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A Framework for Identifying Appropriate Sub-Regions for Ecosystem-Based Management in Northern Gulf of Mexico Coastal and Marine Environments

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A framework for identifying appropriate sub-regions for Ecosystem-Based Management in Northern Gulf of Mexico coastal and marine environments

By

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A framework for identifying appropriate sub-regions for Ecosystem-Based Management in Northern Gulf of Mexico coastal and marine environments

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Nearly half of the population of the United States lives in coastal regions, and millions of visitors from across the nation and world enjoy the coasts every year. Coastal and marine areas provide for recreation, economic activities essential for the financial health of the nation, and vital ecological services. As they provide so many benefits to the U.S., it is vital to protect and preserve the coastal and ocean areas from the increasing, competing demands they are facing. In order to protect and preserve these complex systems, a comprehensive approach incorporating science, engineering, humanities, and social sciences should be taken; this approach is commonly referred to as Ecosystem-Based Management.

This dissertation focuses on developing a framework that can be used to identify appropriate sub-regions in Northern Gulf of Mexico coastal and marine environments for the purposes of Ecosystem-Based Management. Through this work, the roles of three management protocols used for managing coastal areas – coastal and marine spatial planning, ecosystem-based management, and integrated ecosystem assessment – were examined individually as well as their integrations with each other. Biological, ecological, physical, human, and economic indicators for partitioning an ecosystem were developed and weighted for each management protocol using the analytic hierarchy process and expert elicitation. Using the weighted indicators, a framework for identifying sub-regions and estuarine classification system was developed. The framework and classification system were applied to five estuaries within the Northern Gulf of Mexico: Barataria, Galveston, Mobile, and Perdido Bays and Mississippi Sound.

Initial results from this work show that:

1. Sub-regions can be identified as associated to each other based upon indicator data values and not upon physical location.
2. Even though the weights calculated for the management protocols vary significantly, for systems that were not highly homogeneous in indicator data values, the different weights did not produce the vastly different cluster maps expected.
3. The scale work indicates that to identify appropriate sub-regions using the developed framework, a larger grid size produces more consistent results for larger systems whereas a smaller grid size produces more consistent results for smaller systems.

Recommendations for further research are also presented.

DEDICATION

I would like to dedicate this dissertation to my husband, Brett Ziegler; my parents, Jim and Denise Sloan; and my siblings, Liz and Sam Presley, Katie Sloan, and Anell and Howard Wright. I would have never made it this far without your love and support.

To Sandra Ortega-Achury, John Ramirez-Avial, and Santiago Ramirez-Ortega; Brittany Gunkle; Evan Howlett; Michael Littrell; Emily Smith; and many more – thanks for keeping me sane and dragging me away from my computer when I needed a break!

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GLOSSARY OF TERMS

ADEM	Alabama Department of Environmental Management
AHP	analytical hierarchical process
BTNEP	Barataria-Terrebonne National Estuary Program
CAS	complex adaptive systems
CCMA	center for coastal monitoring and assessment
CCMP	comprehensive conservation and management plan
CEQ	White House council on environmental quality
CHL	Coastal and Hydraulics Laboratory
Chl a	Chlorophyll A
CI	computational intelligence
CI	consistency index (in AHP)
CMSP	coastal and marine spatial planning
CR	consistency ratio (in AHP)
CSC	Coastal Services Center (under NOAA)
CWA	clean water act
DEP	department of environmental protection (Florida)
DMR	department of marine resources (Mississippi)
DOE	Department of Energy
DPSER	driver, pressure, state, ecosystem service, response

DPSIR	driver, pressure, state, impact, response
DPSSIR	driver, pressure, stressor, state, impact, response
EAM	ecosystem approach to management
EBM	ecosystem based management
EBM TN	Ecosystem Based Management Tools Network
ENOW	Economics: National Ocean Watch
EPA	Environmental Protection Agency
ERDC	Engineering Research and Development Center (Vicksburg, MS)
ESA	endangered species act
FAO	Food and Agriculture Organization (part of UN)
FGDC	Federal Geographic Data Committee
FWS	Fish and Wildlife Service (U.S.)
GBNEP	Galveston Bay National Estuary Program
GDP	gross domestic product
GOMA	Gulf of Mexico Alliance
HRI	Harte Research Institute
IEA	integrated ecosystem assessment
LK	local knowledge
LME	large marine ecosystem
MBNEP	Mobile Bay National Estuary Program
MEA	Millennium Ecosystem Assessment
ML	machine learning
MSE	management strategy evaluation

MSP	marine spatial plan
NEON	national ecological observatory network
NERI	National Environmental Research Institute (Denmark)
NEPA	national environmental policy act
NOAA	National Oceanic and Atmospheric Administration
NOC	National Ocean Council
NOEP	National Ocean Economics Program
NOS	National Ocean Service
NPS	National Park Service
NSF	National Science Foundation
OECD	Organization for Economic Co-operation and Development
OSE	Ocean Service Education (entity of NOAA)
PDCA	plan-do-check-act/adjust cycle or the Deming/Shewhart cycle
PMNM	Papahānaumokuākea Marine National Monument
PI	primary investigator
PSU	practical salinity units
RI	random index (in AHP)
RPB	regional planning body
SBNMS	Stellwagen Bank National Marine Sanctuary
SLOSEA	San Luis Obispo Science and Ecosystem Alliance
SPC	Storm Prediction Center (entity of NOAA)
TKE	traditional ecological knowledge
TN	total nitrogen

TP	total phosphorous
UN	United Nations
UNEP GPA	United Nations Environmental Program, Global Program of Action for the Protection of the Marine Environment from Land-based Activities
WASP	water quality analysis simulation program

CHAPTER I

INTRODUCTION

1.1 Marine and Coastal Environments

Nearly half of the population of the United States of America lives in coastal regions, and millions of visitors from across the nation and world enjoy the coasts every year. Coastal and marine areas provide recreation such as fishing, swimming, boating, and diving. Economic activities essential for the financial health of the nation include commercial fisheries, offshore oil production and the transportation of goods via waterborne routes. These areas provide vital ecological services to the nation including natural protection from floods and storms, essential habitat for animals and plants, and natural water filters to assimilate wastes. The marine environment is a system formed through the interconnection between natural systems on several scales, designed human systems, and social systems. Therefore, a holistic approach is needed to understand the connections that can exist within and between elements of the marine environment, as well as to support policy makers in their decisions.

Oceans are extremely rich and productive ecosystems with characteristics that vary greatly from one area to another. Oceans are not only susceptible to changes within the ecosystem itself, but also to practices on land. Oceans are changing rapidly due to increased stressors such as overfishing, pollution, climate change, and habitat destruction.

As they provide so many benefits to the United States, it is vital to protect and preserve the coastal and ocean areas from the increasing, competing demands they are facing. In order to protect and preserve the oceans, a comprehensive scientific approach should be taken (e.g. Halpern et al, 2012). Not only does the long-term health of the ecosystem need to be examined, but the human benefits and well-being must also be considered. Thus, science and engineering alone are not enough to protect an ecosystem, but social sciences and humanities must be incorporated in the plans to protect the oceans as well.

Not only is wildlife affected by the rapidly changing ecosystem, humans are impacted as well. Governments depend upon oceans for economic and defensive purposes and citizens depend upon oceans and large bodies of water for food and protection from storms. The oceans hold cultural significance or have religious value. As the oceans become increasing vulnerable to changes from increasingly present pressures, the services and benefits governments and citizens expect and rely upon from the oceans change and can be depleted and degraded beyond use (e.g. UN Conference on Sustainable Development, 2011; Sherman and Duda, 1999).

Scientists, engineers, law makers, policy makers, and stakeholder groups from numerous sectors have all acknowledged the essential services coastal and ocean areas provide to the United States (for example provisioning services, regulating services, cultural services, and supporting services (National Research Council, 2011)). As such, multiple ecosystem assessment protocols have been established in order to measure the health of the ecosystem and then form and implement management schemes to protect the region. Different management schemes place emphasis upon not only different coastal areas (estuaries versus continental shelf, etc.), but also upon different services the management scheme hopes to provide as an outcome.

Sound scientific knowledge is the basis for all of the ecosystem assessment protocols that will be discussed; as it can improve the current understanding we have of ocean systems and help inform decision-makers about choices for oceans. Because oceans are affected by not only what happens in them, but what also happens on the terrain surrounding them, holistic approaches are necessary to understand exactly what is affecting the oceans and what steps and actions need to be taken in order to create a more sustainable ecosystem.

While traditional approaches to ecosystem management focus upon a specific problem, desired result, or activity (the most common example is fisheries management), holistic ecosystem approaches need to be developed, implemented, and regulated in order to find a way to create a more sustainable ecosystem. While it has been recognized (Slocombe, 1993; Slocombe, 1998; Sherman and Duda, 1999; Lawrence, Kenchington, and Woodley, 2002; McLeod et al., 2005; Halpern et al., 2008; Lubchenco and Petes, 2009; White House Council on Environmental Quality, 2010; Christensen, et al., 2012) that more holistic and integrated approaches to coastal and ocean management are needed, there are few specific guidelines for these approaches, and both policy and practice need to be considered.

When developing holistic, integrated approaches to marine management, it is imperative to note that neither humans nor the ecosystem are more important than the other, but both are dependent on each other. Ecosystem-based management (EBM) is a holistic, integrated approach to marine management protocol that is used to develop, implement, and monitor management plans for coastal and marine environments.

EBM is defined as "[…] an integrated approach to management that considers the entire ecosystem, including humans. The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive, and resilient condition so that it can provide the services humans want and need. Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity, or concern; it considers the cumulative impacts of different sectors" (McLeod et al., 2005). Jane Lubchenco, former NOAA Administrator, has said that "ecosystem-based management, also called 'the ecosystem approach,' is beginning to consider the interdependencies, to integrate the collective activities, and to consider the cumulative impacts of the relevant activities on the ecosystem. Ecosystem-based management provides a mechanism for making decisions about those activities in light of the goal of maintaining (or restoring) the ecosystem in (to) a healthy, productive, and resilient state. In this new approach, the system is the focus. The system sustains the pieces. And, because the sectors are numerous and the drivers of degradation are complex and multiple, solutions must be comprehensive" (Lubchenco and Petes 2009).

The overall goal of applying EBM to marine ecosystems is to sustain the long-term capacity of the ecosystem to deliver services that the public needs. Due to its holistic approach, and unlike management approaches before, EBM requires synthesizing and applying knowledge from across multiple disciplines including natural sciences (biology, chemistry, physics), engineering, and social sciences (economics, socio-economics, policy). While EBM uses sound science from multiple sectors, it depends upon policy and management for setting the bounds within which the process is implemented and for setting the goals that are the hopeful outcome of implementing EBM in an area. As such, EBM provides both a process for policy analysis and action and a framework for the formulation of policy goals and objectives. For the EBM process, it is important to remember that science and engineering are used to help develop and inform the policy and management schemes.

There are multiple protocols that can be used to implement EBM in marine ecosystems. Two of these protocols are integrated ecosystem assessment and coastal and marine spatial planning.

Integrated Ecosystem Assessment (IEA) is “a syntheses and quantitative analysis of information on relevant physical, chemical, ecological, and human processes in relation to specified ecosystem management objectives” (NOAA, 2011) and begins with the identification of a critical management or policy question which helps shape and inform ecosystem management. IEAs provide a process where scientists can work closely with stakeholders and managers to identify management issues and to provide robust decision support information. IEAs integrate diverse ecosystem data to analyze ecosystem and community status relative to a defined issue and then predict a future status based upon forecasts of natural ecosystem variability together with the evaluation of alternative management strategies. Through the process of Integrated Ecosystem Assessment, the benefits and risks of the alternative management actions are evaluated and defined in order to inform stakeholders and managers of the decisions. After a decision is made, there is a continuous evaluation of the alternative management action which then informs the IEA process to allow for adaptive management.

Coastal and Marine Spatial Planning (CMSP) is a "comprehensive, adaptive, integrated, ecosystem-based, and transparent spatial planning process, based on sound science for analyzing current and anticipated uses of ocean, coastal, and Great Lakes areas. Coastal and marine spatial planning identifies areas most suitable for various types or classes of activities in order to reduce conflicts among uses, reduce environmental impacts, facilitate compatible uses, and preserve critical ecosystem services to meet economic, environmental, security, and social objectives. CMSP provides a public policy process for society to better determine how the ocean, coasts, and Great Lakes are sustainably used and protected, now and for future generations" (White House Council on Environmental Policy, 2010).

1.2 Problem: Managing Ecosystems on a Large Scale

In order to implement both IEA and CMSP in the United States, the coastal and marine areas have been broken down by the National Oceanic and Atmospheric Administration (NOAA) into regions based upon physical location. For coastal and marine IEA, the United States is divided into eight areas based upon physical location which are called "regional ecosystems"; the eight regional ecosystems are the Great Lakes Regional Ecosystem, the Gulf of Mexico Regional Ecosystem, the Puerto Rico/Caribbean Regional Ecosystem, the Southeast Regional Ecosystem, the Northeast Regional Ecosystem, the West Regional Ecosystem, the Alaska Complex Regional Ecosystem, and the Pacific Islands Regional Ecosystem (NOAA, n.d.(b)). The National Ecological Observatory Network (NEON) is an effort by the National Science Foundation to monitor and observe the continental United States for and IEA to management and partitions the terrain into "twenty eco-climatic domains, each of which represents different regions of vegetation, landforms, climate, and ecosystem performance" (NSF, 2012). In order to implement CMSP, the nation was divided into nine different regions which are Alaska/Arctic Region, Caribbean Region, Great Lakes Region, Gulf of Mexico Region, Mid-Atlantic Region, Northeast Region, Pacific Islands Region, South Atlantic Region, and West Coast Region (CEQ, 2010).

Although the IEA and CMSP framework divide the coastal and marine areas of the United States into different regions, both frameworks recognize the Gulf of Mexico as a region. However, managing the entire Gulf of Mexico presents a problem in the fact that (a) the area is very large (b) sub-ecosystems exist within the larger marine ecosystem, and (c) it includes territorial waters of the U.S., Mexico, and Cuba. In order to create, implement, and maintain an ecosystem management plan to protect the Gulf of Mexico, individual sub-regions within the larger region need to be identified. After sub-regions are identified based upon physical, biological, economic, social, and management similarities, sub-region ecosystem management plans can be successfully developed and implemented in order to improve and maintain the health of the sub-regions and the larger region as a whole.

In order to define sub-regions within the Gulf of Mexico for ecosystem-based management protocols, research is needed to identify parameters and scales that can be used to create defensible sub-regions for different management protocols.

1.3 Objectives

This research is intended to contribute to ecosystem-based management for coastal and marine ecosystems by developing a systematic process and tool using sound science to classify sub-regions within the Gulf of Mexico appropriate to EBM goals. In order to accomplish this goal, the following sub-objectives are established,

- Parameter matrices and scales will be developed that can be populated and used to identify sub-regions within the Gulf of Mexico.
- A GIS map will be created with different layers representing sub-regions for different EBM protocols.
- A first-level classification of estuaries will be developed based upon the parameters identified that define sub-regions.
- A systematic process for identifying sub-regions within large marine ecosystem other than the Gulf of Mexico will be provided.
- The resulting process will be evaluated by applying the framework to Gulf of Mexico ecosystems and validating the resulting sub-regions using expert opinion.

1.4 Methodology

The research will be developed with the final purpose of creating a process and tool that can be used to identify sub-regions within large marine ecosystems for ecosystem-based management plans. The tools and framework developed are expected to aid engineers, scientists, and policy makers with developing management plans to protect and improve the health of coastal and marine ecosystem within the United States.

Five ecosystems within the Northern Gulf of Mexico will be considered initially to develop and test the tools and framework for this research. These systems are: Perdido

Bay, Florida; Mobile Bay, Alabama; Mississippi Sound, Mississippi; Barataria Bay, Louisiana; and Galveston Bay, Texas.

Using several of these ecosystems, a matrix of properties and sub-properties that are important for ecosystem-based management will be developed as well as scales for each property and sub-property. Each ecosystem will be divided into smaller areas based on data availability and aggregated into larger scale groupings. Using the data for the sub- and super-regions and the scales created, the properties matrix will be populated for each of the regions.

A secondary matrix will be created which will weight each property and sub-property for different ecosystem management approaches. The EBM approaches matrix will be populated from information gathered from EBM expert opinions and the literature.

After the properties matrix and management plan matrix have been fully populated, the management plan matrix will be used to weight the properties matrix for each sub-region resulting in an index number for each location. Once an index number representing the properties and chosen management protocol have been generated for each location, cluster analysis will be used to group similar locations together. After the cluster analysis is completed, the larger region will have been examined as well as broken down into sub-regions based upon the properties of each location and the management schemes used. Expert elicitation will be used to test if the identified management regions identified are valid.

After the matrices and scales are refined, the framework as a whole will be applied to another ecosystem to test the validity of the process and tools developed. Once again, expert opinion will be used to determine if the regions identified are valid.

Using the properties and sub-properties identified in the properties matrix, a first level classification system for estuaries will be produced. The classification system will organize estuaries based upon different features such as system energy, morphology, predominant forcing, and mixing.

CHAPTER II

ECOSYSTEM-BASED MANAGEMENT FOR COASTAL AREAS

2.1 Introduction

As they provide so many benefits to the United States (see Chapter 1), it is vital to protect and preserve the coastal and ocean areas from the increasing, competing demands they are facing. In order to protect and preserve the oceans, a comprehensive approach must be taken. Not only does the long-term health of the ecosystem need to be looked at, but the human benefits and well-being must also be considered. Thus, not only is science and engineering sufficient to protect an ecosystem, but social sciences and humanities need to be incorporated in the plans to protect the oceans as well. While currently considered within most management plans, humanities and social sciences research needs to be continued to further understanding in these fields and incorporation within management plans.

2.2 Background

Oceans are extremely rich and productive ecosystems that can vary greatly from one area to another; in fact, "the coastal ocean encompasses a broad range of saltwater ecosystems, from estuaries and coral reefs to rocky shores and mangrove forests," (National Ocean Service, 2013). Oceans are not only susceptible to changes within the ecosystem itself, but also to practices on land. Oceans are changing due to increased demands upon them and natural and anthropogenic changes within the ecosystem (Sherman and Duda, 1999; NOS, 2013). Ocean ecosystems are becoming depleted due to stressors such as overfishing, pollution, climate change, and habitat destruction (Christensen et al., 1996; Sherman and Duda, 1999; McAnally et al., 2012; NOS, 2013).

Scientists, engineers, law makers, policy making bodies, and stakeholder groups have all acknowledged the essential services coastal and ocean areas provide to the United States (Christensen et al., 1996; McLeod et al., 2005; Halpern et al., 2008; Lubchenco and Petes, 2009; White House Council on Environmental Quality, 2010; Christensen, et al., 2012; McAnally et al., 2012; NOS, 2013). As such, multiple ecosystem assessment protocols have been established in order to measure the health of the ecosystem and then form and implement management schemes to protect the region. While different ecosystem management protocols have the same desired outcome – sustaining ecosystem composition, structure, and function (Christensen et al., 1996) – the different management schemes vary greatly in how the outcome is reached.

Sound scientific knowledge is the basis for all of the ecosystem assessment protocols that will be discussed (Slocombe, 1998; Halpern et al., 2007; Crowder and Elliott, 2008; Douvere, 2008; Gilliland and Lafolle, 2008; Levin et al., 2008 (NMF-NWFSC-92); Levin et al., 2009; Ocean Policy Task Force, 2009; Tallis et al., 2010; White House Council on Environmental Quality, 2010; National Oceanic and Atmospheric Administration, 2011 (NOAA response to SAB/ESMWG Letter). That a sound scientific knowledge is the foundation for ecosystem assessment and management protocols is imperative as it can improve the current understanding we have of ocean systems and help inform decision-makers about choices for oceans.

Because oceans are affected by not only what happens in them, but what also happens in the areas surrounding them, holistic approaches are necessary to understand exactly what is affecting the oceans and what steps and actions need to be taken in order to create a more sustainable ecosystem (NOS, 2013).

2.3 Scope

While traditional approaches to ecosystem management focus upon a specific problem, desired result, or activity (a common example is fisheries management), holistic ecosystem approaches need to be developed, implemented, and regulated in order to find a way to create a more sustainable ecosystem (McLeod et al., 2005; Levin et al., 2009; Lubchenco and Petes, 2009). McLeod et al. say that "[…]ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity, or concern; it considers the cumulative impacts of different sectors," (2005) and Lubchenco and Petes add that ecosystem-based management "is beginning to consider the interdependencies, to integrate the collective activities, and to consider the cumulative impacts of the relevant activities on the ecosystem […] In this *new* approach, the *system* is the focus" (2009). While it has been recognized that more holistic and integrated approaches to coastal and ocean management are needed (Slocombe, 1993; Slocombe, 1998; Sherman and Duda, 1999; Lawrence, Kenchington, and Woodley, 2002; McLeod et al., 2005; Halpern et al., 2008; Lubchenco and Petes, 2009; White House Council on Environmental Quality, 2010; Christensen, et al., 2012), there are few specific guidelines for these approaches as they are so novel, and both policy and practice need to be considered (Lawrence, Kenchington, and Woodley, 2002; Lubchenco and Petes, 2009; Tallis et al., 2010).

Four ecosystem assessment protocols will all be detailed and discussed as holistic, integrated approaches to assess and manage marine ecosystems. The interaction between coastal and marine spatial planning and ecosystem approach to management will be investigated as will numerical models used for ecosystem approach to management. The complexity and scaling issues when dealing with ecosystem based approaches will be discussed.

2.4 Ecosystem Assessment Protocols

In this section, ecosystem approach to management, integrated ecosystem approach, driving forces-pressures-states-impacts-responses, and coastal and marine spatial planning will be detailed, examples of each protocol will be given, and a step-by-step breakdown of each protocol will be described.

2.4.1 Ecosystem Approach to Management

Ecosystem approach to management (EAM) is also called ecosystem-based management (EBM) and is defined as "[…] an integrated approach to management that considers the entire ecosystem, including humans. The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive, and resilient condition so that it can provide the services humans want and need. Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity, or concern; it considers the cumulative impacts of different sectors" (McLeod et al., 2005). Jane Lubchenco has said that "ecosystem-based management, also called 'the ecosystem approach,' is beginning to consider the interdependencies, to integrate the collective activities, and to consider the cumulative impacts of the relevant activities on the ecosystem. Ecosystem-based management provides a mechanism for making decisions about those activities in light of the goal of maintaining (or restoring) the ecosystem in (to) a healthy, productive, and resilient state. In this new approach, the system is the focus. The system sustains the pieces. And, because the sectors are numerous and the drivers of degradation are complex and multiple, solutions must be comprehensive" (Lubchenco and Petes, 2009).

The overall goal of applying EBM to marine ecosystems is to sustain the long-term capacity of the ecosystem to deliver ecosystem services. Due to its holistic approach, and unlike management approaches before, EBM requires synthesizing and applying knowledge from across multiple disciplines including natural sciences (biology, chemistry, physics), engineering, and social sciences (economics, socio-economics, policy) (McLeod et al., 2005). While EBM uses sound science from multiple sectors, it depends upon policy and management for setting the bounds within which the process is implemented and for setting the goals that are the hopeful outcome of implementing EBM in an area. As such, EBM provides both a process for policy analysis and action and a framework for the formulation of policy goals and objectives (Lubchenco and Petes, 2009). For the EBM process, it is important to remember that science and engineering are used to help develop and inform the policy and management schemes.

Rosenberg and Sandifer (2009) identified five principles that guide the development of an ecosystem-based approach to marine management: "1) setting goals that include the full range of ecosystem services, 2) determining the spatial scale for management planning, 3) integrating across sectors of human activities (e.g.

transportation, fisheries, energy production, recreation), 4) accounting for cumulative impacts within and across sectors, and 5) making decisions under uncertainty."

Since the specific objectives and goals of EBM will vary based upon location and the scale at which the management plan is implemented, there is no rigid framework for the process. However, there are steps within the process that experts recognize as vital to making and implementing EBM decisions. Figure 2.1 shows a simple schematic of the EBM process according to EBM Tools (2010) in a layout reminiscent of a do-plan-check-act/adjust (PDCA) or Deming/Shewhart cycle. The first step includes identifying goals and priorities for the management decision. The second step is to collect data to feed into models. The third step is to analyze the data obtained, develop models, and identify different management scenarios for the goals and priorities identified. After the different scenarios are compared, the EBM decision is made and implemented within the ecosystem. The final step is to monitor and assess the results of the implemented management plan. While monitoring and assessment are continuously occurring, the goals and priorities are compared to the assessment. The management plan can be changed after implementation in order to meet the goals and priorities set for the ecosystem. As more and more data become available, the plan can become more refined.

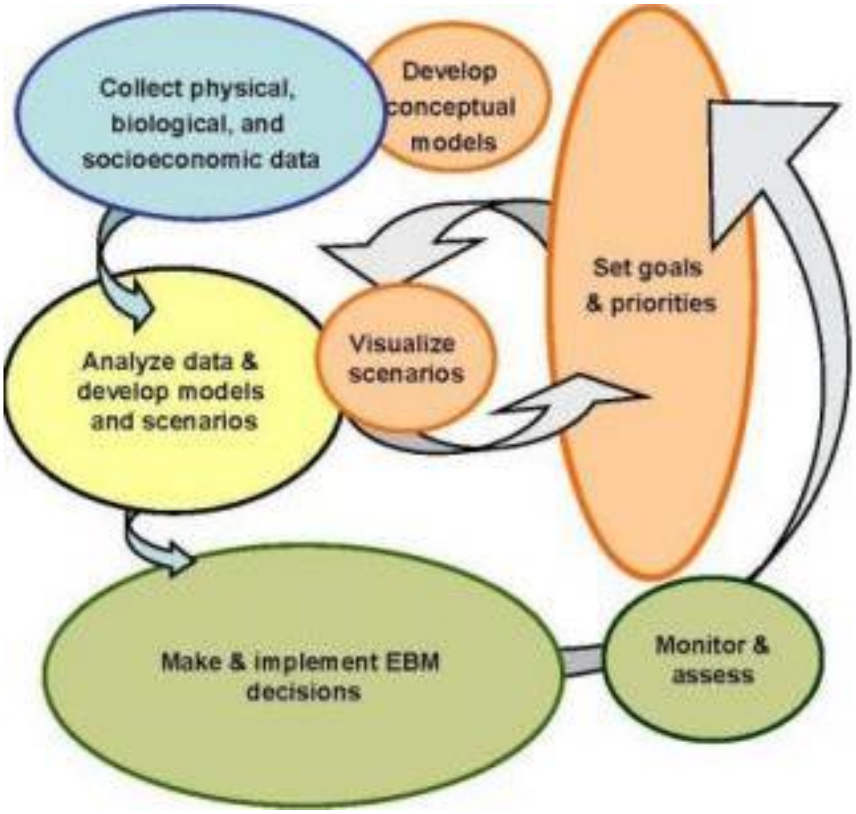


Figure 2.1 Ecosystem-Based Management Schematic (EBM Tools, 2010)

To better understand the principles set forth by Rosenberg and Sandifer (2009), each principle has been defined and described below (paraphrased from Rosenberg and Sandifer, 2009):

1. *Setting goals and priorities:* Setting goals and priorities that need to be achieved within the ecosystem is generally easy. The biggest problem with this step is identifying too many goals and establishing a list of priorities that can be agreed upon. As EBM is a holistic approach, stakeholders from multiple sectors are involved in the goal setting and priority identification step. Because the sectors are competing for the

ecosystem services and resources, getting stakeholders to agree upon *one* priority list can be a challenge. Also, as the number of stakeholders in the process increases, the number of goals also increases as different stakeholder groups bring different views and problems to the table. While this can be a good thing, it is important not to identify too many goals at the outset of developing a management plan, as it can be easy to become overwhelmed with what needs to be done to meet all of the goals identified.

2. *Collecting data:* After the goals have been set, collecting the data needed to model the system to formulate and implement an EBM plan is done. If the goal of the ecosystem were to decrease eutrophication in an estuary, water quality, hydrodynamic, air quality, and other data need to be collected in order to accurately model the system to identify sources and impacts of pollutants. This step is often very time consuming and extremely costly as sometimes multiple seasons or even years of data are needed in order to understand what is occurring in the system.
3. *Developing models and scenarios:* after the data are collected, models of the system can be developed. After the model is validated to the system in which it is being applied, different management scenarios can be applied to the model to see how the ecosystem will react when the pressures exerted on it change.
4. *Make and implement EBM decisions:* The different management scenarios tested within the model can then be used to develop a

management plan. One of the important aspects about this step that is stressed in EBM is the ecosystem services trade-offs that must be evaluated. In order to perform trade-off evaluation, the services provided by the ecosystem must be valued in order to assist in the assessment of trade-offs. The gains associated with converting and using coastal and marine ecosystems must be compared with the resulting services losses associated with converting and using these ecosystems. Not only does ecosystem services valuation aid in assessing the trade-offs of different management scenarios, but it also helps identify the economic "winners" and "losers" and can even help identify ecosystem services that need to be protected under EBM.

5. *Monitoring and assessment:* While this is the last step in the EBM process, it is the most important step. After the EBM plan has been developed and implemented, it is extremely important to continuously monitor the ecosystem to determine if the plan is having the desired effect, if it is harming the ecosystem in unforeseen ways, or if it needs to be changed in order to meet the goals and priorities outlined in step 1. As EBM is recognized as an adaptive management solution, the plan outlined in step 4 does not have to be the final plan implemented in the ecosystem. The monitoring and assessment phase helps scientists, engineers, and policy makers decide if the plan needs to be changed or if it is having the desired effect.

The principle of EBM is based upon three key elements: connections, cumulative impacts, and multiple objectives (Rosenberg and Sandifer, 2009). An important part of EBM is acknowledging connections between marine ecosystems and social systems. It is important to note that the connections between marine ecosystems and social systems occur across multiple scales. For instance (in increasing scale), social systems may include individuals, communities, and cultures; marine ecosystems may include local ecosystems, regional ecosystems, and large marine ecosystems. Large marine ecosystems (LMEs) are “relatively large areas of ocean space of approximately 200,000 km^2 or greater, adjacent to the continents in coastal waters where primary productivity is generally higher than in open ocean space. The LMEs produce about 80% of the annual world’s marine fisheries catch” (NOAA, 2013:) Individuals not only effect the local ecosystem, but the cumulative effects of individuals may affect the regional ecosystem and large marine ecosystem as well; just as the large marine ecosystem provides goods and services to the social systems across all the scales mentioned. Acknowledging these connections and understanding them as well as the ecosystem goods and services that link the marine ecosystems to the social systems is an integral part of EBM (Rosenberg and Sandifer, 2009). Another key element to EBM is understanding and recognizing the cumulative impacts that multiple activities within the ecosystem have on the goods and services the ecosystem is able to deliver (Rosenberg and Sandifer, 2009). As with understanding the EBM connections, understanding cumulative impacts occurs over and between multiple scales, generally scales of management. The final key principle EBM is based upon understanding and acknowledging the multiple objectives facing ecosystems (Rosenberg and Sandifer, 2009). Social systems impose multiple objectives on marine ecosystems such as commercial goods, recreational uses, renewable energy sources, and ecosystem conservation as well as many others. In order for EBM to be fully implemented, the connections among these objectives and drivers need to be understood. Once the multiple objective connections are established, a more comprehensive approach to marine management (EBM) can be developed (Rosenberg and Sandifer, 2009).

In the Final Recommendations of the Interagency Ocean Policy Task Force, the White House Council on Environmental Quality (CEQ) identified the adoption of ecosystem-based management as a foundation for comprehensive management of marine ecosystems as a national priority objective (2010). Further in the document, the CEQ states that "the broad-based application of ecosystem-based management would provide a framework for the management of our resources, and allow for such benefits as helping to restore fish populations, control invasive species, support healthy coastal and Great Lakes communities and ecosystems, restore sensitive species and habits, protect human health, and rationally allow for emerging uses of the ocean, including new energy production" (2010).

