. 2009; Pittman & Brown in press). Marine and terrestrial regions are typically interlinked through ecosystem flows such as run-off, fishing pressure and other direct human activity that can be a function of population density, therefore classifications and data products including decision making must rapidly move toward an integrated land-sea spatial planning approach. New classifications will be required that represent land-sea interactions and are spatially seamless between landscapes and seascapes.

1.10.12.2 Understanding and Communicating Errors and Uncertainty

An important challenge for management is to ensure that decision making where ecological goals and objectives are central, such as conservation prioritization, are objective and science driven and not driven primarily by data availability or technological advancement. In reality the desire for a rapid, quantitative and defensible approach can sometimes override uncertainty in the data. Very rarely are the uncertainties quantified and communicated in a spatially explicit way before marine classifications are applied in management. For robust decision making to take place, more effort must be focused on evaluating data errors, bias and uncertainty and this will become very important in MSP where a diverse array of spatial datasets are being assembled together with novel untested procedures for developing classified maps. Uncertainty comes in a variety of forms and representations and requires different techniques for presentation. It is important to acknowledge that a classification scheme is a model of reality and in many cases is a 2^{nd} or even 3^{rd} derivative of the original data. Misclassifications occur and can be due to spatial accuracy, observer bias, environmental variability, processing techniques, thematic, temporal and spatial resolution, etc. Some will say that all maps are a “lie” and that decisions can be made at various stages to make maps “lie” (Monmonier 1996). Inevitably some maps represent more of the true reality than others. Error is particularly problematic when a highly dynamic system is represented by a static map, yet management decisions will and must be made on best-available data. As noted by Alfred Russell Wallace in 1876 “nothing like a perfect zoological division of the earth is possible. The causes that have led to the present distribution of animal life are so varied, their action and reaction have been so complex, that anomalies and irregularities are sure to exist which will mar the symmetry of any rigid system".

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FIGURE LEGENDS

Figure 1. A) Classes of topographic complexity calculated from 4m resolution bathymetry collected by an airborne laser using LiDAR (Light Detection and Ranging). B) Average fish species richness from underwater surveys grouped for each class of topographic complexity.

Figure 2. (A) Combined benthic and pelagic seascapes of the Scotian Shelf. (B) Seascape heterogeneity of combined pelagic and benthic seascapes. Intensity of color increases with number of unique seascapes quantified within a sliding window of 18 km radius that passes over the entire pelagic-benthic seascape map (adapted from Roff et al. 2003).

Figure 3. A.) Topographic classification based on topographic and bed-form features, B.) Coastal physiographic classification based on major coastal features (estuaries, lagoons, sounds, bays, archipelago, and fjords) identified by coastline, bathymetry and salinity (figures adapted from Al-Hamdani and Reker 2007).

Figure 4. Map showing five classes of habitat heterogeneity at a 1 x 1 km grid for the Archipelago Sea region of the Baltic Sea based on summed values of classes based on variability of wave exposure, depth classes and ratio of shallow water, proximity to land and shoreline complexity (reproduced with permission from Snickars and Pitkänen 2007.

Figure 5. Sample of output from the habitat mapping component of the online NRM Reporting module illustrating the presence and absence of seagrass-dominated habitats at: (a) the national

scale (50 kilometre grid cells) and (b) in Tasmania (10 kilometre grid cells). (c) Users can also zoom to scales <10 square kilometres to obtain the actual habitat maps.

Figure 6. A). Geomorphic features of the Southwest Planning Region, Australia (from Harris et al. 2005); B.) Seascape classification, and C.) Seascape heterogeneity calculated as the sum of the variety of geomorphological features and the variety of seascape classes. Blue is relatively homogeneous and red is highly heterogeneous.

Figure 7. A.) Shaded relief bathymetric map of the FBNMS, created from ship-based sonar (Wright et al., 2002). Solid line delineates the estimated track of a rebreather diving mission in the sanctuary, immediately following bathymetric surveying. B.) Classification of FBNMS bathymetry into "structures," according to the bathymetric position index (Lundblad et al., 2006).

Figure 8. A classification of seamless land-seafloor terrain represented as marine terrestrial units (MTUs) of Hogrefe (2008), along with the rapid ecosystem assessment survey locations (REAs) of Brainard et al. (2008).

Figure 9. Simple spatial analysis using a classified map of bioregions overlaid with the spatial distribution of marine national parks or green zones to determine whether the network of MPAs is comprehensive, adequate and representative. Numbers in blue bars are the percentage of each biotopes protected within green zones.

Figure 10. Ecological evaluation index (EVI) developed for the Massachusetts Ocean Plan developed to support identification of special, sensitive, or unique estuarine and marine life and habitats.

Figure 11. An example of the use of classifications in ocean zoning and optimizing zoning in marine spatial planning in the Baltic Sea (Ekebom et al. 2008).

Figure 12. A.) Map showing all the legally permitted activities and uses of the UK Irish Sea; B.) Proposed Multiple Use Zoning Map for the UK Irish Sea based on existing legal and political management jurisdictions and mechanism showing the locations of the five rarest marine landscape types (adapted from Boyes et al. 2007).

Figure 13. A.) Distribution of demersal fishing effort, and B.) Relative economic value of demersal fishery around Britain and Ireland. (CEFAS Sensitivity Maps report 1998).

Figure 14. A.) Marine landscape categories in UK (England and Wales) waters based on a 2 x 2 nautical mile grid resolution (modified after Connor et al. (2006); B.). Average annual fishing pressure (AvAFPcell), as a proportion of grid cell affected by beam trawling, otter trawling, and scallop dredging (Stelzenmüller ety al. 2008).

Figure 15. Location of a Natura 2000 conservation area and listed habitat types in the SE North Sea within the German Exclusive Economic Zone. Inset map shows fishing effort from trawlers encroaching on the conservation area and listed habitat types based on GPS coordinates of satellite tracked vessels (adapted from Pederson et al. 2009).

Figure 16. Classes or themes represented in maps can be utilized as strata in the optimal design of monitoring or sampling strategies. Most biological populations are heterogeneous, therefore, a stratified random sampling design is one option for optimizing sampling design.

Figure 17. Trend analysis for coastal habitats of Barnegat Bay, New Jersey from 1972 to 1995 showing how a consistent classification framework can be effectively applied to detect changes over time. Analyses conducted by Rutgers University Center for Remote Sensing and Spatial Analysis (Lathrop and Bognar 2001).

Figure 18. Spatial classification of losses and gains in wetlands from 1990 to 2000 in southwestern Louisiana (Barras et al. 2003).

Figure 19. A.) Spatially explicit change detection using a consistent land use classification reveals where changes occurred and type of class that mangrove was converted to in several SE Asian countries. B.) Example of land change map showing spatial distribution of mangrove deforestation in Ayeyarwady Delta, Burma, from 1975-1990, 1990-2000, and 2000-2005 (Giri et al. 2007).

Figure 20. Environmental Sensitivity Index (ESI) map for a section of the Alabama coastline.

Figure 21. Combining 'intolerance' and 'recoverability' assessments to classify and rank 'sensitivity' for UK marine environments. NS = not sensitive, NR = not relevant. http://www.marlin.ac.uk/sensitivityrationale.php

Figure 22. Estimated general sensitivity (1 = low; 10 = high) to aggregate extraction based on the sensitivity index of the eleven commercially important fish and shellfish species (left) and a map of associated uncertainty (right) (Stelzenmüller et al. 2010).

Figure 23. Classification of Pass-a-Grille Beach NW, Pinellas County, Florida including classes representing geomorphic structure and urban development for the USGS Coastal Hazards Maps.

Figure 24. Selected data relevant to climate change impacts for the Papahãnaumokuãkea Marine National Monument. Maps a-d represent raw data layers and panels e-f are cumulative impact models (reproduced from Selkoe et al. 2009).

Figure 25. A ‘smartline’ geomorphology map from the Landforms and Stability module in OzCoasts. Each line segment includes multiple attribute fields that describe important aspects of the geomorphology of the coast including its vulnerability to coastal erosion.

Figure 26. Sample of report card showing the locations of estuaries and the proportion of the condition classes of estuaries in the Southern Rivers NRM region in 2000 (Scheltinga and Tilden 2008).

Figure 27. Distribution of broad habitat types within 11 regions of UK waters, used for assessing habitat status for Charting Progress 2 (habitats aggregated from EUNIS types, based on modeled data from MESH; intertidal rock and sediment habitats not shown, but were assessed).

Figure 28. Aggregated impact scores across all habitats (6) per region of UK waters. Aggregated scores allocated to one of five categories to indicate overall severity of each pressure. Final column provides overall ranking for the UK.

Figure 29. Restoration classes for Buckridge Coastal Reserve identified through the wetland restoration and enhancement site identification procedure developed by North Carolina Division of Coastal Management (Williams 2002).

Figure 30. Priority areas identified and ranked with Priority 1 indicating the highest priority areas for restoring vegetated habitat for juvenile salmon in the Skagit Estuary, Washington State.

Figure 31. A.) Estimated value of labor costs for marine tourism businesses. The number of employees was multiplied by an estimated average salary and a factor proportional to the level of dependence on marine tourism. B.) Combined economic value of boats, shoreline cottages and labor costs of marine tourism related businesses. The class values indicate cumulative economic importance.

Figure 32. Spatial analysis of biodiversity and the selected ecosystem services. The seven benefit functions (feature values) are displayed in color with the accompanying best networks of

selected planning units in gray insets. Feature values range from 0 (or locked out; white), to low (light blue), moderate (dark blue), and high (purple). The boundary indicates the ecoregion plus the 10-km buffer. Yellow lines indicate stratification units, within which individual targets were pursued. Numbers in the thousands (3000) are stratification unit labels. B) Ecosystem service and biodiversity hotspots. Colors represent the number of features for which each planning unit was selected in the best MARXAN network (Chan et al. 2006).

Figure 33. Estimated percentage reduction in yearly ecosystem service value flows between current conditions and full zoning buildout conditions by parcel for Maury Island (Troy and Wilson 2006).

Box 1. Definitions of ecosystem-based management and marine spatial planning.

Ecosystem-based management (EBM) and integrated marine spatial planning (MSP) have recently emerged as strategic priorities for many natural resource stewardship agencies around the world, with the overall objective of managing diverse marine uses in a comprehensive and sustainable way using a holistic and spatially-explicit framework (Douvere and Ehler 2009).

OSPAR (Commission for the Protection of the Marine Environment of the Northeast Atlantic) defines ecosystem-based management as:

"The comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of goods and services and maintenance of ecosystem integrity".

NOAA defines an ecosystem approach to management (EAM) as:

"A geographically specified, adaptive approach that takes account of ecosystem knowledge and uncertainties, considers multiple external influences, and strives to balance diverse societal objectives".

The UK government defines the purpose of MSP as:

"The creation of a strategic marine planning system that will clarify marine objectives and priorities for the future, and direct decision-makers and users towards more efficient, sustainable use and protection of marine resources" (Defra, 2007).

Box 2. Classifications as thematic maps.

Classifications as thematic maps

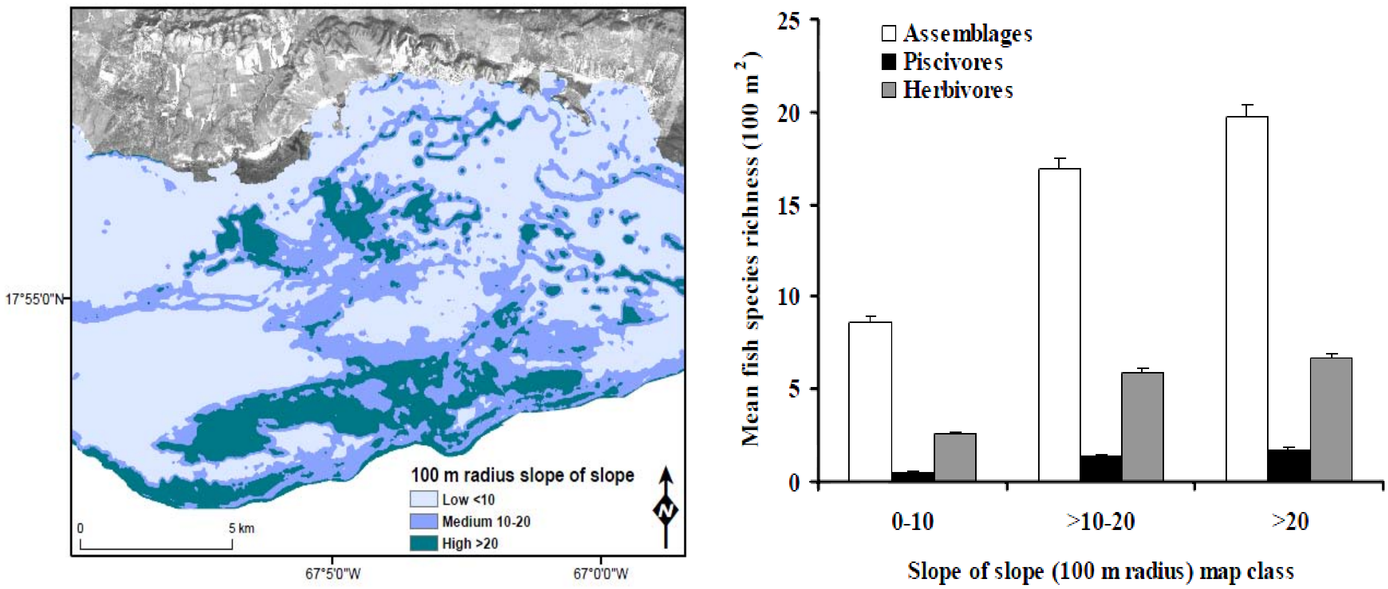
Classes of environmental data including social data within a known geographical location can be represented as a map to create a spatially explicit classification schemes or thematic map. This helps to organize, visualize and analyze diverse information in a systematic, transparent, cost-effective and operationally meaningful way to support efficient management decision making.

- Classes can be a single textual descriptor or a numeric value or a range of values and can be derived from expert opinion or numerically through a multivariate group i.e. “cluster group” based on a statistical classifier or some combination
- When mapped, classes are usually composed of a number of discrete and spatially homogeneous units that are assigned to grid cells or represented as polygons with discrete boundaries in a Geographical Information System (GIS)
- The map accuracy, spatial and temporal resolution, geographical extent and thematic resolution (i.e. detail of the classes) are important consideration when applying classifications to support management decision making

Box 3. Potential applications of the Scotian Shelf marine habitat classification (Roff et al. 2003).

- Definition of habitat-community associations
- Assessment of resource conflicts
- Judging potential impact of invading species
- Assessment of the potential role of focal species
- Guide to habitat management
- Framework evaluation of ecosystem processes
- Framework for assessment of global climate change
- Assessment of habitat suitability
- Examining patterns of biodiversity
- Evaluating marine protected areas
- Guide to environmental monitoring

Figure 1.



17°55'0"N
100 m radius slope of slope
Low <10
Medium 10-20
High >20
0
5 km
N
67°5'0"W
67°0'0"W
Assemblages
Piscivores
Herbivores
Mean fish species richness (100 m²)
25
20
15
10
5
0
0-10
>10-20
>20
Slope of slope (100 m radius) map class

Figure 2.