Experts have recognized the importance in integrating local ecological knowledge within the management plan (McLeod et al., 2005). In the past, the long-term knowledge within the communities that are within the ecosystem may have been ignored by those developing management plans. Policy makers and scientists have realized the necessity for including this local ecological knowledge within management plans (Kliskey, Alessa, and Barr, 2009). While most of the knowledge that can be gleaned from the communities is not quantitative, experts recognize that having lived in these ecosystems for such a long period of time, communities have an intuitive knowledge about what can work in an area and what cannot work

Kliskey, Alessa, and Barr give an example in Fogo Island, Newfoundland, Canada where traditional ecological knowledge has been used by cod fishers to develop adaptive strategies to deal with “unpredictable seasonal variation in cod abundance and spatial variability in abundance at different fishing grounds” (2009) based upon their long term local knowledge of the area. While the traditional ecological knowledge and local knowledge of the area were used to develop adaptive strategies, they have not been formally introduced into an EBM plan in this area. An example where traditional ecological knowledge and local knowledge are being used in conjunction with a formal EBM plan is in the Papahānaumokuākea Marine National Monument off of the Northwestern Hawaiian Islands (Kliskey, Alessa, and Barr, 2009). Papahānaumokuākea Marine National Monument was established in 2006 by Presidential Proclomation 8031 (2006). Since its establishment, the native Hawaiian community on the island has actively participated in the management of Papahānaumokuākea Marine National Monument. A “Native Hawaiian working group” made up of Hawaiian cultural experts has been established and is a part of the monument management board. The working group is responsible for “representing and advocating for Native Hawaiian culture” and its integration into the management plans for Papahānaumokuākea Marine National Monument (Kliskey, Alessa, and Barr, 2009).

One of the biggest obstacles policy makers faced when trying to implement the EBM process was if the legal jurisdiction and framework currently existed for EBM to be implemented. Policy makers, scientists, and practitioners generally agree that the knowledge and tools needed to move toward EBM in marine ecosystems exist within the current legal environment (Jones and Ganey, 2010). Current laws such as the Magnuson-Stevens Act (fisheries management), the Endangered Species Act (protected species management), and the National Environmental Policy Act (requires environmental impact statements for all major federal actions that may affect the quality of the human environment) are just a few of the laws currently in place that can be used as a legal basis for application of EBM as a tool to manage marine ecosystems. To add even more standing to the implementation of EBM, both the Pew Oceans Commission and the US Commission on Ocean Policy concluded that the nation would benefit from an enactment of a national ocean policy that would establish a framework for managing marine ecosystems, and in 2010 the White House Council on Environmental Quality published the Final Recommendations of the Interagency Ocean Policy Task Force where EBM is listed as the first national priority objective to protect and preserve the oceans.

To date, EBM has been successfully implemented in multiple areas in North America including Morro Bay, California (Wendt, Pendelton, and Maruska, 2009); Puget Sound, Washington (Ruckelshaus, Essington, and Levin, 2009); The Gulf of California, Mexico (Ezcurra et al., 2009); the Eastern Scotian Shelf, Canada (O'Boyle and Worcester, 2009); and Chesapeake Bay, Virginia (Boesch and Goldman, 2009).

While the development and implementation of EBM are relatively new and there is still much to learn, the examples above show that EBM can work – and on multiple spatial scales. However, creating and implementing EBM plans in these areas did not come without a lot of work, some glitches, and lessons to be learned. In Morro Bay, California, the San Luis Obispo Science and Ecosystem Alliance (SLOSEA) was the organization in charge of creating EBM plans in the area. Based upon SLOSEA's experience, there were three main lessons to be learned: 1) "since EBM necessarily focuses on management of the cumulative impacts of multiple activities on ecosystem services, implementation of this approach requires a governance structure that effectively integrates agencies and jurisdictions. Institutional fragmentation in Morro Bay makes this integration a challenge"; 2) "to be effective, this regional ecosystem-based management program needs to have the authority to craft policies and regulations within the ecosystem region"; and finally, "as a relatively localized EBM effort, SLOSEA needs to connect to management efforts at a broader geographic scale[…]. Otherwise, EBM efforts on the local scale in Morro Bay may be overwhelmed by ecological and institutional changes at larger geographic scales" (Wendt, Pendelton, and Maruska, 2009). From the Puget Sound EBM, one of the most important lessons learned was that a "range of ecological processes in management scenarios and models can change forecasted policy outcomes; more holistic views of the ecosystem – especially including land – sea linkages and their impacts on indicators – produce a richer range of policy options and outcomes than do simpler plans" (Ruckelshaus, Essington, and Levin, 2009). While the lessons learned about governance and policies from developing and implementing EBM on the Eastern Scotian Shelf, Canada are not necessarily useful in the US, a few of the lessons learned are quite valid. One of these lessons is that it is important to remember that EBM manages the actions of people, not the actions of the ecosystem. Another lesson is that a "hierarchical objectives structure – with overarching national objectives at the top, area-based objectives in the middle, and more detailed sector-based operation objectives at the bottom – have been useful at a number of scales" (O'Boyle and Worcester, 2009). While temporal and spatial scales can pose a problem to EBM plans (Chapter 3), one of the most important lessons learned from the Eastern Scotian Shelf EBM is that “regarding management, actions are being undertaken at different spatial scales […]. Certainly, a mixture of spatial management tools and best practices will be required, initially working with what exists and building from there. […] EBM on the Scotian Shelf appears to be moving in the right direction” (O’Boyle and Worcester, 2009).

2.4.2 Integrated Ecosystem Assessment

Integrated Ecosystem Assessment (IEA) is “a syntheses and quantitative analysis of information on relevant physical, chemical, ecological, and human processes in relation to specified ecosystem management objectives” (NOAA, 2011a) and begins with the identification of a critical management or policy question which helps shape and inform ecosystem management. IEAs provide a process where scientists can work closely with stakeholders and managers to identify management issues and to provide robust decision support information. IEAs integrate diverse ecosystem data to analyze ecosystem and community status relative to a defined issue and then predict a future status based upon forecasts of natural ecosystem variability together with the evaluation of alternative management strategies. Through the process of Integrated Ecosystem Assessment, the benefits and risks of the alternative management actions are evaluated and defined in order to inform stakeholders and managers of the decisions. After a decision is made, there is a continuous evaluation of the alternative management action which then informs the IEA process to allow for adaptive management.

An IEA consists of identifying key issues that need to be addressed through policy and management; assessing the status, indicators, and trends of the current ecosystem in relation to the management targets; assessing the environmental, economic, and social causes and ramifications of the ecosystem trends; forecasting ecosystem conditions under different scopes of policy and/or management actions; periodic re-evaluation of the effectiveness of the management process chosen relative to emerging ecosystem issues; and identifying crucial knowledge and data gaps that will help guide future research and data acquisition efforts (Levin, et al., 2008).

The overarching goal of the IEA process is to create well-defined ecosystem objectives based on science, as well as to integrate diverse coastal, marine, and Great Lakes data together and think about the way decisions affect the ecosystem and services the ecosystem provides in order to promote ecosystem sustainability under the ever increasing demand placed on the coastal, marine and Great Lakes environments (Levin et al., 2008). IEAs also involve and inform stakeholders and governmental agencies and integrate data collected by federal agencies, states, non-governmental organizations, regional entities, and academic institutions (Levin et al., 2008).

An IEA "uses approaches that determine the probability that ecological or socioeconomic properties of systems will move beyond or return to within acceptable limits as defined by management objectives" (Levin, et al., 2008). IEAs also provide a way to evaluate trade-offs in management strategies among competing ecosystem-use sectors. In order to achieve the goals NOAA has set forth for IEAs and to evaluate management strategies, five steps were identified that now form the IEA process (Levin, et al., 2008). NOAA's IEA framework details the IEA scope, indicator development, risk analysis, assessment of ecosystem status, management strategy evaluation, and monitoring and evaluation (NOAA, 2011b).

1. *Scoping:* This step begins with a review of existing documents and information and ends with stakeholder, resource manager, and policy maker involvement to identify the management objectives, define the ecosystem to be assessed, identify ecosystem attributes of concern, and identify stressors relevant to the ecosystem being examined. Scoping is where broad goals are reduced to specific ecosystem objectives that managers and policy makers need to consider. The scoping process includes working closely with stakeholders and managers to detail priority management issues that need to be addressed through the IEA process where the issues are clearly identified and defined. This step enables the iteration of the IEA process. The scale and scope of the identified issues drive the assessment process. Engagement with stakeholders and mangers begins with the scoping step but continues through the entire process.
2. *Indicator Development*: After the issues and goals are identified, the indicator development step comes in where the goals and indicators are tested and prioritized in order to measure the ecosystem status. The indicator development stage is where researchers develop and test indicators that reflect the ecosystem attributes and stressors identified in the scoping process. Specific indicators are dictated by the identified problems and are linked with decision criteria. In some cases, this means following a species or numerous species. In other cases, the indicator may be a substitute for an ecosystem attribute indicated in the scoping process (e.g. resiliency to perturbation may be an attribute and species diversity

may be an indicator of resiliency) (Levin, et al., 2008). For most problems, numerous indicators are needed. The indicator development step allows the identification of indicators that need to be monitored. The management scenarios are evaluated as are the tradeoffs, the socio-economic implications, and management performances. The key interactions among ecosystem components are considered. The data gaps are identified as are the risks and uncertainties associated with the alternative management scenarios.

3. *Risk Analysis*: After the indicators are identified, a risk analysis is performed. This analysis evaluates the risk human activities and natural processes pose to the indicators. NOAA has set the risk analysis to follow a hierarchical approach that moves from a comprehensive, qualitative analysis to a more focused, semi-qualitative approach, and finally ends with a highly focused, fully quantitative approach. Initially, this step helps filter out potential risks so that more in-depth and quantitative analyses are limited to select ecosystem indicators and threats to those indicators. The goal of this step is to fully explore the susceptibility of an indicator to threats and to the resiliency of the indicator. Another goal of the risk analyses is to explain if new indicator values are due to natural variability or not. This step identifies the relationship between each IEA indicator and the potential threats in order to assess the current state of each risk and the probability that an indicator will reach an identified undesired state. The ecological, economic, and social processes that drive the current

system are considered so that it can be seen how they might change in the future and change the ecological, economic, and social processes.

4. *Overall Ecosystem Assessment*: After a risk analysis is run for each ecosystem indicator, the results are then integrated in the overall ecosystem assessment phase. This assessment quantifies the status of the ecosystem relative to historical status and identified targets. The risk analysis quantifies the status of each ecosystem indicator and the overall ecosystem assessment considers the status of all the ecosystem indicators simultaneously. The interaction between the broad ecosystem components are considered as they were in the risk analysis step. The management strategy evaluation builds on the previous steps to allow for the evaluation of management actions in terms of effectiveness and performance. Assessment of the management action in relation to the targeted elements in the system occurs. Management strategy evaluation also facilitates the analysis for the trade-offs in the plans and provides managers and stakeholders with informed management options. The quantification of the trade-offs among ecosystem services is very important as it can describe the potential trade-offs resulting from current and future management decisions.
5. *Evaluation*: The final step in the IEA framework is monitoring and evaluation using developed ecosystem modeling frameworks to evaluate to what potential different management strategies influence the state of natural and human indicators. In order to accomplish this, a Management

Strategy Evaluation (MSE) is implemented. "In MSEs, a simulation model is used to generate true ecosystem dynamics. Data are sampled from the model to simulate research surveys, then thes data are passed to risk analysis and assessment models. These assessment models estimate the predicted status of individual indicators and the ecosystem as a whole. Based on this assessment of the simulated ecosystem, a management decision is simulated. Human response to this simulated decision is modeled and potentially influences the simulated ecosystem state. By repeating this cycle, the full management cycle can be simulated. This allows the testing of the utility of modifying indicators and threshold levels, assessments, monitoring plans, management strategies, and decision rules," (Levin, et al., 2007). As such, MSEs can filter which policies and methods meet acknowledged management objectives in IEA. After the managers or stakeholders chose a management option they feel is the best approach to the problem, this step allows for the monitoring of the defined indicators to assess the effectiveness of the adaptive management. This step also allows for external peer review and routine updates of the assessments.

Figure 2.2 shows a flow diagram of the five step IEA process.

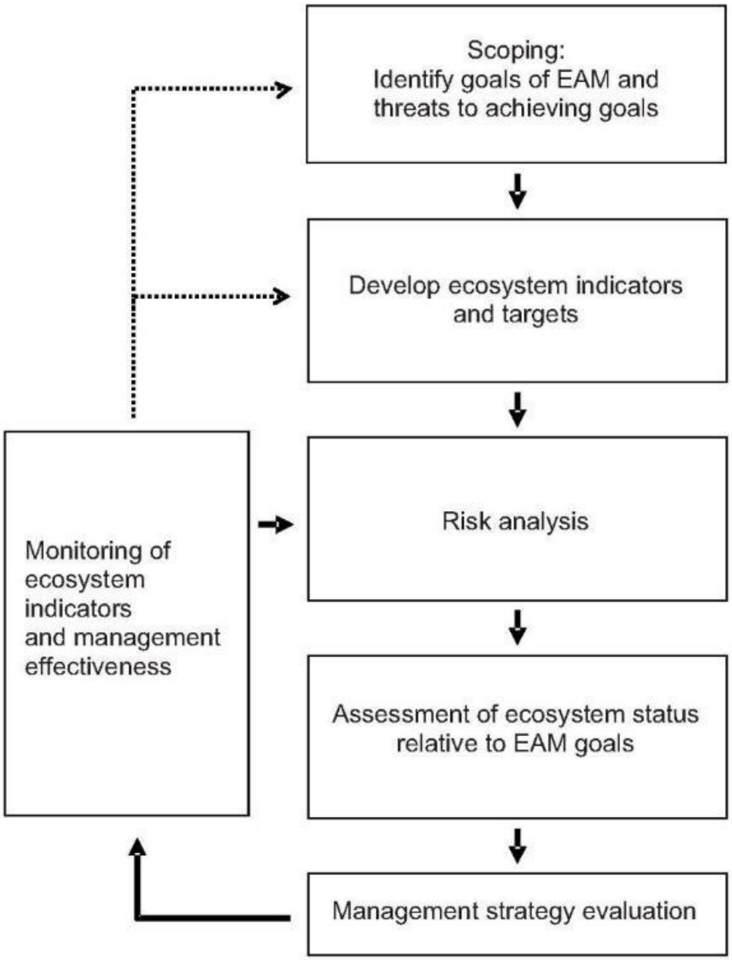


Figure 2.2 5-Step Integrated Ecosystem Assessment Process

(Northern Gulf Institute adapted from Levin et al., 2008)

The IEA approach has roots in decision theory and when IEAs are implemented it forces decision makers, managers, and scientists to confront multiple issues at the same time. IEAs approach allows for a quantitative method to consider goals identified in the indicator development step. It also allows for the identification and evaluation of trade-offs among diverse objectives.

In order to follow the IEA framework to inform decision makers, managers, and scientists, the United States was divided by NOAA into eight areas based upon physical location. While the nation is divided into regions, sometimes problems are on more of a local scale than a regional scale. IEAs are able to address problems not only on a regional scale but also on a local scale.

Issues associated with marine and coastal ecosystems include things as diverse as navigation, tourism, ecosystem conservation, energy, and fisheries management (McAnally et al., 2012). In McAnally et al., the main stressors in four ecosystems in the Northern Gulf of Mexico – Galveston Bay, Texas; Barataria Basin, Louisiana; Mississippi Sound, Mississippi; Mobile Bay, Alabama; and Perdido Bay, Florida – were identified and discussed (2012). The stressors were divided into three broad categories: hydrologic modifications, climate, and human-related processes. Each category was then divided into sub-categories as: hydrologic modifications – exploration and navigation canals, flood levee and dam construction, and freshwater diversion; climate – sea level rise/subsidence, extreme weather events, and climate variability; and human-related processes – local population size, trade/industry, socio-political-educational perceptions, and tourism/recreation (McAnally et al., 2012). While this list is not exhaustive, it serves to highlight some of the main concerns in these estuaries (for more, see McAnally et al., 2012). Despite the complex issues in coastal and marine areas, parts of the IEA framework have been successfully implemented to develop management plans for marine areas. An example of this IEA framework implementation is in the Puget Sound (Levin et al., 2009). In Puget Sound a comprehensive scoping process (step 1) lead to the identification of ecosystem indicators (step 2) and perform risk assessment (step 3) and MSEs (step 5) (McClure and Ruckelshaus, 2007). During the scoping process, "more than 30 contributors […and…] 100 natural and social science reviewers representing more than 35 organizations – universities, non-governmental organizations, tribes, county, state, and federal agencies, industry, and the public" (McClure and Ruckelshaus, 2007) participated. This same group worked to identify ecosystem indicators and solicited participation through multiple methods including workshops. These workshops were open to anybody who wanted to participate and focused on "human interactions, landscape processes, food webs, and habitats" (McClure and Ruckelshaus, 2007) which were identified in the scoping process as the key principles for IEA in the Puget Sound. A risk assessment was conducted by experts and then the steering committee – made up of "expert scientists and others from 14 organizations" finalized the plan and MSEs by serving as arbitrator in disagreements between the reviewers and workshop participants (McClure and Ruckelshaus, 2007).

Integrated ecosystem assessment is a framework that can be used to organize science which influences decisions in marine and coastal environments. IEAs can be implemented on multiple scales and across different sectors.

2.4.3 Driver-Pressure-State-Impact-Response

The DPSIR framework is an approach to integrated ecosystem assessment that distinguishes between the driving forces, pressures, states, impacts, and responses of an ecosystem (Levin et al., 2009). The framework provides a structure that allows the impacts of a policy choice to be viewed, and thus allows for policy feedback and change. DPSIR has become a popular framework among researchers and policy makers because it allows for organizing and communicating environmental research that is necessary for policy.

In the DPSIR framework, there is a link between drivers on to pressures, to states, to impacts, and finally ending in responses where targets can be set and policy can be changed before the process is started over at drivers. The DPSIR framework and the framework terms described by Levin et al., (2009) are:

6. *Driving forces*: The driving forces (or drivers) within the framework denote a human or environmental need. Humans are reliant upon marine ecosystems for multiple benefits including recreational areas, economic activities, and ecological services. All of these benefits represent a need humans place upon the ecosystem. These needs can be further broken down into smaller, less encompassing titles such as waterborne transportation (ports, harbors, channels), offshore oil production, flooding protection, habitat for plants and animals, natural water filtration systems, and many more.

   When the DPSIR framework is applied to marine and coastal areas, the DPSIR application can have several focuses including the entire coastal zone, marine areas, terrestrial areas, estuarine areas, or a specific coastal issue. Driving forces associated with coastal zones are related to the social and economic activities that depend upon the natural resources in the ecosystem. When Borja et al. (2006), Cave et al. (2003), and Henriques et al. (2008) applied DPSIR to estuaries and coastal areas, they used population, industry, ports, fisheries, and agricultural as the drivers (Camanho et al., 2010).

7. *Pressures*: The need for these services lead to human activities where the services are harvested and used. When this happens, humans exert a pressure upon the environment, which according to Peter Kristensen can be broken down into three main types: 1) excessive use of environmental resources, 2) changes in land use, and 3) emissions to air, water, and soil (2004).

   Pressures on coastal and marine ecosystems can include water pollution and nutrient discharge (e.g. Borja et al., 2006), and even commercial fisheries landings and percent of the population with access to wastewater treatment (e.g. Bowen et al., 2003).

8. *States*: As a result of the pressures exerted on the ecosystem, the state of the environment is changed (Levin et al., 2009). Examples of the change in state can most often be seen in the ecosystem changes in the number and diversity of plants and animals in an ecosystem. Some unseen state changes that occur most rapidly are changes to air, soil, and water quality which all affect the state of marine ecosystems.

   Nuttle et al. (n.d.) describe states as a representation of the conditions in the marine environment which are geographically defined by habitat (Kelble, C, n.d.). When referring to *state* Kelble et al. define it further as "quantity and quality of physical phenomena (such as temperature), biological phenomena (such as fish stocks), and chemical phenomena (such as atmospheric [carbon dioxide] concentrations)".

The population in coastal areas and the economic value of employment in coastal industries are two social and economic state indicators that can be used when DPSIR is applied to coastal areas (Bowen et al., 2003).

While the definition of *state* vary from Levin et al.to Kelble et al., it can be seen from the definitions above that these definitions can be synonymous with each other. While Levin et al. uses state to describe the changes the ecosystem experiences, Kelble et al., uses state to describe the present conditions of the ecosystem. The main difference is that one definition describes *where* the ecosystem came from (Levin et al., 2009) and the other describes *how* it is now (Kelble et al., n.d.).

9. Impacts: As the ecosystem changes, the benefits and products the ecosystem is able to provide changes, and thus an impact is seen on the ecosystems functions (Levin et al., 2009). One of the best examples of a visible impact is the reduction of fish species due to overharvesting. Humans presented the need for fish consumption. As a result, fish were harvested and sold. Since there were no laws or policies in place to govern the number of fish a person or company could harvest, too many fish were removed from the ecosystem which resulted in a reduction in the number, diversity, and quality of fish harvested later.

   Since impacts on the system are viewed from an environmental perspective, various impacts can be seen. Ojeda-Martinez et al. (2009) used abundance, diversity, and species changes as impacts in coastal areas.

A reduction of wetland area and loss of biodiversity are other impacts that can be used within the DPSIR framework (e.g. Karageorgis et al, 2006).

As with the definition of *states*, Kelble et al. (n.d.) describes *impacts* differently and even labels them as *ecosystem services* thus changing the framework from DPSIR to DPSER (driver-pressure-state-ecosystem services-response). Kelble et al., define *ecosystem services* as "services and goods that people receive from the marine environment. [They are] related to 'attributes that people care about' [and] have value that can be measured objectively." (n.d.).

While *impacts* described by Levin et al. (2009) and Ojeda-Martinez et al (2009) are quantifiable, *ecosystem services* described by Kelble et al. (2009) are not. While many are working on developing ways to more accurately quantify ecosystem services (Harte Research Institute, NOAA, GOMA, etc.), currently, ecosystem services remain poorly quantified (e.g. zu Ermgassen et al., 2012). As ecosystem services are currently difficult to quantify, a problem arises with Kelble et al.'s use of *ecosystem services* in place of *impacts*. In the future, however, when a standardized framework has been developed to quantify ecosystem services and their gains and losses, substituting *ecosystem services* for *impacts* will have an additional benefit because people relate more easily to ecosystem services (i.e. aesthetic environment, recreation, flooding protection, food supply and quantity, etc.) than they do to impacts (e.g. Kelble et al., n.d.)

10. *Responses*: When society realized what was happening, policy makers stepped in an implemented policy which placed limits upon the number of fish a person or company is allowed to harvest. This step is the response phase of the DPSIR framework. In the response phase, society or policy makers recognize the impacts the drivers are having on the system, and therefore take action to mitigate undesired impacts on the system. The response can be implemented at any part of the DPSIR framework. After a policy or law is set, the DPSIR process starts again, as the drivers on the system never go away.

    Pirrone et al., (2005) used an increase in protected areas and an increase in farming practices as responses to coastal and marine problems while Ojeda-Martinez et al., (2009) used indicators that are related to the available budget (local, state, and federal) for improvement activities in coastal and marine areas.

Due to its nature, the DPSIR framework is typically depicted in a circular fashion. Figure 2.3 is a depiction of the entire DPSIR framework obtained from the National Environmental Research Institute in Denmark. The figure is a general DPSIR framework and shows not only the components of DPSIR but also various cause and effect relationships within the framework. Figure 2.4 is an alternative schematic of the DPSIR framework used by NOAA.

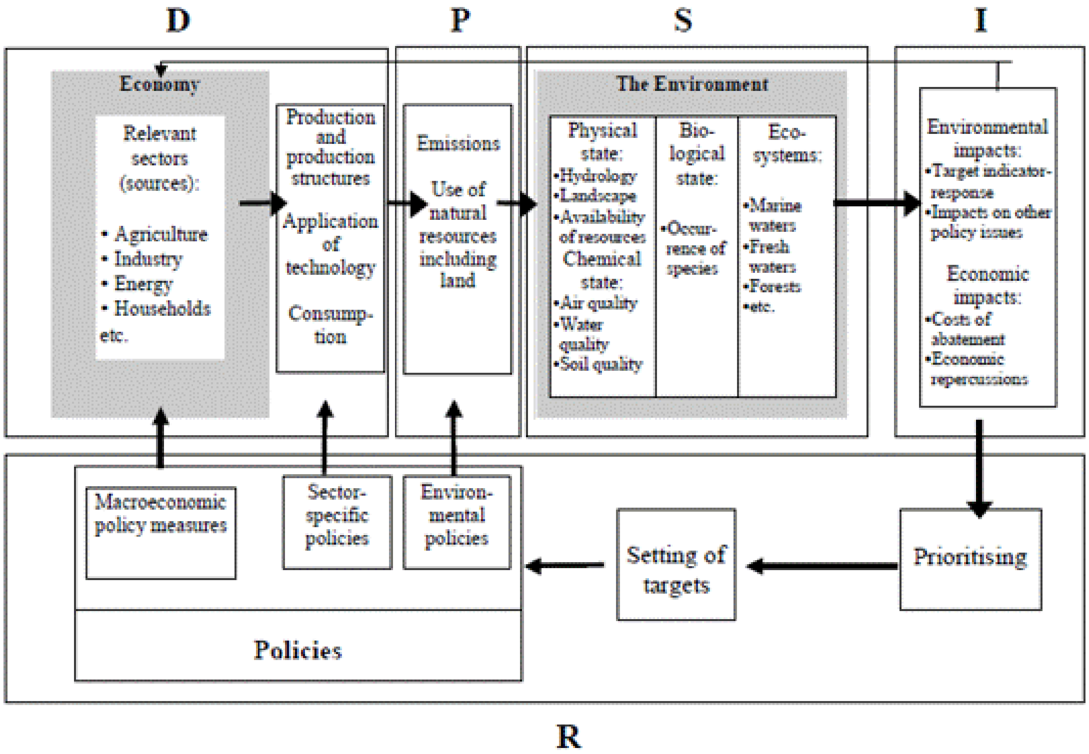


Figure 2.3 DPSIR Framework

(NERI, 1997)

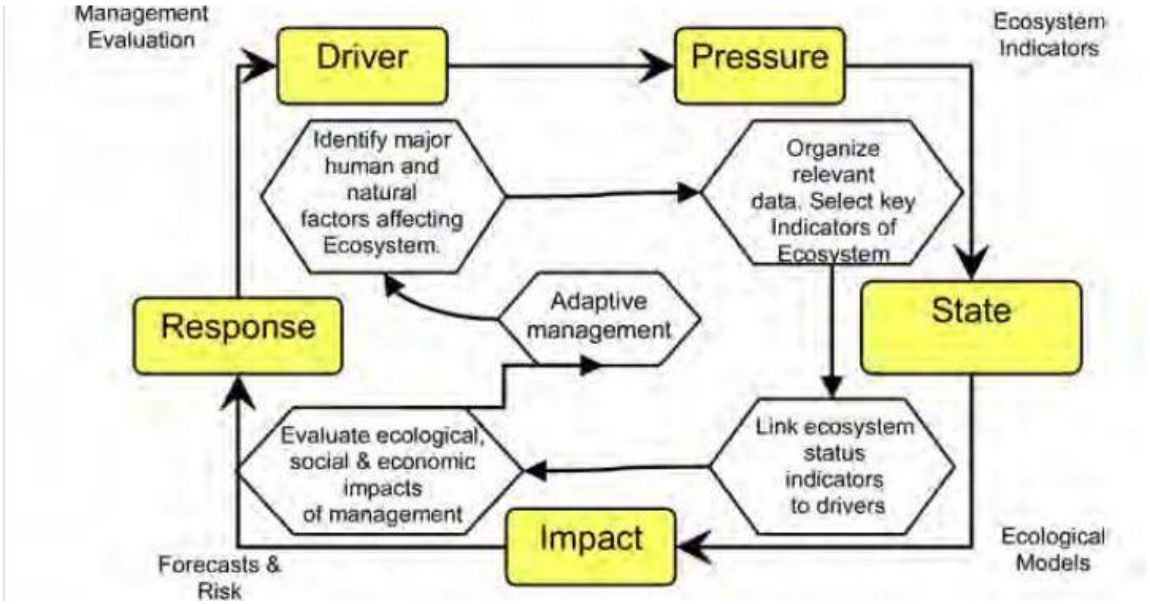


Figure 2.4 Alternative DPSIR Framework

(NOAA, 2009)

One of the strengths of the DPSIR frameworks is that it is a simple method that shows key relationships between factors in society and the ecosystem and can be used as a communication tool between researchers, policy makers, stakeholders, and society.

Developed in the 1970s, the stress-response framework is the predecessor of the DPSIR framework (Rapport and Friend, 1979) and was further developed in the 1990s by the Organization for Economic Co-operation and Development (OECD, 1991; OECD, 1993). In 1995, the European Environmental Agency introduced the current DPSIR framework as shown in Figure 2.3 (NERI, 1997). In 2011, the Harte Research Institute (HRI) introduced the DPSSIR framework which included drivers, pressures, stressors, states, impacts, and responses. HRI defined drivers as the fundamental forces; pressures as human activities and natural processes that cause stressors; stressors as what the ecosystem feels (chemical spills, habitat alteration, etc.); states and impacts are lumped together as "impacts are how the state differs from the goals"; and response is what society and policy makers do to reduce, mitigate, or adapt to the environmental impacts (HRI, 2011). The DPSIR framework introduced in 1995 is still the most commonly used version to date. Due to its nature, the DPSIR framework is used as a framework for structuring case studies relating to human interferences with, and efforts to manage marine ecosystems (Svarstad et al., 2008).

The DPSIR framework can focus on scale issues at two distinct points in the cycle: the impacts phase and the responses and driving forces phase. When determining the scale to use for the impacts, it is important to select the area that is most affected. For instance, the impacts can be viewed on a small scale, such as a single estuary or river, or on a much larger scale as in the case of an entire watershed, country, continent, or the entire world. DPSIR users can not only chose the scale at which they view impacts, but also the responses and driving forces affecting the system as well. Due to their nature, the scale used for impacts may be different from the scale used for the responses and driving forces. For instance, if the goal is to increase biodiversity within an estuary the impact scale would be the estuary but the driver and response scale would be much larger and probably encompass the entire estuary watershed, where land use changes alter freshwater flow and input of nutrients and sediment.

2.4.4 Coastal and Marine Spatial Planning

In 2009 President Obama established the Interagency Ocean Policy Task Force to develop recommendations to "enhance [the United States of America's] ability to maintain healthy, resilient, and sustainable ocean, coasts, and Great Lakes resources for the benefit of present and future generations" (CEQ, 2010). One of the final recommendations of the Task Force was to set a new direction for the improved stewardship of the ocean, coasts, and Great Lakes through the development of a framework for effective coastal and marine spatial planning that "establishes a comprehensive, integrated, ecosystem-based approach to address conservation, economic activity, user conflict, and sustainable use of ocean, coastal, and Great Lakes resources" (CEQ, 2010).

Coastal and Marine Spatial Planning (CMSP) is a "comprehensive, adaptive, integrated, ecosystem-based, and transparent spatial planning process, based on sound science for analyzing current and anticipated uses of ocean, coastal, and Great Lakes areas. CMSP identifies areas most suitable for various types or classes of activities in order to reduce conflicts among uses, reduce environmental impacts, facilitate compatible uses, and preserve critical ecosystem services to meet economic, environmental, security, and social objectives. CMSP provides a public policy process for society to better determine how the ocean, coasts, and Great Lakes are sustainably used and protected, now and for future generations" (CEQ, 2010).

Many countries have implemented CMSP (or Marine Spatial Planning – MSP) out of a need to reduce existing or anticipated conflicts and problems in coastal areas. Most of the time, conflicts arise between economic expansion and environmental preservation. Both Belgium and Germany implemented MSP after questions arose about the location of proposed offshore wind energy facilities in the North Sea (Douvere, 2008). Other countries have also developed CMSPs or MSPs to deal with user conflicts. These countries include, but are not limited to, Australia, parts of the United States of America, Netherlands-Denmark-Germany as a consortium, China, the United Kindgon, and Norway (Douvere, 2008). MSP enables adaptive decision-making in response to possible conflicts over maritime transport safety and protecting natural resources.

CMSP arose to address conflicting interests in the 1960s and early 1970s in Australia at the Great Barrier Reef Marine Park. Oil spills in the United States and the United Kingdom in the 1960s along with increased oil production in the Great Barrier Reef area brought about public concern about preserving the ecologically important area and increasing tourism in the area (Lawrence et al., 2002). In 1972 a bill was introduced to the House of Representatives Select Committee on Wildlife in Australia. The bill contained provisions for "recreation, scientific investigation, and controlled harvesting of renewable resources. It also covered control of pollution, conservation of living and non-living resources, reconciliation of conflicting interests, and the setting aside of representative areas for scientific work, wilderness areas, and areas for recreation and tourism. [… The bill] provided for administrative discretion in defining regions to be included within the [Great Barrier] marine park, the concept of zoning as a means of physically separating conflicting use, the provision for public participation and comment on the proposals for declaration and zoning of sections of the marine park, and provision for the accommodation of both commercial and recreational fishing. Other controversial issues related to the provisions for the managing agency to delegate its powers to other agencies, the involvement of the State Government in management, and the exclusion of [Australia's] internal waters," (Lawrence et al., 2002). The geographic scope of Coastal and Marine Zoning, or CMSP, around the Great Barrier Reef includes the continental shelf and the territorial sea. In 1975, the Great Barrier Reef Marine Park Act was passed in Australia (Commonwealth Parliamentary Debates, House of Representatives, 1975). The aim of the legislation was to "make provisions for, and in relation to, the establishment, control, care, and development of a marine park in the Great Barrier Reef Region," (House of Representatives, 1975). This Act was unique, not only in Australia but in the world, as it provided for the establishment and management of a large significant marine environment and the entire ecosystem through the use of zoning and management plans (Lawrence et al., 2002). The initial zoning plan considered the issues involved with fisheries, conservation, and recreation and tourism. Since its implementation in the 1970's, the zoning principles have changed a little. The most current version of the plan aims to "protect and conserve the biodiversity of the Great Barrier Reef ecosystem within a network of highly protected zones, while providing opportunities for the ecologically sustainable use of, and access to, the Great Barrier Reef

Region by current and future generations," (Great Barrier Reef Marine Park Authority, 2004).

The implementation of CMSP is proposed to yield ecological, social, and economic benefits in the United States of America (CEQ, 2010). In order for this to happen, science for ecosystem-based and adaptive management must be incorporated. CMSP is meant to facilitate sustainable economic growth in coastal communities by providing for economic investments in coastal area industries, transportation, public infrastructure, and associated businesses. Besides providing for economic growth, the designed result of CMSP is improved ecosystem health and services by planning for human uses in connection with conserving important ecological areas. Conserving these areas and enhancing ecosystem services and benefits can be attained through the process of CMSP as they are incorporated in the plan as a desired outcome. The CMSP process encourages community and citizen participation in the planning process which will eventually determine the future of the nation's oceans, coasts, and Great Lakes (CEQ, 2010).

In order to plan for the current and future uses of the nation's oceans, coasts, and Great Lakes, the Interagency Ocean Policy Task Force (CEQ, 2010) developed seven national goals for CMSP which are:

1. Support sustainable, safe, efficient, and productive uses of the ocean, our coasts, and the Great Lakes, including those that contribute to the economy, commerce, recreation, conservation, homeland, and national security, human health, safety, and welfare;

2. Protect, maintain, and restore the Nation's ocean, coastal, and Great Lakes resources and ensure resilient ecosystems and their ability to provide sustained delivery of ecosystem services;
3. Provide for and maintain public access to the ocean, coasts, and Great Lakes;
4. Promote compatibility among uses and reduce user conflicts and environmental impacts;
5. Streamline and improve the rigor, coherence, and consistency of decision-making and regulatory processes;
6. Increase certainty and predictability in planning for and implementing new investments for ocean, coastal, and Great Lakes uses; and
7. Enhance interagency, intergovernmental, and international communication and collaboration (CEQ, 2009).

Currently, coastal areas and the Great Lakes are managed in a sector-by-sector approach. Many of the existing permitting processes – including, but not limited to fisheries management, oil and gas lease permits, Clean Water Act §404 (dredge and fill permits), stormwater discharge permits, and renewable energy lease permits – include some cross-sectorial planning, but focus solely on the outcomes of the process (such as oil production and ecological management plans). However, even though the traditional permitting process does not acknowledge it, integrating other sectoral uses into permits is important in order to reduce cumulative pressures on the oceans and Great Lakes. Some states – such as Mississippi – do have coordinated permitting processes on the state-level that address multi-sectoral uses of coastal and ocean areas. CMSP allows for a flexible, integrated, comprehensive approach to managing the uses and activities of the nation's coastal regions on a federal level.

While CMSP has a national scope, it is acknowledged that coastal regions can vary greatly from one area to another. As such, CMSP is developed and implemented using a regional approach which allows the plans to vary based upon the economic, environmental, and societal aspects of different areas of the United States of America (CEQ, 2010). This new approach to managing the coastal and marine areas can help reduce user conflict and regulatory inefficiencies to achieve the overall good health of the oceans, coasts, and Great Lakes for present and future generations (CEQ, 2010).

In order to implement a regional approach, the nation was divided into nine different regions where the plans are developed and implemented by the Regional Planning Body (RPB). Each RPB will develop a formal working plan for CMSP which the National Ocean Council will review and approve prior to the plan's implementation. The essential elements of the CMSP include regional overview and scope of planning area; regulatory context; regional assessment; objectives, strategies, methods, and mechanisms for CMSP; compliance mechanisms; monitoring and evaluation mechanisms; and dispute resolution process.

The geographic scope of the planning area for CMSP in the United States of America includes the territorial sea, the Exclusive Economic Zone (EEZ), the continental shelf, and extends landward to the mean high-water line. The geographic scope includes inland bays and estuaries in both coastal and Great Lakes areas as there are significant ecological, social, and economic links between these areas and offshore areas. RPB have the authority to extend the scope of the planning area landward – including tributaries - if needed. As an example, the Gulf of Mexico Region RPB may find it necessary to include land to the east and west of the Mississippi River in their geographical scope as the river influences much of what happens in the Gulf of Mexico.

To develop effective CMS Plans, ten steps are followed (Ehler and Douvere, 2009):

1. Identifying Need and Establishing Authority
2. Obtaining Financial Support
3. Organizing the Process through Pre-Planning
4. Organizing Stakeholder Participation
5. Defining and Analyzing Existing Conditions
6. Defining and Analyzing Future Conditions
7. Preparing and Approving the Spatial Management Plan
8. Implementing and Enforcing the Spatial Management Plan Measures
9. Monitoring and Evaluating Performance
10. Adapting the Spatial Management Process.

Figure 2.5 shows a flow diagram of the step-by step approach to coastal and marine spatial planning.

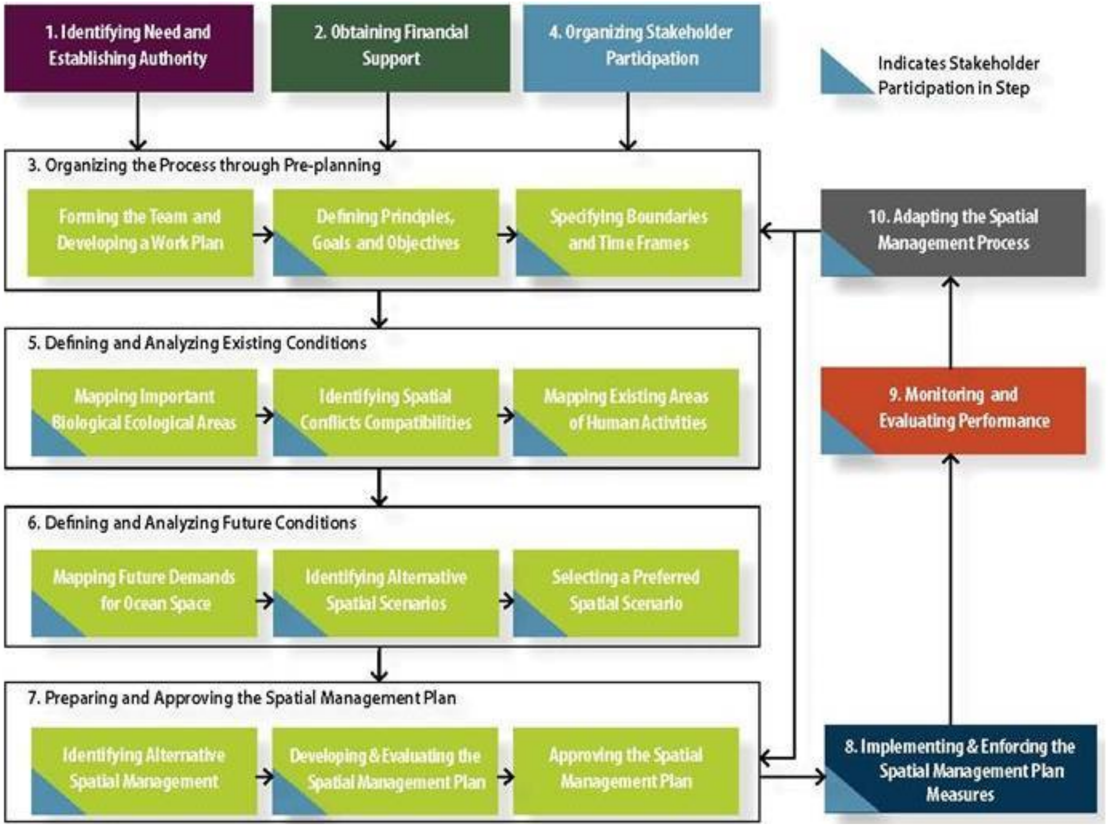


Figure 2.5 Step-by-Step Approach to Marine Spatial Planning

(NGI, n.d. adapted from Ehler and Douvere, 2009)

While CMSP is intended to help facilitate economic growth in coastal areas, it is also intended to be used to improve the ecosystems in the geographic scope of CMSP. By constructing plans that incorporate both human uses and the conservation of ecologically important areas, enhanced ecosystem services and benefits can be attained through CMSP as the conservation of these areas are a desired outcome of the CMSP process. CMSP also allows user to have a comprehensive look at multi-sector demands in an area which helps provide a more complete evaluation of the possible effects of the plan. This ultimately will result in the protection of areas that are essential for the health and resiliency of the ecosystems and allows for the maximization of marine resources to support human uses and demands (CEQ, 2010).

Economic and ecological potentials are not the only benefits of CMSP. The CMSP process is also intended to provide opportunities for coastal communities and citizens to participate in the planning process that will eventually determine the future of the nation’s marine ecosystems. The CMSP process recognizes the social, economic, conservation, and public health benefits of developing plans for sustainable recreational use of the coasts, oceans, and Great Lakes. This is done by providing improved coordination with recreational users of the coasts, oceans, and Great Lakes to ensure that users are allowed continued access and opportunities to enjoy activities that are consistent with safety and conservation goals set forth in the CMS plan (CEQ, 2010).

While the White House Council on Environmental Policy advocate using CMSP to deal with current and future demands upon the United State’s coastal areas, not all are in favor of CMSP. Nuckols posted public comments to the National Ocean Council pertaining to current CMSP efforts and stated that “CMSP currently faces significant opposition from some portions of Congress and industries. This is due in part […] to a lack of clarity on the nature of what sort of CMSP system would be enacted under this Administration” (NOC, 2011). Others have voiced concerns dealing with CMSP over lack of collaboration both between federal agencies and with groups other than federal agencies, difficulty maintaining ecosystem quality, reduced accountability (who takes responsibility), lack of time and funding to design and implement comprehensive plans, lack of baseline data for designing plans, and lack of enforcement (currently, there are no federal mandates to ensure participation in CMSP) (NOC, 2011). Respondents in a survey conducted by U.S. Department of Energy in regards to using CMSP for offshore wind energy permitting expressed opposition to CMSP "mainly over concern that CMSP will take areas away from traditional users (fishermen, specifically) and slow down the ocean energy development process" and other fear that introducing CMSP will result in additional regulations and lengthen permitting processes (USDOE, 2010). While it is clear from just a few comments that there is major opposition to implementing CMSP, a few people have also expressed ways the government can allay their opposition to CMSP. For instance, the respondent in the USDOE interview suggested that the "Fisheries Management Council act [with] the regional CMSP body and that negative impacts of new uses on traditional ocean uses should be mitigated considering cumulative impacts on fisheries" (USDOE, 2010). Some commenters to the NOC felt that additional public education on what CMSP is and why it is being implemented would help alleviate fear of the unknown in regards to CMSP. Others stated that additional transparency was needed from the Administration and those implementing CMSP as to what was happening and why (NOC, 2011). However, unease regarding funding, data availability, time, and collaborative efforts were not addressed.

As previously stated, CMSP has already been applied at various locations throughout the United States. One of those locations is off the coast of Massachusetts in the Stellwagen Bank National Marine Sanctuary (SBNMS) (CEQ, 2010; Battelle, 2013). The Boston Harbor shipping channels run directly through the SBNMS which is home to baleen whales and right whales (listed as endangered under ESA). NOAA, the US Coast Guard, several governmental agencies and stakeholder groups (most notably, commercial fishermen) worked together to realign the shipping channel to reduce the number of fatal whale-ship collisions, maintain shipping needs, and relocated proposed deepwater liquefied natural gas port locations (CEQ, 2010; Battelle, 2013). The realignment of the channel reduced the risk of whale-ship collisions by "an estimated 81% for all baleen whales and 58% for endangered right whales. Industry […] transit times increased by only 9-22 minutes […] and conflict with deepwater ports was eliminated. In addition, the new route […] increased maritime safety" (CEQ, 2010). One of the most notable achievements during this exercise was the inclusion of local commercial fishermen and ship captains in the creation of the CMSP (Battelle, 2013).

2.5 CMSP and EBM

Ecosystem approach to management or ecosystem-based management is currently the focus of policy makers in the United States as a way to restore the health of our marine ecosystems and ecosystem services. One of the most important aspects of EBM is also one of the largest challenges: EBM is applied to the entire defined system, accounting for the interactions among different ecosystem components and management sectors as well as the cumulative impacts of sector uses for the ecosystem. As Complex Adaptive Systems, ecosystem analyses to that degree are exceedingly difficult.

Another challenge for EBM is that, while policy makers have realized the importance of implementing EBM in marine ecosystems, actually implementing the management plan can be difficult as the EBM framework does not provide managers with a method for selecting specific management goals. As a result, numerous experts have proposed multiple frameworks to be implemented within EBM in order to organize science and data to inform EBM decisions in marine ecosystems across multiple sectors. Levin et al. (2009) proposed integrated ecosystem assessment as a tool to use within

EBM. While IEA is a valid approach to help inform EBM, it offers several advantages. The first is that in the 2010 *Final Recommendations of the Interagency Ocean Policy Task Force*, the White House Council on Environmental Quality listed ecosystem-based management as the number one national priority objective in which ecosystem-based management is adopted as the foundation for comprehensive management for marine ecosystems; coastal and marine spatial planning was identified as national priority objective two in order to "implement comprehensive, integrated, ecosystem-based coastal and marine spatial planning and management in the United States." In listing EBM and CMSP as national priority objectives, the federal government has placed a focus on developing EBM plans and implementing them using CMSP. While CMSP if not a required approach, the government has recommended it and is in the process of developing and implementing plans based upon the CMSP framework, which suggests that while CMSP may not be *the best* method for implementing comprehensive ecosystem-based marine management plans the federal government is less likely to fund any other approach to marine ecosystem management.

Another advantage for CMSP over IEA is that CMSP was developed specifically for marine and coastal areas whereas IEA was not. Since CMSP was developed for marine areas, it has only been applied to marine areas, and there are examples of where CMSP has been used for ecosystem-based management with excellent results. IEA was developed for terrestrial use, and when implementing IEA to marine ecosystems, some aspects of marine ecosystems may be overlooked.

The final advantage of CMSP over IEA is since its development in the 1960s, CMSP has been successfully implemented in diverse marine ecosystems in multiple countries across the world. As such, there are experts who have dealt with developing and implementing coastal and marine spatial plans that might be able to help guide the United States in developing and implementing CMSPs.

When comparing IEA and CMSP, it is important to remember that they play two different roles. CMSP is the process of analyzing and allocating ocean spaces for single or multiple uses in order to achieve stipulated ecological, economic, and societal objectives. It is used to maximize societal benefits while minimizing the impacts on ecologically sensitive areas and reducing the conflicts between incompatible marine and coastal sector activities (CEQ, 2010). IEA on the other hand is a formal synthesis and quantitative analysis of information on relevant natural and socioeconomic factors relative to specified ecosystem management goals; it is used to address multi-sector marine and coastal use issued by providing a scientific basis for evaluating the benefits and risks of proposed management options to marine and coastal ecosystems and the social systems that rely on them. Essentially, IEAs are analytical tools and CMSP is a public planning process that can work together to inform and advance ecosystem based management in coastal, marine, and Great Lakes regions. In order for IEAs to inform decision making and adaptive management of coastal and marine environments, they bring together scientific and technological information to inform resource management decisions by incorporating diverse data sets into ecosystem models to evaluate trade-offs among different management scenarios in dealing with incompatible marine and coastal sector activities. Based upon distinct management objectives IEAs can provide managers and stakeholders options for achieving ecosystem goals. CMSPs on the other hand provide planners and stakeholders with a science-based method to match human uses to appropriate coastal and marine areas in a way that minimizes conflicts and impacts while ensuring the area is sustainable for future generations.

Built upon the idea of sustaining ecosystem services, CMSP is a public planning process used to achieve EBM goals through objective spatial planning based upon sound science for current and future uses.

Outlined in the sections above, the steps related to EBM and CMSP can be combined to show the overlap between them as seen in Figure 2.6:

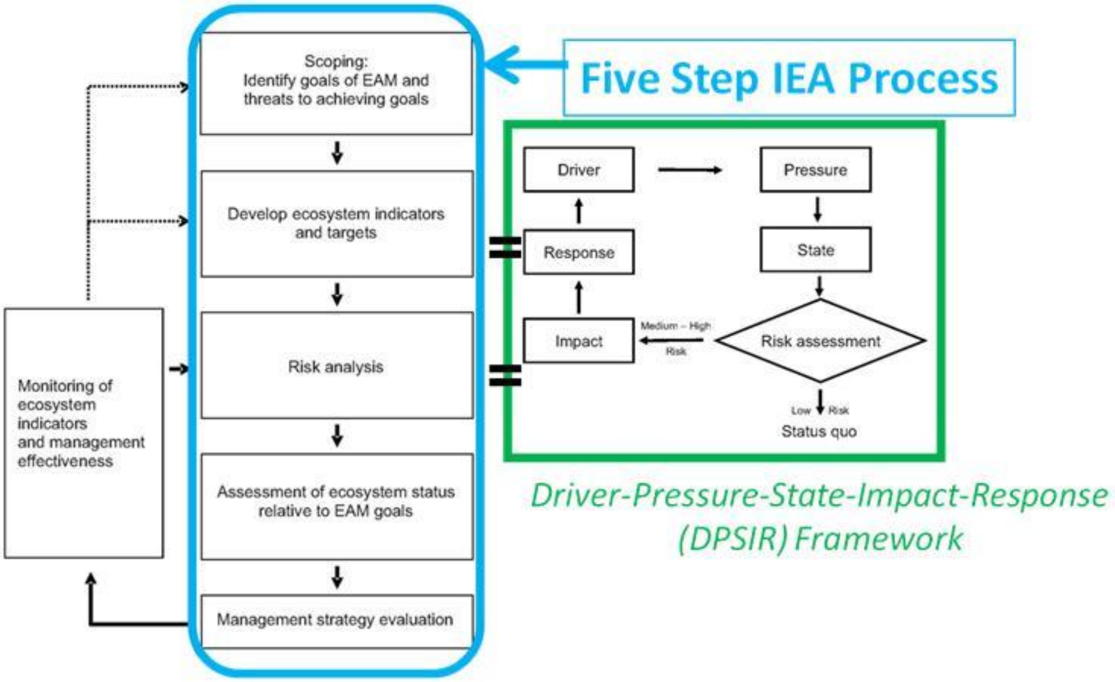


Figure 2.6 EBM, CMSP, and DPSIR Relationship

(adapted from NGI, n.d.)

While EBM and CMSP are different processes set forth by the federal government, they can be used to help inform each other and create a more efficient, objective method for planning for uses in marine ecosystems. The most important part of combining EBM and CMSP is that EBM can fill in gaps within the CMSP framework while CMSP can help provide a method to implement comprehensive, integrated management plans to marine ecosystems.

CMSP needs enabling capabilities such as ecosystem research and data integration and analysis, decision support tools such as gap analysis, ecosystem modeling, and scenario analysis, and help with coordination on a regional, tribal, and interagency level. EBM is able to fill the gaps CMSP presents through its current framework. One of the most comprehensive steps in the EBM process is collecting data in order to develop models and scenarios. EBM is also able to support CMSP by allowing integration on a regional level, helping improve interagency collaboration, and by recognizing the importance of tribal and local historic knowledge in the process.

CHAPTER III

COMPLEXITY AND SCALING OF ECOSYSTEM-BASED MANAGEMENT

3.1 Complexity Associated with EBM

Managing marine ecosystems requires an understanding of complex systems. A complex system is comprised of numerous interacting entities and processes. Understanding these complex systems is vital in order to model them correctly and develop and implement management schemes. Complex adaptive systems (CAS) are "those systems in which complex behavior emerges from the interactions of agents, individuals, or components acting on the basis of local rules and local information" (Harris, 2007).

While a complex system denotes the interactions within one system (e.g. a wetland preserve), a CAS implies an overarching system that not only on the interactions within one particular subsystem, but also consists of interactions between subsystems. According to Harris, the "unfolding properties of CAS are extremely difficult to predict from the behavior of the individual isolated agents. Differing interactions and relationships in differing contexts give differing (or similar) outcomes" (2007).

In order to effectively manage marine ecosystems, not only do the marine systems need to be managed, but the terrestrial, economic, political, and socio-economic systems that influence marine ecosystems need to be accounted for as well. As such, understanding the interconnectedness of the systems is important.

While modeling marine ecosystems can help give insight into how the system will react, sometimes the system reacts in ways that are not easily understood or predictable. When complex systems act this way, it is known as emergent behavior. Emergent behavior is used to describe how complex system behaviors arise out of simpler system behaviors. "Emergent behavior is that which cannot be predicted through analysis at any level simpler than that of the system as a whole. Explanations of emergence, like simplifications of complexity, are inherently illusory and can only be achieved by sleight of hand. This does not mean that emergence is not real. Emergent behavior, by definition, is what's left after everything else has been explained" (Dyson, 1998).

While Dyson was specifically referring to complex software systems, the same definition can be applied to complex ecological systems. As ecosystems are so interconnected at so many levels, sometimes it is difficult to predict how a change in one sub-system will change numerous aspects of other sub-systems. Even though these changes are difficult to predict, they still occur and can be vital to stability of the sub-system or the system as a whole. One of the best examples of a multi-level complex dynamic system showing emergent behavior is a hurricane. Burbeck asserts that hurricanes are a result from "mutual positive feedback between wind, humidity, evaporation of warm ocean waters, and Coriolis effects" (2007) and that while none of these processes on their own can result in a hurricane, when the conditions are right, a hurricane emerges. He goes on to say that "the details of a hurricane or tornado are *fundamentally* not explainable by invoking the physics of individual air and water molecules. […] Tracking cause and effect through these sorts of multiple levels is exceedingly difficult and often impossible," (Burbeck, 2007). Other common examples of natural emergent behavior can be seen in the formation of sand dunes (e.g. Burbeck, 2007), flocks of birds (e.g. Burbeck, 2007; Cucker and Smale, 2007), the configuration of neural networks (e.g. Schaffer et al., 1990), and the self-organization of ant swarms (e.g. Millonas, 1992).

However, just because the system changes and is no longer stable does not mean it must return to its previous state in order to become stable again. This theory is known as alternative stable states. Alternative stable states are where there can be more than one "stable" state within a dynamic system that allow it to proper, grow, and remain healthy. Lotka (1956) referred to multiple stable states dating to 1891 – one of the first known references to the theory. However, it fell out of favor with ecologists and has just recently become a popular theory again (Petraitis and Dudgeon, 2004).

One of the problems with alternative stable states is that while the identification of "stability" and "equilibrium points" for a system is easy in theory, actually defining and identifying them within the ecosystem can be difficult. Grimm and Wissel (1997) and Petraitis and Latham (1999) noted that problems relating to time scales and spatial extent changed what "stability", "equilibrium", and "habitat" mean within the ecosystem.

Equilibrium points in alternative stable states theory are the conditions at which the system is stable – or in equilibrium. Between equilibrium points, the system is not operating under optimal conditions for one reason or another. In order for a system to leave an equilibrium point, the tipping point of that system must be reached.

The tipping point of a system is the point at which a transition to a new state occurs. While most people think that tipping points have a negative connotation, this is not true all of the time. Once a tipping point has been reached and exceeded, the system proceeds to a new state – which may be good, bad, or indifferent.

Gabrielle Walker, however, defines the tipping point of a system as being the "moment at which internal dynamics start to propel a change previously driven by external forces" (2006).

Lindsay and Zhang wrote a paper where they analyzed and modeled Arctic Sea ice data from 1988 to 2003 in order to answer the question: have we passed a tipping point. From their analysis, Lindsay and Zhang concluded that they "believe that 1989 does represent a tipping point for the Arctic ice-ocean system because the system had reached a state in which triggering events were able to initiate a process of continual rapid change even though the external forcings have changed little" (2005). Mark Serreze agrees that the tipping point for the Arctic ice-ocean system has been reached and exceeded and believes that the process is irreversible. Serreze is quoted to have said "once you start melting and receding, you can't go back" (Walker, 2006).

A concern within the Gulf of Mexico is the size, location, and variation of the eutrophic zone. Some scientist who have studied the eutrophic zone fear that it could reach a tipping point in the near future. If and when the eutrophic zone tipping point occurs, if the point is exceeded, scientist who have studied the issue fear that organisms living within the eutrophic zone will no longer be able to reach oxygenated waters before dying and permanently harming their population (Miller and Spoolman, 2011).

Marine ecosystems are complex dynamic systems that are always changing. As such, regardless of the stability of the system, aspects within the system are constantly changing. Even if the system is apparently stable, change will continue to occur. Small changes – and sometime even large changes – may not affect the stability of the system, it just depends upon the dynamic stability of the system.. However, at a certain point, the system will no longer be able to change anymore without moving out of an equilibrium point. The point at which a change – regardless of size – forces the system from stable to unstable is the tipping point.

The opposite is also true. If the system is unstable and not at an equilibrium point it can remain there despite changes. Once the tipping point is reached, however, the system can move back to a stable equilibrium point.

Due to marine ecosystems being complex dynamic systems, it is important to try to understand the emergent behavior of the system (by understanding the connections within the system) and to identify stable states and tipping points for the ecosystem. It is also extremely important to formulate and implement EBM plans at the appropriate scales.

3.2 Scaling for EBM

Choosing the appropriate scale at which to formulate and implement a management plan can be difficult due to the spatial and temporal variability of the ecosystem. To help with choosing the appropriate scale for EBM, creating a diagram similar to Figure 3.1 (below) and using it to choose the most important scale at which the plan is created and implemented can be a great help when trying to reach the goals set for the management activity. It is recommended to create a diagram in order to help set the goals one wishes to obtain through the management activity and then choosing the scale at which the work is done. “Goals and objectives are needed to establish measurable targets and to drive development of criteria to assess programs […] ecosystem-based management needs a linked set of criteria and goals that vary by place, scale, and time and that are pursued in an on-going, adaptive process” (Slocombe, 1998).

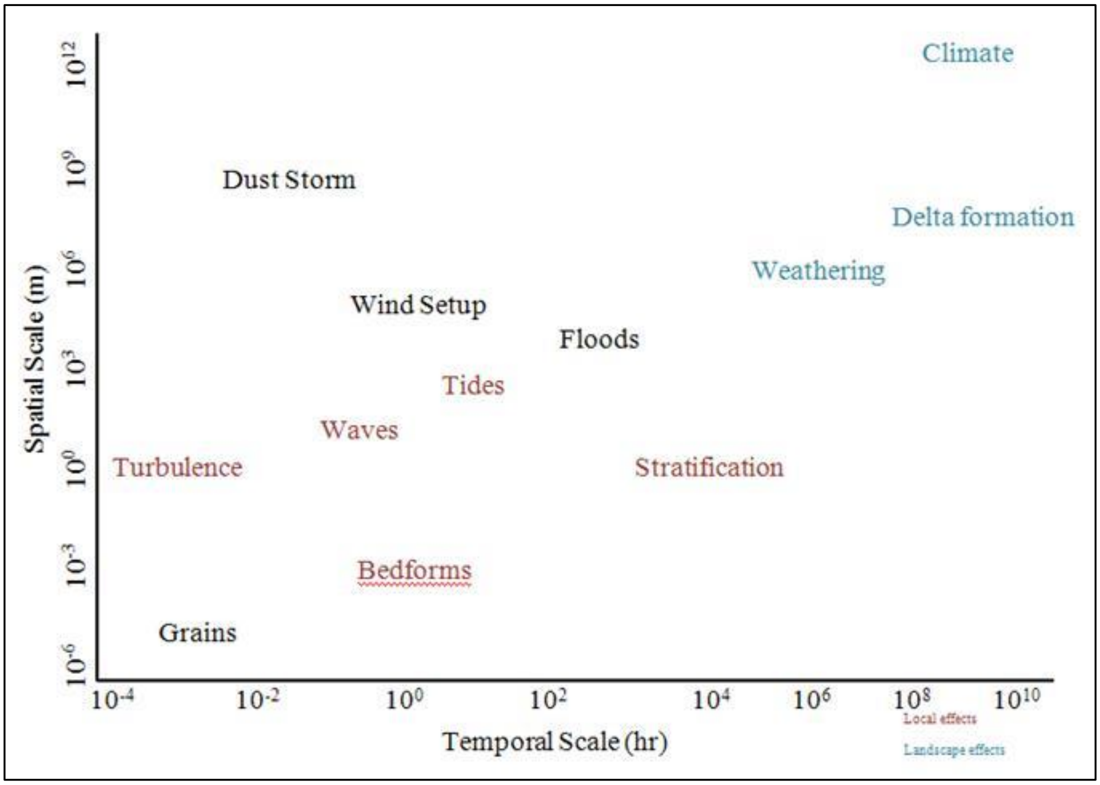


Figure 3.1 Spatial and Temporal Variability for Select Events at Local Levels (red), Landscape Levels (blue), and Extraordinary Events (black)

(adapted from Martin and McCutcheon, 1999; McAnally, 2010)

In order to set meaningful goals, Norton and Ulanowicz (1992) recommend a hierarchical approach. “A hierarchical approach to natural systems, which assumes that smaller subsystems change according to a faster dynamic than do larger systems of which they are a part, is advocated as a useful means to conceptualize problems of scale […] Since ecosystems can be described at many levels of organization, [scientists] must model ecosystems on a scale appropriate to the crucial dynamic that supports the sustainability goal" (Norton and Ulanowicz, 1992). Using this approach, Norton and Ulanowicz recommend setting scale-appropriate goals at multiple scales in the ecosystem, where more goals are set at small scales and an all-encompassing goal of sustainability is set for the ecosystem. Noss suggests characterizing biodiversity in such a way that the characterization identifies several levels of biodiversity using major components (1990). Thus, using a hierarchical approach, a "conceptual framework for identifying specific, measurable indicators to monitor change and assess the overall status of biodiversity" (Noss, 1990) would be provided. The all-encompassing goal in this approach is an increase in the biodiversity of the area. In order to increase biodiversity, goals are set dealing with the major components at different levels identified in Noss's characterization.