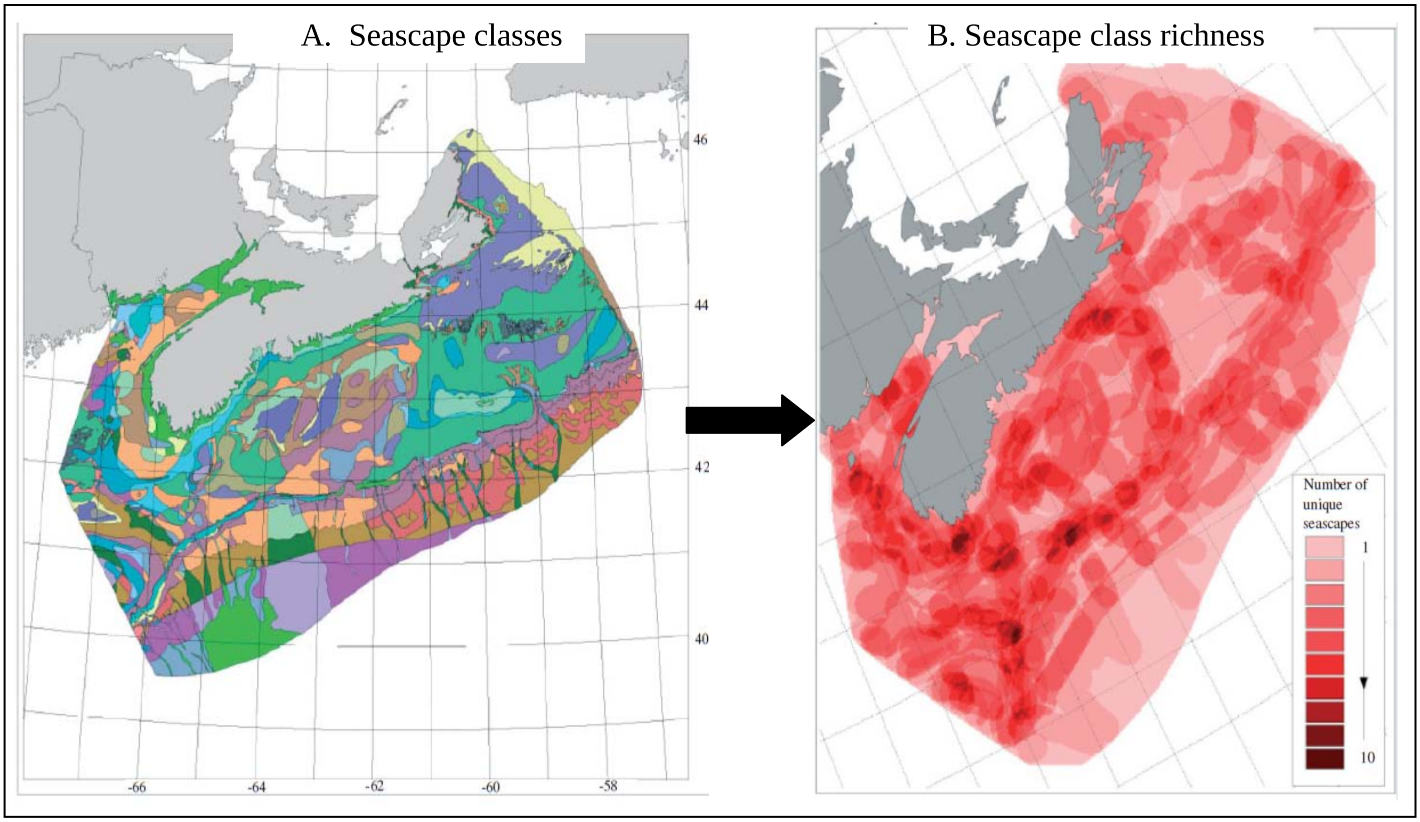
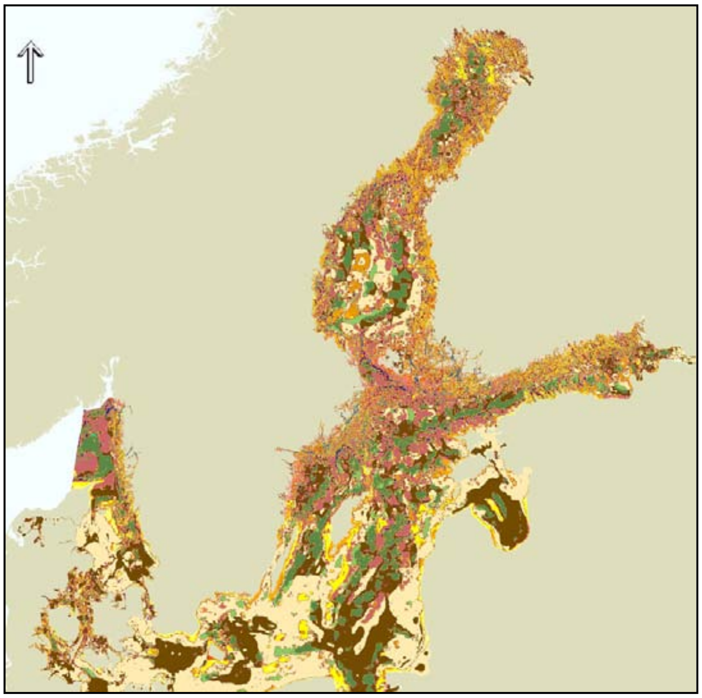
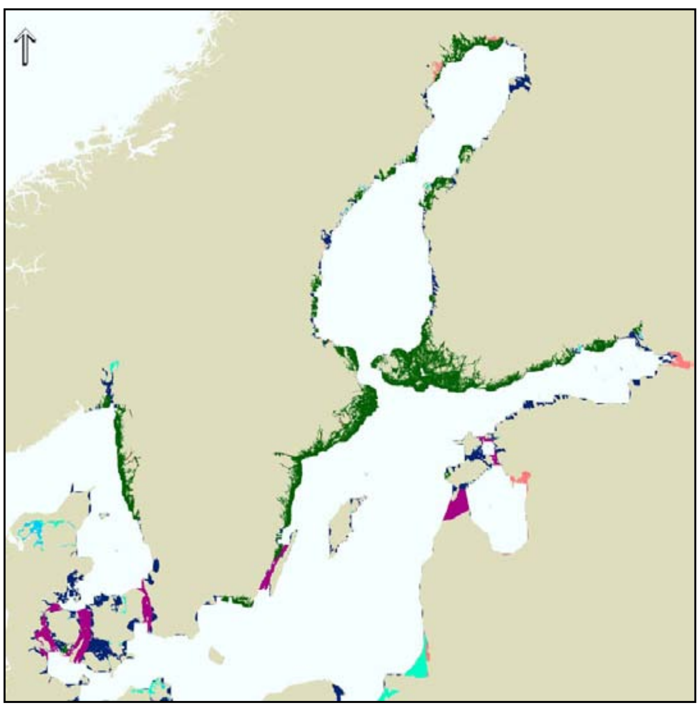

A. Seascape classes
B. Seascape class richness
46
44
42
40
-66
-64
-62
-60
-58
Number of
unique
seascapes
1
10

Figure 3.



Tab. 2: Topographic and bed-form features present in the Baltic Sea.					
GF	Colour code	Topography /BPI	Substrata	Depth	Other criteria
Troughs		Narrow depression	Mud and clay	Varies	Slope > 4%, longitudinal 2/1
			Coarse (gravel, hard clay, sand, hard bottom composite,		
Basins		Wide depression	Mud and clay	Varies, though often at deeper waters	None
			Coarse (gravel, hard clay, sand, hard bottom composite, rock)		
Mounds		Crest	Clay and hard clay	Non-photic	Raised
				Photic	
			Sand, gravel, cobbles	Non-photic	
				Photic	
			Hard bottom complex, unconsolidated material	Non-photic	
				Photic	
			Bedrock and boulders	Non-photic	
				Photic	
Plains		Flat	Fine sediments, mud and clay	Varies	No slope, may be erosional surface
			Coarse sediments		
			Bedrock	Photic	Photic depth
Valleys and holes		Narrow depression	Mud and clay	Varies	Not trough
			Coarse (gravel, hard clay, sand, hard bottom composite, rock)	Varies	
Slope		Slope	Varies	Varies	Slope ≥1%, not in 2km radius from basin
Wave/Mega ripples	N/A	Crests	Sand. Could not be delineated with the available coarse resolution data sets, not in the Baltic Sea		Moderate to strong currents



Tab. 3: Coastal physiographic features (CF) identified in the Baltic Sea.						
CF	Colour code	Topography & other features	Subclasses	Depth	Salinity	Other criteria/ facts
Estuary		Somewhat sheltered area (Max. 20km wide, land in min. of 4 directions in 15km radius)	No	≤ 30 m	≤ 3.5psu in the north ≤ 6psu in the south	
Fjord and fjordlike inlets		Narrow depression/ trough	No	Varies	Varies	"Terraneous", < 5km wide
Bay		Somewhat sheltered area (Max. 20km wide, land in min. of 4 directions in 15km radius)	Lagoons & lagoon-like bays	≤ 5 m	Varies	
			Sheltered bays	Varies	Varies	Entrance < 1km
			Bay	Varies	Varies	Entrance < 1km
Sounds		Located between land areas, channel	No	Varies	Varies	Outlined manually
Archipelago		> 20 islands in 20km×20km	No	Varies	Varies	

Figure 4.

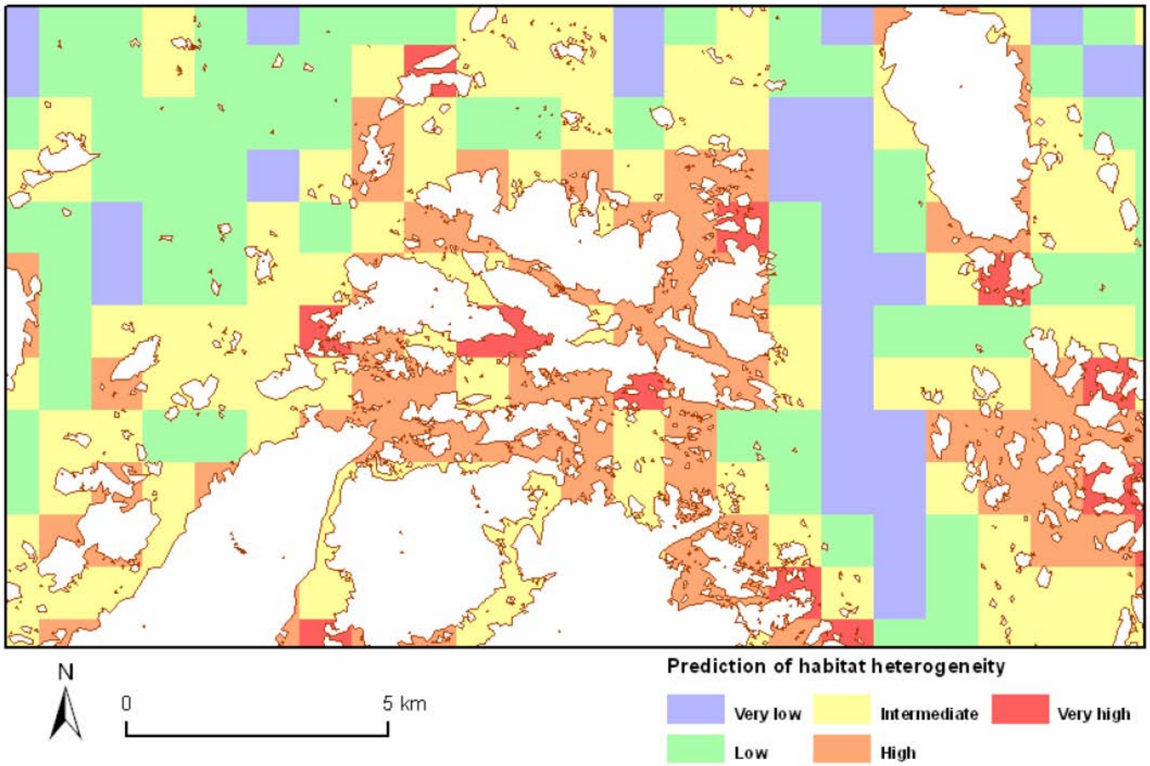

N
0
5 km
Prediction of habitat heterogeneity
Very low
Intermediate
Very high
Low
High

Figure 5.

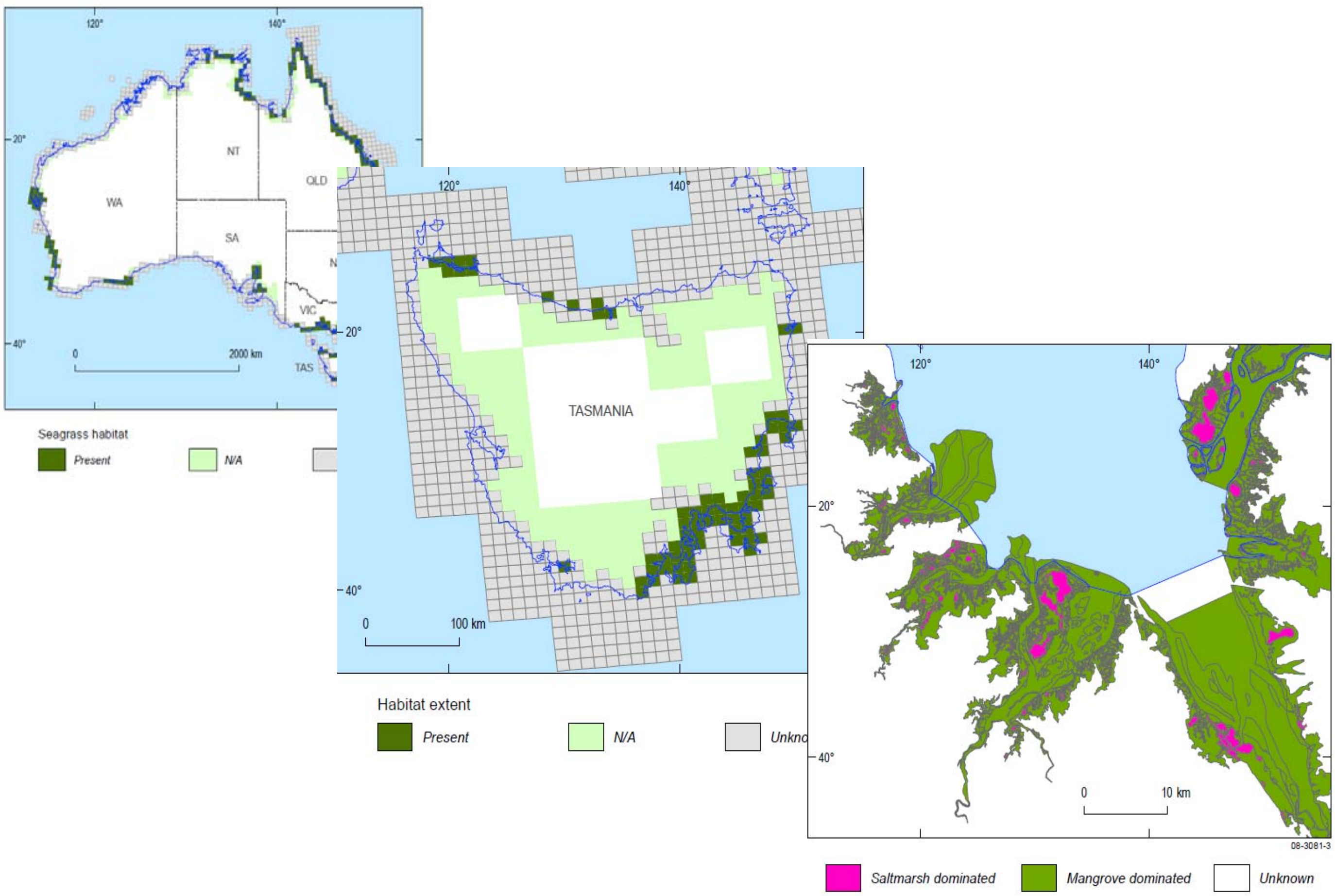
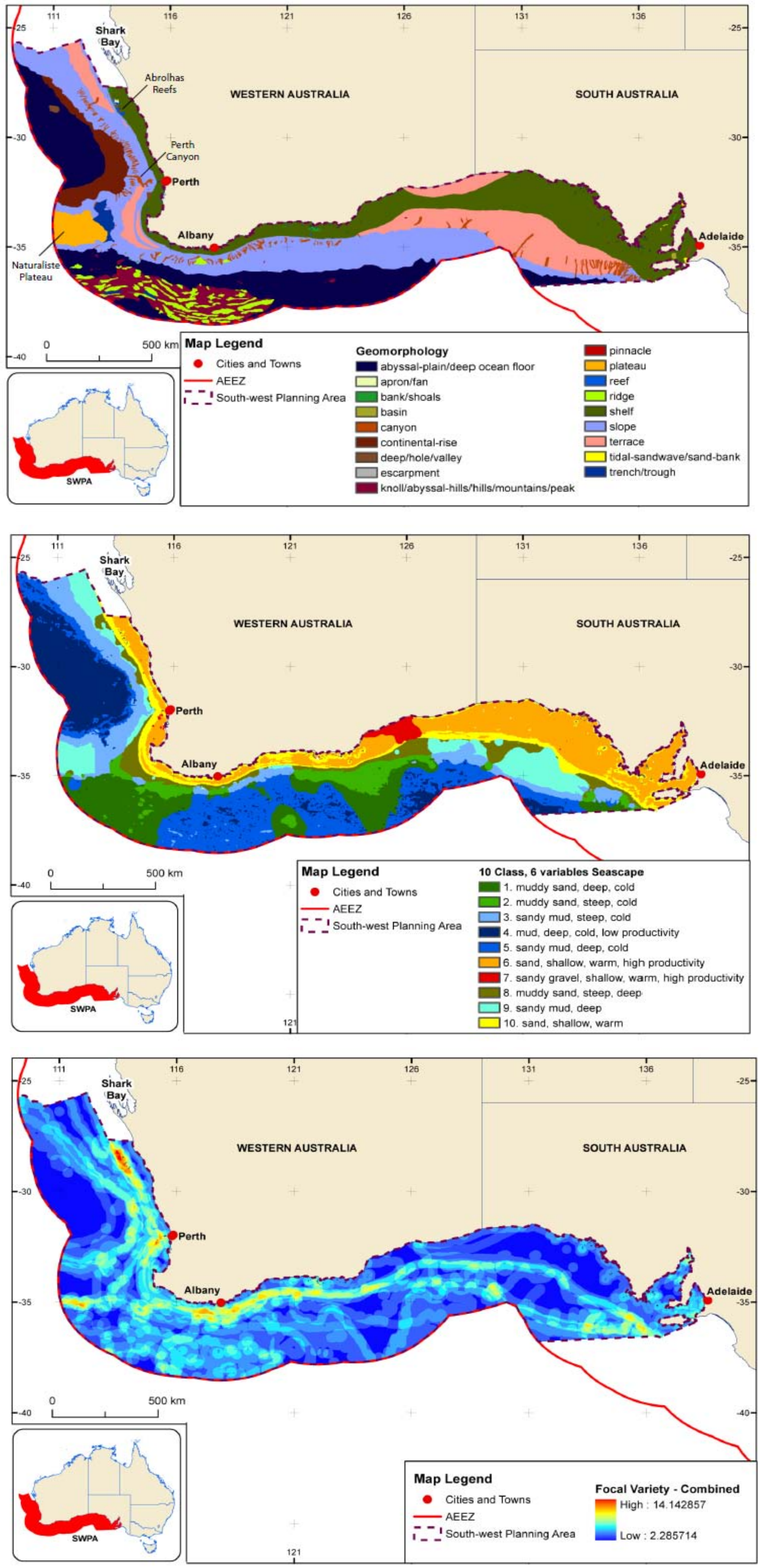

120°
140°
20°
40°
NT
QLD
WA
SA
VIC
TAS
0
2000 km
Seagrass habitat
Present
N/A
TASMANIA
0
100 km
Habitat extent
Present
N/A
0
10 km
08-3081-3
Saltmarsh dominated
Mangrove dominated
Unknown

Figure 6.

A.