Slocombe agrees with this approach. "Implementing ecosystem-based management requires a hierarchical set of goals and objectives that can be extended to identify activities and actions and supported by targets, indicators, and monitoring. Such a suite of goals can be integrated to produce a range of objectives and tailored to provide targets for particular ecosystems.[…] (T)his hierarchy, at least in its lower levels, must be tailored to the particular ecosystem or region. It must reflect the biophysical and socioeconomic conditions and traditions of the particular ecosystem, as well as locally relevant or traditional ethical and ecological principles. Similarly, goals must reflect spatial and temporal variability and the history of the particular system being examined. All available reliable information should be used" (1998).

O'Neill et al. also agree with a hierarchical approach to EBM. However, unlike Norton and Ulanowicz and Slocombe, O'Neill et al. state that an understanding of the hierarchy of scales in the ecosystem need to be understood, but goals do not necessarily need to be set at each level of the hierarchy. "Challenges, such as the management of wildlife populations or development of a recovery plan for an endangered species, may present themselves at one scale of organization, but a complete understanding or resolution of issues usually requires integration across several scales and levels or organization. To determine mechanisms, we often must investigate processes operating at lower levels or organization (say physiology or reproductive biology in the endangered species population) as well as appreciate the context or higher levels of organization within which the processes operate" (1986, in Christensen et al., 1996).

3.3 Appropriate Scale for EBM

Accepting that it is essential to take scale into consideration when working with EBM, the question then becomes, how can we choose appropriate scales for management. "The difficult theoretical problem we have posed for ourselves is as follows: Given that the scale of ecosystem description is relative to choices regarding the concepts and values we operate with – and these, in turn, are relative to goals and value determinations – how can ecosystem scale and boundaries be constructed on a rational basis?" (Norton and Ulanowicz, 1992).

Based upon the hierarchical approach to management, it has been theorized that the Buckingham-Pi Theorem – the foundation for dimensional analysis – can be used for specific management problems to identify the proper scale at which to formulate policy (Norton and Ulanowicz, 1992). Buckingham-Pi Theorem must be used in a hierarchical approach to ecosystem management as it is only applicable to *specific* problems. This means that for every "problem" (see "management goal"), the theorem must be applied to identify what dominant scales describe the problem. Buckingham Pi Theorem "states that there are a limited number of dimensionless groupings of the physical parameters of a system […] that are sufficient to control the dynamics of the system […] Thus, in a real and quantitative way, the Buckingham Pi theorem allows us to circumscribe the domain of applicability – the focal level in a hierarchy – for any given system feature" (Norton and Ulanowicz, 1992). Norton and Ulanowicz exemplify how the Buckingham Pi Theorem can be applied by looking at how German foresters in the 19th century "emphasized production of timber and converted huge areas of the German forest to monocultural spruce" (1992). The theorem was used to determine the proper scale at which policy needed to be formulated to deal with this problem.

As discussed in the section above, numerical models are very useful for understanding how different aspects of a system interact with each other and how different management scenarios affect the system as a whole. "Knowing exactly what to expect from complex systems is a non-trivial challenge, and models are essential to meeting this challenge" (Christensen et al., 1996). However, numerical models (used in steps 3, 4, and 5 of the EBM process), in and of themselves, are complex which can introduce problems with modeling marine ecosystems and in the model results.

3.4 Modeling for EBM

A model is "a small representation of an existing object, usually built to scale" and "a schematic description of a system or theory that accounts for its known properties" (American Heritage Dictionary, 1994). As such, models generally represent a simplified adaptation of reality and can be used to test different scenarios to indicate possible outcomes. There are two main types of models based upon where they are built: physical models and numerical or mathematical models. Physical models are a scaled down version of the physical system (e.g. a 1:100 model of the Mississippi River delta) whereas numerical models use mathematics to represent a system (e.g. a box model of Mobile Bay developed using the Water Quality Analysis Simulation Program). Chapra defines mathematical models as "an idealized formulation that represents the response of a physical system to external stimuli" (1997). Data driven models involve "mathematical equations that are not derived from physical processes […] but from analysis of time series data" (Solomatine et al., 2008) as is exemplified by hydrologic models. According to Solomatine et al., data driven models focus upon computation intelligence (CI) and machine learning (ML) methods "that can be used to build models for complementing or replacing physically based models" (2008) where CI is defined as "neural networks, fuzzy systems, and evolutionary computing as well as other areas within artificial intelligence and machine learning" and ML is a sub-area of artificial intelligence that concentrates on the theoretical foundations used by CI and soft computing" (2008). On the other hand, process based models are based upon the physical processes in an area. Cao et al. created a process based model to estimate methane emissions from wetlands at both the regional and global scale (1996).

Due to the complexity of the systems modeled, it is important to understand not just what is happening in the water body, but how the model that is applied was developed and the simplifications and assumptions that were made in creating the model.

Choosing the correct numerical model to apply to a system is imperative in understanding the interactions that are occurring across all scales, and for interpreting the results and using them to develop ecosystem based management plans (lessons learned from Batelle, 2013). However, a problem with choosing the best model for the system arises – especially with people who are not familiar with numerical models – as there is little to no guidance on how to select the best model for the system.

Models constructed and simplified using numerous mathematical and physical assumptions can become oversimplified; making multiple assumptions can lead to models that are unable to accurately represent a system. Oversimplified models, while computationally efficient, can be so simplified as to not properly simulate the physical, chemical, and biological processes in the water body. This is due to the fact that oversimplified models often include too few verification parameters to accurately represent the system. If an oversimplified model is used for a system, the model results may have increased uncertainty and may not show interactions and management strategy affects within the system. Using results from these models to create and implement a management strategy can be very precarious. As an example, if it is determined that the water quality of an estuary needs to be improved to increase the health of the ecosystem, a water quality model of the system needs to be run. However, if the water quality model is oversimplified, it is difficult to determine what is causing the degradation of the water quality and the steps needed to improve the water quality. Making management decisions for the estuary based upon an oversimplified water quality model can result in management decisions that can cause further harm to the system – especially if important aspects of the system that affect water quality are left out of the model.

However, extremely complex models also present problems. Whereas oversimplified models do not represent enough of the ecosystem interactions, under simplified models are so complex that they can introduce uncertainty in model parameters and may even try to simulate interactions that are not present in the water body. Complex models generally have too many verification parameters and as a result the model may overestimate what is happening in the individual system due to overfitting data. Another problem with models that are too complex is that they are computationally intensive and expensive.

As a general rule of thumb, Martin and McCutcheon (1999) strongly recommend the modeler remember that as model complexity, thus verification parameters, increase, the data need to accurately represent the system increases as well. Thus it is important to choose a model that balances model complexity with data requirements and available data.

Choosing models that accurately reflect the system and its complexities and simplifications is imperative in achieving useful results; overestimations and underestimations in model predictions that yield extremely detrimental outcomes. The 2008 United States stock market crash resulted from an under-prediction of 5-year default rates for AAA-rated collateralized debt obligations (CDO) (Silver, 2012). According to the Financial Dictionary, a CDO is a "security that repackages individual fixed-income assets into a product that can be [divided] into pieces and then sold on the secondary market. They are called collateralized because the assets being packaged […] serve as collateral for investors." (2023). Standard & Poor's estimated that there was about a 0.12 percent probability that a CDO would fail to payout over the next five years. The actual failure rate was over two hundred times higher than predicted – having a CDO failure rate of about 28 percent (Silver, 2012). This under-estimation of AAA-Rated CDO failure rates helped result in bursting the housing bubble and the stock market crash –

something the United States economy is still recovering from. On the other hand, over-estimations can yield equally dire results. Leading up to the devastating April 2009 earthquake in L'Aquila, Italy, Giampaolo Giuliani predicted an earthquake to occur on 29 March. When the earthquake failed to occur as predicted, Giuliani was lambasted and charged with "procurator allarme" (disturbing the peace); however a few days later a devastating 6.3 magnitude earthquake struck L'Aquila killing more than 300 residents and resulting in more than $16 billion in damage (Silver, 2012). While Giuliani's model predictions were, in fact, accurate, they were not precise and over-estimated the earthquake date, predicting it to strike days before it actually did. As a result, the citizens in the area were convinced that Giuliani's predictions were incorrect and were thus unprepared for the ensuing earthquake and its resulting damage.

Just as dangerous as under-predicting or over-predicting occurrences is accurately and precisely predicting results and having the predictions ignored by those possibly affected. This occurred with the Hurricane Center's model predictions of Hurricane Katrina. On 24 August 2005, "the Hurricane Center's computer models [were] already predicting a double landfall [of Hurricane Katrina] in the United States – a first one over southern Florida and a second one that might '[take] the cyclone to New Orleans' (Stewart, 2005)" (Silver, 2012). On 29 August – a full four, almost five, days after the Hurricane Center's landfall predictions – Hurricane Katrina made landfall in Mississippi. The hurricane resulted in billions of dollars' worth of damage and killed thousands of people – the majority of who lived in and around New Orleans, Louisiana. One of the reasons so many lives were lost is because government officials failed to act with haste and heed the Hurricane Center's predictions. 72 hours before the storm made landfall, Governor Barbour of Mississippi called for an evacuation of the southern part of the state and Governor Blanco declared a state of emergency for Louisiana. Mayor Nagin of New Orleans called for a voluntary evacuation of the city less than 48 hours before the hurricane made landfall, and did not issue a mandatory evacuation until about 24 hours before landfall. Failure to heed the warnings issued by the Hurricane Center resulted in loss of life that could have been avoided. Numerical models are not useful when the public and government officials fail to make decisions based upon the model results.

3.4.1 Temporal and Spatial Scales

The temporal and spatial scales chosen for each model depend upon what it is applied to and what is being modeled. One of the largest scaling problems facing modelers is the fact that the scales of interest can vary by multiple orders of magnitude depending upon what the modeler needs for results. For example, if fisheries managers in the Mississippi Delta would like to see when fish consumption advisories for DDT will no longer be in place, a modeler needs to choose a temporal scale of hundreds of years and a spatial scale that covers the Delta and any water inflows.

In order to resolve problems with temporal scales, one needs to determine if the challenge arises from the time step chosen and from the overall simulation period. Models solve equations for constituent values based upon a given time step. The time step used is usually user specified within the model. Problems can arise when choosing a time step if the step is too large or too small.

Using a time step that is too small can cause problems during simulations because it slows the model down and become computationally intensive. Also, if a too small time step is used, rounding errors can be amplified, driving the model to become numerically unstable.

If the time step used is too large, the user runs the risk of missing important features that would have been seen if a smaller time step had been used. Also, large time steps sometime result in instability within the model results and can cause the model to crash.

The most common way to resolve temporal scale issues dealing with the time step is to choose a time step size and test the model with smaller and larger time steps in an iterative fashion until the appropriate value is identified (van Waveren, 2005). While this approach is time intensive in the beginning, it is necessary to make sure that an appropriate time step is used.

Issues with simulation period can also arise. Some of these problems are choosing a simulation period that is too short or too long, or even choosing a simulation period that does not coincide with what the modeler is trying to determine.

As with choosing time steps that are too large or too small, correcting a simulation period that is too short or too long can be easy. With a simulation period that is too short, the modeler runs the risk of not having the necessary data to use for analysis. A simulation period that is too long is computationally expensive and can provide excess data to a modeler that may not be important (Martin, 2011; Martin, 2012).

As with choosing appropriate time steps, choosing appropriate simulation lengths can be done based upon knowledge of the system (especially the physics, chemistry, and biology if water quality modeling is the target) and an iterative process. However, if a modeler does not have the time to perform these iterations, it is better to run the model for a period that is longer than needed in order to capture seasonal, annual and decadal cycles.

Another problem with choosing simulation periods is choosing the correct period of time if a modeler wants to view the effects of a certain event. For example, if the modeler wishes to see how Hurricane Katrina affected Weeks Bay estuary it is essential to choose a simulation period that spans from before the hurricane struck (to give pre-hurricane conditions) to after it made landfall and maybe even longer depending upon what the goal of the modeling is (e.g. looking at ecosystem recovery time, species recovery time, immediate effects, etc.).

One of the largest problems with choosing a temporal scale is that for the scale chosen, data must be available for the model input. If data are not available, the modeler must use judgment about how to deal with that (e.g. time series analysis, forecasting, hindcasting, shifting simulation period, etc.). The temporal scale for model input parameters can vary greatly. For example, when modeling water quality, redox reactions of chemicals and compounds can have a profound effect on the water quality; however, redox reactions can occur anywhere from fractions of a second to hundreds of years (Martin and McCutcheon, 1999).

One problem with spatial scales is making sure that the area that is affected is modeled. If a modeler is interested in looking at hurricane effects on a particular location within an estuary, the entire estuary must be modeled as what happens within the entire estuary has an effect on that point. However, it is better to include too much surrounding area in the model than too little. While it may take more time to run the simulations, it can result in more accurate results.

Another problem with spatial scales is deciding how to discretize the area and at what resolution. In order to more accurately capture what is happening within the system, waterbodies are often gridded so that what happens within each individual piece can be looked at. This can help the modeler see how the system changes in pieces. Usually systems are gridded depending upon data availability. While this is not necessarily the best way to discretize the system, it is usually the best available method as not all types of data are taken throughout the system whereas other types of data are (e.g. bathymetry, etc.). The resolution of the discretization is important in creating accurate numerical models of a system as the resolution can lead to undersimplified or oversimplified models – the hazards of which are discussed in previous sections.

While it would seem to make sense to discretize an area based upon jurisdictional boundaries as they set obvious spatial scales, these boundaries are seldom associated with a single ecosystem. As such, it is essential to find a way to discretize the waterbody based upon the ecosystem or the ecosystem service one wishes to protect without relying upon jurisdictional boundaries.

While appropriately scaling numerical models for accurate results, which in turn inform policy, is important, there is not framework or method in-place that can help a modeler decide how to scale the model. As such, it is recommended that a framework be developed for this purpose and that it initially be based upon lessons learned from scaling physical models until further research can be performed.

Regardless of the problems associated with scaling, it is essential to take scale into consideration when working with EBM. In fact, Haufler et al. (1999) state that "one of the primary tenets of ecosystem management is that analyzing and managing natural resources at different geographic scales is necessary to account for the function, interaction, and emergent properties within ecological and social systems" (in Cheng and Daniels, 2003). Halpern et al. (2008) agree and even go so far as to recommend that the scale at which you manage an area needs to match the scale of the goal (or ecosystem service) you are trying to meet.

3.4.2 Physical Models

As with numerical models, physical models are constructed to learn more about the system and what happens within it. Physical models are downscaled in order to adequately represent the system. In 1989, an Army Corps of Engineers, Engineering Research and Development Center (ERDC) technical note stated that "determination of quantative information for engineering use from small-scale physical models has not been possible due to poor understanding of scaling relationships between model and field conditions. […] Recent research has provided various guidelines to minimize scaling problems by maintaining similarity of important physical parameters between model and prototype. Generally, the scaling guidance depends on the primary mechanism by which the sediment is being transported."

Physical models are based upon the principle of similitude between the model and the actual system. Similitude between the prototype and model can be achieved when the major factors that influence the reactions are scaled between the physical system and model. Geometric similarity exists between two systems if the ratios for all the dimensions are equal (so, both the horizontal and vertical length scales are scaled the same). Kinematic similarity shows similarity of particle motion between the model and system. Hudson et al. (1979) declared that kinematic similarity is achieved when the ratio between the components of all vertical motions for the system and model is the same for all particles at all times. Dynamic similarity between two systems requires that the ratios of all vectorial forces be the same (Warnock, 1950). There must be constant model to system ratios for all masses, constituents, and forces acting in and on the system. For a model to have hydraulic similitude, the Froude number must be the same between the model and the system, the Strouhal number must be the same, and the Reynold's number must be the same in the turbulent range (Hughes and Cohen, 2006; McAnally, 2012). To simulate bed load transport in a model, the model sand must have the same density as the system, and the sand grain size is scaled according to the model length scale. To accurately scale sediment loads in suspension, the similarity between the model grain and the system grain is assured using the "fall speed parameter" (Dalrymple and Thompson, 1976; Li, 2010).

Many scaled estuary models are geometrically distorted in order to keep the size manageable and turbulent enough to avoid domination of viscous effects. In general, the horizontal length scale is larger than the vertical scale. The coastal and hydraulics laboratory (CHL) conducted a study to determine the potential turbulence scale effects in geometrically distorted models (Hughes, 2003). It was determined that "there will be scale effects present in geometrically distorted models where large-scale turbulence features such a gyres are generated by solid boundaries. The magnitude of the scale effect is difficult to ascertain, but differences between model and prototype decrease as the magnitude of the vertical turbulent fluctuations decreases. Because distorted models have steeper slopes that decrease the magnitude of the vertical turbulence components generated by the slope, it should be expected that the prototype might experience stronger vertical turbulence than demonstrated in the model. Whether or not these scale effects degrade the model results will depend on the goals of the modeling and the relevance of the turbulent flow process to the specific regions of interest within the study area" (Hughes, 2003).

Some of the systems ERDC has modeled include Cook Inlet, Alaska and Half Moon Bay, Greys Harbor, Washington. For these physical models, the physical system was measured and downscaled to create the physical model. An idealized flow table model and 3-D model of Cook Inlet, Alaska was created to examine the hydrodynamics of the system near the Port of Anchorage to try to ascertain how large amounts of shoaling material settled in the area. For the idealized flow table model, the horizontal scale used was 1,300 feet = 1 inch. The vertical scale was 40 feet = 1 inch. 2.2 m/s = 10 cm/s was dictated by Froude scaling for the velocity scale, and the discharge was thus scaled to 203,000 m^3/s = 1.24 L/s. The scales were different for the 3-D inlet model with a horizontal scale of 1,250 feet = 1 inch, vertical scale of 83 feet = 1 inch, velocity scale of 1.6 m/s = 5 cm/s, and discharge scale of 203,000 m^3/s = 0.43 L/s. From this study, ERDC was able to understand more about the shoaling problem in Cook Inlet and compare flow table models to 3-D models. Also, guidelines for what studies flow table models were applicable for were determined (Hughes, 2003).

The model study of Half Moon Bay, Grays Harbor, Washington was constructed to help the Seattle District Army Corps of Engineers office with ongoing investigations into the area. The results from the model were used to assess the long-term responses of the shoreline to expected increased storm surge levels. For the physical model, the following scaling ratios were:

Table 3.1 Model scale ratios and system equivalence for Half Moon Bay, WA

Scale	Target Scale Ratio	Actual Scale Ratio	Model Equivalence
Length Scale	N = 50	N = 50	1 ft = 50 ft
Time Scale	N = 7.1	N = 7.1	1 s = 7.1 s
Velocity Scale	N = 7.1	N = 7.1	1 ft/s = 7.1 ft/s
Sand Size Scale	N = 50	N = 4	0.125 mm = 0.5 mm
Gravel Size Scale	N = 50	N = 50	1 mm = 50 mm
Sand Fall Speed Scale	N = 7.1	N = 4.2	1 cm/s = 4.2 cm/s

(Hughes and Cohen, 2006)

The physical model did a good job eroding the shoreline until a near equilibrium was achieved. The results of the model shows that Half Moon Bay is approaching an equilibrium shoreline shape (Hughes and Cohen, 2006).

Scaled physical models have been very useful in helping researchers understand what is happening within an ecosystem and sometimes why it is happening. Numerical methods are also useful for this purpose.

3.5 Conclusions

Coastal and marine ecosystems are facing increasing competing demands from different sectors. As they provide so many benefits to the country – especially in the way of mitigating damage from coastal disasters – it is imperative to protect and preserve these areas. In order to preserve and protect coastal areas, a comprehensive approach must be taken. Not only does the long-term health of the ecosystem need to be looked at, but the human benefits and well-being must also be considered. Thus, science and engineering alone are not enough to protect an ecosystem; social sciences and humanities also need to be incorporated in the plans to protect the oceans. While currently incorporated, social science and humanities research needs to be continued to enhance understanding of these issues as well as to improve their incorporation within ecosystem based management plans.

Scientists, engineers, law makers, policy makers, and stakeholder groups have all acknowledged the essential services coastal and ocean areas provide to the United States. As such, ecosystem based management has been looked to in order to measure the health of the ecosystem and then form and implement management schemes to protect coastal zones.

The overall goal of applying EBM to marine ecosystems is to sustain the long-term capacity of the ecosystem to deliver services that the public needs. Due to its holistic approach, and unlike management approaches before, EBM requires synthesizing and applying knowledge from across multiple disciplines including natural sciences, engineering, and social. While EBM uses sound science from multiple sectors, it depends upon policy and management for setting the bounds within which the process is implemented and for setting the goals that are the hopeful outcome of implementing EBM in an area. As such, EBM provides both a process for policy analysis and action and a framework for the formulation of policy goals and objectives. For the EBM process, it is important to remember that science and engineering are used to help develop and inform the policy and management schemes.

However, choosing the correct scale at which to develop and implement EBM plans can be very difficult. The hierarchical approach to goal-setting along with the implementation of Buckingham-Pi Theorem to identify appropriate scales for the goals has been put forth as a way to solve the issue of correctly scaling for EBM.

Correctly identifying the scales at which problems need to be addressed is not the only scaling issue related to EBM. Correctly scaling numerical models which will help inform management decisions can present a problem.

CHAPTER IV

INTRODUCTION TO SITES

4.1 Introduction

The goal of this research is to create a framework and tools that can be applied to large marine ecosystems (LME) in order to sub-divide them into smaller sub-ecosystems for management purposes. The development and validation of the framework and tools needs to occur on a scale much smaller than a LME as systems within the LME can vary greatly necessitating different management plans for different systems. In order to understand the effects of varying scale and local processes, five estuarine systems of various sizes and locations across a nearly constant latitude of the northern Gulf of Mexico were selected for detailed examination: Perdido Bay, Florida and Alabama; Galveston Bay, Texas; Barataria Bay, Louisiana; Mississippi Sound, Mississippi, Alabama, and Louisiana; and Mobile Bay, Alabama. An introduction that describes the size, watershed, physical, ecological, and societal characteristics, and environmental stressors for each site is given below.

4.2 Perdido Bay, Florida and Alabama

Perdido Bay is a small estuary located on the border between Alabama and Florida (Figure 4.1). The southern edge of Perdido Bay connects to the Gulf of Mexico through Perdido Pass and is connected to Big Lagoon and Mobile Bay though the Gulf

Intracoastal Waterway. Perdido Key separates the Gulf of Mexico from Perdido Bay and is a sandy barrier island.

4.2.1 Physical Characteristics

Located north of Perdido Bay, the Perdido River is the primary tributary for the bay and has a watershed of approximately 2,900 kilometer squares (Bricker, 2007) which provides the estuary with approximately 62 cubic feet per second of freshwater inflow on average (McAnally, et al., 2012); however, Perdido River is precipitation driven and the flows, therefore, vary with by season (FDEP, 2011). According to Sigsby (2012), the average precipitation for the Perdido River watershed range from 150 to 160 centimeters yearly; however, average low precipitation of 112 centimeters and average high precipitation of greater than 200 centimeters per year have been recorded. The Bay exhibits an average (potential) evaporation of 117 centimeters per year which can lead to prolonged drought-like conditions (Grubbs and Pittman, 1997; Paulic, 2006; Sigsby, 2012). Sigsby noted that for Perdido Bay the "freshwater systems are a major contributor to the dynamics of the bay and have the ability to alter the bay's water level and circulation" (2012).

Perdido Bay is approximately 50 kilometers long, has an average width of four kilometers, and is classified as a shallow estuary with an average depth of three meters. The estuary has a surface area of approximately 130 kilometer squares (McAnally, et al., 2012).

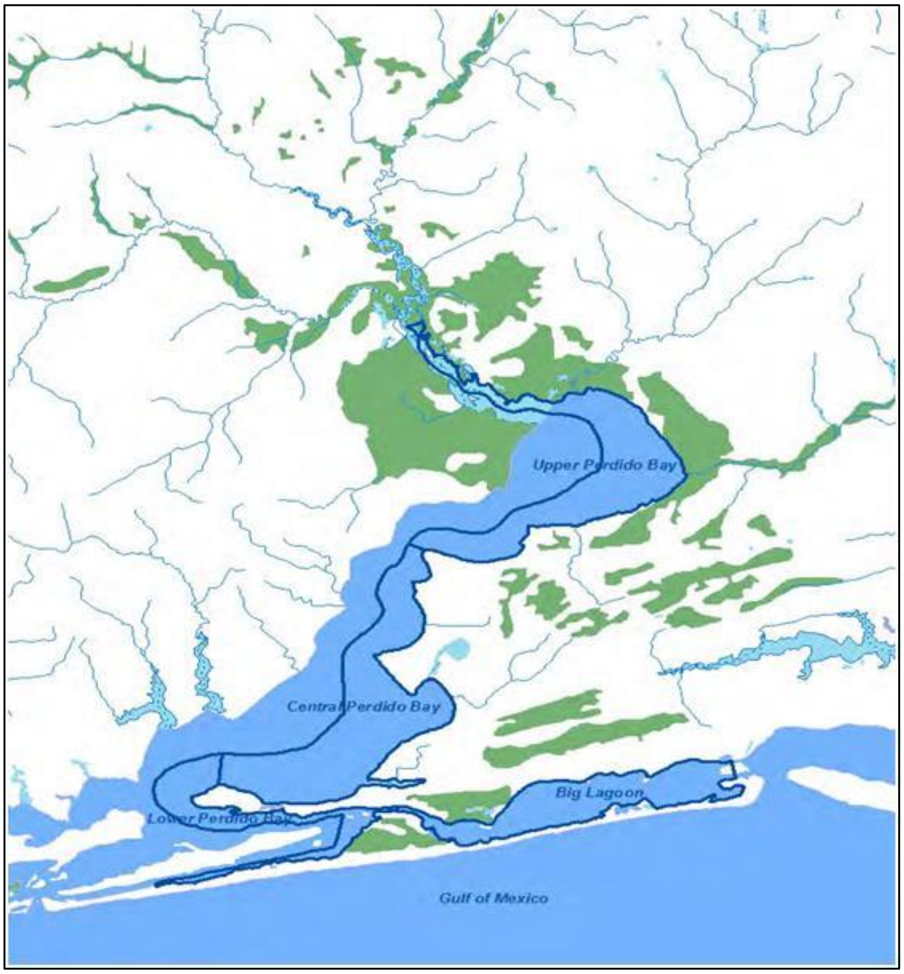


Figure 4.1 Perdido Bay estuary, Florida and Alabama
(Florida DEP, 2012)

For a system such as Perdido Bay, the hydrodynamics of the system are important to note. Grubbs and Pittman (1997) studied the hydrodynamics in the center of Perdido Bay as it is a “location where freshwater and tidal forces have similar influences and strength” (Sigsby, 2012). The study showed that not only do the freshwater inflow and tidal influence strongly contribute to the magnitude of the flow, but also on the direction of the flow through the system (Grubbs and Pittman, 1997; Sigsby, 2012). Due to the size and depth of the system, wind and precipitation also influence the flow direction in Perdido Bay (Kirschenfeld et al., 2006).

Perdido Bay experiences micro tides with a mean tidal range of 0.6 meters (Seabergh and Thomas, 2002) and is a stratified estuary (Bricker, 1997; Niedoroda, 2010; Sigsby, 2012) due to the bay's physical characteristics and the large freshwater inflows compared to the small tidal prism (1.23×10^7 cubic meters (Seabergh and Thomas, 2002)) of the bay (Niedoroda, 1992). In fact, Niedoroda notes that Perdido Bay is strongly stratified in the upper bay where the Perdido River meets the bay and having constant stratification through the rest of the bay (Niedoroda, 1992; Niedoroda, 2010) The steep density gradient within the bay and the short fetch across the bay help to enhance stratification in the deeper parts of the estuary (Lower Perdido River and Lower Perdido Bay) as does the small tidal range. "The stratified salinity regime sheds light on the flow dominance; the surface water flow will be ebb dominant (moving towards the mouth), while the bottom layer will be flood dominant (moving inland). This specific flow dominance is seen in Perdido Bay, and is most noticeable near the mouth of the Perdido River" (Sigsby, 2012).

The Florida Department of Environmental Protection divided Perdido Bay into four distinct segments based on work Niedoroda performed to summarize the physical properties of the estuary (Table 4.1).

Table 4.1 Physical properties of Perdido Bay

Location	**Physical Property**
Lower Perdido River	Depth: 7 meters Benthic sediment: silty mud Strong stratification Circulation: fast at surface but stagnant on bottom
Upper Perdido Bay	Depth: 2 meters Benthic sediment: sand-silt-clay River, creek, and bayou inflows Low to moderate stratification Advective flushing: 1 to 2 days Circulation: slow circulation due to tides
Middle Perdido Bay	Depth: 3 meters Benthic sediment: clayey silt Persistent stratification Advective flushing: 0.5 to 1 day Circulation: moderate circulation due to tides
Lower Perdido Bay	Depth: 4-5 meters Benthic sediment: clayey silt to sand Persistent stratification Saltwater input from the Gulf of Mexico Advective flushing: 1 to 3 days Circulation: good circulation due to tides

(after Florida DEP, 2012)

4.2.2 Biological and Ecological Characteristics

Perdido Bay exhibits large species diversity relative to its small size (Kirschenfeld et al., n.d.). The water quality in Perdido Bay greatly influences the overall health of the system as changes in water quality can influence both the flora and fauna of the estuary. Perdido Bay and its surrounding area are home to numerous species listed as threatened or endangered under the Endangered Species Act including one amphibian (endangered), three birds (two endangered, one threatened), six clams (three endangered, three threatened), two fish (one endangered, one threatened), one flowering plant (endangered), one lichen (endangered), three mammals (endangered), and seven reptiles (five endangered, two threatened) (FWS, 2013). To protect these endangered and threatened species, numerous protection plans have been drafted (e.g. Habitat Conservation Plan: a Plan for the Protection of the Perdido Key Beach Mouse, Sea Turtles, and Piping Plovers on Perdido Key, Florida by Escambia County, Florida Board of County Commissioners). Kirschenfeld et al. attribute the large species diversity to Perdido Bay to the fact that the system is extremely diverse and includes oligohaline, mesohaline, and euryhaline sub-systems (n.d.). However, Kirschenfeld et al., note that the water quality in Perdido Bay is degrading due to "increased shoreline and watershed development, stormwater runoff, septic tanks, wastewater treatment plant effluent, industrial discharges, agriculture, silviculture, and natural occurrences" and this degradation can be seen though a reduction in diversity and quantity of sea grasses (n.d.). The degradation of the water quality can also be seen though increasing algal blooms (Sigsby, 2012).