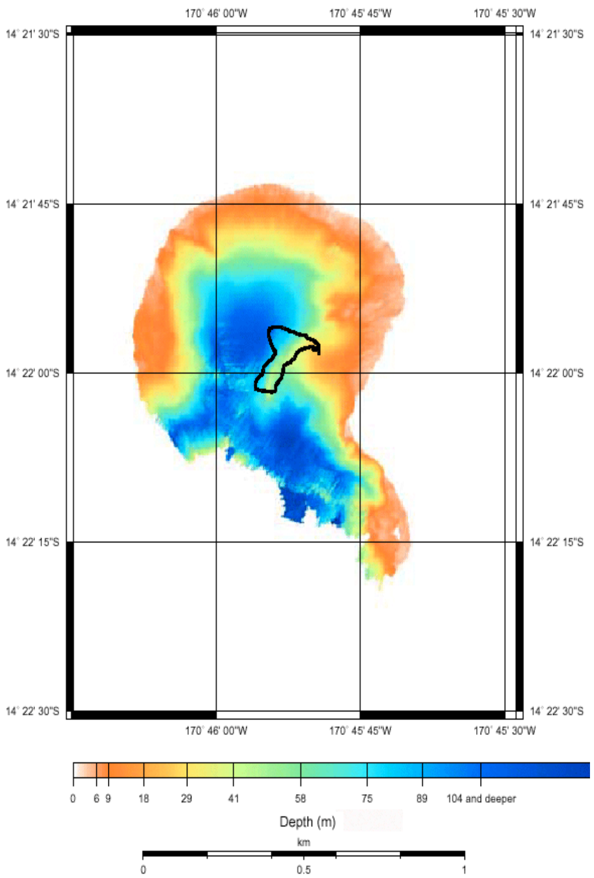
B.

C.



Shark Bay
Abrolhas Reefs
Perth Canyon
Perth
Albany
Naturaliste Plateau
Adelaide
WESTERN AUSTRALIA
SOUTH AUSTRALIA
500 km
SWPA
Map Legend
Cities and Towns
AEEZ
South-west Planning Area
Geomorphology
abyssal-plain/deep ocean floor
apron/fan
bank/shoals
basin
canyon
continental-rise
deep/hole/valley
escarpment
knoll/abyssal-hills/hills/mountains/peak
pinnacle
plateau
reef
ridge
shelf
slope
terrace
tidal-sandwave/sand-bank
trench/trough
10 Class, 6 variables Seascape
1. muddy sand, deep, cold
2. muddy sand, steep, cold
3. sandy mud, steep, cold
4. mud, deep, cold, low productivity
5. sandy mud, deep, cold
6. sand, shallow, warm, high productivity
7. sandy gravel, shallow, warm, high productivity
8. muddy sand, steep, deep
9. sandy mud, deep
10. sand, shallow, warm
Focal Variety - Combined
High : 14.142857
Low : 2.285714

Figure 7.


170° 46' 00"W
170° 45' 45"W
170° 45' 30"W
14° 21' 30"S
14° 21' 45"S
14° 22' 00"S
14° 22' 15"S
14° 22' 30"S
0
6
9
18
29
41
58
75
89
104 and deeper
Depth (m)
km
0
0.5
1

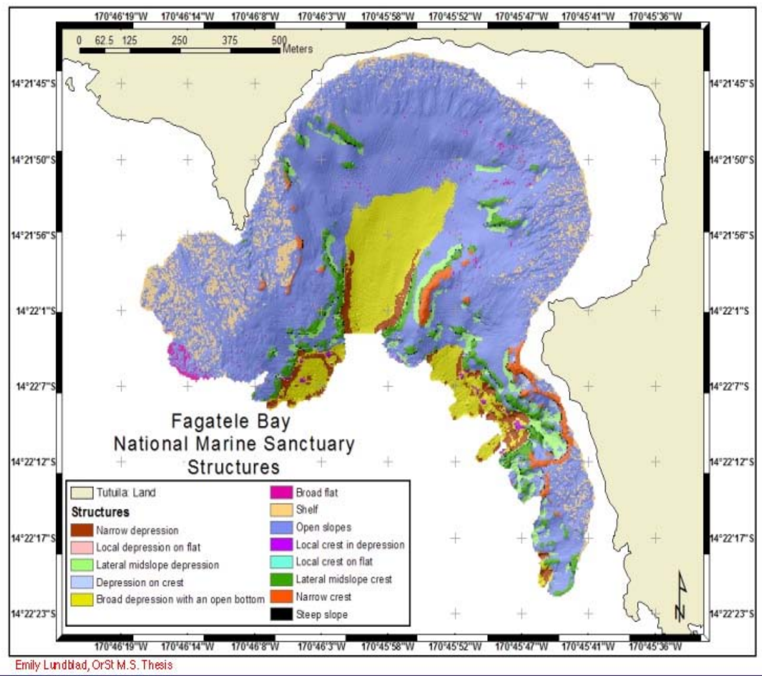

0 62.5 125 250 375 500 Meters
Fagatele Bay
National Marine Sanctuary
Structures
Tutuila Land
Structures
Narrow depression
Local depression on flat
Lateral midslope depression
Depression on crest
Broad depression with an open bottom
Broad flat
Shelf
Open slopes
Local crest in depression
Local crest on flat
Lateral midslope crest
Narrow crest
Steep slope
Emily Lundblad, OrSt M.S. Thesis

Figure 8.

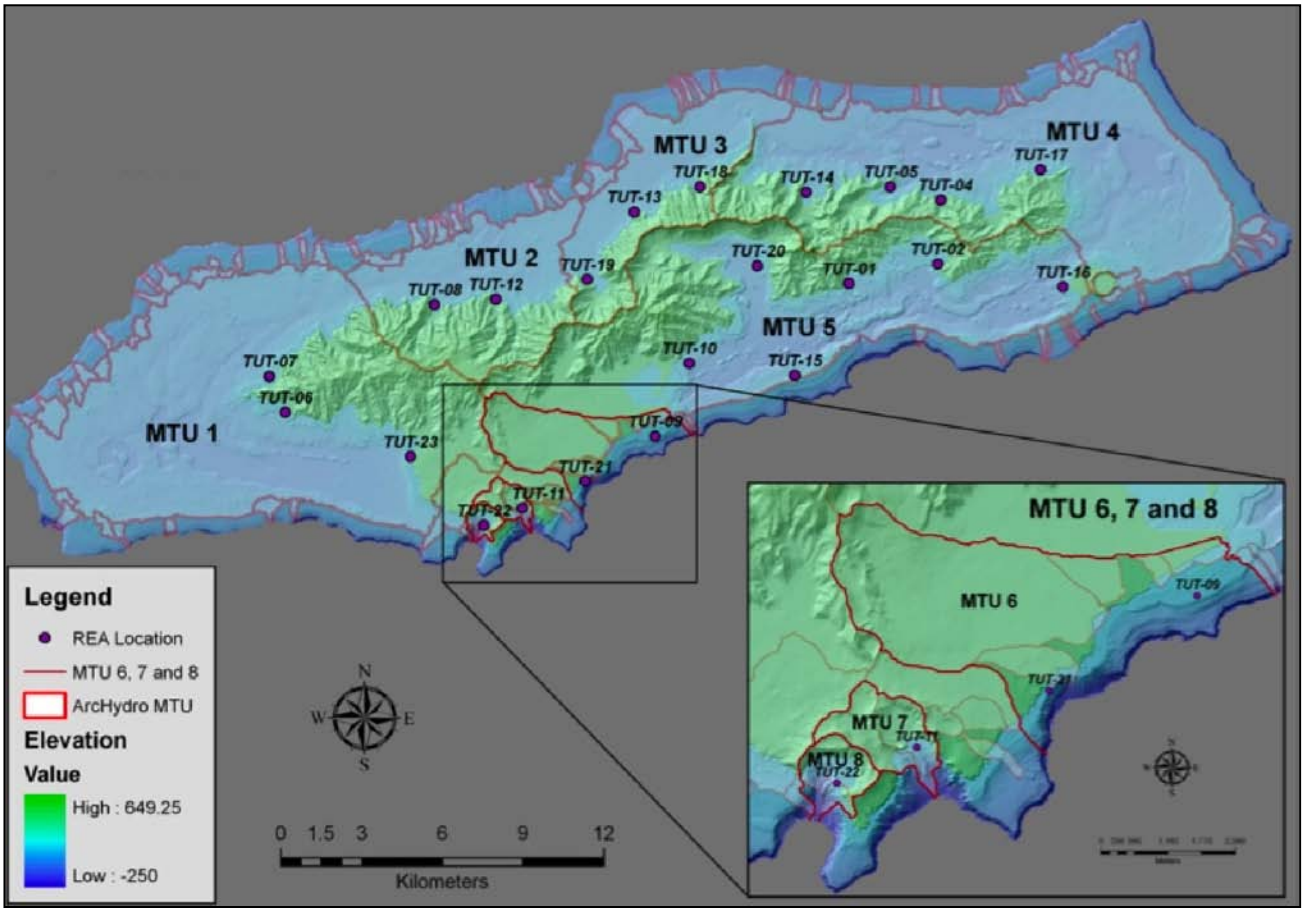
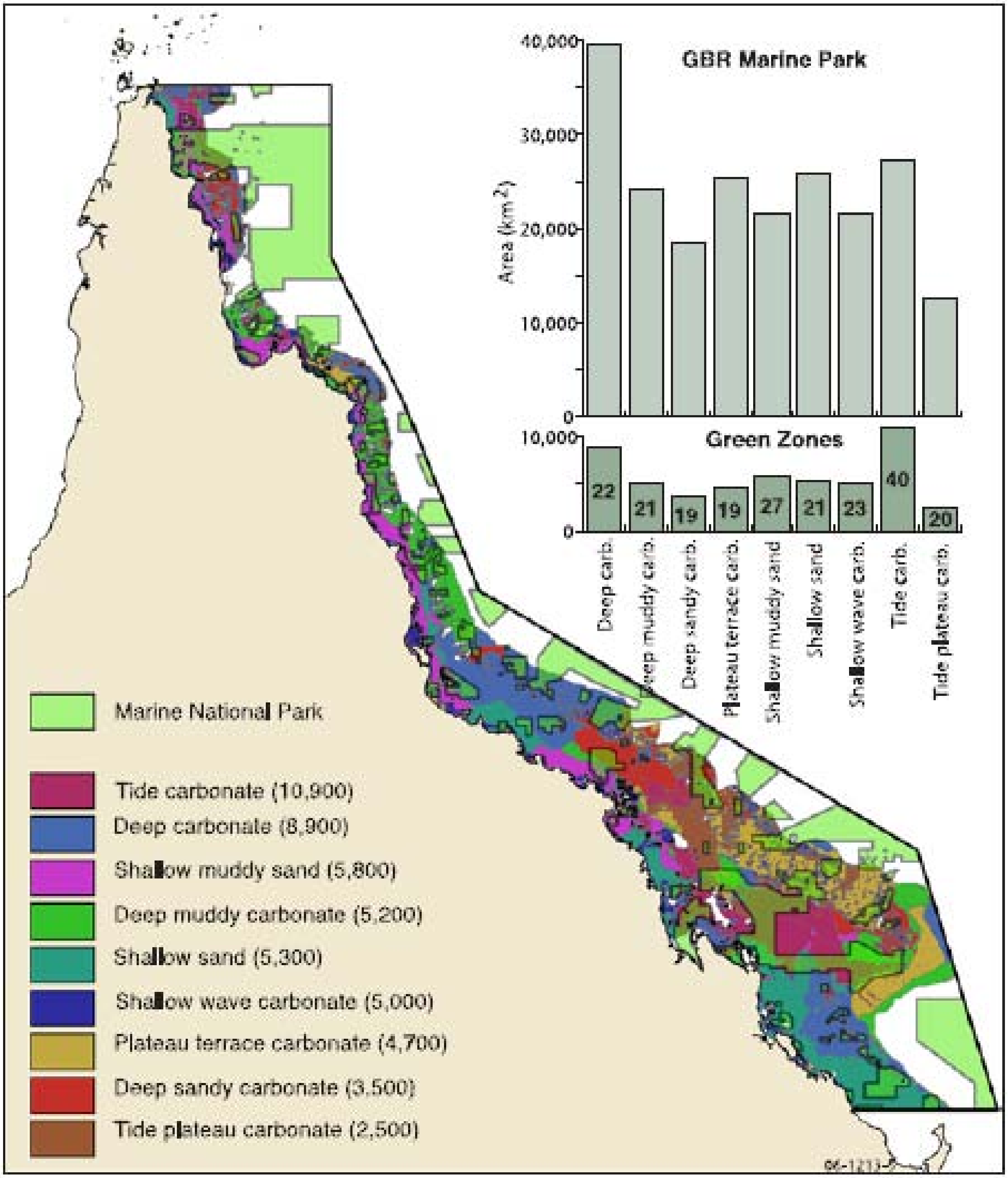

MTU 1
MTU 2
MTU 3
MTU 4
MTU 5
TUT-01
TUT-02
TUT-04
TUT-05
TUT-06
TUT-07
TUT-08
TUT-09
TUT-10
TUT-11
TUT-12
TUT-13
TUT-14
TUT-15
TUT-16
TUT-17
TUT-18
TUT-19
TUT-20
TUT-21
TUT-22
TUT-23
MTU 6, 7 and 8
MTU 6
MTU 7
MTU 8
Legend
REA Location
MTU 6, 7 and 8
ArcHydro MTU
Elevation
Value
High : 649.25
Low : -250
N
W
E
S
0 1.5 3 6 9 12
Kilometers

Figure 9.



GBR Marine Park
Area (km²)
40,000
30,000
20,000
10,000
0
Green Zones
10,000
0
22
21
19
19
27
21
23
40
20
Deep carb.
Deep muddy carb.
Deep sandy carb.
Plateau terrace carb.
Shallow muddy sand
Shallow sand
Shallow wave carb.
Tide carb.
Tide plateau carb.
Marine National Park
Tide carbonate (10,900)
Deep carbonate (8,900)
Shallow muddy sand (5,800)
Deep muddy carbonate (5,200)
Shallow sand (5,300)
Shallow wave carbonate (5,000)
Plateau terrace carbonate (4,700)
Deep sandy carbonate (3,500)
Tide plateau carbonate (2,500)

Figure 10.

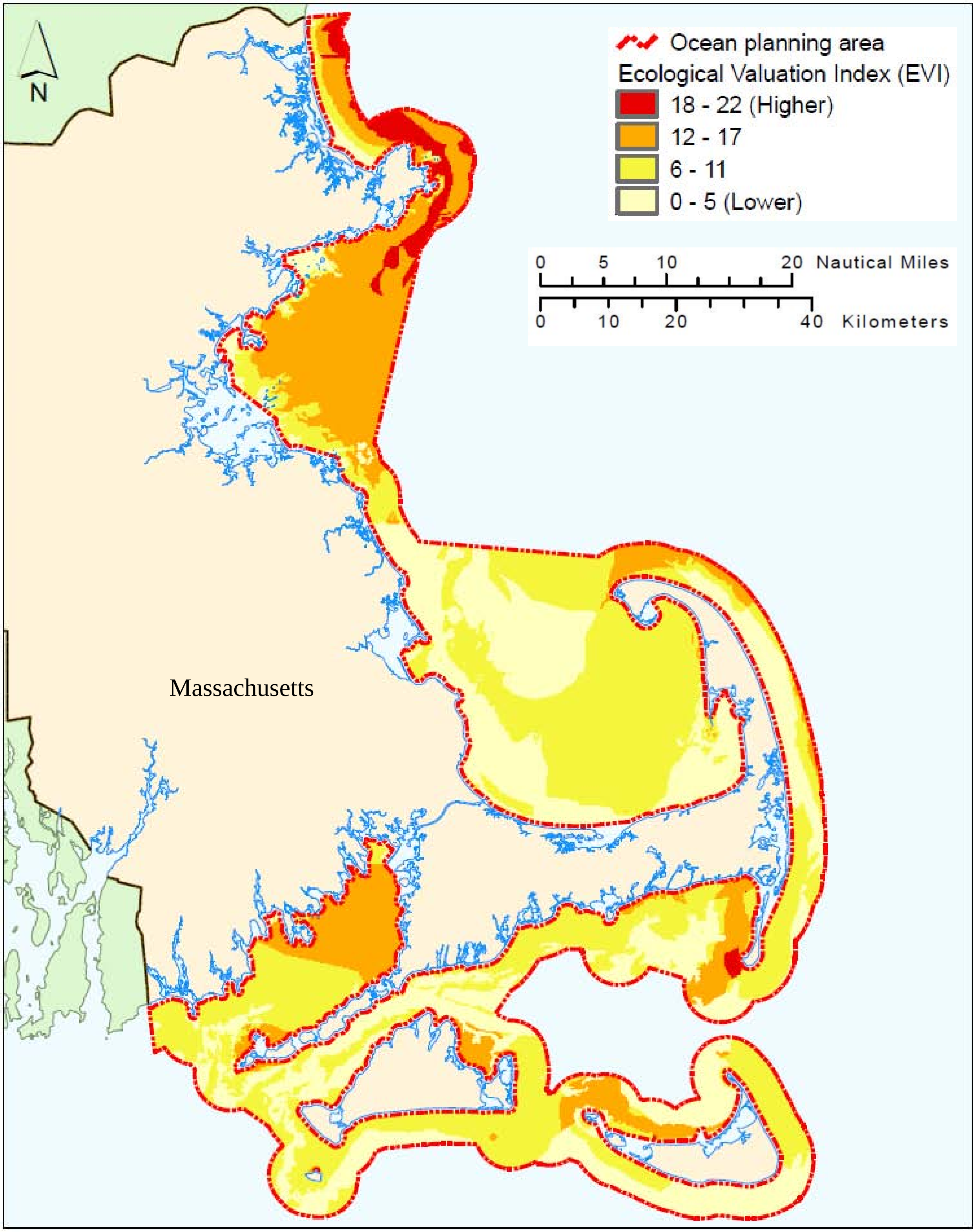

N
Ocean planning area
Ecological Valuation Index (EVI)
18 - 22 (Higher)
12 - 17
6 - 11
0 - 5 (Lower)
0 5 10 20 Nautical Miles
0 10 20 40 Kilometers
Massachusetts

Figure 11.