A 2012 study by the Northern Gulf Institute Ecosystem Team used a Driver Pressure State Impact Response (DPSIR) (Chapter 2) process to identify natural and human induced stressors in multiple coastal systems in the Northern Gulf of Mexico with Perdido Bay being one of the estuaries examined. This work indicated primary stressors Perdido Bay experiences: increased point and non-point source nutrients, increased point and non-point source pollutants, increased dredging, increased fishing activities, increased boat traffic, increased urban and coastal development, and increased critical habitat degradation (McAnally, et al., 2012). These stressors indicate that the majority of the pressures in Perdido Bay are human activity induced. Further study into the stressors in Perdido Bay indicate that the Lower Perdido River, Upper Perdido Bay, and Middle

Perdido Bay increases in nutrients and pollutants are the dominant pressures whereas the dominant pressures in Lower Perdido Bay are increasing urban and coastal development and increasing boat traffic. The stressors in different parts of the estuary are driven by the industry experienced in these areas. Lower Perdido River, Upper Perdido Bay, and Middle Perdido Bay experience greater amounts of nutrients and pollutants due to the agriculture industry in the watershed. However, Lower Perdido Bay is closer to the Gulf of Mexico, so most of the stressors in this area are a result of the increasing population and the tourism and recreation industry.

Increasing critical habitat degradation experienced in Perdido Bay is driven by climate-driven processes, primarily altered riverine discharge. As the climate continues to change, more interannual variability is seen in regards to precipitation which changes the riverine discharge into the estuary. During dry periods the salinity within the estuary increases whereas the salinity in the estuary decreases with storms. This increase in variability directly affects not only salinity with Perdido Bay but also stratification in the water column which can lead to an increase in hypoxia, which then alters the habitat in the bay (McAnally et al., 2012). An example of the degradation of critical habitat areas within Perdido Bay was demonstrated in a study that took place between 1987 and 2002 which indicated that seagrasses within the estuary diminished 82% in area (Heck et al., 2011).

As a result of increasing degradation of the Perdido Bay ecosystem, the Florida Department of Environmental Protection published “Site-Specific Information in Support of Establishing Numeric Nutrient Criteria for Perdido Bay” (2011). As a result of the study, Florida DEP recommended numeric criteria for total phosphorous (TP), total nitrogen (TN), and chlorophyll a (Chl a) levels. A reduction in the TP, TN, and Chl a levels are hoped to lead to a biological recovery in the ecosystem.

4.2.3 Human and Economic Characteristics

Perdido Bay is bounded by Baldwin County, Alabama to the west and Escambia County, Florida to the east. In 2012, The U.S. Census Bureau estimated a population of 302,715 (factoring in a 1.7% increase per year since the 2010 Census) in Escambia County and 190,790 (with a 4.7% increase per year) in Baldwin County. Based upon the Census Bureau's estimates, the population in both Escambia County and Baldwin County is growing with alarming pace. As the area becomes more developed, the potential for increased human-induced stressors increases (e.g. increased wastewater effluent discharge, increased stormwater runoff, etc) as described in the section above.

As the population continues to increase, so do the coastal-related economies in these areas. Table 4.2 shows a summary of economic growth in both Escambia and Baldwin Counties between 2005 and 2010 in four indicators based upon NOAA's Coastal Services Center Economics: National Ocean Watch (NOAA CSC ENOW) database.

Table 4.2 Economic Growth in Escambia County and Baldwin County Between 2005 and 2010

	Escambia County, Florida	**Baldwin County, Alabama**
Establishments	26.50%	29.59%
Employment	12.75%	35.49%
Wages	22.03%	40.09%
GDP	11.96%	37.06%

Establishments" refers to "individual places of business; a single firm may have multiple places of business"; "employment" is the "number of people employed by business establishments, including part-time and seasonal workers; this figure does not include the number of self-employed workers"; "annual wages" are the wages paid to employees; and "gross domestic product (GDP)" is "the value of goods and services that are produced; in ENOW, this is based on the state estimates of GDP that are produced by the Bureau of Economic Analysis called Gross State Product or GSP" (NOAA CSC ENOW, n.d.). It is important to remember that ENOW only provides data based upon ocean economies and does not include data from indicators that are not related to the coastal economy. For more on NOAA CSC's ENOW please refer to Section 4.4.2.

While economics are important, the health of the coastal community is also important. The Social Vulnerability Index to Environmental Hazard (SoVI) (Section 4.4.4) is a score put out by the University of South Carolina (2012) that measures the vulnerability of counties in the United States to deal with environmental hazards. On the SoVI scale, Baldwin County, Alabama is regarded as having a low vulnerability and Escambia County, Florida has a medium vulnerability and tells about the county's capacity to prepare for and respond to hazards (e.g. hurricanes). NOAA's State of the Coast ranks coastal vulnerability to sea level rise. NOAA ranks this area as having low to moderate vulnerability to sea level rise. Coastal vulnerability is not the only measure of the health of a community. The general health and mental health of community members is another important index of community health. Unfortunately, data is currently unavailable on the general health and mental health of the population on a county-wide basis; however, data is available on the general health and mental health for children (ages two to seventeen) and is provided by Kids Count (Section 4.4.5), a project of the Annie E. Casey Foundation (2013) on a state-by-state basis. Kids Count measures mental health as the percentage of "children who have one or more emotional, behavioral, or developmental condition" (Annie E. Casey Foundation, 2013). The national average is 15%. Alabama is ranked as high (18%) as in 2007 there were 186,000 children meeting the criteria. Florida, on the other hand is "moderately low" (16%) with 550,000 children meeting the criteria. Kids Count also ranks states on the overall health of children. In 2012, Alabama was ranked 41st and Florida was ranked 38th. The overall health of children in these states has increased over the past year as Alabama has moved up 6 spots to 35th and Florida has been bumped up to 37th (Annie E. Casey Foundation, 2013).

It cannot be denied that humans affect coastal areas (see Physical Characteristics and a discussion on environmental stressors). However, actions are being taken to try to reduce the negative impacts humans have on coastal areas. Multiple areas in and around Perdido Bay are currently managed to improve the ecosystem of the area. These include Gulf State Park (Alabama), Tarkiln Bayou Preserve State Park (Florida), parts of the Gulf Island National Seashore (federal), and Fort Pickens State Park Aquatic Preserve (Florida). Different management plans are created for each area. The areas are then managed under the plans to achieve particular goals set by the management body. To see a complete list of currently managed areas in the Northern Gulf of Mexico, please see Appendix A.

4.3 Galveston Bay, Texas

Galveston Bay is located on the south eastern Texas coast located about 50 miles west of the Texas-Louisiana State line (Figure 4.2) adjacent to the Houston-Galveston metropolitan area. Galveston Bay connects to the Gulf of Mexico on its southern end through a pass between West Bay and East Bay. The Intracoastal Water Way runs through the southern end of Galveston Bay, and the Houston Ship Channel is found on the north-northwestern side of the bay.

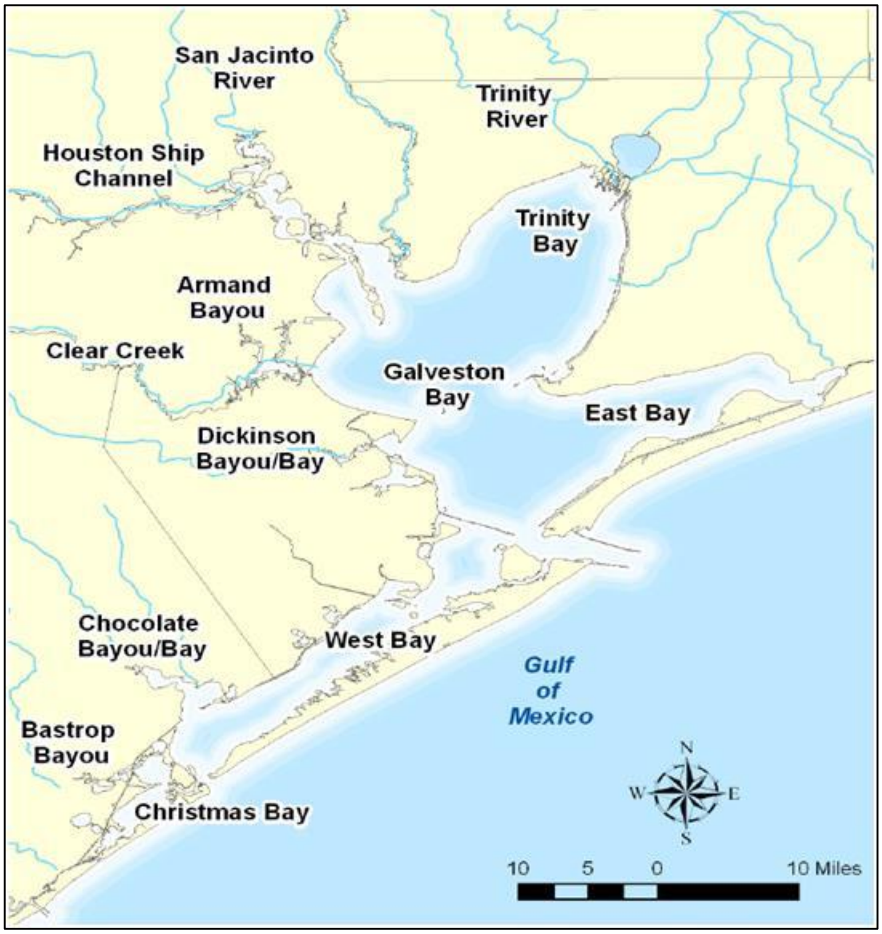


Figure 4.2 Galveston Bay estuary, Texas

(Geotechnology Research Institute, 2005)

4.3.1 Physical Characteristics

Galveston Bay is the largest estuary in Texas which has a surface area of approximately 1600 kilometer squares (McAnally et al., 2012) and is comprised of four major sub-bays: West Bay, East Bay, Galveston Bay, and Trinity Bay. The estuary is a coastal plain/bar-built system that experiences diurnal tides measuring 0.6 meters (McAnally et al., 2012). The bay is about 50 kilometers long and 27 kilometers wide (Texas A&M University, n.d.). Despite its large surface area, the bay is relatively shallow and only reaches an average depth of 2.5 meters in most locations (TAMU, n.d.). The tidal influence in Galveston Bay is not extremely strong; however, the processes in the bay are greatly affected by winds (GBEP, 2011). "Prevailing winds are from the southeast, with occasional strong northerly winds that are associated with passing cold fronts. Wind-driven tides of up to 1 meter above and below mean tide occur during strong winds" (GBEP, 2011).

Galveston Bay receives the majority of its freshwater inputs from the San Jacinto River to the northwest and the Trinity River to the northeast as well as smaller rivers located around the bay. The total watershed of Galveston Bay is approximately 64000 kilometer squares (McAnally et al., 2012). The average freshwater inflow into the Galveston Bay system is 430 cubic meters per second (McAnally et al., 2012).

As Galveston Bay is a shallow estuary sediment flow into the system has the potential to greatly affect the estuary. According to Phillips, there are three main sources of sediment input into the bay: fluvial input, coastal and marine sources, and shoreline erosion (n.d.). The sediment supply into Galveston Bay comes primarily from the San Jacinto and Trinity rivers (GBEP, 2011) and the significant coastline erosion (Paine et al., 1986; Phillips, n.d.). However, sediment supply to the bay is diminishing over time and has been altered due to the construction and consequent dredging of the Houston Ship channel, shoreline armoring, and the construction of roads which block sediment transport (GBEP, 2011).

Galveston Bay is classified as a mixed estuary (Galveston Bay Estuary Program, 2011). The freshwater inflow into Galveston Bay fluctuates with the seasons. During drought conditions, the salinity in the bay ranges from 20-35 psu and during flood conditions, the salinity ranges from 0-10 psu (GBEP, 2011). The salinity in the bay changes with the ebb and flow of tidal exchanges; however, a salt wedge is almost consistently present throughout the bottom of the Houston Shipping channel (GBEP, 2011).

4.3.2 Biological and Ecological Characteristics

In 1967, the Houston Ship Channel was identified as a prime example of poor water quality (Melosi and Pratt, 2007) and in response, the Texas Water Quality Board initiated water quality corrective measures in Galveston Bay and the Houston Ship Channel. As a result, an improvement is being seen in the water quality of Galveston Bay. In the State of Galveston Bay, the Galveston Bay Estuary Program ranked the water quality in Christmas Bay, West Bay, East Bay, Upper and Lower Galveston Bay, and Trinity Bay using data from the 1970s and the 2000s. This ranking, based off of the percent of nutrients above the screening level, showed that between the 1970s and 2000s the water quality across the bay increased. In the 1970s, West Bay, East Bay, Upper and Lower Galveston Bay, and Trinity Bay were all classified as “poor” (>30%) and Christmas Bay was classified as “moderate” (16%-30%). In the 2000s, Christmas Bay, West Bay, and East Bay had all been increased to “good” (6% -15%), and Upper and Lower Galveston Bay and Trinity Bay were ranked as “moderate” (16%-30%) (GBEP, 2011). Now, levels of fecal coliform bacteria, pH, and dissolved oxygen are concerns being addressed by the Texas Commission on Environmental Quality (formerly the Texas Water Quality Board) (GBEP, 2011).

While the water quality in Galveston Bay has seen an improvement over the past few decades, the ecosystem in the bay continues to be threatened by rapidly disappearing wetlands. GBEP estimates that approximately half of the natural wetlands in the bay have disappeared over time due to “a combination of sea level rise, diminished sediment supply, and human interventions” (GBEP, 2011); GBEP has also estimated that between 1953 and 1989 the total wetland coverage in the Lower Galveston Bay decreased by nineteen percent but that this trend has slowed down and only a one percent loss in wetland area was recorded between 1996 and 2005 (2011).

Even with the marked decrease of critical wetland habitat in Galveston Bay, the estuary itself is home to surprisingly few threatened or endangered species. In fact, Galveston Bay is home to only nine threatened or endangered species protected under the ESA and include three species of birds (endangered), one species of flowering plants (endangered), one species of mammals (endangered), and four species of reptiles (three endangered, one threatened) (FWS, 2013).

As humans continue to exert their presence onto coastal areas, the stressors and effects from human-based activities continue to increase. In a 2011 study by the NGI Ecosystem Team, the following stressors were identified to exist in Galveston Bay: altered riverine input, altered internal wetland connectivity, increased point and non-point source nutrients, increased point and non-point source pollutants, increased dredging, increased fishing, increased boat traffic, the introduction of non-indigenous species, increased urban and coastal development, increased resource extraction, redistribution of marsh and barrier island sediment, decreasing land elevation, and critical habitat degradation. A publication by the Galveston Bay National Estuary Program (1993) discusses, in depth, the stressors listed above and their causes; however, most of the stressors in Galveston Bay are human activity induced. For example, the San Jacinto River encompasses two large metropolitan areas within its watershed-Dallas/Ft Worth and Houston/Galveston-which can result in an increase in point and non-point source pollutants into the estuary.

The Port of Houston is a large port in the Gulf of Mexico and is connected to the Intracoastal Water Way via Galveston Bay. As the amount of goods shipped using waterborne transportation increases, so does the amount of ship traffic seen in the bay. An increase in shipping traffic can possibly result in the introduction of non-indigenous species to the estuary as plants and animals attach themselves to ships and can be displaced along the shipping route.

4.3.3 Human and Economic Characteristics

Galveston Bay is surrounded by five counties: Brazoria, Chambers, Galveston, Harris, and Liberty and in 2012 the U.S. Census Bureau estimated the total population of these counties to be 4,991,720 taking into account a 3.02% average population increase from the 2010 census. All of the counties surrounding the bay show a trend of population increase with Harris County having the largest increase (3.9%) and Liberty County having the smallest (1.20%). The majority of the population in these counties lives in Harris County (where Houston is located) and number 4,253,700.

The economy in these five counties is also growing (on average). Table 4.4 shows a summary of economic growth in all five counties between 2005 and 2010 (NOAA CSC ENOW, n.d.). For more information on NOAA CSC's ENOW, please refer to Section 4.4.2.

Table 4.3 Economic Growth around Galveston Bay Between 2005 and 2010

	Brazoria County	**Chambers County**	**Galveston County**	**Harris County**	**Liberty County**
Establishments	3.55%	29.55%	12.37%	24.03%	N/A
Employment	2.33%	-7.92%	13.30%	12.47%	N/A
Wages	32.02%	-8.24%	50.96%	33.24%	N/A
GDP	96.37%	-32.45%	54.37%	8.33%	N/A

As previously discussed, Galveston Bay is experiencing wetland loss and one of the primary reasons is attributed to sea level rise. NOAA's State of the Coast rates the coastal vulnerability to sea level rise in the estuary as moderate, high, and very high depending upon the location in the bay you are most concerned about (n.d.). However, the SoVI ranking for Brazoria County, Chambers County, and Galveston County is low and the SoVI ranking for Harris County and Liberty County is medium showing that while these counties are prone to sea level rise and its effects, the social vulnerability to these hazards is relatively low.

The overall health for children in the State of Texas is showing an improvement. Texas moved from ranking 42nd in Kids Count general health rankings in 2012 to 36 in 2013 (2013). Not only is the general health improving, but the percent of "children having one or more emotional, behavioral, or developmental condition" is well below the national average of 15% and ranks in at 12% (691,000 children) (Annie E. Casey Foundation, 2013).

The area surrounding Galveston Bay is changing rapidly and the increase of human-induced stressors on the bay can be seen. To help protect precious ecosystems in and around the bay, multiple federal, state, and cooperatives have been established. These include Anahuac National Wildlife Refuge (federal), Brazoria National Wildlife Refuge (federal), the Flower Garden Banks National Marine Sanctuary (federal), Galveston Bay National Estuary Program (cooperative), Atkinson Island Wildlife Management Area (state), Candy Cain Abshier Wildlife Management Area (state), and the Galveston Island State Park (state). For a complete list of marine protected areas, please see Appendix A.

Due to the importance of Galveston Bay on a state and national level, the Galveston Bay National Estuary Program (GBNEP) was created in 1989 to preserve Galveston Bay and its resources (GBNEP, 2007). One of twenty-nine estuaries in the United States Environmental Protection Agency's (EPA) NEP, a twenty year science-based plan was developed in 1995 to protect and restore the ecological health and water quality in Galveston Bay (EPA, 2012). Known as The Galveston Bay Plan, the plan identifies priority problems in Galveston Bay and lays out steps to preserve the estuary including a water-quality and ecology monitoring plan, coordinated activities between GBNEP and its partners, improving communication between GBNEP and its stakeholders, conducting public outreach and education, and iterative development of the plan as a whole if needed (GBNEP, 1995).

4.4 Barataria Bay, Louisiana

Barataria Bay is part of the Barataria-Terrebonne Estuarine System located in southeastern Louisiana on the Gulf of Mexico (Figure 4.3). While the Barataria-Terrebonne Estuarine System is comprised of two estuaries, only the eastern estuary (Barataria Bay) indicated in dark green below will be used for calculation purposes.

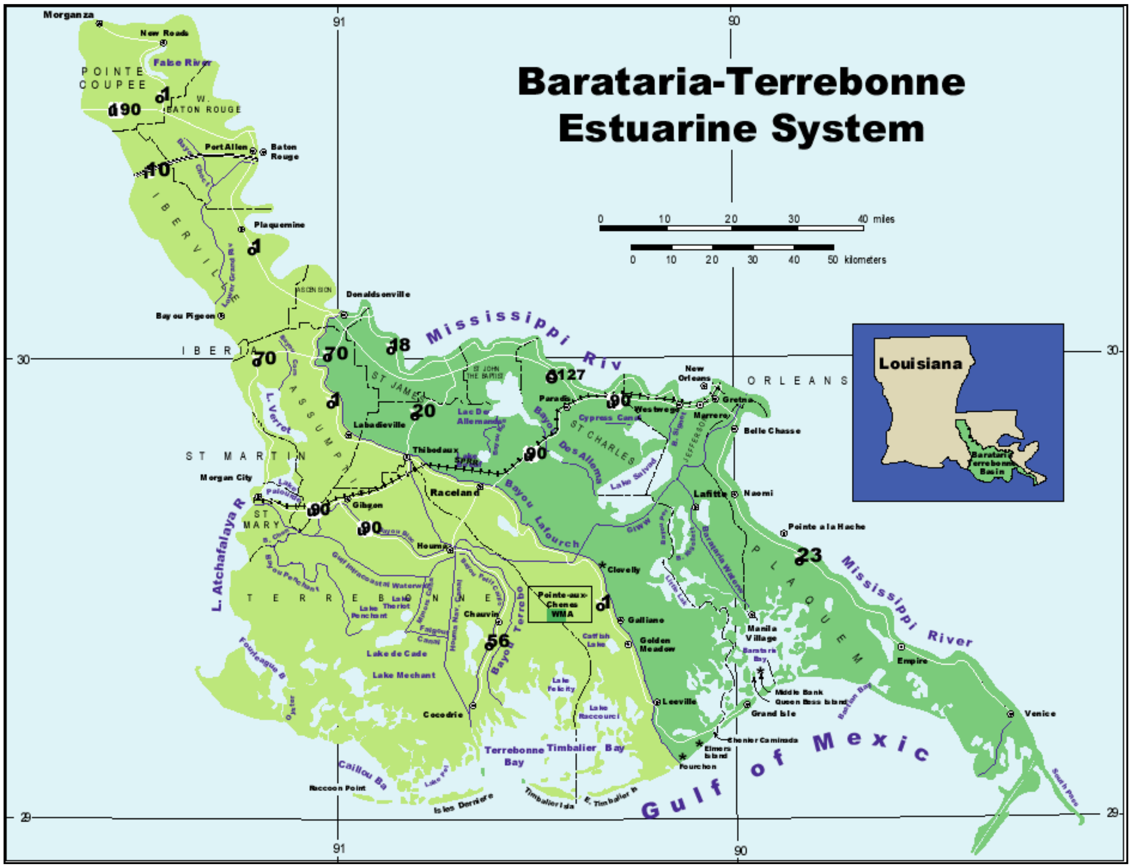


Figure 4.3 Barataria-Terrebonne Estuarine System

(BTNEP, 1996)

4.4.1 Physical Characteristics

Located between Bayou Lafourch on the west and the Mississippi River on the east, Barataria Bay is a shallow estuary that has a surface area of approximately 1700 kilometer squares and a watershed of approximately 5700 kilometer squares (McAnally, et al., 2012). The estuary is comprised of several small, complex bayou and channel systems and meets the Gulf of Mexico on its southern edge. Swenson and Welsh reported that within Barataria Bay, there are five sub-basins: swamp forest, fresh marsh, intermediate marsh, brackish marsh, and salt marsh. Barataria Bay is primarily connected to the Gulf of Mexico though the Quatre Bayoux Pass in the Grand Terre Islands (Harte Research Institute, 2002). Barataria Bay has a bar-built/deltaic morphology and experiences diurnal tides with a mean range of 0.1 meter (McAnally, et al., 2012).

Barataria Bay is irregularly shaped estuary that is roughly 190 kilometers long and has an average width between 39 kilometers and 56 kilometers (Louisiana Coast, n.d; Swenson and Welsh, n.d..). According to Louisiana Coast, both water volumes and water levels in the bay are “strongly influenced by tides, winds, and precipitation” (n.d.). While the bay experiences an average tidal range of 0.3 meter, it also experiences a meteorological forcing of approximately 1 meter (Swenson and Welsh, n.d.).

The estuary is a very complex system with multiple freshwater inputs, tidal inputs, and man-made diversions. Freshwater enters the system through precipitation, runoff, and multiple riverine systems. Saltwater enters the system through multiple tidal inlets on the southern end of the estuary where it meets the Mississippi River. The diversions in the system include those located at Davis Pond, Naomi, Myrtle Grove, West Pointe a la Hache, and the Gulf Coast Intracoastal Water Way (Swenson and Welsh, n.d.).

The tidal mixing regime, tidal range, and salinity within the bay varies depending upon location. The tidal range decreases from a maximum of 0.3 meters where the bay meets the Gulf of Mexico to practically 0 meters at the very top of the bay indicating a lack of tidal amplification within the system. The salinity also decreases as you move away from the Gulf of Mexico. The maximum (average) salinity is around 15 psu, and the salinity decreases to 0 psu (Swenson and Welsh, n.d.) indicating that while the lower part of the estuary is greatly influenced by tides, the upper part of the estuary is primarily influenced by freshwater inflow.

As the majority of Barataria Bay consists of wetlands, the sedimentation processes in and around the estuary are vitally important to the ecosystem. However, sediment supply into Barataria Bay has been depleted due to man-made structures and diversions. In fact, the Mississippi River Delta (including Barataria Bay) “has one of the highest rates of land loss of any system on Earth” (Kolker et al., n.d.). Barras et al. reported that currently, land loss is occurring at a rate of close to 63 kilometer squares per year, a decrease from the rate of 100 kilometer squares per year experienced earlier in the decade (2003). While there a numerous potential causes of this land loss, many believe that subsidence rates, depleted sediment input, salt water intrusion, peat collapse, and canal construction are primarily to blame (DeLaune et al., 1989; DeLaune et al., 1994; Turner, 1997; Reed, 2002; Day et al., 2007; Tornqvist et al., 2008). To combat the decreasing sediment supply into Barataria Bay, a 21 kilometer long pipeline that will carry sediment from the Mississippi River into the estuary is in the works (Winter, 2009; Associated Press, 2013). The project is anticipated to start in 2013 and take about 2 years to complete and is being supervised by the State of Louisiana's Coastal Protection and Restoration Authority (Associated Press, 2013).

4.4.2 Biological and Ecological Characteristics

Barataria Bay is an extremely diverse ecosystem made up of multiple channels, bayous, and waterbodies and is home to approximately 735 species of flora and fauna (Swenson and Welsh, n.d.). There are nine species listed under the ESA in Barataria Bay: one species of bird (threatened), two species of fish (one endangered, one threatened), two species of mammals (one endangered, one threatened), and four species of reptiles (three endangered, one threatened).

The water quality in Barataria Bay is defined as "fair" (USEPA, 2007) and the estuary has problems with high levels of dissolved nitrogen and phosphorus, large levels of Chlorophyll a, and water clarity. Surprisingly, dissolved oxygen levels within the estuary were good when the survey was taken (USEPA, 2007). Since the estuary experiences high levels of Chlorophyll a, that area is plagued by eutrophication in the form of nuisance/toxic blooms (CCMA, n.d.) which occur in the middle of the estuary (between the fresh water area and the seawater area).

In order to continuously assess the condition of Barataria Bay (and Terrebonne Bay as part of the Barataria-Terrebonne National Estuary Program), BTNEP monitors eutrophic conditions and nutrient levels, areas of hypoxia, pathogens, levels of toxic substances in the water column and sediments, and the area of oyster bed closures (USEPA, 2007). To assess the condition of living resources within the estuary, BTNEP uses the abundance and nesting success of endangered and threatened species (e.g. brown pelican and American bald eagle), abundance of waterflow (e.g. mottled duck), density of alligator nests, invasive species (e.g. number or acres damaged by nutria), and the number of fish consumption advisories and mercury levels in fish tissue (USEPA, 2007).

McAnally, et al., identified the main stressors in Barataria Bay to be altered riverine input, altered internal wetland connectivity, increased point and non-point source nutrients, increased point and non-point source pollutants, increased dredging, increased fishing, increased boat traffic, introduction of non-indigenous species, increased urban and coastal development, increased resource extraction, redistribution of marsh and barrier island sediment, decreasing land elevation, and degradation of critical habitat. These stressors are driven by numerous processes, but the majority of the drivers are flood levee and dam construction, freshwater diversion, sea level rise and subsidence, extreme weather events, local population size, and trade through industry and recreation (2012). USEPA also added that increased boating (and its associated sewage dumping) is an environmental stressor in Barataria and has resulted in the outbreak of illnesses due to the pathogens the dumping puts into the water (2007).

4.4.3 Human and Economic Characteristics

Barataria Bay is comprised of and surrounded by St. James parish, St. John the Baptist parish, St. Charles parish, Jefferson Parish, Plaquemines parish, and Lafourche parish. Unlike the other estuaries described for this work, the populations within these parishes show almost no growth. The U.S. Census Bureau estimates the populations and growth within these parishes to be: 21,722 with -1.70% (St. James), 44,758 with -2.30% (St. John the Baptist), 52,681 with -0.40% (St. Charles), 433,676 wih 0.30% (Jefferson), 23,921 with 3.80% (Plaquemines), and 97,029 with 0.5% (Lafourche) (2013). These estimates are based off of the 2010 Census.

Even with the population in these parishes staying fairly constant, the economy within the area has shown improvement between 2005 and 2010 (ENOW, 2013).

Table 4.4 Economic Growth for Parishes Surrounding Barataria Bay Between 2005 and 2010

	St. James Parish	**St. John the Baptist Parish**	**St. Charles Parish**	**Jefferson Parish**	**Plaquemines Parish**	**Lafourche Parish**
Establishments	N/A	3.57%	N/A	100.35%	-4.79%	12.44%
Employment	N/A	13.14%	N/A	54.53%	129.50%	32.10%
Wages	N/A	76.99%	N/A	49.14%	286.41%	66.69%
GDP	N/A	87.83%	N/A	17.90%	267.49%	74.10%

The Annie E. Casey Foundation reports that 19% of children in Louisiana between the ages of 2 and 17 have “one or more emotional, behavioral, or developmental condition” (2013). This is 4% higher than the national average of 15% and higher than any of the other states in the Gulf of Mexico. The Annie E. Casey Foundation also reports that the health ranking for children in the State of Louisiana dropped from 39 in 2012 to 41 in 2013 (2013).

As previously discussed, wetland loss has a major effect on Barataria Bay and one of the causes of this loss is sea level rise. NOAA’s State of the Coast ranks Barataria Bay as having “very high” vulnerability to sea level rise (2011). However, the entire area has a medium to low ranking for social vulnerability to environmental hazards with St. James, Jefferson, and Lafourche parishes ranking as “medium” and St. John the Baptist, St. Charles, and Plaquemines parish ranking as “low” (University of South Carolina, 2012).

As with other estuaries in the Gulf of Mexico, there are multiple areas within the bay that are currently under federal, state, or cooperative management agreements. In Barataria Bay, the main managed areas are Bayou Sauvage National Wildlife Refuge (federal), Biloxi Wildlife Management Area (state), and the Barataria-Terrebonne National Estuary Program (cooperative).

Barataria Bay is part of the Barataria-Terrebonne National Estuary Program (BTNEP) formed in 1990 between the United States EPA and the State of Louisiana. BTNEP was formed to preserve both Barataria Bay and Terrebonne Bay by "identifying problems, assessing trends, designing pollution control, developing resource management strategies, recommending corrective actions, and seeing implementation commitments" (BTNEP, n.d.). In June 1996, BTNEP published its Comprehensive Conservation Management Plan (Plan) which outlines how BTNEP operates and defines the vision and goals of the BTNEP managers. The Plan is broken into four broad categories that are meant to address the vast array of problems the estuarine systems face. These areas are: Coordinated Planning and Implementation Action Plans, Ecological Management Action Plans, Sustained Recognition and Citizen Involvement Action Plans, and Economic Growth Action Plans (BTNEP, 1996).

Approximately 93 kilometer squares (2300 acreas) of Barataria Bay is located in the Jean Lafitte National Historical Park and Preserve (National Park Service, 2012). This area of Barataria Bay is located south of Marrero, Louisiana on the western side of Lake Cataouatche and Lake Salvador. Jean Lafitte National Historical Park and Preserve was designated to preserve the cultural and natural resources found in the Mississippi River Delta of Louisiana.

4.5 Mississippi Sound, Mississippi, Alabama, and Louisiana

A bar-built, shallow, partially stratified estuary, Mississippi Sound stretches from Lake Borgne, Louisiana on its western edge to just west of Mobile Bay, Alabama on its eastern edge (Figure 4.4 and 4.5) and is separated from the Gulf of Mexico on its southern edge by a series of barrier islands including Cat, Horn, East Ship, West Ship, Petit Bois, and Dauphin Islands (Harte Research Institute, 2002b).

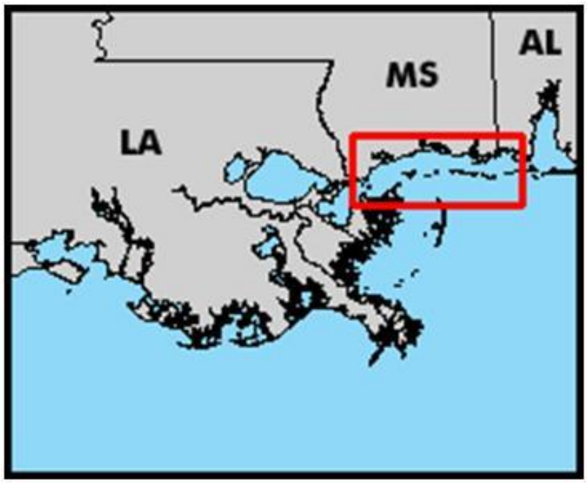


Figure 4.4 Mississippi Sound

(NOAA, n.d.(c))

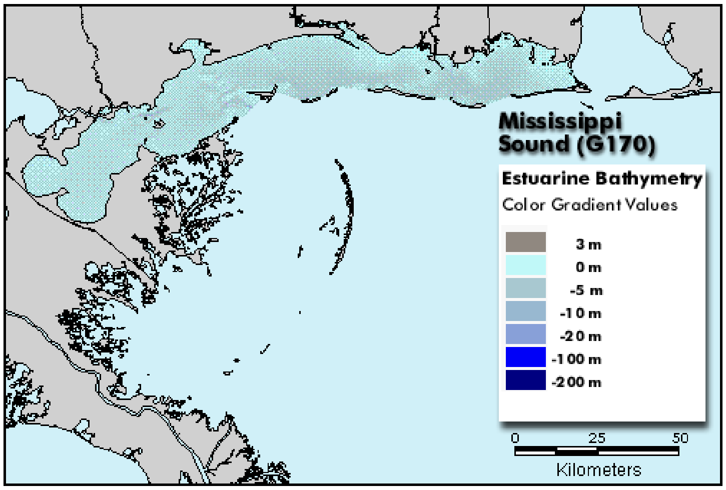


Figure 4.5 Closer View of Mississippi Sound

(NOAA, n.d.(c))

4.5.1 Physical Characteristics

Mississippi Sound includes St Louis Bay in the west, Biloxi Bay in the center, and Pascagoula River embayments and Grand Bay in the east. The Sound has an approximate surface area of 4800 kilometer squares which includes open waters, coastal wetlands, oyster reef habitat, and emergent marshes (McAnally, et al., 2012). Mississippi Sound receives approximately 1240 cubic meters per second freshwater inflow (McAnally, et al., 2012) from multiple tributaries including Turkey Creek, Biloxi River, Wolf River, Jourdan River, Pearl River, and Pascagoula River (Glenn, 2012). Blumberg et al. noted that the summer (dry season) mean flow into the Sound is 854 cubic meters per second and the spring (wet season) mean flow is 3366 cubic meters per second (2001). The mean annual precipitation for the Mississippi Sound is 154 centimeters (Moncreiff, 2002).

With a mean tidal range of 0.75 meters (McAnally, et al., 2012), Mississippi Sound has the largest tidal range of any system used in this research. Mississippi Sound is a partially stratified estuary, as is expected given that is greatly influenced by the Gulf of Mexico and has a shallow mean depth of 4 meters.

The Mississippi Sound is connected to the Gulf of Mexico through four main passes: Petit Bois Pass, Horn Island Pass, Dog Keys Pass, and Ship Island Pass (Byrnes and Berlinghoff, 2011). Tidal exchanges between the Gulf of Mexico and the Mississippi Sound affect water and sediment circulation within the estuary. Kjerfve reported that at least half of the flow variance in the Mississippi Sound is a result of tides; however, meteorological forcing has the ability to greatly affect the flow in the estuary (1986).

The presence of a large tidal prism (approximately 3.8 x 10^{10} cubic feet) compared to the freshwater inflow causes the estuary to be well-mixed vertically (Kjerfve, 1986; Byrnes and Berlinghoff, 2011; McAnally et al., 2012).

4.5.2 Biological and Ecological Characteristics

The U.S. EPA divides the Mississippi Sound into eight sub-systems (from east to west): Pearl River; Bayou Caddy; St. Louis Bay; Back Bay of Biloxi; Escatawpa, Pascagoula, and West Pascagoula Rivers; Bayou Casotte, and Bangs Lake in order to perform routine monitoring across the Gulf of Mexico (2005). The results from the 2005 study of the water quality in the Sound indicate that overall the water quality meets requirements set forth by the Mississippi Department of Environmental Quality and EPA's National Ambient Water Quality Criteria. Of the eight sites studied, only two had dissolved oxygen levels below the minimum criteria; bacteriological densities and sediment dioxin results for all sites were below the standard; only two of the sites exhibited high algal bloom results (USEPA, 2005).

In a study preformed in 2002, Moncreiff estimated total area covered in sea grass in the Mississippi Sound between two periods. Between 1962 and 1992, the Sound lost approximately 11,496 acres (47 square kiloometers); however, between 1992 and 1999, 1,712 acres (7 square kilometers) of sea grasses were added (Moncreiff, 2002). While there was still a net loss of 40 square kilometers of sea grass between 1969 and 1999, the trend did see a reversal in the later part of the study – a good indicator that the multiple sea grass restoration projects that have been established in and around the Mississippi Sound are experiencing success.

Within the Mississippi Sound ecosystem, there are twenty species listed as threatened or endangered under the ESA. These include one species of amphibian (endangered), four species of birds (endangered), two species of clams (one endangered, one threatened), one species of fish (threatened), two species of mammals (one endangered, one threatened), and nine species of reptiles (four endangered, five threatened) (FWS, 2013).

McAnally, et al., identified the main stressors in Mississippi Sound to be altered riverine input, altered internal wetland connectivity, increased point and non-point source nutrients, increased point and non-point source pollutants, increased dredging, increased fishing, increased boat traffic, introduction of non-indigenous species, increased urban and coastal development, redistribution of marsh and barrier island sediment, decreasing land elevation, and degradation of critical habitat. These stressors are driven by numerous processes, but the main drivers are human-related processes such as the increase in local population size, industry, and recreation. Extreme weather events and freshwater diversion are also drivers in this system (2012).

4.5.3 Human and Economic Characteristics

Hancock County, Mississippi; Harrison County, Mississippi; Jackson County, Mississippi; and Mobile County, Alabama border the Mississippi Sound. As with most other coastal counties in the United States, all four of these counties exhibit population growth (U.S. Census Bureau, 2013). The population in these counties and the percent growth per year as reported by the U.S. Census Bureau is: 45,255 with 3% growth (Hancock), 194,029 with 3.7% growth (Harrison), 140,298 with 0.5% growth (Jackson), and 413,936 with 0.2% growth (Mobile) (2013). These numbers, reported for 2012, are estimated off of the 2010 Census. In 2002, the total population in Hancock, Harrison, and Jackson counties was 366,263 (U.S. Census Bureau, 2002). In 2013, the total population in these counties was listed as 379,582 (U.S. Census Bureau, 2013) which indicates a 3.64% population growth in these three counties in 11 years. However, the decade before, these counties experienced a 21.8% population increase (U.S. Census Bureau, 2002).

As expected, as the population in these counties grows, so does the economy. Table 4.6 shows a summary of economic growth in Hancock, Harrison, Jackson, and Mobile counties between 2005 and 2010. Data for four indicators are shown based upon NOAA CSC's ENOW database (2013).

Table 4.5 Economic Growth in Mississippi Sound Counties between 2005 and 2010

	Hancock County, Mississippi	**Harrison County, Mississippi**	**Jackson County, Mississippi**	**Mobile County, Alabama**
Establishments	1.12%	4.82%	18.05%	6.41%
Employment	36.42%	35.90%	6.65%	29.89%
Wages	57.33%	89.08%	32.13%	72.01%
GDP	57.63%	56.55%	12.23%	1.76%

The general and mental health of the population is important. The Annie E. Casey Foundation ranked Mississippi as the 48th most healthy state in the U.S. for children in both 2012 and 2013. Alabama was ranked 41st in 2012 and rose in the rankings to 35th in 2013. The percentage of children exhibiting "one or more emotional, behavioral, or developmental condition" in 2007 (the most recent year reported) was 18% for Alabama and 15% for Mississippi; the national average is 15% (Annie E. Casey Foundation, 2013).

According to the University of South Carolina's SoVI ranking, Hancock, Harrison, and Mobile counties exhibit "medium" social vulnerability to environmental hazards while Jackson county ranks as "low" (2013). The coastal areas adjoining the western and central areas of the Mississippi Sound are very highly vulnerable to the effects of sea level rise while the eastern area demonstrates moderate vulnerability according the NOAA's State of the Coast (2011).

Many efforts have been made to restore and preserve parts of the Mississippi Sound. As such, different parts of the Sound are managed by various state and federal programs. East and West Ship Islands, Horn Island, Cat Island, and Petit Bois Island have been designated as part of the Gulf Islands National Seashore under the care of the

National Park Service (2012b). The U.S. Fish and Wildlife Service manages both the Grand Bay National Wildlife Refuge and the Mississippi Sandhill Crane National Wildlife Refuge. The Grand Bay National Wildlife Refuge is located in coastal Mississippi and Alabama and was established in 1992 to preserve one of the largest "Gulf Coast wet pine savanna habitat" remaining (U.S. FWS, n.d.). Established in 1975, the Mississippi Sandhill Crane National Wildlife Refuge is part of the Grand Bay National Wildlife Refuge in Mississippi and is aimed to protect the habitat of the endangered Mississippi sandhill crane under the Endangered Species Act (U.S. FWS, 2011).

Grand Bay National Estuarine Research Reserve is a federal-state cooperative established in 1999 to "protect the unique natural habitat of Grand Bay and manage the site for long-term research, education, and compatible public uses" (Showalter and Schiavinato, 2003). The Reserve is approximately 75 square kilometers (18,400 acres) between the Mississippi/Alabama state line and Pascagoula, Mississippi. The eastern-most portion of the Reserve is within the Grand Bay National Wildlife Refuge (Showalter and Schiavinato, 2003).

There are numerous areas in and around the Mississippi Sound managed by the Mississippi Department of Marine Resources (DMR), Land Trust for the Mississippi Coastal Plain, Wolf River Conservancy Society, and many other organizations both public and private. These areas include the Grand Bay Savanna Coastal Preserve, Hancock County Marsh Coastal Preserve, Bayou La Croix Coastal Preserve, Biloxi River Marshes Coastal Preserve, Wolf River Marsh Coastal Preserve, Escatawpa River Marsh Coastal Preserve, Jourdan River Coastal Preserve, and Pascagoula River Marsh Coastal Preserve (Showalter and Schiavinato, 2003).

4.6 Mobile Bay, Alabama

Mobile Bay is a drowned-river valley estuary situated in south Alabama (Figure 4.6) that contains multiple sub-estuaries including Bon Secour Bay, Weeks Bay, and Pelican Bay. Mobile Bay meets the Gulf of Mexico along its southern border by an inlet between Dauphin Island on the west and the Mobile Peninsula on the east.

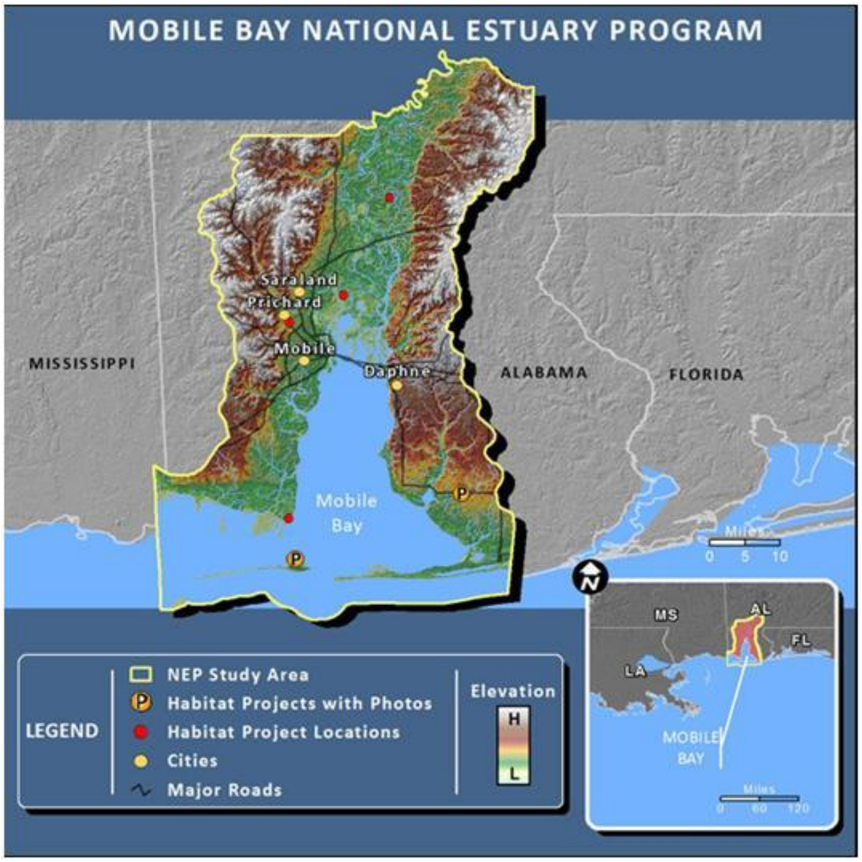


Figure 4.6 Mobile Bay

(EPA, 2010)

4.6.1 Physical Characteristics

One of the largest estuarine systems in the United States with a surface area of approximately 1050 square kilometers, Mobile Bay is a shallow estuary averaging a depth of only 3 meters (Chermock et al., 1974; NOAA, 1985; Mobile Bay National Estuary Program, 2002; MBNEP, 2010). The estuary is approximately 50 kilometers long and 27 kilometers wide (Hummell, 1996; Byrnes et al., 2013). The watershed for Mobile Bay drains approximately 115,500 square kilometers and includes the riverine systems of Mobile River, Middle River, Tenesaw River, Raft River, Apalachee River, Blakeley River, Dog River, and Fish River; the average daily freshwater inflow into the system is approximately 2,250 cubic meters per second (HRI, 2002c). The bay is connected to the Gulf of Mexico through the Main Pass (also known as Mobile Pass), an opening between Dauphin Island to the west and the Fort Morgan peninsula (USEPA, 2007b; Byrnes et al., 2013)).

In the northern part of Mobile Bay lies the Port of Mobile, a deepwater port established in 1928 (MBNEP, 2010). In 2009, the Port of Mobile ranked 12th in total domestic trade and14th in total foreign trade (MBNEP, 2010).

Mobile Bay experiences diurnal tides with an average tidal range of 0.36 meters at the mouth of the bay (National Ocean Service, n.d.) and 0.45 meters in the northern portion of the bay (Byrnes et al., 2013) indicating that tidal amplification occurs within the system. The salinity in Mobile Bay varies based upon seasonal changes in freshwater inflow, strong winds, and tidal flows into the estuary (USEPA, 2007b). Noble et al., noted in 1996 that the bay is a highly stratified. A 2005 study confirmed this and noted that the salinity varies greatly with depth in the estuary and river channels (Braun and Neugarten). Average annual precipitation into Mobile Bay ranges between 127 centimeters and 152 centimeters with the lower ranges falling in the northern part of the estuary and the higher ranges being deposited in the lower part of the estuary near the Gulf of Mexico (Ward et al., 2005).

Tides and freshwater discharge are the primary forcing factors in Mobile Bay; however, during tropical and extratropical events, meteorological conditions becoming the forcing factor affecting not only water flow, but sediment flow throughout the estuary (Isphording, 1994; Schroeder et al., 1998; Zhao and Chen, 2008).

Byrnes et al., reported that between the years of 1984 and 2011, annual net deposition occurs within Mobile Bay at a rate of approximately 2.08 million cubic yards (2013). Isphording et al., estimated that less than 30% of the sediment entering the bay actually leaves the estuary and enters the Gulf of Mexico (1996). This net deposition is primarily due to “the general configuration of the bay, relatively low velocity discharge from the river, and quiescent wave and current conditions within much of the bay” (Byrnes et al., 2013) causing much of the sediment entering the system to be deposited within the estuary (Isphording et al., 1996; Cordi et al., 2003).

4.6.2 Biological and Ecological Characteristics

Mobile Bay is a biologically and ecologically diverse area. The Mobile Bay National Estuary Program reported that this area is home to “49 species of mammals, 126 species of reptiles and amphibians, 337 species of freshwater and saltwater fish, and 355 species of birds” (MBNEP 2002; USEPA, 2007). Of these species, 17 are listed as endangered or threatened under the ESA including two species of birds (one endangered, one threatened), two species of clam (one endangered, one threatened), two species of fish (one threatened, one endangered), one flowering plant (endangered), three mammals (endangered), and seven reptiles (five endangered, two threatened) (USFWS, 2013).

The Mobile Bay NEP monitors both sediment and water quality within the bay. The water quality indicators MBNEP uses are “chlorophyll a, total phosphates, ammonia, nitrates and nitrites, dissolved oxygen, salinity, pH, biochemical oxygen demand, turbidity, and water temperature” (USEPA, 2007b). Baya et al. reported that dissolved oxygen standards set forth by the Alabama Department of Environmental Management (ADEM) were achieved in 95% of the estuary (1998); however, data collected between 1993 and 1995 indicate that 55% of the bottom of the estuary had dissolved oxygen levels below the minimum of 4 milligrams per liter and 30% of the bay had dissolved oxygen levels below 2 milligrams per liter (MBNEP, 2002; USEPA, 2007b). Despite the dissolved oxygen problems in the estuary, the overall water quality condition was rated as “fair” with 23% of the waters rated as “good” and 77% rated as “fair” by the U.S. EPA in 2007(b). The sediment quality monitored by sediment toxicity, sediment contaminants, and total organic carbons was also rated as “fair” with 9% of the sediment rated as “poor”, 24% rated as “fair”, and 67% rated as good (USEPA, 2007b).

In 1998, three years after it was established, MBNEP went through extensive technical and citizen review to identify water quality issues within the estuary so they could be used for the development of the Comprehensive Conservation Management Plan (CCMP) for the NEP. The categories identified through this process were pathogens, toxic chemicals, nutrient and organic overloading, physical and hydrologic modifications, and erosion and sedimentation (Baya, et al., 1998).

30 scientists and resource managers were brought together to complete an exercise where they would evaluate the impact that environmental stressors have on the ecosystem in Mobile Bay. They also determined what these environmental stressors

were. From the exercise, thirteen stressors were identified. These stressors are: chemical contamination, dredging and filling, fire suppression, land fragmentation, invasive species, land use change, nutrient enrichment, high levels of pathogens, sedimentation, sea level rise, climate variability, freshwater discharge, and resource extraction (Brown and Lehrter, 2012). Human activities and hydrologic modifications were also identified as environmental stressors for Mobile Bay by Hutchings and Yokel, (2000).

4.6.3 Human and Economic Characteristics

Mobile Bay is bordered by Mobile County, Alabama to the west and Baldwin County, Alabama to the east. The U.S. Census Bureau reports that the population in both of these counties has grown over the past two years. The population in Mobile County is 413,936 with a 0.20% per year growth and the population in Baldwin County is 190,790 with a 4.70% growth per year (U.S. census Bureau, 2013).

The economies in both of these counties is also growing. Table 4.7 shows a summary of economic growth demonstrated through four indicators (NOAA CSC ENOW, n.d.).

Table 4.6 Economic Growth in Mobile and Baldwin Counties Between 2005 and 2010

	Mobile County	**Baldwin County**
Establishments	6.41%	29.59%
Employment	29.89%	35.49%
Wages	72.01%	40.09%
GDP	1.76%	37.06%

In 2012 the Annie E. Casey Foundation ranked the State of Alabama as 41st for general health ranking for children between the ages of 2 and 17. In 2013, however, Alabama moved up six slots and is ranked 35th. In a 2007 report of the number of children with “one or more emotional, behavioral, or developmental condition” the Annie E. Casey foundation reported that 186,000 children met these requirements (or roughly 18% of children) which is higher than the national average of 15%.

Even though one of the environemtnal stressors identified by Brown and Lehrter was sea level rise (2012), NOAA’s State of the Coast ranks the entire Mobile Bay estuary as having “low” to “moderate” vulnerability to sea level rise (2013). This low to moderate ranking also hold true for the area’s social vulnerability index (SoVI) (University of South Carolina, 2012). Mobile County is ranked as “medium” or “moderate” while Baldwin County is ranked as having a “low” vulnerability (University of South Carolina, 2012).

There are multiple federal, state, and cooperative entities that manage different parts of this extremely diverse estuary. Bon Secour National Wildlife Refuge is located in the southeastern part of the estuary and is federally managed. Meaher State Park and the Mobile-Tenesaw River Delta both fall under state management. Federal and state cooperative agreements have been set up to manage the Weeks Bay National Estuarine Research Reserve, located just north of Bon Secour NWR, and the Mobile Bay National Estuarine Program, which encompasses all of the formerly mentioned sites.

Established in 1995, the Mobile Bay National Estuary Program (MBNEP) works toward solving environmental problems in the estuary. In the Comprehensive Conservation and Management Plan (CCMP) (2002), the MBNEP identified the priority environmental concerns for Mobile Bay as increased erosion, increased dredging, introduction of non-native species, and hydrologic modifications. To achieve the goals set forth in the CCMP and mitigate the adverse impacts the stressors have on the estuary, each year the MBNEP prepares a Work Plan that details the activities that will be undertaken in the coming year.

In 2012, MBNEP started drafting its second CCMP for years 2013-2018. In the Second CCMP, MBNEP identified thirteen key stressors in Mobile Bay. These stressors include chemical contamination from the Deepwater Horizon Oil Spill, dredging and filling for navigation, fire suppression, fragmentation of wetlands, invasion of non-native species, land use change in the watershed, increase in point and non-point source nutrients, increase in pathogens, sedimentation in the estuary, sea level rise, climate variability, changes in freshwater discharge into the system, and an increase in resource extraction. Currently, the 2013-2018 CCMP is open for public comment. In the new CCMP, 12 essential ecosystem services were identified as well as 11 priority habitats (MBNEP, 2012). Restoration plans for different priority habitats aimed at mitigating the adverse impacts of environmental stressors to increase ecosystem services are laid out in the new CCMP.

CHAPTER V

INITIAL DEVELOPMENT OF FRAMEWORK

5.1 Introduction

The goal of this research is to develop a framework and tools that can identify sub-ecosystems within large marine ecosystems (LMEs) for management purposes on the sub-ecosystem level. In order to effectively manage LMEs at any level, it is important to understand characteristics and interactions that occur within the ecosystem. It is also important to understand how these characteristics and interactions can be translated to the different management protocols discussed in Chapter 2. As such, it is important to adequately describe the ecosystem in order that sub-ecosystems may be identified based upon their characteristics and the management protocol that will be used to manage the area.

As LMEs can cover such an extensive area, it is useful to divide them into sub-ecosystems to create and implement management plans to maximize the ecosystem services and outputs. For this work, five ecosystems in the northern Gulf of Mexico were used to develop and validate the framework. The purpose of the framework is to adequately describe each system in a succinct, methodical approach. To describe the ecosystem for management purposes, two different matrices were developed: an indicators matrix and a management matrix. The indicators matrix describes characteristics of the system while the management matrix weights each indicator for the individual systems. A grid of different mesh sizes overlaid each of the ecosystems in order to divide the area into smaller pieces appropriate for analysis. Once the grid is in place, the matrices will be populated with data based upon the descriptions of each indicator and sub-indicator discussed below. Then using clustering techniques, grids that have similar matrices were grouped together to indicate sub-systems of the larger system.

Since identifying sub-systems in the framework is dependent upon the matrices, it is imperative that the matrices include enough information to differentiate between areas, but not include too much information to make the framework ineffective. The purpose and components of the individual matrices are described in the following sections.

The indicators used in the indicator matrix were chosen based upon literature review, expert elicitation, and data availability. For literature supporting the use of each indicator in the framework, refer to the indicator sub-section (below).

The management matrix was developed based upon expert elicitation. The process used to develop the matrix is described in the management matrix section (below).

5.2 Indicators Matrix

The indicators matrix is the first level matrix that describes the area. It is broken down into three sub-matrices that describe 1) the biological and ecological characteristics of the area, 2) the physical characteristics of the area, and 3) the human and economic characteristics of the area.

Each sub-matrix is comprised of multiple indicators that can be used to characterize the sub-ecosystem. The indicators for each sub-matrix were chosen using literature review and expert opinion.

5.2.1 Biological and Ecological Indicators

The biological and ecological indicators are meant to characterize the health of the ecosystem. Components of this sub-matrix describe the growing environment for the flora and fauna, identifies areas of concern, and can indicate the overall health of the area using the health of indicator species. Seven biological and ecological indicators have been identified to describe the health of the system. These indicators are:

- Phytoplankton productivity values
- Coastal habitat: indicator species health
- Marine trophic index
- Critical habitat designation
- Habitat areas of particular concern
- Endangered species act: number of threatened and endangered species
- Environmental sensitivity index

5.2.1.1 Phytoplankton Productivity Values

Based upon the CMECS classifications for productivity which was modified from the NOAA Estuarine Eutrophication Survey (1997), phytoplankton productivity values are measured based upon the level of chlorophyll a in the water column. Chlorophyll a is a form of chlorophyll that is used in photosynthesis by eukaryotes, cyanobacteria, and prochlorophytes (Raven et al., 2012). Chlorophyll a content in the water column reflects the productivity of the system and can indicate the balance and status of the system.

Chlorophyll a is an important indicator for estuaries as the level of chlorophyll a in the water can be used to determine phytoplankton density and the level of primary production taking place (NOAA OSE, 2012). Since chlorophyll a is the base of the estuarine food web it often directly affects the abundance of healthy animals in the ecosystem (NOAA OSE, 2012). The concentration of chlorophyll a in an estuary can also be an early warning sign of high levels of nutrients entering the system and can foretell of possible eutrophication (Bricker, et al., 2008); the National Estuarine Eutrophication Assessment uses chlorophyll as an indicator of nutrient-related problems in estuaries. In a 2002 study of the Senegal River estuary, chlorophyll a concentrations were used to help determine the health and water quality status of the estuary (Troussellier et al., 2004)

For water column phytoplankton, productivity values were taken from CMECS (Table 5.1) and measured based upon chlorophyll a levels measured in micrograms of chlorophyll a in the water column per liter of water.

Table 5.1 Phytoplankton Productivity Value

Phytoplankton Productivity Value	**Chlorophyll a (µg/L)**
Oligotrophic	< 5
Mesotrophic	5 to < 50
Eutrophic	≥ 50

(FDGC, 2012)

The five year seasonal mean, as estimated using satellite imagery, will be used for this work as reported by NOAA's Gulf of Mexico Data Atlas (n.d.). The value that will be used in the framework will be from the season with the highest Chlorophyll a concentrations.

5.2.1.2 Coastal habitat: indicator species health

Indicator species health and trends will be used as a gauge of the overall habitat health of an area. Also known as sentinel organisms, indicator species' health and population trends are useful for monitoring the health of an ecosystem. Generally, an indicator species is chosen for two reasons: first, the species must convey meaningful information, and second, the species must be able to be reliably measured.

In 2011, Harte Research Institute (HRI) released a vision and preliminary work on a Gulf of Mexico Report Card that would comprehensively measure ecosystem health using integrated assessment and a modified DPSIR (ch. 2) framework. In the preliminary report card, HRI used two different indicator species to monitor the Gulf of Mexico: brown pelicans and seagrass. HRI chose brown pelicans as an indicator species as they "utilize a wide range of habitats within the Gulf of Mexico" (HRI, 2011) and the brown pelican migratory routes and trends can indicate the health of a habitat based upon the pressures acting on them. For instance, brown pelican population in an area will decrease with increasing habitat alterations such as land development. HRI also chose to use seagrass as an indicator species. The total area covered in seagrass over time was recorded and the health of the ecosystem was rated based upon the trend of seagrass area over time. Seagrass is an indicator that speaks to the water quality in a particular habitat as they are susceptible to changes in water quality (HRI, 2011).

For this work, a minimum of three indicator species will be used to gauge the habitat health. While the indicator species will vary from estuary to estuary, when applying the framework to LMEs multiple species may represent habitat health.

To determine the trend of each indicator species, historical data will be used. For the time series of data, the overall trend (in regards to total area, number of species present, etc) will be determined based upon the indicator species being used. Based upon this trend, each indicator species will be designated as very poor, poor, moderate, good, or very good according to the rankings described in Table 5.2.

Table 5.2 Indicator Species Health Trends

Indicator Species Trend (%)	**Designation**
< -60	Very Poor
-60 to -20	Poor
-20% to 20%	Moderate
20% to 60%	Good
>60%	Very Good

5.2.1.3 Marine Trophic Index

The marine trophic index (MTI) was established by the University of British Columbia's Fisheries Center to describe the complex interactions between fisheries and marine ecosystems (Biodiversity Indicators Partnership, 2010). The MTI of an ecosystem is calculated using "catch composition data collected by the Food and Agricultural Organization of the United Nations" (BIP, 2010).

The MTI for each country's exclusive economic zone (EEZ) and all LMEs were calculated from 1950 to 2011. The MTI expresses the trend of the diversity and abundance of different fish species high in the food chain.

In some parts of the world, the MTI can be viewed on a regional, country, or sub-country basis. However, only MTI designations for LMEs and the EEZ are shown. As a result, for the purposes of this work, all of the estuaries will have the same MTI designation as all of the estuaries are located within the same LME. If the framework were to be applied to a system in different LMEs or EEZs (such as off the coast of Alaska), the MTI designation would be different regions.

5.2.1.4 Critical Habitat Designation

The total surface area designated as critical habitat under the Endangered Species Act (ESA) to protect threatened and endangered species' habitat in each area will be denoted. Under the ESA, critical habitat is defined as: "1. Specific areas within the geographical area occupied by the species at the time of listing, if they contain physical or biological features essential to conservation, and those features may require special management considerations or protection; and 2. Specific areas outside the geographical area occupied by the species if the agency determines that the area itself is essential for conservation" (NOAA Coastal Services Center in the Marine Cadastre, n.d.).

Based upon the total surface area designated as critical habitat, the amount of each grid square covered in critical habitat will be calculated and represented as a percent. Ranges for the percent area covered by critical habitat were developed (Table 5.3).

Table 5.3 Critical Habitat Designations by Area Covered

Critical Habitat Designation	**Area Covered By Critical Habitat (%)**
Slight Coverage	0 to < 20
Light Coverage	20 to < 40
Moderate Coverage	40 to < 60
High Coverage	60 to < 80
Full Coverage	≥ 80

5.2.1.5 Habitat Areas of Particular Concern

Habitat areas of particular concern are designated by NOAA National Marine Fisheries Service as “discrete subsets of Essential Fish Habitat that provide extremely important ecological function or are especially vulnerable to degradation” (NOAA National Marine Fisheries Service in Marine Cadastre, n.d.).

The total surface area of each grid square designated as a habitat area of particular concern (HAPC) will be used to determine the amount of HAPC located in each square as a percent. Ranges for the percent each square is covered by a HAPC were developed (Table 5.4).

Table 5.4 Habitat Area of Particular Concern Designations by Area Covered

HAPC Designation	**Area Covered By HAPC (%)**
Slight Coverage	0 to < 20
Light Coverage	20 to < 40
Moderate Coverage	40 to < 60
High Coverage	60 to < 80
Full Coverage	≥ 80

5.2.1.6 Endangered Species Act: Number Threatened and Endangered Species

An endangered species is a species classified under the Endangered Species Act of 1973 as a plant or animal that is in danger of extinction in the foreseeable future. Designated as threatened or endangered species by Congress, these species are added to the endangered and threatened species list and programs are put into place for the protection of the species to prevent its extinction.