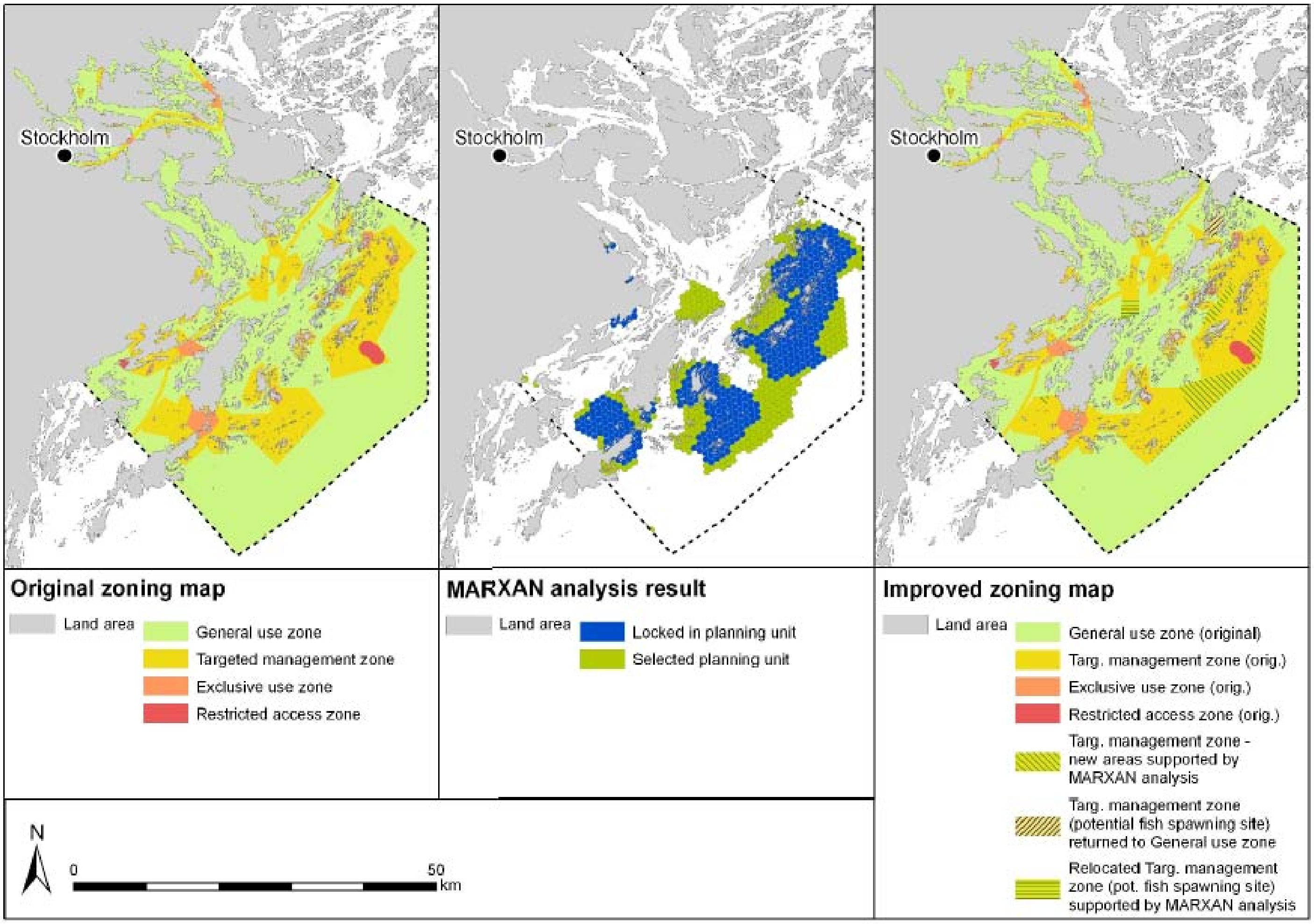

Stockholm
Stockholm
Stockholm
Original zoning map
Land area
General use zone
Targeted management zone
Exclusive use zone
Restricted access zone
MARXAN analysis result
Land area
Locked in planning unit
Selected planning unit
Improved zoning map
Land area
General use zone (original)
Targ. management zone (orig.)
Exclusive use zone (orig.)
Restricted access zone (orig.)
Targ. management zone - new areas supported by MARXAN analysis
Targ. management zone (potential fish spawning site) returned to General use zone
Relocated Targ. management zone (pot. fish spawning site) supported by MARXAN analysis
N
0
50
km

Figure 12.

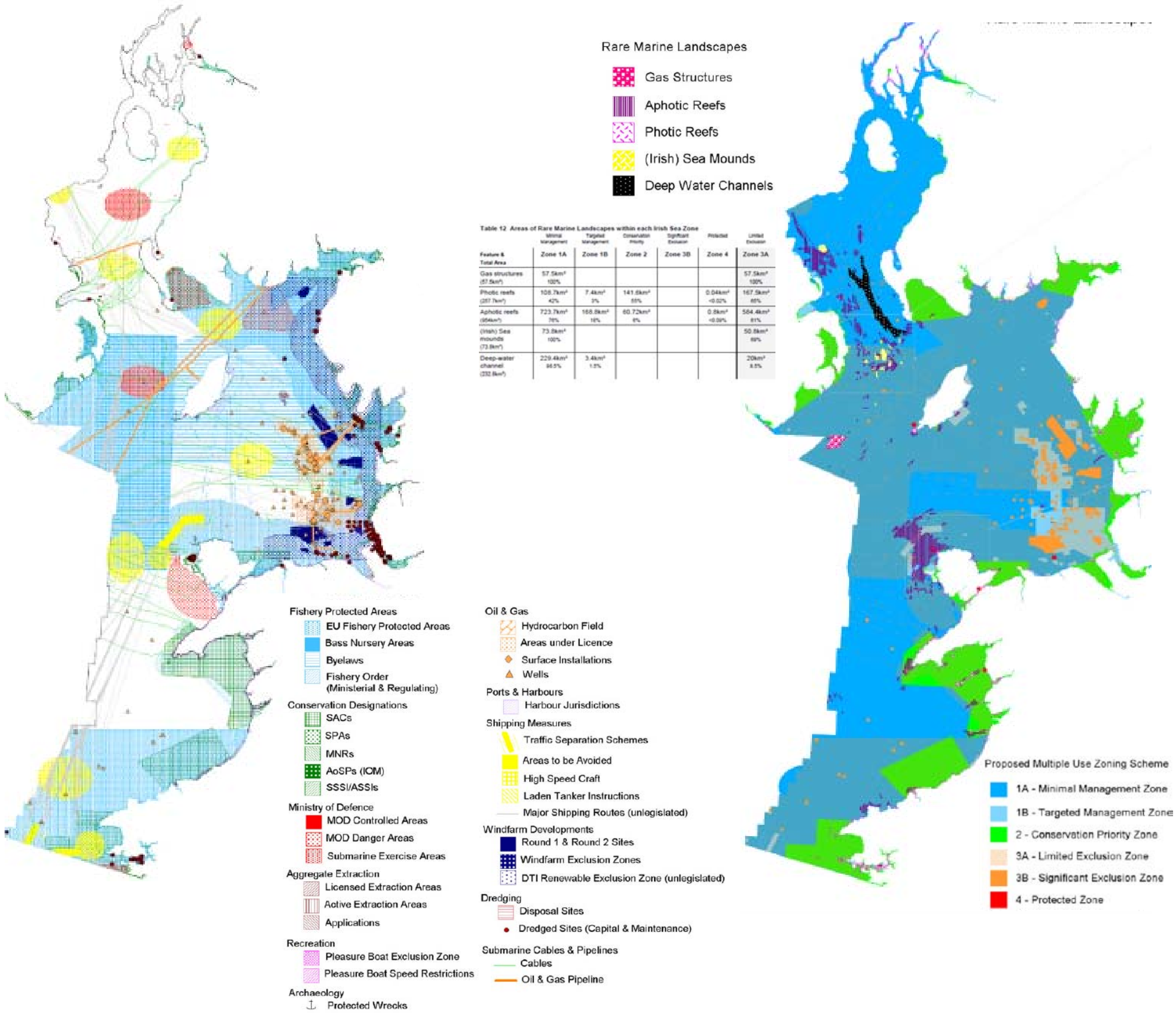
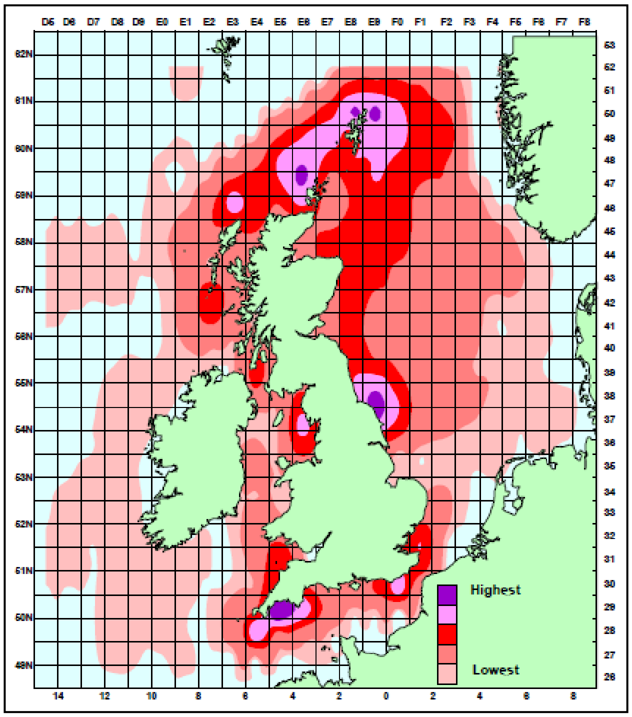


Table 12 Areas of Rare Marine Landscapes within each Irish Sea Zone

Feature & Total Area	Minimal Management Zone 1A	Targeted Management Zone 1B	Conservation Priority Zone 2	Significant Exclusion Zone 3B	Protected Zone 4	Limited Exclusion Zone 3A
Gas structures (57.5km²)	57.5km² 100%					57.5km² 100%
Photic reefs (257.7km²)	108.7km² 42%	7.4km² 3%	141.6km² 55%		0.04km² <0.02%	167.5km² 65%
Aphotic reefs (954km²)	723.7km² 76%	168.8km² 18%	60.72km² 6%		0.8km² <0.09%	584.4km² 61%
(Irish) Sea mounds (73.8km²)	73.8km² 100%					50.8km² 69%
Deep-water channel (232.8km²)	229.4km² 98.5%	3.4km² 1.5%				20km² 8.5%

Figure 13.



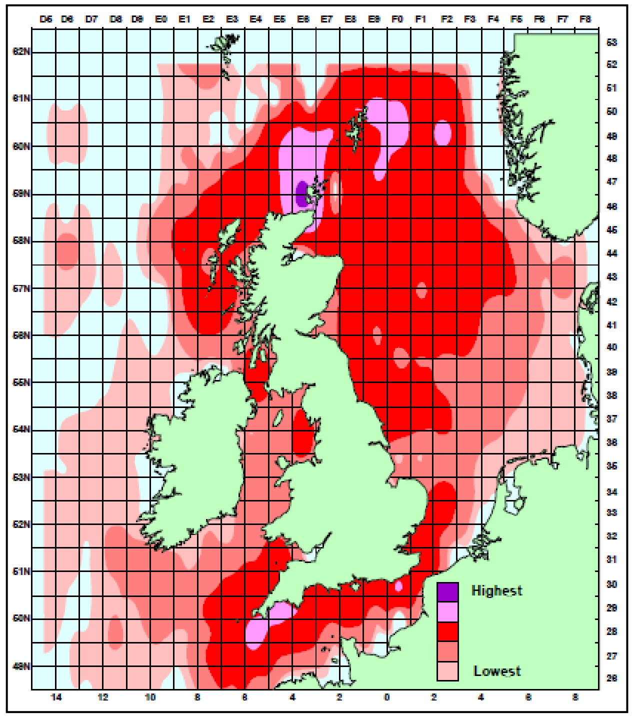


Figure 14.

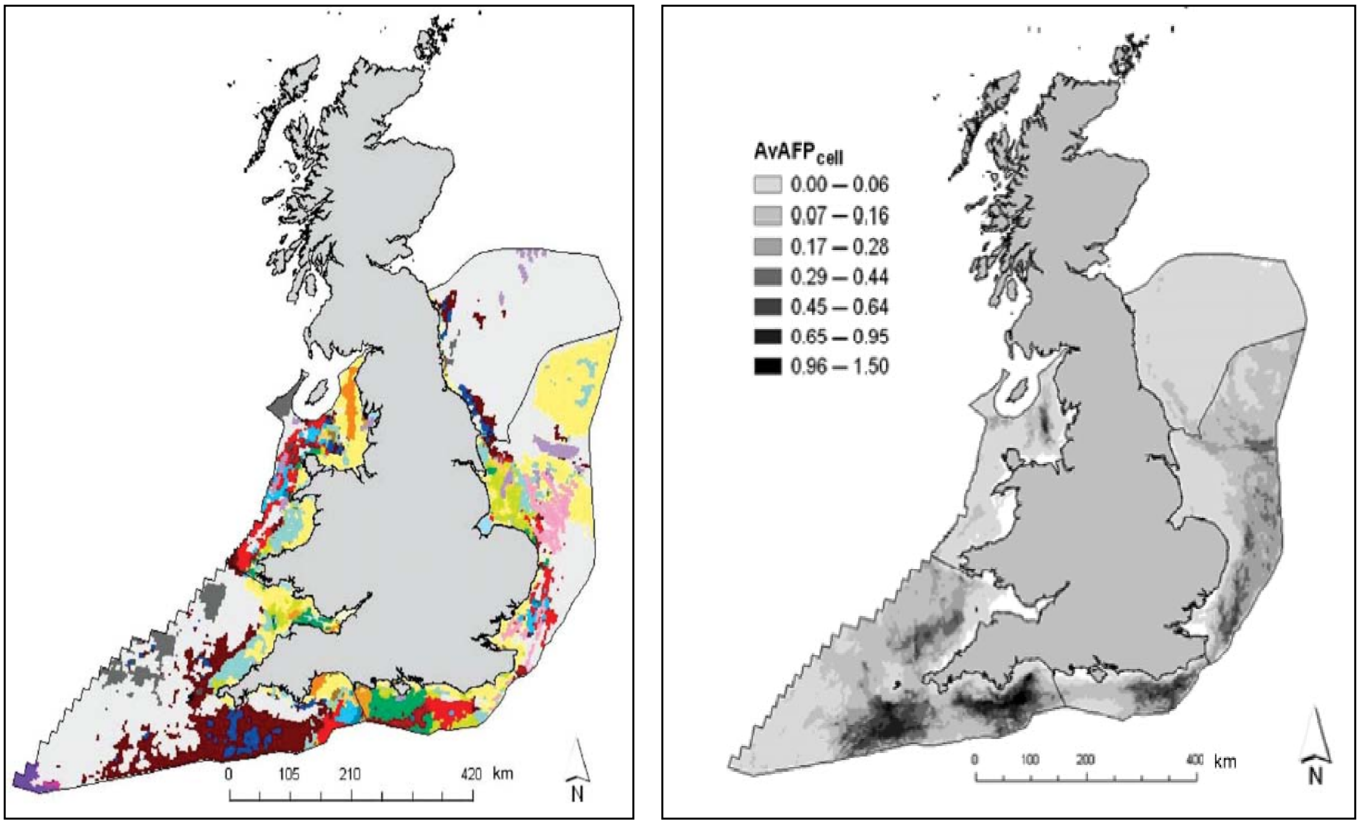
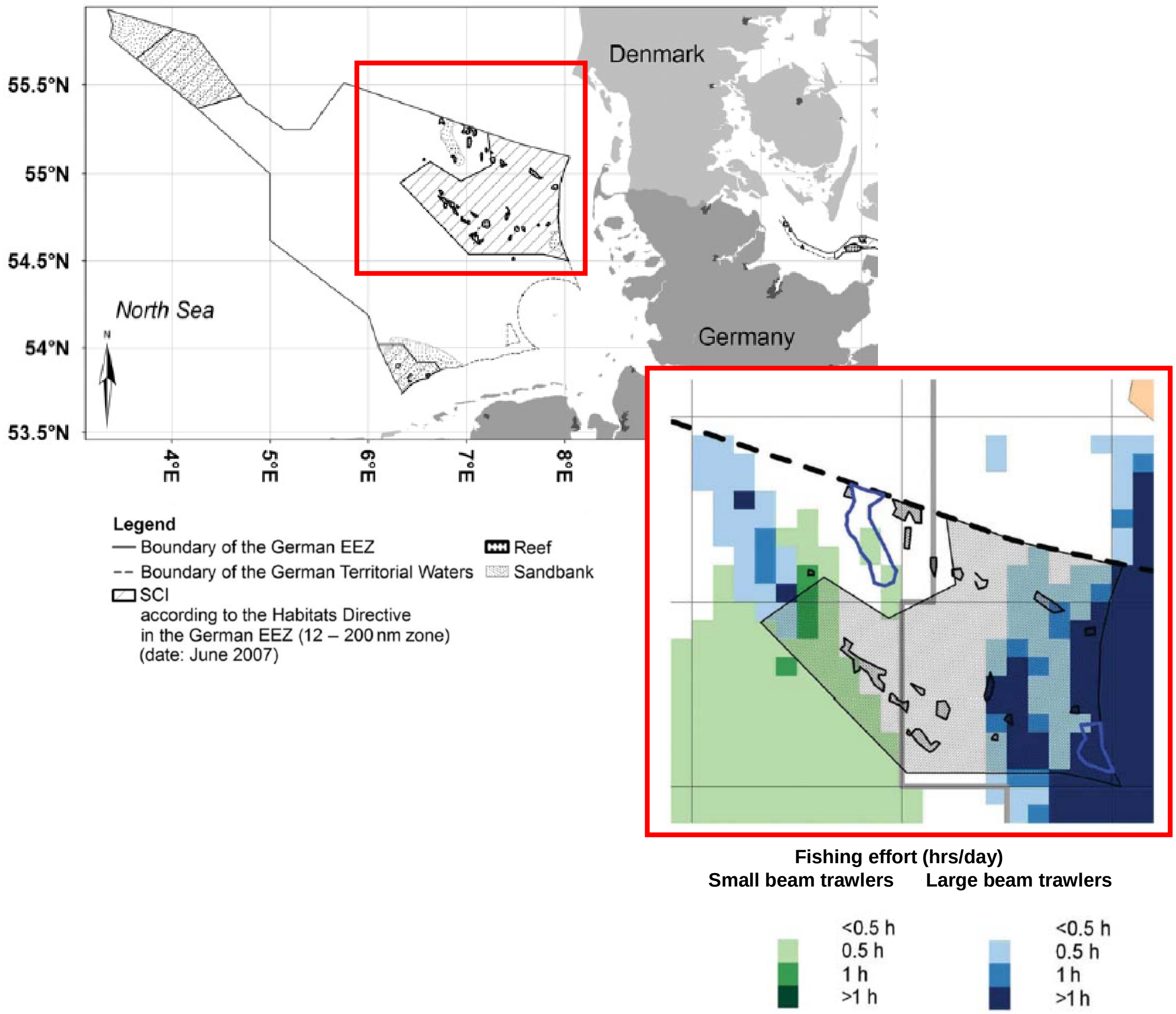

0
105
210
420 km
N
AvAFPcell
0.00 – 0.06
0.07 – 0.16
0.17 – 0.28
0.29 – 0.44
0.45 – 0.64
0.65 – 0.95
0.96 – 1.50
0
100
200
400 km
N

Figure 15.



Denmark
Germany
North Sea
55.5°N
55°N
54.5°N
54°N
53.5°N
4°E
5°E
6°E
7°E
8°E
Legend
Boundary of the German EEZ
Boundary of the German Territorial Waters
SCI
according to the Habitats Directive
in the German EEZ (12 – 200 nm zone)
(date: June 2007)
Reef
Sandbank
Fishing effort (hrs/day)
Small beam trawlers
Large beam trawlers
<0.5 h
0.5 h
1 h
>1 h
<0.5 h
0.5 h
1 h
>1 h

Figure 16.

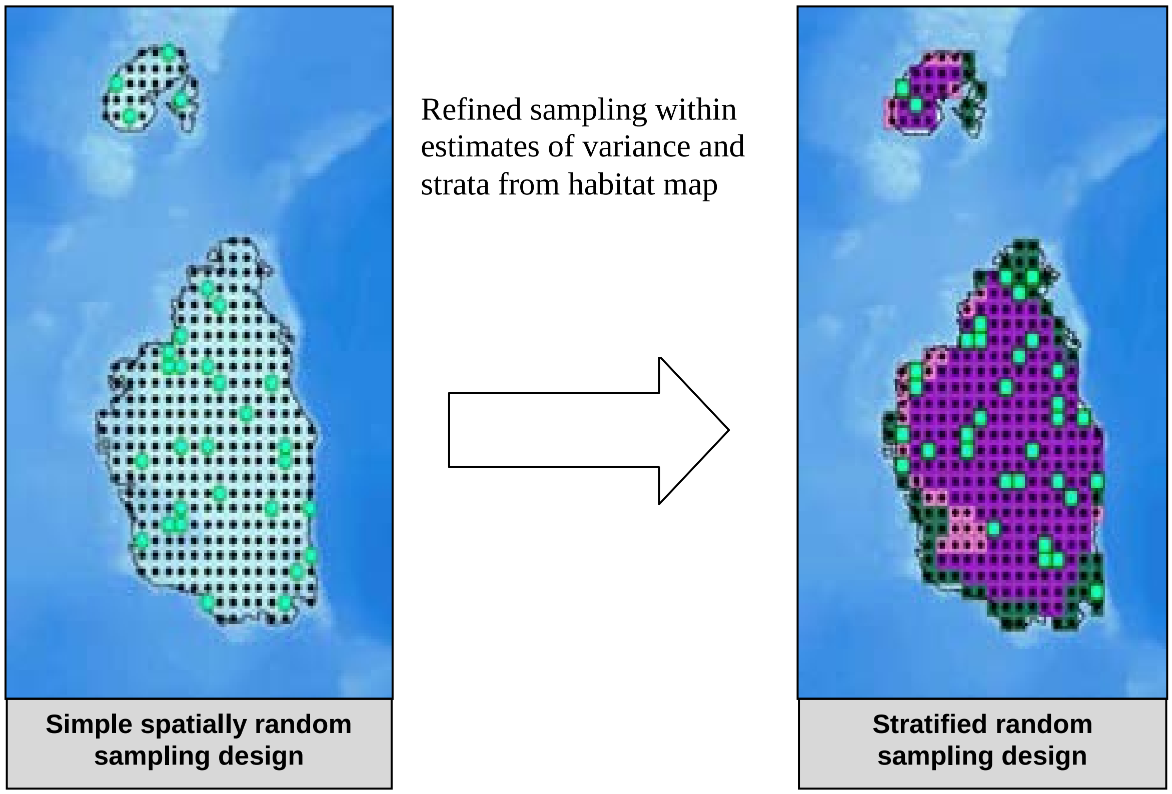

Refined sampling within estimates of variance and strata from habitat map
Simple spatially random sampling design
Stratified random sampling design

Figure 17.

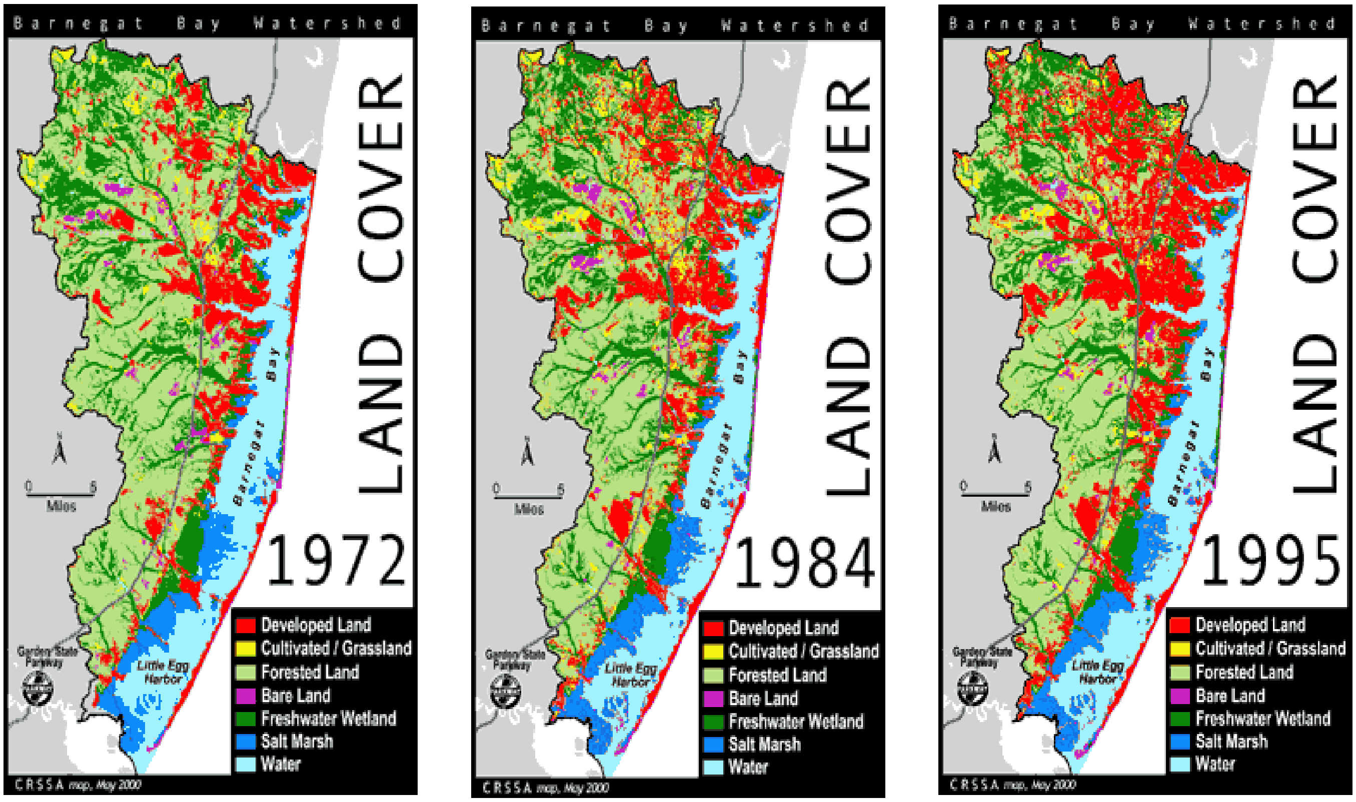
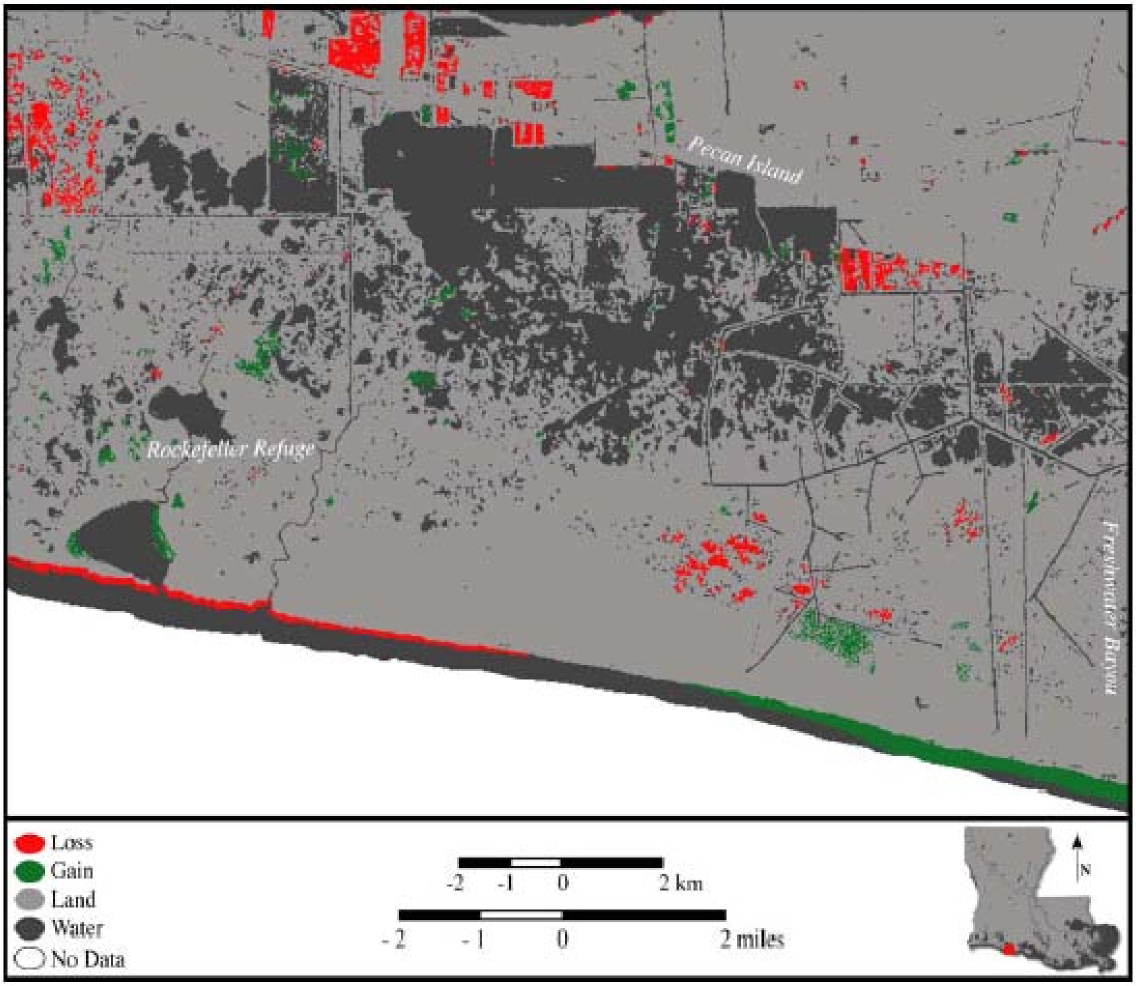
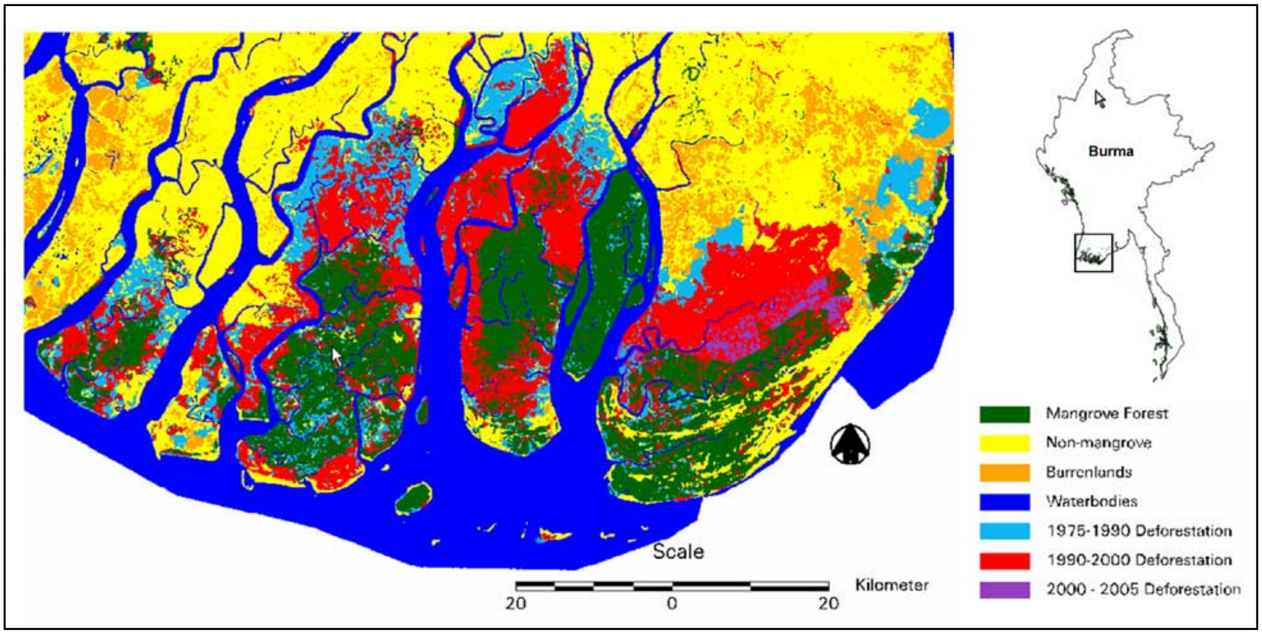

Barnegat Bay Watershed
LAND COVER
1972
Developed Land
Cultivated / Grassland
Forested Land
Bare Land
Freshwater Wetland
Salt Marsh
Water
Barnegat Bay
Little Egg Harbor
Garden State Parkway
Miles
CRSSA map, May 2000
Barnegat Bay Watershed
LAND COVER
1984
Developed Land
Cultivated / Grassland
Forested Land
Bare Land
Freshwater Wetland
Salt Marsh
Water
CRSSA map, May 2000
Barnegat Bay Watershed
LAND COVER
1995
Developed Land
Cultivated / Grassland
Forested Land
Bare Land
Freshwater Wetland
Salt Marsh
Water
CRSSA map, May 2000

Figure 18.



Pecan Island
Rockefeller Refuge
Freshwater Bayou
Loss
Gain
Land
Water
No Data
-2 -1 0 2 km
- 2 - 1 0 2 miles
N

Figure 19.