The number of endangered and threatened species in a particular habitat can indicate the overall health of the habitat and surrounding area. As the amount of endangered and threatened species in an area increases, the more likely it is that irreversible changes are being made to the ecosystem. As such, both the number of threatened and endangered species that can be found in each area is noted (separately) so that management actions can be decided upon that will not harm these species.

5.2.1.7 Environmental Sensitivity Index

Environmental Sensitivity Index (ESI) maps provide a summary of coastal resources that are at risk from natural disasters and usually include information for at-risk resources such as biological resources, sensitive shorelines, and human resources (NOAA ORR, 2012). Initially developed after the Exxon-Valdez oil spill off the coast of Alaska in 1989, ESI maps are a succinct way to relay to responders susceptible areas where environmental consequences need to be mitigated as quickly as possible. ESI maps can also help aid cleanup efforts by prioritizing areas to alleviate environmental damage. While ESI maps were originally developed to mitigate damages caused by oil spills, they can also be useful to ecosystem managers as they can identify vulnerable habitats and species.

Each state on the Gulf of Mexico has ESI maps; however it is important to note that the designations vary from state to state. As such, ESI maps will be reviewed to identify at-risk resources and sensitive shorelines as protecting these areas are essential in creating effective management plans. However, when applying the framework to LMEs, ESI maps can only be used as a guide to identify at-risk resources. In order to integrate ESI maps into this framework when applied across multiple states, ESI maps and their designations would need to be standardized.

5.2.2 Physical Indicators

The physical indicators are meant to describe the properties of the ecosystem from a purely descriptive perspective. Components of this sub-matrix can be used to describe the system – from the way it was originally formed to the processes that are currently influencing it. Six physical indicators and ten sub-indicators have been identified to adequately describe the properties of the system. These indicators are:

- Water quality
    - Water temperature
    - Salinity
    - Photic quality
    - Oxygen level
    - Turbidity
- Predominant bottom sediment type
- System energy
    - Freshwater flow
    - Wave energy regime
    - Wind energy
    - Tidal regime
- Mixing regime
- Bed slope
- Wave climate
- Other considerations

5.2.2.1 Water Quality

Water quality refers the condition of water in an area. The description of water quality in an area can vary depending upon the situation and water quality values are typically dictated by state or federal regulations. For instance, both the federal government and state-level governments have water quality standards that regulate drinking water to protect the public. Water quality regulations are also in place to protect ecosystems, and current regulations are being developed and implemented in multiple states the set total daily maximum loads for nutrients in estuaries.

Multiple factors affect the water quality in an area, and as such, the water quality indicator will be described using six different sub-indicators:

- Water temperature
- Salinity
- Photic quality
- Oxygen Level
- Turbidity
- Predominant bottom sediment type

All of the values for the water quality sub-indicators will be noted on a monthly or seasonal basis depending upon data availability. From the management expert survey (Chapter 5.2 below), it was indicated that the most important temporal scale to be used when managing estuarine ecosystems is on a monthly basis.

5.2.2.1.1 Water Temperature

Temperature has a profound impact on ecosystem function and can affect organism growth, decay, and metabolism. Temperature also affects the rate of microbial processes. Typically, organisms are susceptible to changes in temperature and have a range at which they function most efficiently. In most cases, water temperature increases with depth; however, as all of the systems used for this work are relatively shallow, we can assume that the temperature gradient is not very steep for any system and thus use a mean temperature for the entire water column.

Water temperature is an important aspect with classifying estuarine areas as temperature has a considerable impact on the entire ecosystem and can tell about how productive and healthy an ecosystem is (NOAA OSE, 2012). In the United States, all of the estuaries that are part of the National Estuary Program or are a National Estuarine Research Reserve maintain water temperature records as it is so important to estuarine ecosystem health. Multiple studies have been performed in which water temperature was used in estuarine studies (e.g. Hansen and Rattray, 1966; Stevens et al., 1975;Kjerfve, 1980)

Temperature ranges were established in intervals of sufficient range to differentiate ecological differences in areas and are the same as those set forth in the Coastal and Marine Ecological Classification Standard (CMECS) (2012) by the Federal Geographic Data Committee (FGDC) and "are based on the *British Columbia Marine Ecological Classification for Canada*" (FGDC, 2012). The temperature categories are shown in Table 5.5.

Table 5.5 Water Temperature Categories

Temperature Category	**Degrees (°C)**
Frozen/Superchilled Water	0 and below
Very Cold Water	0 to < 5
Cold Water	5 to < 10
Cool Water	10 to < 15
Moderate Water	15 to < 20
Warm Water	20 to < 25
Very Warm Water	25 to < 30
Hot Water	30 to < 35
Very Hot Water	≥ 35

(FGDC, 2012)

Seasonal water temperature data will be accessed using the Gulf of Mexico Data Atlas. The available data is a five day average based upon data taken from 1982 through 2009 broken into seasons (NOAA Gulf of Mexico Data Atlas, n.d). The season that produces the hottest temperature will be used as warmer water temperatures can lead to conditions such as decreased dissolved oxygen and increased eutrophication in estuaries.

5.2.2.1.2 Salinity

Salinity is the result of a concentration of dissolved salt in water. Salinity is a measure of the conductivity ratio of the water and is measured in practical salinity units (psu) on the practical salinity scale which was established in 1978 by the International Association for the Physical Sciences of the Oceans (UNESCO, 1981 in FGDC, 2012). Typically, ocean water has a salinity of approximately 35 psu while freshwater has salinity of 1 psu or below. As estuaries are usually a mixture of freshwater and ocean water, it is expected that estuaries will have a salinity range anywhere between 1 and 35 psu; however, some estuaries have salinities higher than 40 psu. These estuaries are considered to be hyperhaline. An example of a hyperhaline estuary on the Gulf of Mexico is Laguna Madre, Texas.

As with water temperature, the salinity in those estuaries included in the NERR system or designated as a NEP is monitored as the salinity of the estuary directly affect the ecosystem. In a 1993 study of the Chesapeake Bay and Delaware Bay, salinity was used to derive estuarine zones (Bulger et al). Another study in 1992 characterized South African estuarine systems based upon physiographic, hydrographic, and salinity (Whitfield). Numerous studies use the Venice System (1959) to classify estuaries according to salinity (e.g. Mclusky, 1993; Moreira et al., 1993; Ferreira et al., 2006).

Salinity in an estuary is directly affected by the freshwater inflow from tributaries, runoff, groundwater discharge, and precipitation as well as ocean water which is forced into the estuary by the tide. Salinity can indicate how dynamic a system is based upon circulation. As with temperature, most organisms optimally function within a small salinity range; therefore, changes in salinity can disrupt the ecological balance of an area. Salinity ranges were established to adequately describe the ecological differences and are the same as the CMECS classification for salinity as modified from the Venice System (1959) (Table 5.6).

Table 5.6 Salinity Categories

Salinity Regime	**Salinity (psu)**
Oligohaline Water	< 5
Mesohaline Water	5 to < 18
Lower Polyhaline Water	18 to < 25
Upper Polyhaline Water	25 to < 30
Euhaline Water	30 to < 40
Hyperhaline Water	≥ 40

(FGDC, 2012)

Seasonal water temperature data will be accessed using the Gulf of Mexico Data Atlas. The available data is a five day average based upon data taken from 1982 through 2009 broken into seasons (NOAA Gulf of Mexico Data Atlas, n.d). The season that produces the hottest temperature will be used as warmer water temperatures can lead to conditions such as decreased dissolved oxygen and increased eutrophication in estuaries.

5.2.2.1.3 Photic Quality

The photic quality of the water column refers to the depth of water that is exposed to sufficient light to allow photosynthesis to occur. Photic quality is highly variable and depends upon multiple factors including water column depth, turbidity, the angle of the sun, the season, and cloud cover.

The photic quality expresses light penetration adequacy for aquatic plants and animals. Photic quality values and the conditions that describe them were taken from the CMECS classification (Table 5.7).

Table 5.7 Photic Quality Categories

Photic Quality Value	Condition
Aphotic	Region of the water column where no ambient light penetrates. No photosynthesis occurs and animals cannot make use of visual cues based on reduced levels of ambient light
Dysphotic	Region of the water column that receives less than 2% of the surface light; plants and algae cannot achieve positive photosynthetic production in this region, but some ambient light does penetrate such that animals can make use of visual cues based on reduced levels of ambient light
Photic	Region of the water column where ambient light is >2% of surface light and phototrophic organisms can photosynthesize.
Seasonally Photic	An area that regularly varies between photic and dysphotic/aphotic.

(FGDC, 2012)

The photic quality of an estuary is important because it tells about the light penetration and attenuation in the water column. The depth of light penetration is important for an estuarine ecosystem as it directly affects where plants can grow due to their photosynthetic needs and it also effects what plants are able to grow in the estuary. French et al., noted that the "second parameter of importance in water quality computations is the euphotic or photic depth" (1982). A 1989 study by Sheavly and Marshall related phytoplankton productivity and water quality to the euphotic (or photic) zone in Lake Trashmore, Virginia.

The location, depth, and size of the photic zone is extremely important to know for estuaries as this is the zone in which organisms can photosynthesize. Since typically photosynthetic organisms are located at the bottom of the food chain, the ability of organisms to carry out photosynthesis can directly correlate to the health of the entire estuarine ecosystem.

The determination of photic quality for the estuaries in this work will be calculated using the total depth of the estuary and the secchi disc depth recorded by NOAA's Gulf of Mexico Data Atlas. The secchi disc depths are recorded for each season using a five year average. The season that produces the shallowest secchi disc depth will be used in this framework as it helps identify what is typically the least productive season for the ecosystem.

5.2.2.1.4 Oxygen Level

Adequate oxygen levels are critical for aerobic organism respiration. Dissolved oxygen levels vary greatly depending upon multiple factors. By using the lowest mean dissolved oxygen level (for a month), the aim is to describe persistent oxygen conditions for the area. Dissolved oxygen is measured in milligrams per liter (mg/L) which represents the milligrams of oxygen dissolved in a liter of water.

"Dissolved oxygen plays a critical role in most oceanic biogeochemical processes and is essential for most living resources" (NOAA Gulf of Mexico Data Atlas, n.d.). As such, the level of dissolved oxygen in an estuary is a major factor in both the type and abundance of organisms that can live in the ecosystem. Dissolved oxygen levels are influenced by water temperature and salinity (NOAA Ocean Service Education, 2012) and is "one of the most important water quality parameters" (South Central Eco Institute, n.d.). NEPs and NERRs recognize how important dissolved oxygen levels are to the health and wellbeing of estuarine ecosystems and monitor dissolved oxygen levels for the estuaries under their purview.

Areas that have little to no dissolved oxygen are classified as anoxic. Few organisms will survive in anoxic conditions. If an area remains anoxic for a long enough period of time a dead zone occurs in which there is little to no life existing in the zone other than anaerobic bacteria. These dead zones are typically referred to as eutrophic zones. The third largest eutrophic zone in the world is located in the Gulf of Mexico where the Mississippi River enters the system (Miller and Spoolman, 2011). Noting locations of recurring anoxic areas and dead zones is important for managers as they can indicate up-stream management options an ecosystem manager can implement to improve the health of the ecosystem.

The dissolved oxygen values in Table 5.8 show the six oxygen regimes used in CMECS and their associated concentrations.

Table 5.8 Mean Oxygen Level Categories

Oxygen Regime	**Dissolved Oxygen Concentration (mg/L)**
Anoxic	0 to <0.1
Severely Hypoxic	0.1 to < 2
Hypoxic	2 to < 4
Oxic	4 to < 8
Highly Oxic	8 to < 12
Very Oxic	≥ 12

(FGDC, 2012)

Dissolved oxygen data for each of the estuaries will be obtained from previous studies including any data that can be found from federal resources including, but not limited to, data collected by NEPs and NERRs. Monthly averages will be used. The month in which the lowest dissolved oxygen levels are recorded will be used in the framework and for classifying the estuary. This is due to the fact that as dissolved oxygen has such a profound impact on the health of the ecosystem, low levels of dissolved oxygen can harm the ecosystem and indicate that the estuarine ecosystem may be least healthy during months of low dissolved oxygen levels.

5.2.2.1.5 Turbidity

Turbidity is the measure of water clarity and is dependent upon the amount of suspended and dissolved solids in the water column. Turbidity has a direct effect on light penetration in the water column and affects photic quality (ch. 4.2.1.3). Suspended solids that impact turbidity can include sediment, plankton, algae, and microbes to name a few. Dissolved materials such as tannins from leafs color water, causing turbidity. Turbidity has a direct affect upon the temperature and dissolved oxygen levels in the water column (EPA, 2012). Generally, as turbidity increases, water temperature increases as well (ch. 4.2.1.1). This is due to the fact that suspended solids absorb heat which in turn heats the water column. As the temperature in the water column increases, the amount of dissolved oxygen decreases (ch. 4.2.1.4). As turbidity affects photic quality, water temperature, and dissolved oxygen levels, it is an important biological and ecological feature of an area.

The United States EPA recognized turbidity as a water quality parameter and states that "[t]urbidity is a principal physical characteristic of water and is an expression of the optical property that causes light to be scattered and absorbed by particles and molecules rather than transmitted in straight lines through a water sample (1999). Both the EPA and NOAA use turbidity as an indicator that there are other currently unseen problems with an ecosystem (NOAA Ocean Service Education, n.d.; EPA, 2012). NOAA uses turbidity as a preliminary indicator of possible increased shoreline erosion and a preliminary indicator that a wastewater treatment plant may not be functioning properly and discharging more effluent than allowed into the waters of the United States (n.d.). EPA notes that turbidity can indicate if soil erosion, excess waste discharge, urban runoff, stream bank erosion, increased numbers of bottom feeders, and/or excessive algal growth is occurring in an area (2012). As both EPA and NOAA recognize the importance of monitoring turbidity, most of the NERRs sites monitor turbidity using electronic monitors (NOAA Ocean Service Education, n.d.).

Turbidity is typically measured in one of two ways: using Nephelometric Turbidity Units (NTUs) or using Secchi disk depths. NTU is measured by sending light through a water sample and measuring light scattered at a 90 degree angle by the particles within the water sample (EPA, 2012). To measure Secchi disk depth, a Secchi disk (Figure 5.1) that is mounted to a pole is slowly lowered into the water column until the pattern on the disc is no longer visible. This depth is recorded as the Secchi disk depth and is measured in meters.

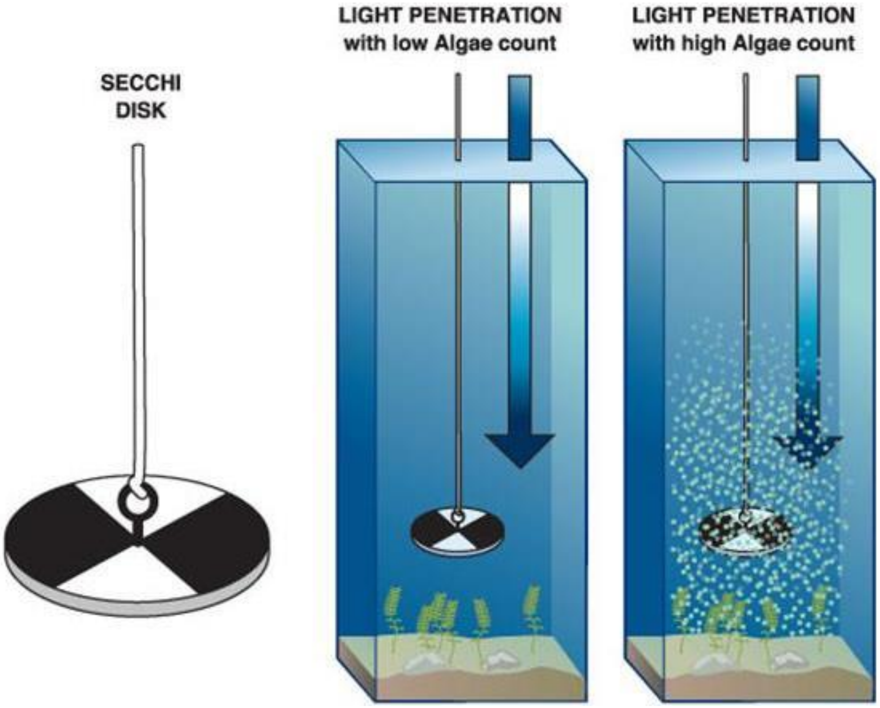


Figure 5.1 Secchi Disc

(University of Michigan, n.d.)

The Australian Environmental Protection Authority developed a “rule of thumb” conversion between NTUs and Secchi Disk Depth for estuaries (Australian EPA, 2007) (Table 5.9 and Figure 5.2).

Table 5.9 Secchi Disk Depth and NTU Relationship

NTU	Secchi (m)
2	10
5	4
10	2
25	0.9
100	0.2

(Australian EPA, 2007)

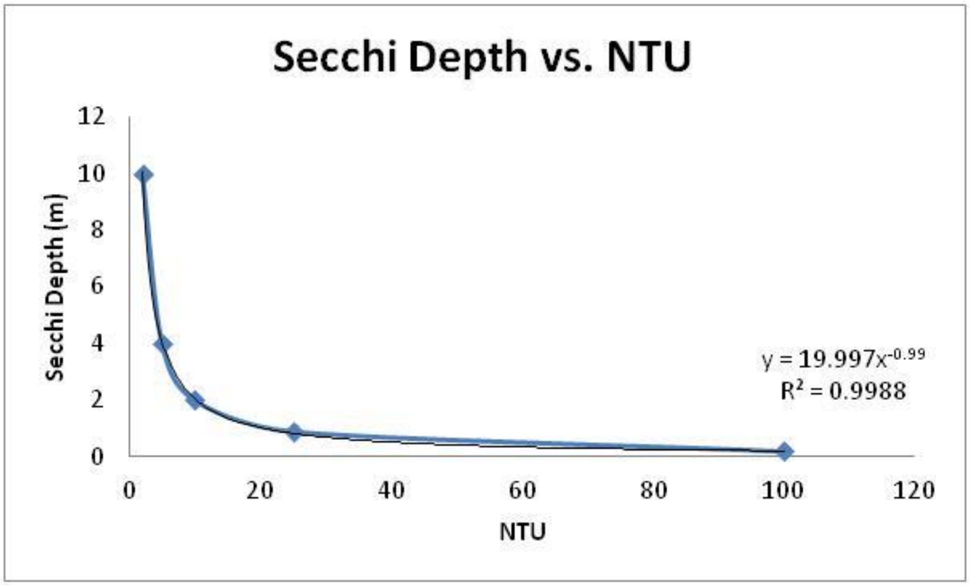


Figure 5.2 Secchi Disk Depth vs. NTU

(based on Australian EPA, 2007)

Turbidity values were established from CMECS which reports turbidity based on Secchi disk depth (Table 5.10).

Table 5.10 Turbidity Values

Turbidity Value	**Euphotic Depth (meters)**
Extremely Turbid	< 1
Highly Turbid	1 to < 2
Moderately Turbid	2 to < 5
Clear	5 to < 20
Extremely Clear	≥ 20

(FGDC, 2012)

For turbidity data, five year seasonal averages from the Gulf of Mexico Data Atlas will be used. The data was acquired through the Naval Research Laboratory at Stennis Space Center, Mississippi through the use of the MODIS-Aqua satellite (NOAA Gulf of Mexico Data Atlas, n.d.). The season that produces the highest level of turbidity will be used in the framework as the more turbid the water column is, the less light attenuates the water column. This is important as light is necessary for the photosynthetic process that plants must undergo in order to survive. Too little light attenuation due to turbidity can cause the ecosystem to stagnate due to a decrease in the organisms that are on the bottom of the food chain (NOAA Ocean Service Education, 2012).

5.2.2.2 Predominant Bottom Sediment Type

Sediment refers to material that is transported and then deposited through the actions of water, wind, or ice and is generally a term that represents soil, rock, and/or mineral particles that are transported by moving water (ASCE, 2007). The sediment found in an estuary integrates what is happening upstream of the estuary, within the estuary, and at the estuary/ocean boundary. The sediment type can influence (grain sizes, density, organic content, etc.) and affect ecosystem function.

Sediment sizes are measured in two ways: using the sediment grain size diameter, typically measured in millimeters or using the phi scale. Sediment grain size diameter is generally used in applications with rivers and streams whereas the phi scale is applied in coastal areas. As estuaries form at river/coastal boundaries, the sediment size in an estuary can be reported using either sediment grain size diameter or the phi scale.

A conversion between mean sediment diameter and a phi value is expressed as:

$$\varphi = -log_2 D \tag{5.1}$$

Or

$$D = 2^{-\varphi} \tag{5.2}$$

Where φ is the phi value and D is the diameter of the particle in millimeters (Smith, 2010).

The predominant sediment type in an area is expressed as the phi value of the mean sediment type that occurs most frequently. Predominant sediment type categories were established based upon sediment size classification in ASCE Manual 110 (Table 5.11). While both sediment grain size diameter and phi value are shown for each classification, phi values are used for this work.

Table 5.11 Predominant Sediment Type Classification

Sediment Classification	**Diameter (mm)**	**Phi Value**
Gravel	64 to ≥ 2	-6 to -1
Very Coarse to Medium Sand	2 to ≥ 0.25	-1 to ≤ 2
Fine to Very Fine Sand	0.25 to ≥ 0.0625	2 to ≤ 4
Coarse to Medium Silt	0.0625 to ≥ 0.016	4 to ≤ 6
Fine to Very Fine Silt	0.016 to ≥ 0.004	6 to ≤ 8
Clay	0.004 to < 0.00024	≥ 8

(based on ASCE, 2007)

The classification of the predominant bottom sediment type is important as sediment directly affects what can grow and where. Wall noted that sediment is an essential component of ecosystems as “they provide habitat and substrate for a variesy of organisms, as well as playing vital roles in a number of essential ecosystem functions” (Apitz, 2011) (2004). Gerbersdorf noted that “the initial settlement of organisms, their further development, architectural capacity and functionality depends on and interacts with abiotic factors in the environment (e.g. sediments […])” (2010). NOAA notes of bottom sediments that “if one of the four – rock, gravel, sand, or mud – is more dominant in an area, then strong control is exerted over the types of organisms (benthos) that live on the ocean floor" (NOAA Gulf of Mexico Data Atlas, n.d.).

Data from the Gulf of Mexico Data Atlas will be used to determine the predominant bottom sediment type. If necessary, additional data from federal sources will be used to further classify the sediment type beyond NOAA's Gulf of Mexico Data Atlas' four sediment classifications (n.d.) of:

- Seabed mud content: a particle having a diameter finer than 63 micrometers. If an estuary is classified as "mud" it will fall into the "clay" classification above.
- Seabed sand content: sediment coarser than 63 micrometers but finer than 2 millimeters. An estuary having this classification will be classified as a "very coarse to medium sand", "fine to very fine sand", "coarse to medium silt", or "fine to very fine silt".
- Seabed gravel content: sediment coarser than 2 millimeters but finer than 256 millimeters. Estuaries meeting these requirements will be classified as "gravel".
- Seabed rock content: sediments coarser than 256 millimeters. Estuaries having sediments of this size will be classified as "gravel".

5.2.2.3 System Energy

The energy in a system can have a tremendous effect on what happens within a system. The energy of an estuarine ecosystem can usually be seen through the circulation and movement of the water, sediments, and nutrient through the system. If a system exhibits low energy, the water will not be circulated and can grow stagnant, harming the ecosystem. However, high energy systems are typically not conducive to highly-productive ecosystems. It is believed that estuaries are the extremely productive systems they are because while they are protected from the high energy of a coastal environment, they have enough energy within their systems to continuously circulate water preventing stagnation.

The energy in a system also tells about the saltwater/freshwater mixing that occurs within estuaries. Estuaries are able to be classified by water circulation. NOAA divides this classification scheme into five categories: salt-wedge, fjord, slightly stratified, vertically mixed, and freshwater (NOAA Ocean Service Education, 2008). For more information on these mixing regimes, please see Ch. 4.1.2.4.

Typically referred to as "forcing" in engineering terms, the predominant forcing of the estuary describes the primary source of energy into the system. It is important to know not only the predominant forcing of an estuary, but also the other sources of energy as well. As the predominant forcing, or source of system energy, is so important in the circulation of the estuary, multiple studies have been done in estuaries throughout the world on the effect of forcing on estuaries. Smit, et al., preformed a study of how the St. Lawrence Estuary, Canada responds to tidal forcing in the winter (2006). Atwood et al. conducted a study on how hydrological forcing (via freshwater input to the system) effected an estuarine food web in Hilo Bay, Hawaii (2011). The estuarine impacts of sea breeze (or meteorological) forcing was studied by Orton et al. in the Hudson River and New York Bay estuaries (2010). Xin et al. preformed a study to determine how wave forcing impacted flow and mixing processes in a subterranean estuary located in Australia (2010).

Energy can be added to a system in a variety of ways. For this framework, four sub-indicators of energy have been identified (McAnally, 2011):

- Freshwater flow into the system,
- Energy added to the system through waves,
- Energy added to the system through wind, and
- Energy added to the system though tidal exchanges.

5.2.2.3.1 Freshwater Flow

The amount of freshwater that enters a system has a profound impact on the ecosystem in two main ways: the freshwater dilutes the salinity of the ecosystem which can cause a large change in the flora and fauna in the system, and the incoming flow can be the predominant forcing mechanism of the area contributing large amounts of energy to the system. To determine the impact of the freshwater flow on the system, the amount of freshwater that enters the system during one tidal cycle will be divided by the tidal prism. Different freshwater flow regimes have been established based upon this ratio (Table 5.12).

Table 5.12 Freshwater Flow Regime

Freshwater Flow Regime	**Ratio of freshwater to tidal prism (%)**
Slight Impact	0-20
Low Impact	20-40
Moderate Impact	40-60
High Impact	60-80
Complete Impact	>80

The total amount of freshwater to enter a system during one tidal cycle will be calculated using information from USGS's river monitoring stations. Monthly averages of freshwater discharge will be used. The month that has, on average, the most freshwater entering the system will be used in the framework.

5.2.2.3.2 Wave Energy Regime

As waves enter a system they contribute energy to the system. An increase in energy within a system can affect multiple aspects of the ecosystem. For instance, an increase in wave energy can result in an increase in coastal erosion, an increase in turbidity by causing perturbations on the estuary floor, and even an increase in dissolved oxygen levels in the system.

Generally, as wave amplitude increases the energy supplied to the system increases as well. Different wave energy regimes have been established based upon wave amplitude. The categories for wave energy and their names are taken from CMECS (Table 5.13).

Table 5.13 Wave Energy Regimes

Wave Energy Regime	**Wave Amplitude (m)**
Quiescent	< 0.1
Very Low Energy	0.1 to < 0.25
Low Energy	0.25 to < 1
Moderate Energy	1 to < 2
Moderately High Energy	2 to < 4
High Energy	4 to < 8
Very High Energy	≥ 8

(FGDC, 2012)

The mean wave amplitude will be used to determine the wave energy regime. Data on the wave amplitude for each estuary will be collected from federal sources, including but not limited to NEPs and NERRs. Monthly averages of wave amplitude will be calculated. The largest wave amplitude will be used in the framework.

5.2.2.3.3 Wind Energy

As the wind velocity of an area increases, so does the amount of energy within the system. The mean wind velocity over a tidal period in each area will be computed and ranked using the Beaufort scale. Each area will be assigned a Beaufort number and description depending upon the wind speed (Table 5.14).

Table 5.14 Wind Energy Regime

Wind Velocity (m/s)	Beaufort Number	Description
< 0.3	0	calm
0.3-1.5	1	light air
1.6-3.4	2	light breeze
3.5-5.4	3	gentle breeze
5.5-7.9	4	moderate breeze
8.0-10.7	5	fresh breeze
10.8-13.8	6	strong breeze
13.9-17.1	7	high wind
17.2-20.7	8	gale
20.8-24.4	9	strong gale
24.5-28.4	10	storm
28.5-32.6	11	violent storm
≥32.7	12	hurricane

(Oliver, 2005; Schwartz, 2005; NOAA SPC, n.d.)

The seasonal average prevailing wind data from NOAA's Gulf of Mexico Data Atlas will be used in this work. The season that has the highest wind speed will be used as this will be the season where the most energy is put into the system.

5.2.2.3.4 Tidal Regime

The tidal regime of each area is based upon the mean wave amplitude in meters per tidal cycle in each grid box. Tidal regime is important because it can inform of the potential influence the tides have on the coastline. Tidal regimes have been developed based upon wave amplitude (Table 5.15).

Table 5.15 Tidal Regimes

Tidal Regime	Wave Amplitude (m)
Microtidal	< 2
Mesotidal	2 to < 4
Macrotidal	4 to < 6
Hypertidal	≥ 6

Each grid box will be designated using a tidal regime description. Tidal regimes may vary between boxes in the same system due to tidal amplification and dissipation.

The mean wave amplitude will be used to determine the wave energy regime. Data on the wave amplitude for each estuary will be collected from federal sources, including but not limited to NEPs and NERRs. Monthly averages of wave amplitude will be calculated. The largest wave amplitude will be used in the framework.

5.2.2.4 Mixing Regime

Salinity can range from 0 psu to greater than 35 psu. When freshwater from a riverine system and saltwater from an ocean system meet, the water does not mix instantaneously. As freshwater is less dense than saltwater (1000 kilograms per cubic meter versus 1027 kilograms per cubic meter), the freshwater tends to slide over the saltwater forming what is known as a salt wedge in the bottom of the system.

Perturbations in the interface between the saltwater and freshwater cause mixing, resulting in brackish water. Mixing between the saltwater and freshwater can also occur due to sources of energy in the system such as tidal energy, wave energy, circulation, etc.

Simmons Number (Ippen, 1966) is a ratio of the freshwater inflow during one tidal cycle to the tidal prism and is represented as:

$$S = \frac{Q_{FV}}{P_T} \qquad 5.3$$

where Q_{FV} is the freshwater inflow volume during one tidal cycle and P_T is the tidal prism.

$$Q_{FV} = Q_f t \qquad 5.4$$

where Q_f is the freshwater flow rate (cubic meters per second) and t is the tidal cycle time (seconds).

$$P_t = \Omega = 2\frac{u_o}{\sigma}A \qquad 5.5$$

where u_o is the maximum velocity, A is the entrance cross section, and σ is represented as:

$$\sigma = \frac{\pi}{t} \qquad 5.6$$

(Ippen, 1966)

Mixing regimes have been identified based upon Simmons Number (Table 5.16). As seen, the higher the Simmons Number, the more stratified the system is:

Table 5.16 Mixing Regimes

Mixing Regime	**Simmons Number**
Stratified	≥ 1
Partially Mixed	0.2 to 0.5
Well Mixed	< 0.1

(Ippen, 1966)

5.2.2.5 Bed Slope

The mean bed slope of each grid box will be calculated using bathymetric information. As the mean depth of each box will be recorded, having an indicator of the slope is important to indicate to the manager using the framework what is happening in the system. When applying the framework to LMEs, the slope of each box will be used to determine if the grid resolution in an area needs to be refined for a more precise view of the area. If the bed slope is very high, this might indicate a navigation channel or a natural phenomenon the manager may need to be aware of in order to properly account for it within the management plan.

Bed slope classifications have been developed based upon percent slope (Table 5.17).