Burma
Mangrove Forest
Non-mangrove
Barrenlands
Waterbodies
1975-1990 Deforestation
1990-2000 Deforestation
2000 - 2005 Deforestation
Scale
20
0
20
Kilometer

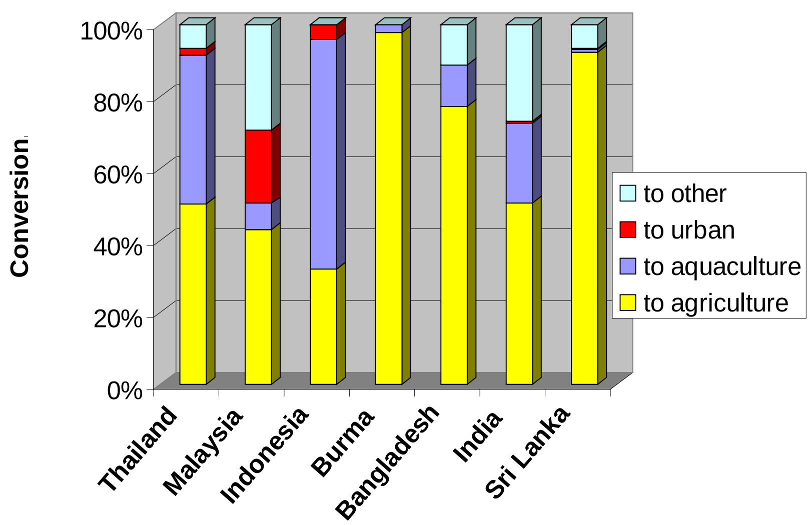
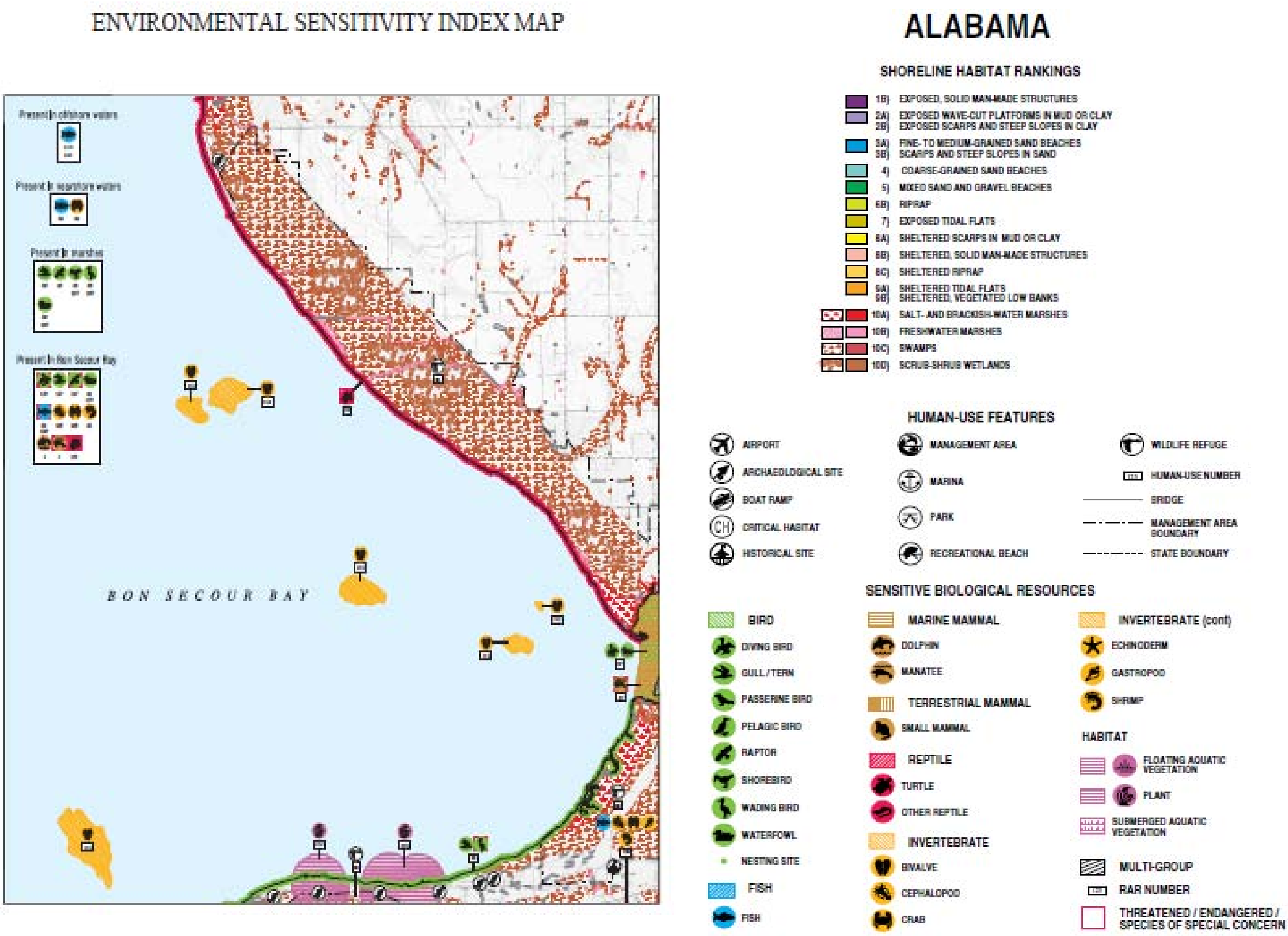

Conversion
100%
80%
60%
40%
20%
0%
Thailand
Malaysia
Indonesia
Burma
Bangladesh
India
Sri Lanka
to other
to urban
to aquaculture
to agriculture

Figure 20.



ENVIRONMENTAL SENSITIVITY INDEX MAP
ALABAMA
Present in offshore waters
Present in nearshore waters
Present in marshes
Present in Bon Secour Bay
BON SECOUR BAY
SHORELINE HABITAT RANKINGS
1B) EXPOSED, SOLID MAN-MADE STRUCTURES
2A) EXPOSED WAVE-CUT PLATFORMS IN MUD OR CLAY
2B) EXPOSED SCARPS AND STEEP SLOPES IN CLAY
3A) FINE- TO MEDIUM-GRAINED SAND BEACHES
3B) SCARPS AND STEEP SLOPES IN SAND
4) COARSE-GRAINED SAND BEACHES
5) MIXED SAND AND GRAVEL BEACHES
6B) RIPRAP
7) EXPOSED TIDAL FLATS
8A) SHELTERED SCARPS IN MUD OR CLAY
8B) SHELTERED, SOLID MAN-MADE STRUCTURES
8C) SHELTERED RIPRAP
9A) SHELTERED TIDAL FLATS
9B) SHELTERED, VEGETATED LOW BANKS
10A) SALT- AND BRACKISH-WATER MARSHES
10B) FRESHWATER MARSHES
10C) SWAMPS
10D) SCRUB-SHRUB WETLANDS
HUMAN-USE FEATURES
AIRPORT
ARCHAEOLOGICAL SITE
BOAT RAMP
CRITICAL HABITAT
HISTORICAL SITE
MANAGEMENT AREA
MARINA
PARK
RECREATIONAL BEACH
WILDLIFE REFUGE
HUMAN-USE NUMBER
BRIDGE
MANAGEMENT AREA BOUNDARY
STATE BOUNDARY
SENSITIVE BIOLOGICAL RESOURCES
BIRD
DIVING BIRD
GULL / TERN
PASSERINE BIRD
PELAGIC BIRD
RAPTOR
SHOREBIRD
WADING BIRD
WATERFOWL
NESTING SITE
FISH
FISH
MARINE MAMMAL
DOLPHIN
MANATEE
TERRESTRIAL MAMMAL
SMALL MAMMAL
REPTILE
TURTLE
OTHER REPTILE
INVERTEBRATE
BIVALVE
CEPHALOPOD
CRAB
INVERTEBRATE (cont)
ECHINODERM
GASTROPOD
SHRIMP
HABITAT
FLOATING AQUATIC VEGETATION
PLANT
SUBMERGED AQUATIC VEGETATION
MULTI-GROUP
RAR NUMBER
THREATENED / ENDANGERED / SPECIES OF SPECIAL CONCERN

Figure 21.

		Recoverability						
		None	Very low (>25 yr.)	Low (>10–25 yr.)	Moderate (>5 -10 yr.)	High (1 - 5 yr.)	Very high (<1 yr.)	Immediate (< 1 week)
Intolerance	High	Very high	Very high	High	Moderate	Moderate	Low	Very low
	Intermediate	Very high	High	High	Moderate	Low	Low	Very Low
	Low	High	Moderate	Moderate	Low	Low	Very Low	NS
	Tolerant	NS	NS	NS	NS	NS	NS	NS
	Tolerant*	NS*	NS*	NS*	NS*	NS*	NS*	NS*
	Not relevant	NR	NR	NR	NR	NR	NR	NR

Figure 22.

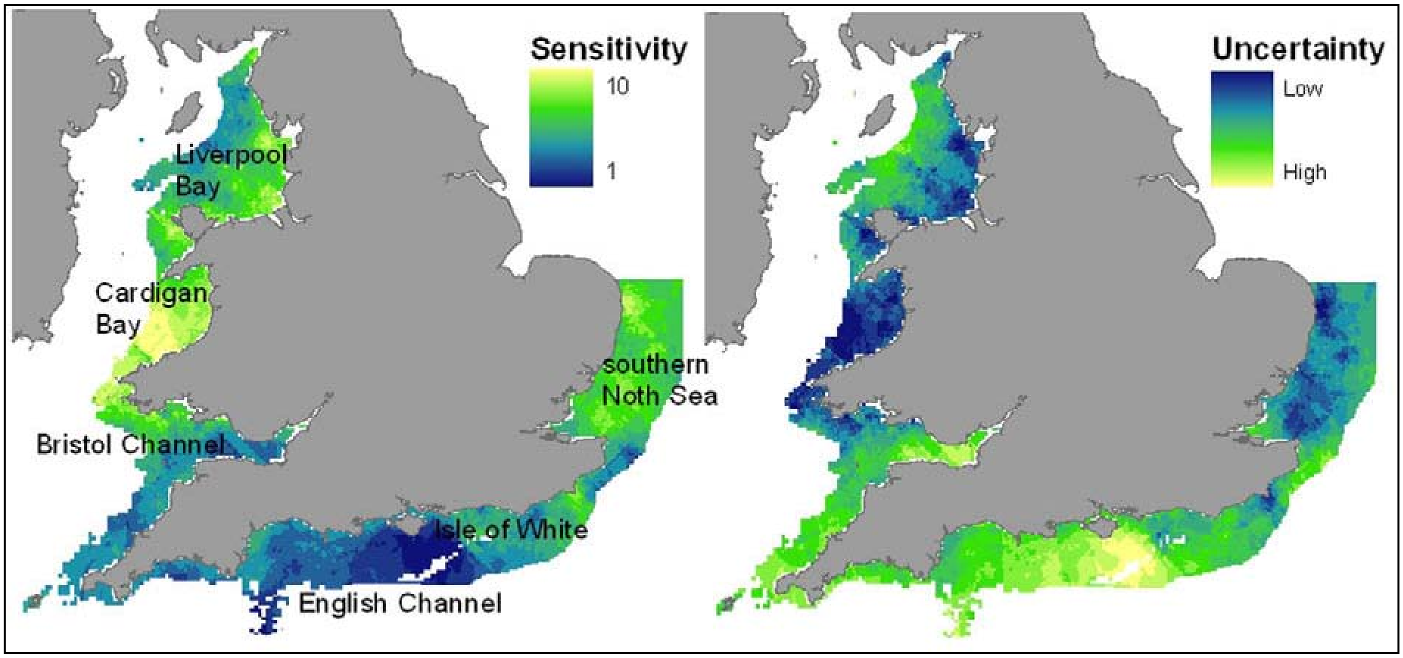

Sensitivity
10
1
Liverpool Bay
Cardigan Bay
Bristol Channel
southern Noth Sea
Isle of White
English Channel
Uncertainty
Low
High

Figure 23.

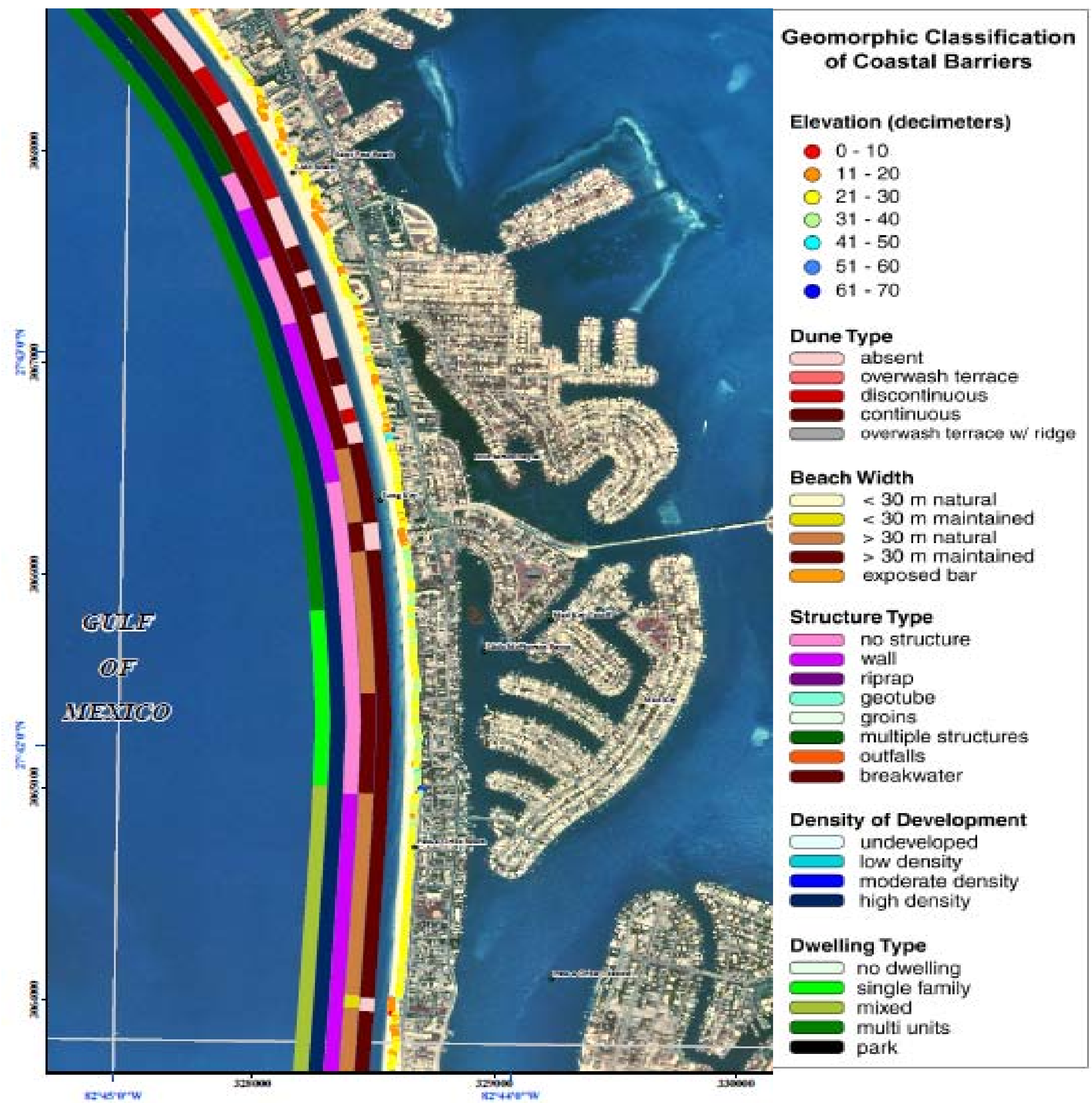

GULF
OF
MEXICO
Geomorphic Classification of Coastal Barriers
Elevation (decimeters)
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
Dune Type
absent
overwash terrace
discontinuous
continuous
overwash terrace w/ ridge
Beach Width
< 30 m natural
< 30 m maintained
> 30 m natural
> 30 m maintained
exposed bar
Structure Type
no structure
wall
riprap
geotube
groins
multiple structures
outfalls
breakwater
Density of Development
undeveloped
low density
moderate density
high density
Dwelling Type
no dwelling
single family
mixed
multi units
park

Figure 24.

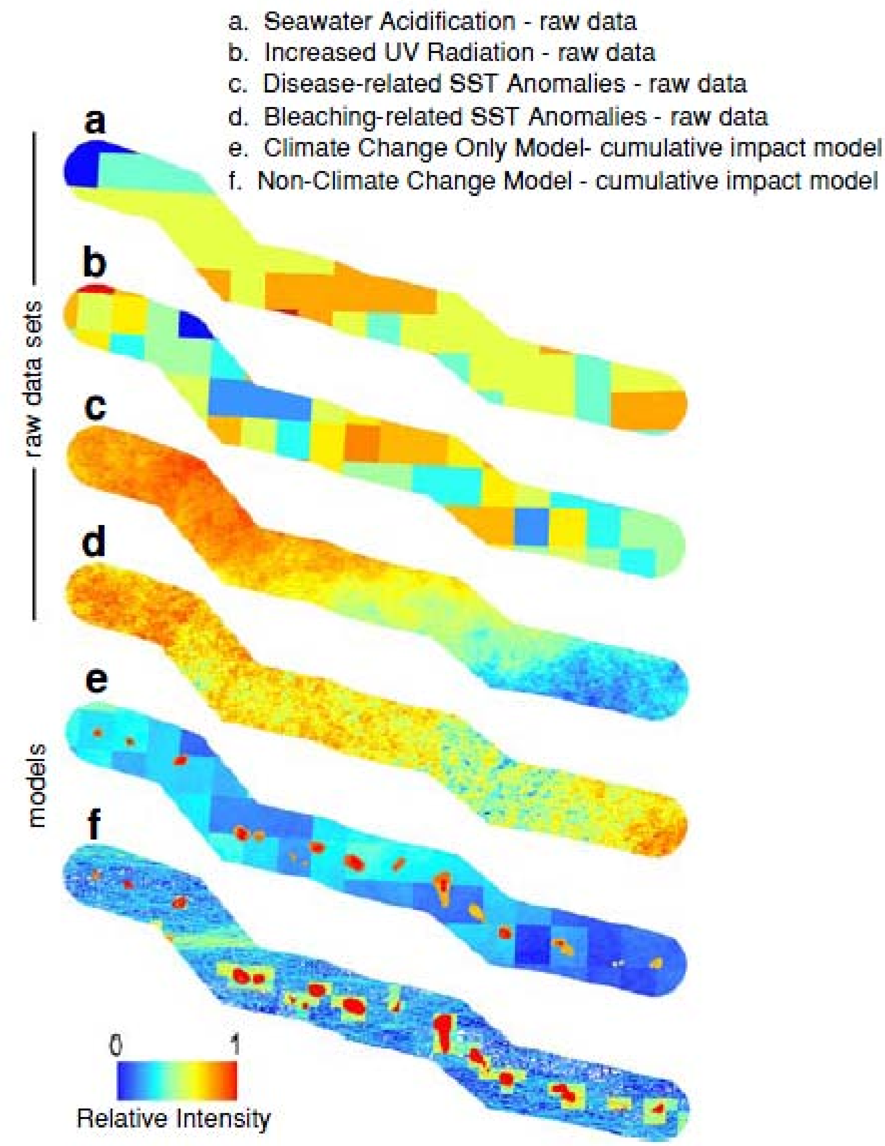

a. Seawater Acidification - raw data
b. Increased UV Radiation - raw data
c. Disease-related SST Anomalies - raw data
d. Bleaching-related SST Anomalies - raw data
e. Climate Change Only Model- cumulative impact model
f. Non-Climate Change Model - cumulative impact model
a
b
c
d
e
f
raw data sets
models
0
1
Relative Intensity

Figure 25.

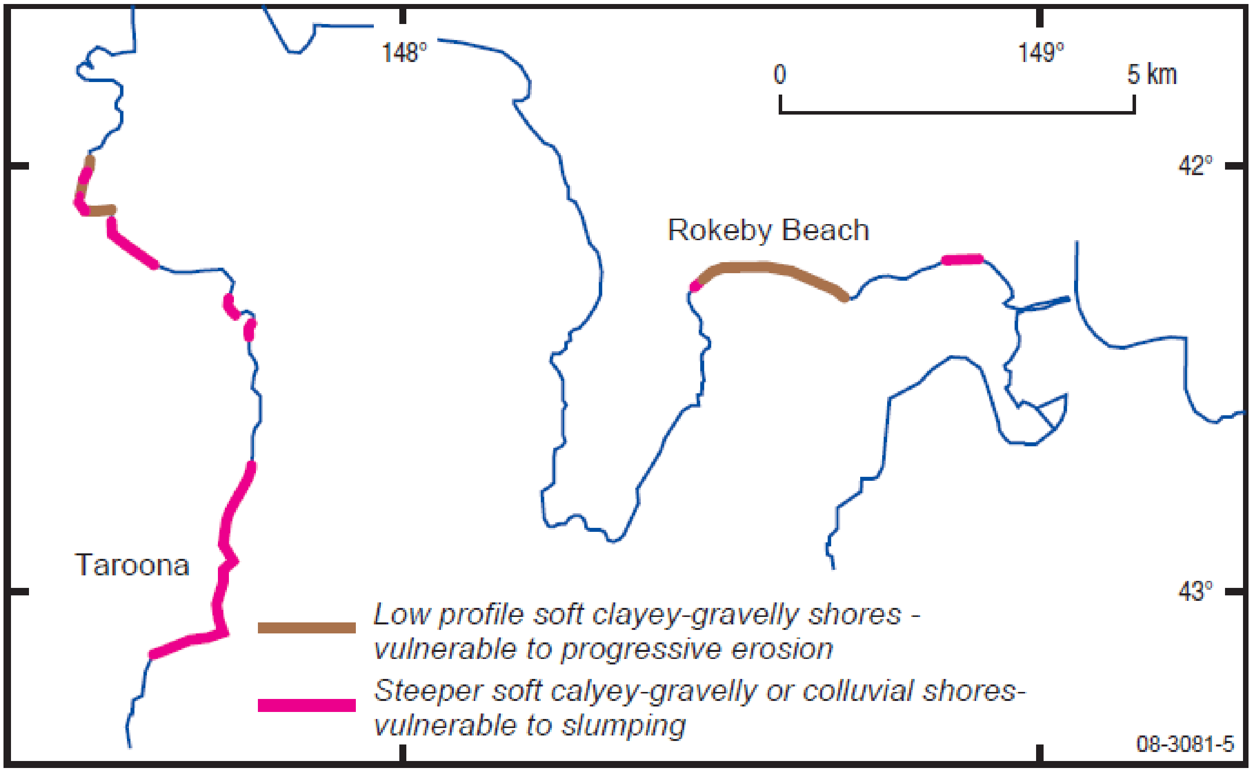
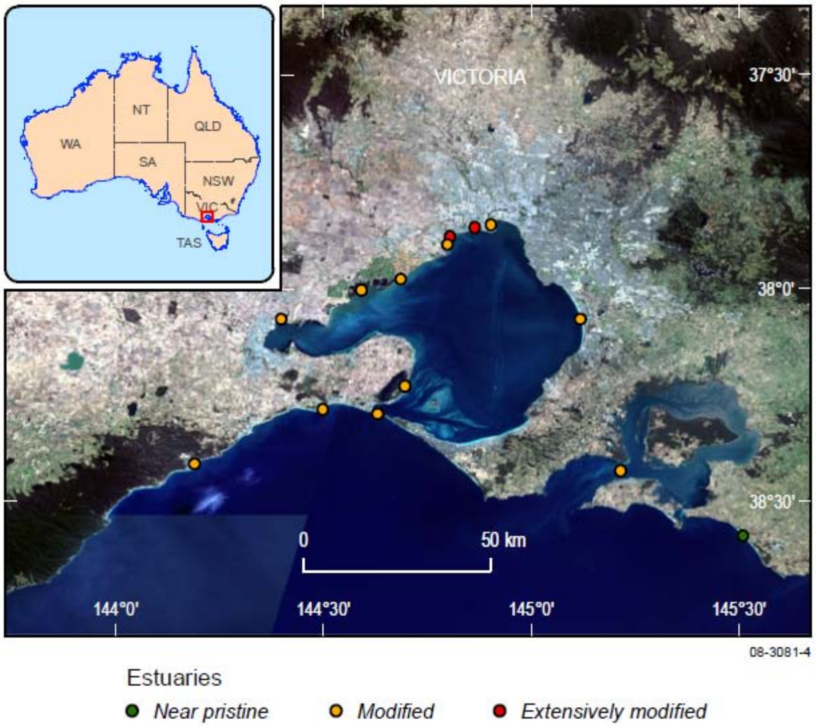
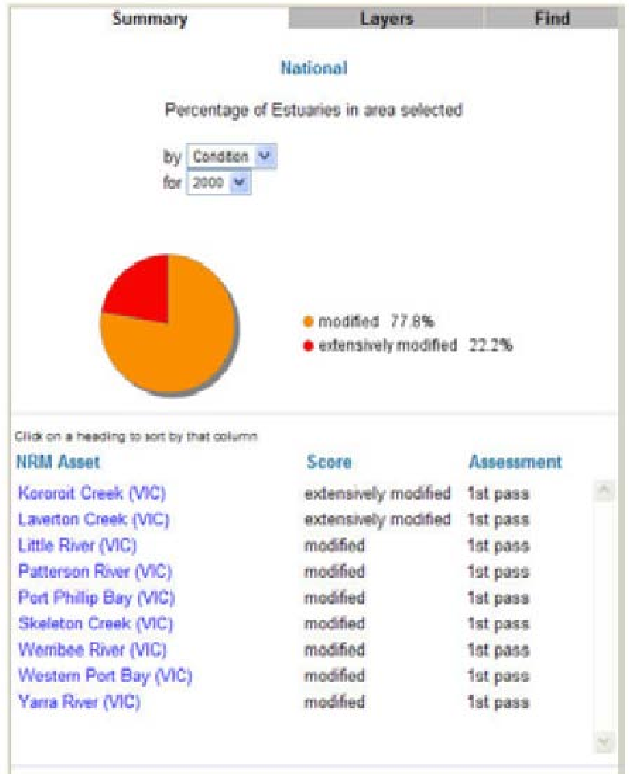

148°
149°
0
5 km
42°
Rokeby Beach
Taroona
43°
Low profile soft clayey-gravelly shores - vulnerable to progressive erosion
Steeper soft calyey-gravelly or colluvial shores- vulnerable to slumping
08-3081-5

Figure 26.

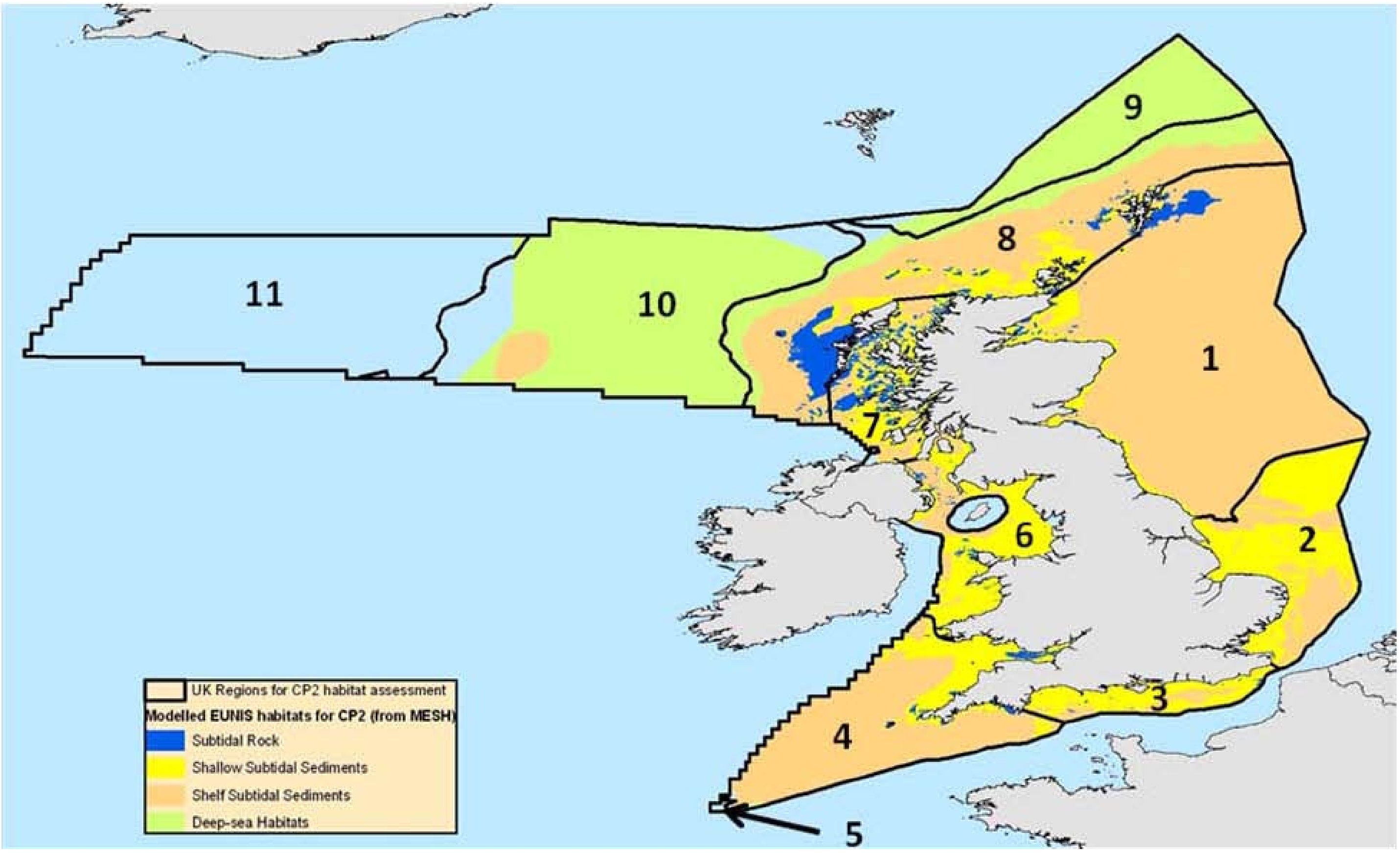


WA
NT
QLD
SA
NSW
VIC
TAS
VICTORIA
37°30'
38°0'
38°30'
0
50 km
144°0'
144°30'
145°0'
145°30'
08-3081-4
Estuaries
Near pristine
Modified
Extensively modified



Summary
Layers
Find
National
Percentage of Estuaries in area selected
by Condition
for 2000
modified 77.8%
extensively modified 22.2%
Click on a heading to sort by that column
NRM Asset
Score
Assessment
Kororoit Creek (VIC) extensively modified 1st pass
Laverton Creek (VIC) extensively modified 1st pass
Little River (VIC) modified 1st pass
Patterson River (VIC) modified 1st pass
Port Phillip Bay (VIC) modified 1st pass
Skeleton Creek (VIC) modified 1st pass
Werribee River (VIC) modified 1st pass
Western Port Bay (VIC) modified 1st pass
Yarra River (VIC) modified 1st pass

Figure 27.



9
8
11
10
1
7
6
2
3
4
5
UK Regions for CP2 habitat assessment
Modelled EUNIS habitats for CP2 (from MESH)
Subtidal Rock
Shallow Subtidal Sediments
Shelf Subtidal Sediments
Deep-sea Habitats

Figure 28.

	Regional Sea	1	2	3	4	5	6	7	8	9	10	11	Overall RANK
Climate change	Climate change	L	L	L	M		L	L	L		VL		10
Hydrological pressures (local)	Temperature changes (local)	VL	VL	VL	VL		VL	VL	VL				14
	Salinity changes (local)	VL	VL	VL	VL		VL	VL	VL				15
	Changes in water flow, wave action & emergence regime (local)	L	VH	H	H		M	VL	VL				3
Pollution & other chemical pressures	Contamination by hazardous substances	L	M	M	M		M	L	L	VL	VL		7
	Radionuclide contamination	VL	VL	VL	VL		VL	VL	VL				17=
	De-oxygenation	VL	VL	VL	VL		L	VL	VL				12
	Nitrogen & phosphorus enrichment	L	M	M	L		L	L	L				8
	Organic enrichment	M	M	M	M		M	L	L				6
Other physical pressures	Electromagnetic changes	VL	VL	VL	VL		VL	VL	VL				13
	Litter	L	L	L	L	L	L	L	L	L	L	L	11
	Underwater noise	VL	VL	VL	VL		VL	VL	VL				17=
	Barrier to species movement												21=
	Death or injury by collision	VL	VL	VL	VL		VL	VL	VL				17=
Physical changes	Siltation rate changes	M	M	M	M	VL	M	L	M	L	L	L	5
	Physical damage	VH	VH	H	VH	VL	VH	H	VH	L	VH	VL	2
	Physical loss	M	H	M	M	VL	M	L	M	VL	H	VL	4
Biological pressures	Visual disturbance												21=
	Genetic modification	VL	VL	VL	VL		VL	VL	VL				16
	Introduction of microbial pathogens		VL		VL		VL	VL					20
	Introduction of non-indigenous species & translocations	L	M	M	M		VL	VL	VL				9
	Removal of species (target & non-target)	VH	VH	H	VH	VL	VH	H	VH	L	VH	VL	1

Cumulative impact across all 6 habitats, per Regional Sea	Very high (>50)	High (25-<50)	Moderate (10-<25)	Low (1-<10)	Very low (<1)	Negligible impact (0)

Figure 29.

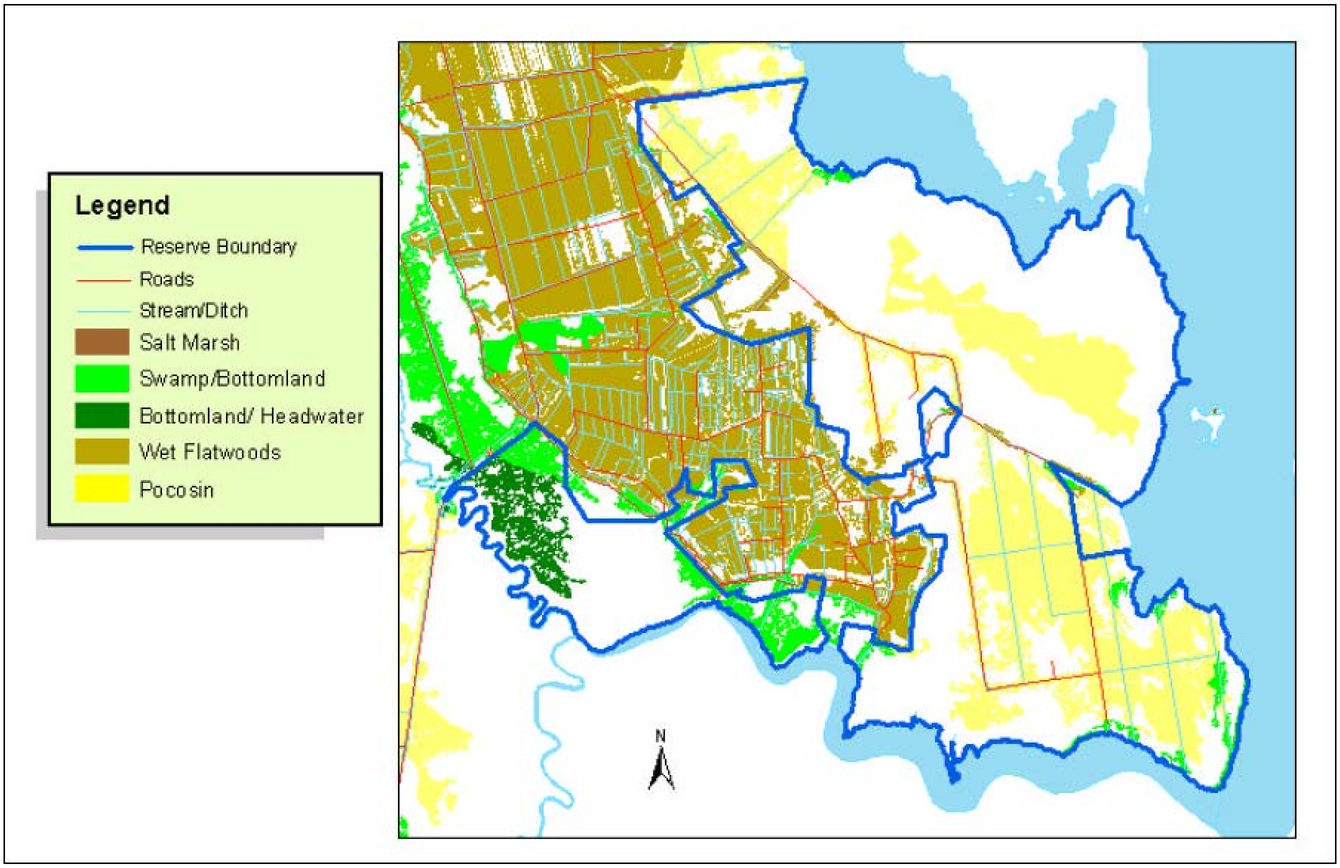
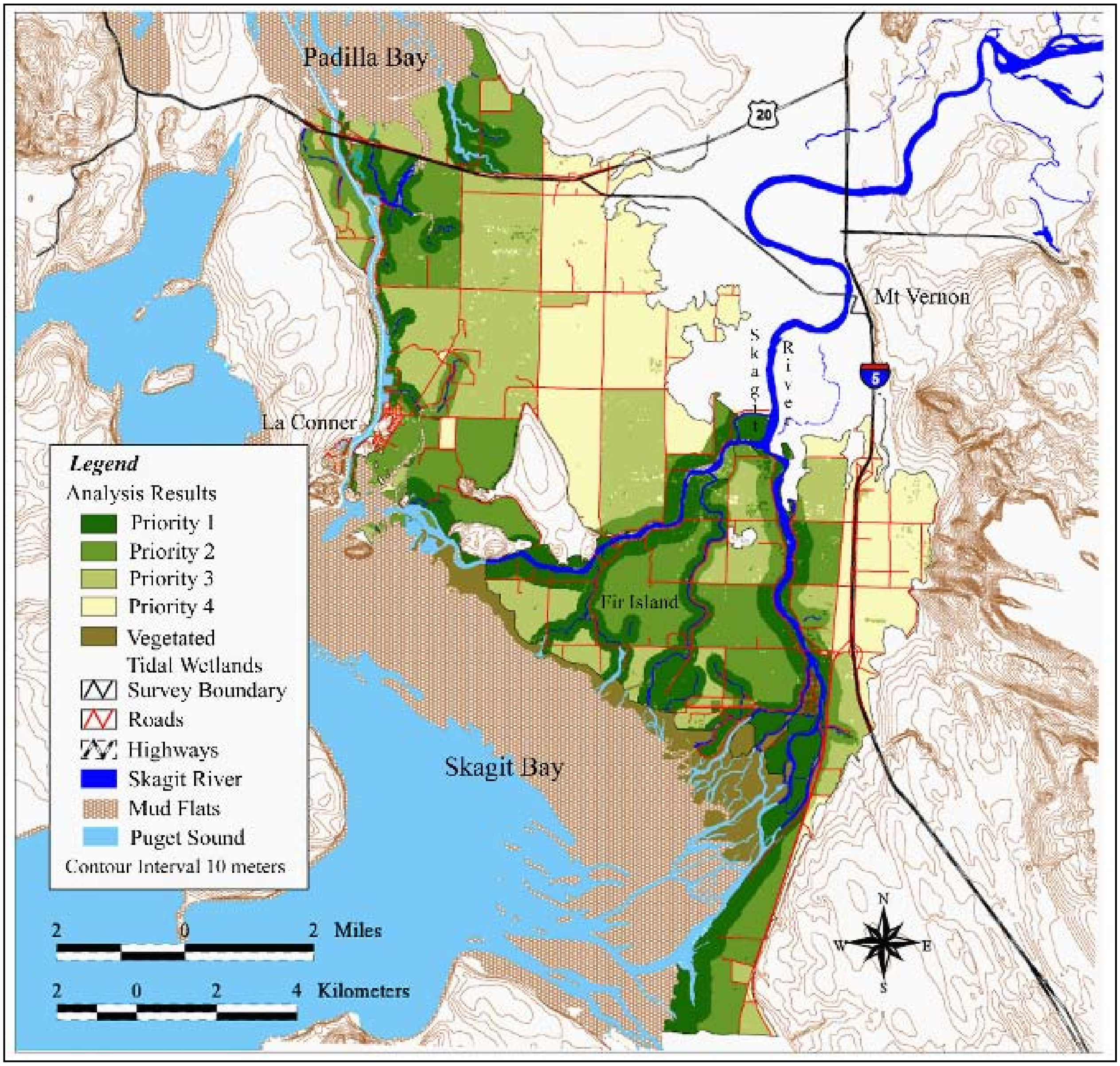
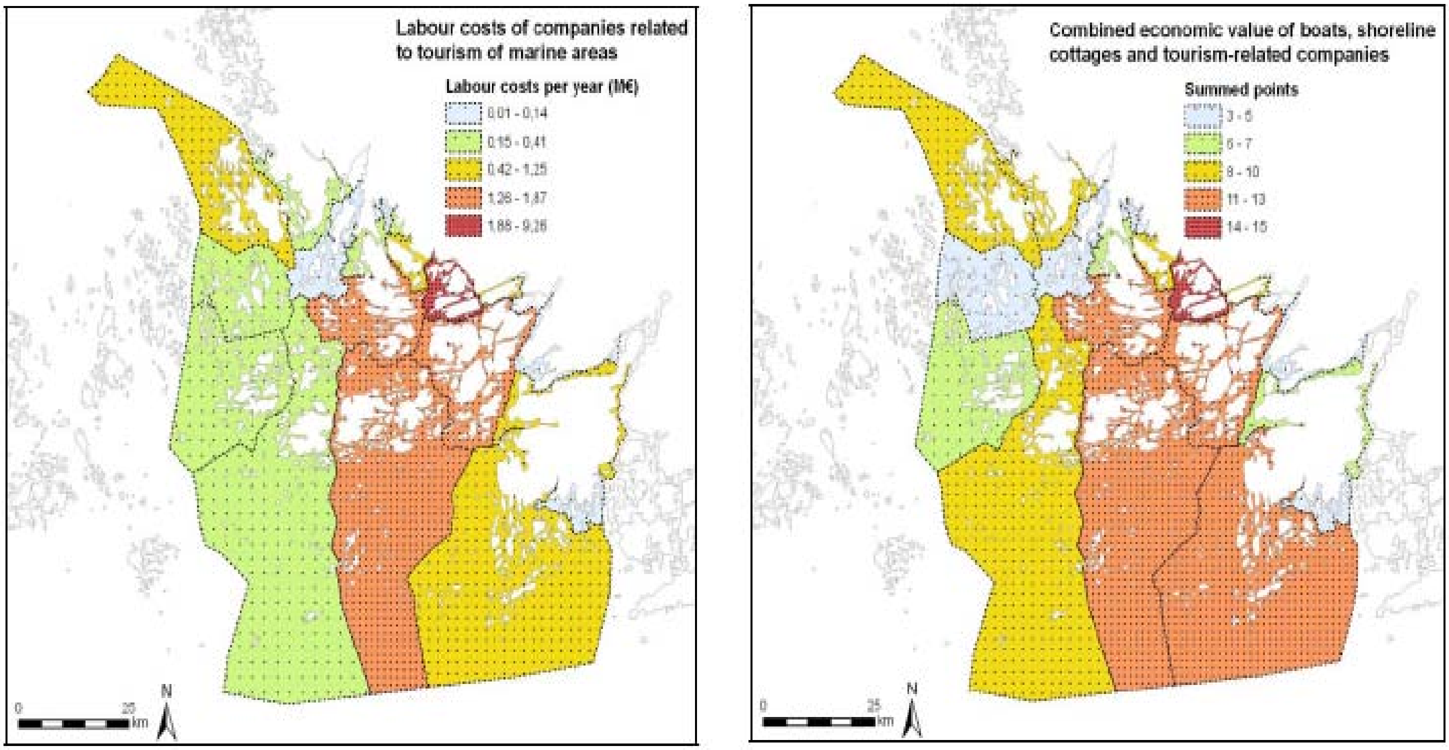

Legend
Reserve Boundary
Roads
Stream/Ditch
Salt Marsh
Swamp/Bottomland
Bottomland/ Headwater
Wet Flatwoods
Pocosin
N

Figure 30.



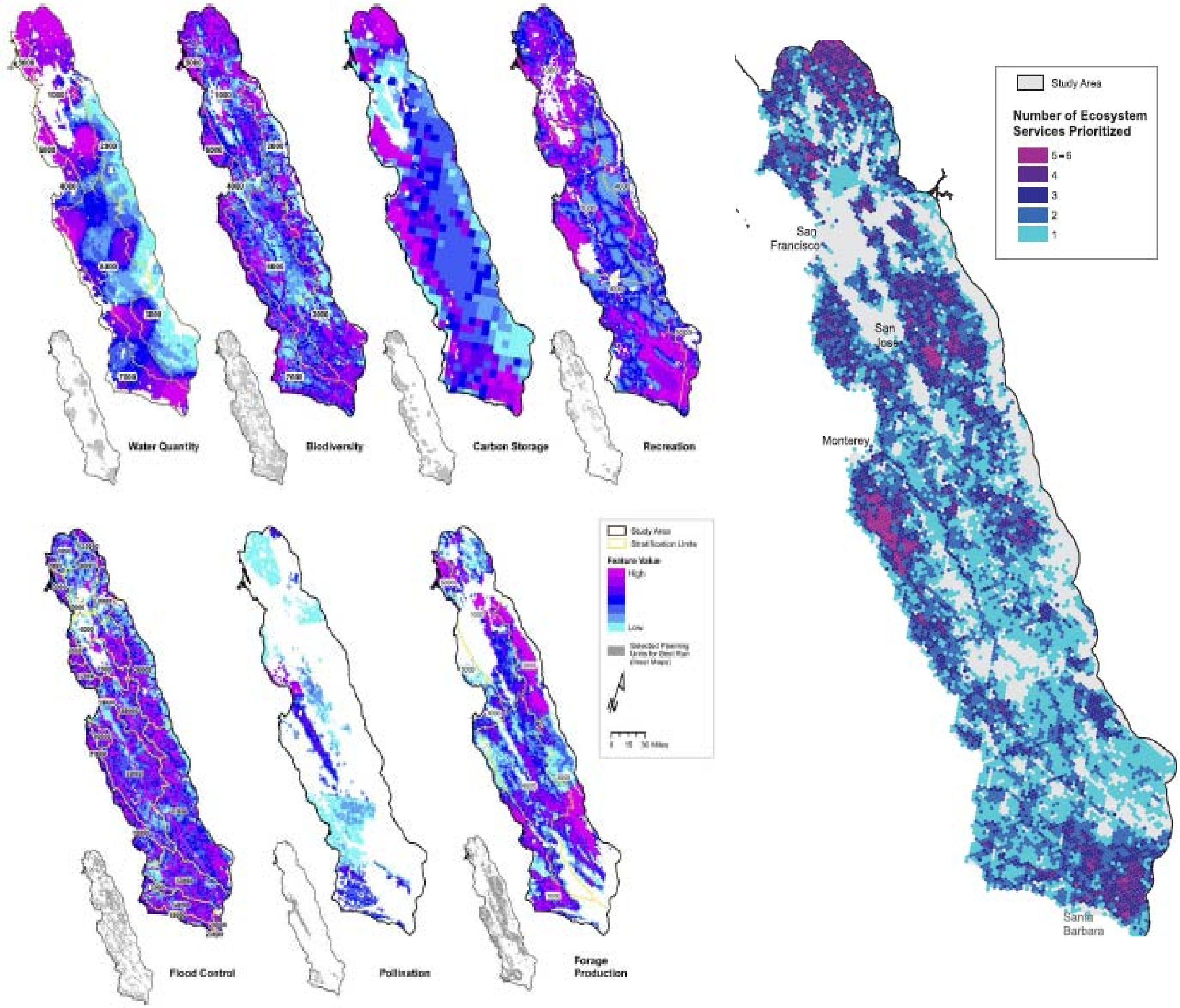
Padilla Bay
20
Mt Vernon
Skagit River
5
La Conner
Fir Island
Skagit Bay
Legend
Analysis Results
Priority 1
Priority 2
Priority 3
Priority 4
Vegetated Tidal Wetlands
Survey Boundary
Roads
Highways
Skagit River
Mud Flats
Puget Sound
Contour Interval 10 meters
2 0 2 Miles
2 0 2 4 Kilometers
N
W
E
S

Figure 31.



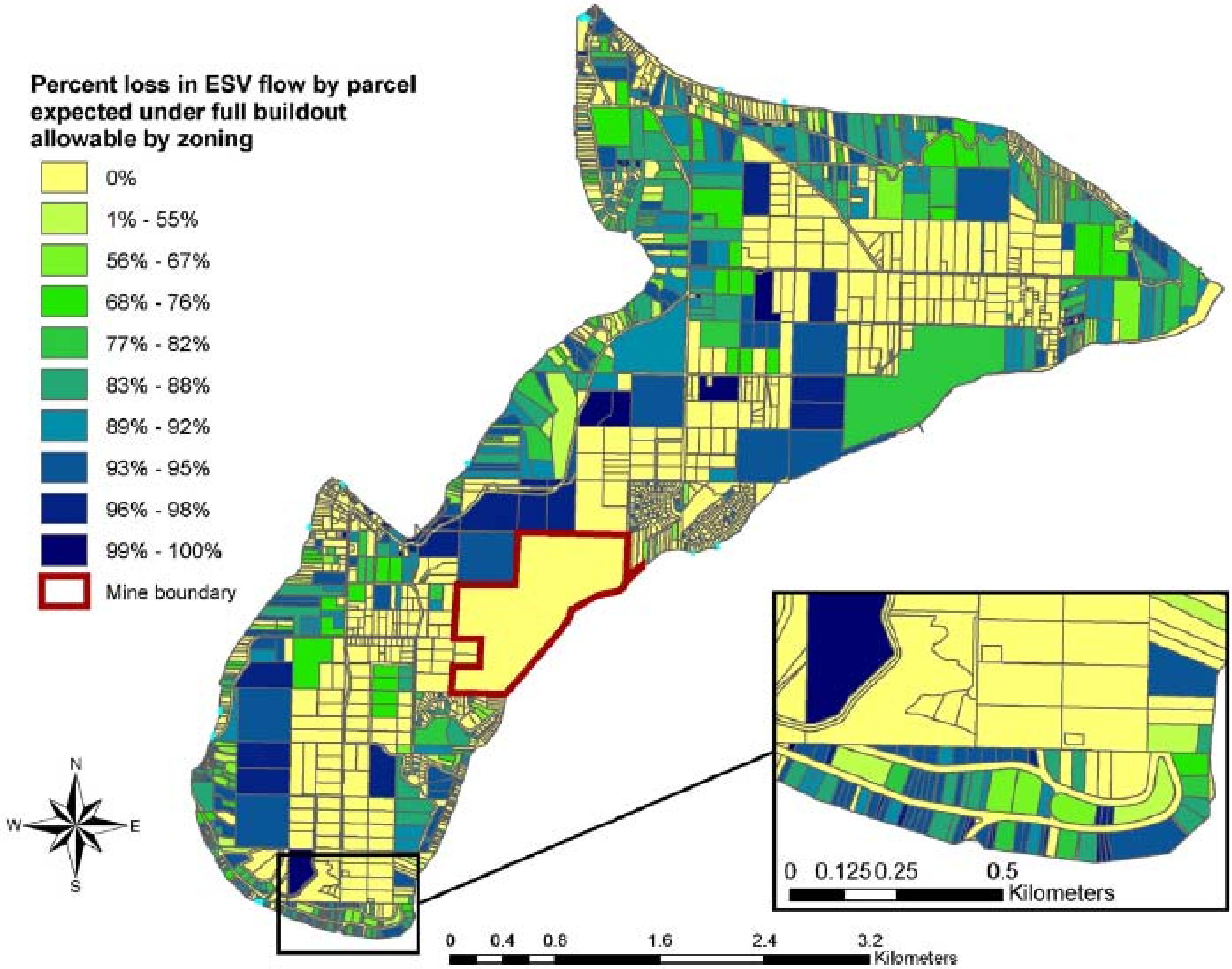
Labour costs of companies related to tourism of marine areas
Labour costs per year (M€)
0,01 - 0,14
0,15 - 0,41
0,42 - 1,25
1,26 - 1,87
1,88 - 9,26
0
25
km
N
Combined economic value of boats, shoreline cottages and tourism-related companies
Summed points
3 - 5
6 - 7
8 - 10
11 - 13
14 - 15
0
25
km
N

Figure 32.



Water Quantity
Biodiversity
Carbon Storage
Recreation
Flood Control
Pollination
Forage Production
Study Area
Feature Value
High
Low
Study Area
Number of Ecosystem Services Prioritized
5 - 6
4
3
2
1
San Francisco
San Jose
Monterey
Santa Barbara

Figure 33.



Percent loss in ESV flow by parcel expected under full buildout allowable by zoning
0%
1% - 55%
56% - 67%
68% - 76%
77% - 82%
83% - 88%
89% - 92%
93% - 95%
96% - 98%
99% - 100%
Mine boundary
N
W
E
S
0 0.4 0.8 1.6 2.4 3.2
Kilometers
0 0.125 0.25 0.5
Kilometers