Table 5.17 Bed Slope Classification

Bed Slope Classification	**Slope (%)**
Horizontal	< 20
Mild	20- <40
Critical	40- < 60
Steep	60-< 80
Adverse	>80

To determine the bed slope classification, the average slope of each grid box will be calculated using estuarine bathymetry data located on NOAA's Gulf of Mexico Data Atlas site (n.d.). Bathymetry data for twenty estuaries in the Gulf of Mexico are available. These estuaries are: Apalachicola Bay, Florida; Aransas Bay, Texas; Atchafalaya Bay, Louisiana; Baffin Bay, Texas; Barataria Bay, Louisiana; Calcasieu Lake, Louisiana; Charlotte Harbor, Florida; Choctawhatchee Bay, Florida; Corpus Christi Bay, Texas; Galveston Bay, Texas; Matagorda Bay, Texas; Mississippi Sound, Mississippi; Mobile Bay, Alabama; Pensacola Bay, Florida; Peridio Bay, Florida; San Antonio Bay, Texas; St. Andrew Bay, Florida; Sarasota Bay, Florida; Tampa Bay, Florida; and Terrebonne-Timbalier Bays, Louisiana (NOAA Gulf of Mexico Data Atlas, n.d.).

5.2.2.6 Wave Climate

The wave climate refers to where the waves within the estuary are generated. There are three categories of wave climate: full exposure, partial exposure, and locally generated.

A full exposure wave climate refers to an estuary that is fully exposed to the ocean. An example of this might be a drowned river valley as there are no barrier islands to protect the estuary from the ocean-generated waves. A partial exposure wave climate refers to an estuary in which the ocean-generated waves enter the estuary through an inlet or over a bar. A bar-built estuary is an example of a partial exposure wave climate. In these systems, the inlet or bar dissipates the amount of energy entering the system though ocean-generated waves. Locally generated wave climates refer to estuaries in which ocean-generated waves have a negligible effect, but waves generated locally can have a large effect on the system. Locally generated wave climates can be characterized as an estuary that is protected from ocean-exposure, but is a large open body of water.

5.2.2.7 Additional considerations

Four additional parameters have been identified as additional considerations when applying the framework to an area. These considerations are:

- Surface area,
- Mean depth,
- Estuary type, and
- Coastline type.

These considerations are described below.

5.2.2.7.1 Surface Area

The mean surface area of each grid box will be calculated and recorded. For the development and validation of the framework, the surface area of each box will be equal. However, when applying the framework to LMEs, multiple size grid boxes may be used (e.g. smaller boxes closer to shore and larger boxes in open waters) which would change this value. The area will also be used in subsequent scaling assessments.

5.2.2.7.2 Mean Depth

The mean depth of each grid box will be determined based upon bathymetry data. This value is expected to change from box to box and can be used to locate areas that are deeper or shallower than other the rest of the estuary as these areas may indicate areas of varying habitat. To determine the mean depth of each grid box, bathymetric data from NOAA's Gulf of Mexico Data Atlas (n.d.) can be used.

5.2.2.7.3 Estuary Type

The estuary type refers to the formation of the estuary. There are five formation types: coastal plain/drowned river valley, coastal lagoon/bar built, delta, tectonic, and fjord.

Coastal plain/drowned river valley estuaries were formed when a rise in sea level permanently flooded existing river valleys. An example of a coastal plain/drowned river valley estuary is Chesapeake Bay on the east coast of the United States (NOAA, 2008). Coastal lagoons or bar built estuaries are characterized by barrier islands that develop parallel to the shoreline due to waves. These barrier islands separate the estuary from the ocean. Bar built estuaries are common in the Gulf of Mexico (NOAA, 2008). Deltas form at the mouths of large riverine systems when sediments deposit and form a complex set of channels, islands, and marshes. The Mississippi River delta in south Louisiana is the most well-known delta in the United States. Fjords are characterized as steep-walled river valleys that were formed as glaciers moved across the earth's surface. The river valleys flooded with ocean water when the glaciers retreated and melted. Usually, fjords are very deep but narrow channels that have a sill separating the valley from the ocean. The sill prevents large amounts of saltwater from entering the estuary. Most fjords in the United States are found in Alaska and northern parts of the State of Washington (NOAA, 2008). Tectonic estuaries form when the earth's tectonic plates collide with each other, causing one of the plates to subside, thus creating an estuary. As tectonic estuaries from along fault lines, most of these estuaries are located in the western United States. San Francisco Bay is an example of a tectonic estuary (NOAA, 2008).

5.2.2.7.4 Coastline Type

The coastline type refers to the formation method of the coastline where applicable. There are five different formation types: emergent, submergent, tectonic, plateau-shield, and depositional.

An emergent coastline forms when either the land rises relative to the sea level. Conversely, submergent coastlines form when the sea level rises relative to the land. Tectonic coastlines emerge when the earth's tectonic plates collide with each other causing one to rise out of the ocean forming a coast. Plateau-shield coastlines are comprised of a series of plateaus and mountain ranges. Depositional coastlines are formed when large amounts of sediment deposit in an area.

5.2.3 Human and Economic Indicators

Incorporating human and economic indicators in this framework is important as human actions and economic incentives not only affect coastal zones, but are, in turn, affected by coastal zones. Vandweerd, the coordinator of the United Nation's Environmental Program, Global Program of Action for the Protection of the Marine Environment from Land-based Activities (UNEP GPA) states that "the complexity of the economic, social, and environmental realities requires ecosystem-based, multi-sectoral approaches in policy and management" (2006). It was later added that "increasingly human activities are causing changes in ecosystems that have transboundary consequences. […] On a planet dominated by the impacts of human activities it is increasingly necessary to design and implement management programmes that address the complex linkages" (UNEP GPA, 2006). Ecosystem-Based Management Tools

Network (EBM TN) agrees that EBM requires a multi-sectoral approach and states that the key aspects of EBM include (2010):

- "Integration of ecological, social, and economic goals and recognition of humans as key components of the ecosystem.
- Consideration of ecological- not just political- boundaries.
- Accounting for the complexity of natural processes and social systems and using an adaptive management approach in the face of resulting uncertainties.
- Engaging multiple stakeholders in a collaborative process to define problems and find solutions.
- Incorporating understanding of ecosystem processes and how ecosystems respond to environmental perturbations.
- Concerned with the ecological integrity of coastal-marine systems and the sustainability of both human and ecological systems."

Note that in multiple key aspects of EBM, EBM TN includes the words "human", "economic" and "social" – a testament to the fact that human actions and economic incentives are important when describing an ecosystem for the purposes of EBM. Wilson agrees and stated in an interview that "obviously, people are having a big impact on these [coastal and marine] systems, and resource management decisions based on science have economic, political, and social implications. All of that needs to be taken into consideration" (NOAA CSC, 2011).

McLeod and Leslie noted that biophysical, social, and integrated drivers have changed ocean systems in the past, continue to change these ecosystems, and will continue to change the ecosystems in the future (2009). They go further and state that marine ecosystems can be defined in two main ways: “1. At the ecosystem level (e.g., watersheds, coral reefs, the open ocean, deep sea hydrothermal vents) [and] 2. Based on constituent parts of the ecosystem such as components (e.g., species, populations, communities), patterns (e.g., distribution, genetic variability, species richness, food webs), or processes (e.g., oceanographic linkages, dispersal of organisms, seascape connectivity)” (McLeod and Leslie, 2009). This work is focused on defining estuarine ecosystems based upon its constituent parts. As human activities and economic incentives are drivers that cause changes within ecosystems, it is necessary to incorporate human and economic indicators into this framework to adequately describe the ecosystem based upon all of its constituent parts.

The human and economic indicators are meant to define the relationships that exist between humans and the ecosystem. Components of this sub-matrix are used to detail human activities in the ecosystem, societal values placed upon the ecosystem, and the economic impact the ecosystem has on those living in the area. Five human and economic indicators and twenty six sub-indicators have been identified to describe the dependence humans have on the ecosystem. These indicators are:

- Economic impact
- Ecosystem services
- Environmental justice
- Public health
- Social vulnerability to environmental hazards

5.2.3.1 Economic Impact

NOAA's Coastal Services Center, the Bureau of Economic Analysis, and the Bureau of Labor Statistics have worked together to develop Economics: National Ocean Watch (ENOW) as a part of NOAA's Digital Coast. ENOW is a web-based service that "describes six economic sectors that depend on the oceans and Great Lakes: living resources, marine construction, marine transportation, offshore mineral resources, ship and boat building, and tourism and recreation

ENOW contains annual time-series data […] derived from the Bureau of Labor Statistics and the Bureau of Economic Analysis. Four economic indicators are provided: establishments, employment, wages, and gross domestic product" (NOAA ENOW, n.d.).

From ENOW, the indicators are defined as:

- "Business establishments: ENOW counts individual places of business; a single firm may have multiple places of business
- Employment: the number of people employed by business establishments, including part-time and seasonal workers; this figure does not include the number of self-employed worker
- Annual wages: wages paid to employees
- Gross domestic product (GDP): the value of goods and services that are produced; in ENOW, this is basd on the state estimates of GDP that are produced by the Bureau of Economic Analysis, called Gross State Product or GSP" (NOAA ENOW, n.d.).

The sectors are defined as:

- “Living resources: includes industries such as fishing, fish hatcheries, aquaculture, seafood processing, and seafood markets.
- Marine construction: includes oil and gas pipeline construction, beach nourishment, and harbor dredging
- Marine transportation: includes shipping, including port services, cargo handling, and warehousing, ferries, pipeline transportation, and the manufacture of navigational equipment. Warehousing is refined to shore adjacent counties, all other industries in this sector are for the entire county.
- Offshore mineral resources: includes oil and gas exploration and production, and sand and gravel mining. All industries have been refined to shore adjacent counties
- Ship and boat building: includes ship and boat building and repairs
- Tourism and recreation: includes eating and drinking establishments, hotels, marinas, boat dealers, campsites and RV parks, scenic water tours, manufacture of sporting” (NOAA ENOW, n.d.).

Data on the ENOW website is available on an aggregated country, aggregated regional, aggregated state, and aggregated county basis and is available for years 2005 through 2010. Data can be viewed at each level for a single year or as a general trend for multiple years.

Since the waterbodies used in the development and validation of the framework contribute to the economies in multiple counties, the aggregated trend data for all of the counties bordering the waterbody will be compiled to yield an average trend for the entire system. Then, using the state-level aggregated data, the percent each sector-indicator combination contributes to the state government will be calculated. Ranges for the percent each waterbody contributes to the state economically were developed (Table 5.18). Each sector-indicator combination will be designated a contribution level. There are 24 sector-indicator combinations: living resources/establishments, living resources/employment, living resources/wages, living resources/GDP, marine construction/establishments, marine construction/employment, marine construction/wages, marine construction/GDP, ship and boat building/establishments, ship and boat building/employment, ship and boat building/wages, ship and boat building/GDP, marine transportation/establishments, marine transportation/employment, marine transportation/wages, marine transportation/GDP, offshore mineral extraction/establishments, offshore mineral extraction/employment, offshore mineral extraction/wages, offshore mineral extraction/GDP, tourism and recreation/establishment, tourism and recreation/employment, tourism and recreation/wages, and tourism and recreation/GDP.

Table 5.18 Economic Impact Designations by Contribution to State Economics

Economic Impact	**Contribution to state economics (%)**
Slight Impact	0 to < 20
Light Impact	20 to < 40
Moderate Impact	40 to < 60
High Impact	60 to < 80
Complete Impact	≥ 80

5.2.3.2 Ecosystem Services

Ecosystem services are “a wide range of conditions and processes through which natural ecosystems, and the species that are part of them, help sustain and fulfill human life" and support the production of goods "such as seafood, wild game, forage, timber, biomass fuels, natural fibers, and many pharmaceuticals, industrial products, and their precursors" (Daily et al., 1997).

In 2005, the Millennium Ecosystem Assessment (MEA) was published. The MEA is "an international assessment of the consequences of ecosystem change for human well-being" (Food and Agriculture Organization of the United Nations, 2010). The MEA defines ecosystem services as "all benefits that humans receive from ecosystems. These benefits can be direct or indirect, through the function of ecosystem processes that produce direct services" (FAO UN, 2010). The National Research Council (NRC) agrees with this definition, but words it as "the benefits people receive from a multitude of resources and processes provided by ecosystems, produced as consequences of the functioning of the ecosystem" (2012). Ecosystem services are classified into four categories (MEA, 2005; FAO UN, 2010; NRC, 2012):

- Supporting services (e.g. nutrient cycling, biomass production)
- Provisioning services (e.g. food, fuel, other material goods)
- Regulating services (e.g. flood control, natural water purification, climate regulation), and
- Cultural services (e.g. aesthetics, recreational use, spiritual connotation)

The MEA detailed ecosystem services in different regions across the world. According to the MEA, all of the ecosystems used in the development and validation of the framework are defined as coastal systems. A list of ecosystem services for coastal systems was provided. These services include: food; fiber, timber, and fuel; medicines; biodiversity; biological regulation; freshwater storage and retention; biochemical;

nutrient cycling and fertility; hydrological; atmospheric and climate regulation; human disease control; waste processing; flood/storm protection; erosion control; cultural and amenity; recreational; and aesthetics (FAO UN, 2010).

Ecosystem services can be quantified in three main ways (Pendleton, 2008):

- Use value: the value placed on directly-used goods (e.g., jobs, taxes, businesses),
- Indirect use value: the value placed on indirectly used goods (e.g. flood control, water purification), and
- Non-use value: the value placed on resources that may never be used (e.g. aesthetics, spiritual/religious).

The use value of ecosystem services are included in the framework under “Economic Impact”. The “Ecosystem Services” indicator seeks to establish the economic impact of indirect use value and non-use value services.

Both Harte Research Institute (HRI) (2012) and The National Ocean Economics Program (NOEP) (2012) maintain online databases that include information from around the world of results from non-market value studies. NOEP’s website summarizes data from recreational non-market value uses in coastal areas of the Gulf of Mexico. In 2009, Kildow et al. used this data to summarize the non-market use values for the five states in the Gulf of Mexico region (Table 5.19). It is important to note that the tax revenue generated from these uses is not included in the estimation and that the values for Florida include the entirety of the state (from both the Gulf of Mexico and the Atlantic Ocean).

Table 5.19 Estimated Non-Market Values for Selected Recreational Activities in nearest $Millions

Activity		**Alabama**	**Louisiana**	**Mississippi**	**Texas**	**Florida***
Beach	Low	237	81	174	705	3543
	High	592	202	434	1762	8858
Bird Watching	Low	118	228	181	401	1949
	High	472	911	725	1605	7795
Fishing	Low	253	749	280	986	3377
	High	422	1249	466	1643	5629
Other Wildlife	Low	161	264	60	315	1257
	High	644	1056	238	1260	5026
Swimming	Low	164	92	135	592	3222
	High	410	230	337	1480	8055
Total	Low	933	1414	830	2999	13348
	High	2540	3648	2200	7750	35363

*includes data from the entire State of Florida (from Kidlow et al., 2009)

While this data does not cover all of the indirect use markets or any of the non-use markets, this is the most information that can currently be obtained about ecosystem services.

To incorporate this information into the framework, data from NOAA's ENOW Explorer from 2009 will be used. The average non-market value for each state will be calculated and then added to the GDP for that state as obtained from the ENOW Explorer for 2009. The percent of the total GDP obtained from the non-market value will be calculated. Ranges for the percent the non-market value contributes to the state (with regards to GDP) were developed (Table 5.20).

Table 5.20 Economic Impact Designations of Non-Market Use

Economic Impact	**Contribution to state economy (%)**
Slight Impact	0 to < 20
Light Impact	20 to < 40
Moderate Impact	40 to < 60
High Impact	60 to < 80
Complete Impact	≥ 80

Multiple projects are currently being conducted into valuing ecosystem services. Some of the completed ecosystem services valuation studies completed include a valuation of the Mississippi River Delta of regulating and supporting services (Bakter et al., 2010) and a study by Yoskowitz et al., that identified expected changes in ecosystem services in Galveston Bay due to sea level rise (2012).

5.2.3.3 Environmental Justice

Defined in the Principles and Requirements for Federal Investments in Water Resources (March 2013), environmental justice is "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies." When implementing ecosystem-based management plans, care should be taken to avoid "disproportionate adverse effects on these communities" as stated in a Guidance Under the National Environmental Policy Act (59 Fed. Reg. 7629 (1994) and 42 USC §4321 et seq.).

A group of former employees of the Environmental Defense Fund have created "Scorecard" sponsored by GoodGuide which profiles the "environmental burdens" of communities in the United States based upon demographics using information from the

U.S. Census Bureau and EPA reports (e.g. EPA exposure estimates reports). The Environmental Burdens analyzed include: cancer risks from hazardous air pollutants, toxic chemical releases, superfund sites, and facilities emitting criteria air pollutants (Scorecard, 2011). The distribution of each of these burdens is found in relation to the following demographics: race/ethnicity, income, poverty, childhood poverty, education, job classification, and home ownership (Scorecard, 2011).

For this work, the ratios calculated for toxic chemicals with relation to poverty will be used. The average ratio of the entire waterbody will be calculated based upon the individual county scores reported. Classifications of the environmental justice ratio have been established (Table 5.21).

Table 5.21 Environmental Justice Classification

Environmental Justice Classification	**Ratio**
None	1.0
Slight	1.01 to 1.20
Mild	1.21 to 1.40
Severe	1.41 to 1.60
Extreme	≥ 1.61

5.2.3.4 Public Health

The quality of human health in an area is extremely important. Decreased health ratings can indicate unseen problems in the environment that can be corrected before irreversible damage is done. Typically there are two main concerns when dealing with public health: mental health status and general health status. Both mental health and general heath have been identified as sub-indicators for the public health indicator.

Data for the mental and general health status of the overall population in a state is not recorded. However, the mental health and general health of children between the ages of two and seventeen is recorded every year by the Annie E. Casey Foundation's Kids Count. Kids Count "is a national and state-by-state effort to track the well-being of children in the United States" (2012).

5.2.3.4.1 Mental Health

Mental health is a "state of well-being in which the individual realizes his or her own abilities, can cope with normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community" (World Health Organization, 2001). Mental health data in Kids Count® refers to the percent of "children who have one or more emotional, behavioral, or developmental condition". The percent of children meeting this definition is recorded for each state and will be used in the framework. Classifications for the percent of children being diagnosed as having "one or more emotional, behavioral, or developmental condition" have been established (Table 5.22).

Table 5.22 Mental Health Classifications

Mental Health Classifications	Percent of Children having One or More Emotional, Behavioral, or Developmental Condition
Low	12 to 14
Medium Low	14 to 16
Medium High	17
High	18 to 20

(From Annie E. Casey Foundation, 2011)

5.2.3.4.2 General Health

General health is a measure of the overall physical health and wellbeing of an individual. Kids Count® ranks each state with an overall health rank where a low rank indicates a high general health whereas a higher rank indicates poorer general health. The overall rank of a state will be reported for the waterbody in the state. General health classifications have been developed (Table 5.23) and will be used in the framework.

Table 5.23 General Health Classification

General Health Classification	Ranking
Above Average	1 to 16
Average	17 to 33
Below Average	34 to 50

5.2.3.5 Social Vulnerability to Environmental Hazards

An indicator that tells about how vulnerable a population (and its needed infrastructure) is to environmental hazards is important to include in the framework as the index can indicate how prepared an area is to deal with a disaster. A county that is more vulnerable will be less prepared and able to respond to disasters whereas a county that is less vulnerable will be more prepared. This is important, especially in light of current environmental disasters in the Gulf of Mexico, including Hurricane Katrina in 2005 and the Deep Water Horizon Oil Spill in 2010. From these experiences, and many others, it has been seen that quick decisive action is important when trying to mitigate the damages from coastal hazards.

"The Social Vulnerability Index (SoVI) 2006-2010 measures the social vulnerability of U.S. Counties to environmental hazards. This index is a comparative metric that facilitates the examination of the differences in social vulnerability among counties. It graphically illustrates the geographic variation in social vulnerability. It shows where there is uneven capacity for preparedness and response and where resources might be used most effectively to reduce the pre-existing vulnerability. The index synthesizes 30 socioeconomic variables which the research literature suggests contribute to reduction in a community's ability to prepare for, respond to, and recover from hazards. SoVI data sources include primarily those from the United States Census Burerau" (University of South Carolina, 2012).

This index rates how socially vulnerable a county is but does not rate how environmentally vulnerable a county is to environmental hazards. However, it can be extrapolated that a county that demonstrates a high level of preparedness (a low vulnerability) will be more adequately prepared to deal with the environmental effects of an environmental hazard than a county that is less prepared.

SoVI scores are generated by county and then a national percentile is calculated for each county and the counties are ranked based off of their national percentile. The average national percentile for counties surrounding a waterbody will be and that value will be assigned to the waterbody. Social vulnerability classifications have been established (Table 5.24) based off of SoVI (University of South Carolina, 2012).

Table 5.24 Social Vulnerability Classification

Social Vulnerability Classification	**National Percentile**
High	Upper 20%
Medium	Middle 60%
Low	Lower 20%

5.2.3.6 Additional considerations

Six additional parameters have been identified as additional considerations when applying the framework to an area. These considerations are:

- The location of currently managed areas,
- The location of active oil and gas leases,
- The location of active renewable energy leases,
- The location of danger zones and restricted areas,
- Current uses of the ecosystem, and
- The USGS designated ecoregion.

These considerations are described below.

5.2.3.6.1 Managed Areas

Many sections in coastal areas are currently being managed under federal or state jurisdiction. These areas, most commonly referred to as marine protected areas have management plans in place already. Even though the overall goal of this research is to separate LMEs for management purposes, and marine protected areas are already managed areas, for the purpose of developing and validating the framework, these areas will be included in the classification. However, when applied to a LME, marine protected areas can be designated as one sub-ecosystem for management purposes.

Outlined in Showalter and Schiavinato (2003) Table A1 shows the marine protected areas in the Gulf of Mexico and designates them as federally managed areas, federal-state cooperatives, or state managed areas.

5.2.3.6.2 Active oil and gas leases

Designated by the Bureau of Ocean Energy Management (BOEM), active oil and gas lease maps show the “portion of outer continental shelf lease blocks which are currently leased out to private entities for oil and/or gas mining rights. Active leases include those that are exploratory, non-producing, and producing" (BOEM, n.d.). While these areas will not be considered in developing the framework as there are no active oil and gas leases in the estuaries being used to develop and validate the framework, these areas are important when applying the framework to LMEs. As such, areas that have active oil and gas leases will be designated as a managed area as described in Ch. 4.2.3.1.

5.2.3.6.3 Active renewable energy leases

Active renewable energy lease maps developed by BOEM show the "blocks which have been leased by a company with intent to build a wind energy facility. No projects are currently in the development stage at this time; permits may be issued for development provided further site assessment for each leased area" (BOEM, n.d.b). As stated, currently there are no active energy projects under development; however, as the coastal areas will be managed for future sustainable growth, it is important to regularly review the renewable energy leases so as to create management plans that account for the growing renewable energy industry.

5.2.3.6.4 Danger Zones and Restricted Areas

Danger zones and restricted areas set forth by the Department of Defense and the United States Navy are areas "with naval or military presence" (DoD, n.d.). As these areas are already managed by the Department of Defense and are restricted areas, when applying the framework to LMEs, these areas should be designated as managed areas as described in Ch. 4.2.3.1.

5.2.3.6.5 Current Uses

What society currently uses an area for can affect future uses and must be incorporated when designating future use in management scenarios. While the current uses of an area will not be included in the development of the framework, current uses will be considered when developing management plans. It is recommend that after the framework is applied to an area to identify sub-ecosystems, a map detailing the current uses of the system overlay a map detailing the future uses of the same system to determine the use-changes that will occur. By doing this, hopefully managers will be able to avoid use-conflicts and reduce tension when changing the designated used of a site.

The current uses of each system should be detailed. Areas will be allowed to be designated for multiple uses. Currently, the designated uses are: recreation (such as jet skiing, windsurfing, etc.), fisheries, oil production, Intracoastal Water Way, ports and harbors, navigation channels (shallow draft and deep draft), water supply, renewable energy production, federally-managed areas, state managed areas, federal-state cooperatives, and beaches.

5.2.3.6.6 USGS Designated Ecoregion

An ecoregion is an area that is ecologically and geographically similar that has a consistent ecosystem. Based on work from Omernik (1987), the Environmental Protection Agency regional offices, United States Geographical Survey, and other federal and state agencies defined ecoregions for the entire United States (EPA 2012). Ecoregions are “designed to serve as a spatial framework for the research assessment, and monitoring of ecosystems and ecosystem components, ecoregions denote areas within which ecosystems (and the type, quality, and quantity of environmental resources) are generally similar […] these general purpose regions are critical for structuring and implementing ecosystem management strategies […] within the same geographical areas” (Omernik et al., 2000; McMahon et al., 2001 in EPA, 2012).

While ecoregions are only designated for terrestrial parts of the Unites States, and will thus not be used in the development of the framework, they can be used when developing and applying management schemes in coastal areas. This is because each regional planning body gets to set the boundaries of its management area (Chapter 2) While it is yet unknown if terrestrial areas will be included in coastal management planning areas, it can be assumed that some terrestrial areas will as they have a direct impact on the health of the ecosystem. As such, when developing and later implementing management plans to protect, preserve, and restore coastal areas, if terrestrial areas are considered for management ecoregion designations need to be incorporated in the management plans.

5.3 Management Matrix

The management matrix is the second level matrix that weights the indicators for different management protocols. Three management matrices were developed: one that weights the indicators for integrated ecosystem assessment, one that weights the indicators for coastal and marine spatial planning, and one that weights the indicators for ecosystem-based management.

The weights for each management protocol were derived using a process called the Analytic Hierarchy Process (AHP).

5.3.1 Analytic Hierarchy Process

The Analytic Hierarchy Process was first introduced by Thomas Saaty in 1980 in a book published by McGraw-Hill New York entitled *The Analytic Hierarchy Process* and is described as "a comprehensive framework for solving [the basic problem of decision making]" (Saaty, 1986). AHP "organizes the basic rationality by breaking down a problem into its smaller and smaller constituent parts and then guides decision makers through a series of pairwise comparison judgments to express the relative strength or intensity of impact of the elements in the hierarchy" (Saaty and Kearns, 1985). These relative strength or intensities are represented at the end of the process as a "weight" which can be used to rank the level of importance of each element in the hierarchy.

The first step in the AHP is to define the problem and determine what it is the user wants to know. For this work the user wanted to know: a) which of the indicator groups are most important in classifying nearshore coastal environments for management purposes, and b) what is the rank of importance for the indicators in each indicator group. After the problem is defined, the hierarchy is constructed. Figure 5.3 shows the hierarchy for this work.

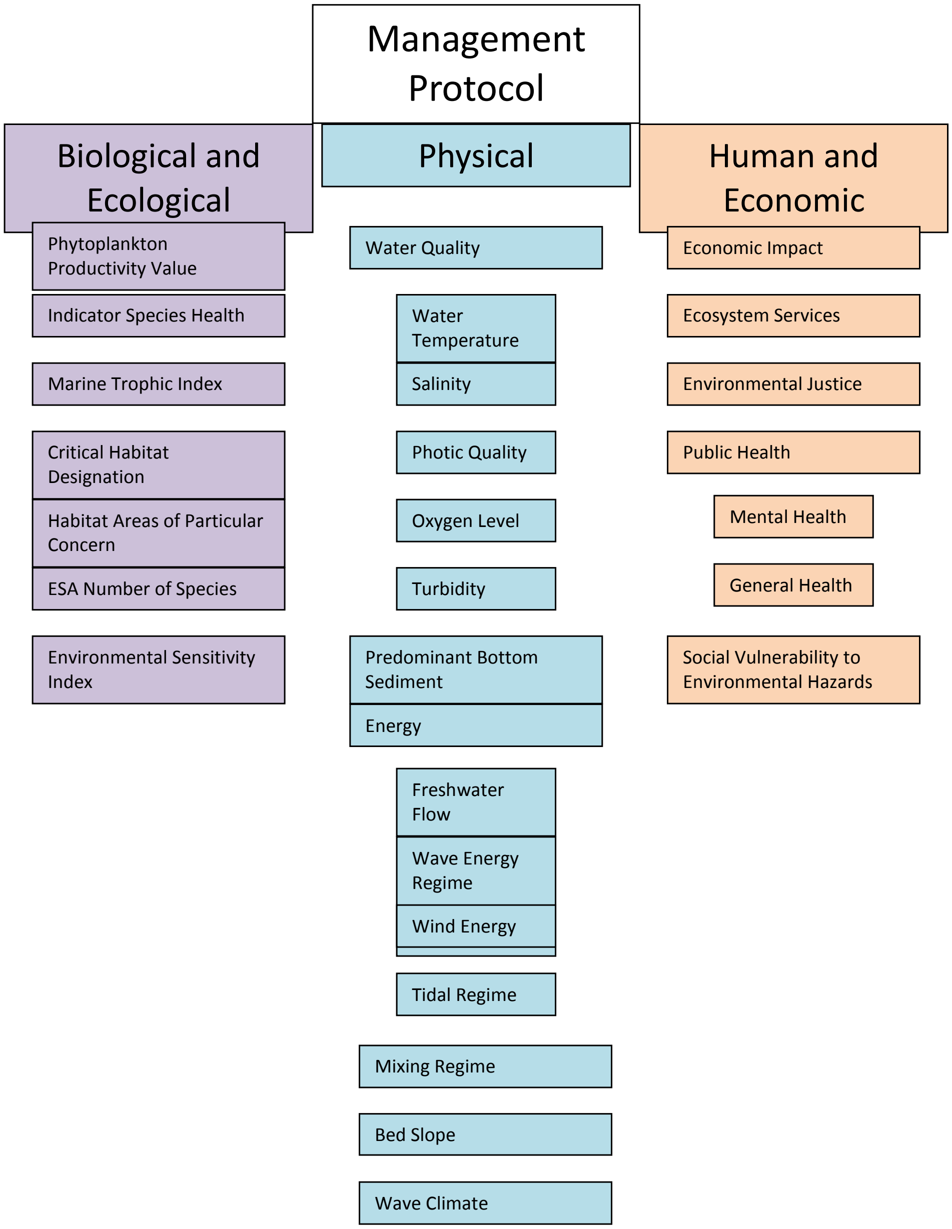


Figure 5.3 Indicator Hierarchy for AHP

After the hierarchy is completed, a set of pairwise comparisons are constructed. Appendix B.1 “Management Protocol Expert Survey” includes the pairwise comparisons for this work. These pairwise comparison tables were constructed and used for expert elicitation in order to collect data to complete the AHP. Management Protocol Experts were identified as people who: 1) work in EBM, CMSP, or IEA either creating and implementing plans for different LMEs or helping draft legislation using their technical background for ecosystem based management, 2) have worked in their field for a minimum of 5 years, 3) have multiple publications concerning EBM, CMSP, or IEA, and 4) work in the United States of America. Experts were also chosen based upon their field of study (e.g. economists, biologists, fisheries management experts, etc. were included) and their location (participants from five LMEs were surveyed) in order to diversify the results. Once the experts were identified, they were contacted by the principal investigator (PI) and were provided with details of the study and were asked if they were interested in participating in the research. For those who answered affirmatively, private interviews were conducted in which the PI described the purpose of the research, what AHP is, how the results would be determined from the survey responses, and go over the survey (Appendix B.1). The experts were then given time to respond to the survey. When the surveys were completed, the PI would collect them and continue with the AHP process.

After the surveys were completed, the survey results were put into a comparison matrix (Table 5.25) where *j* and *k* are numbers gained from the pairwise comparison.

Table 5.25 Sample Comparison Matrix

	Biological and Ecological	Physical	Human and Economic
Biological and Ecological	1	j	k
Physical	$1/j$	1	m
Human and Economic	$1/k$	$1/m$	1
Sum	$\Sigma(1+1/j + 1/k)$	$\Sigma(j + 1 + 1/m)$	$\Sigma(k + m + 1)$

The comparison matrix was then normalized to create the normalized matrix (Table 5.26).

Table 5.26 Sample Normalized Matrix

	Biological and Ecological	Physical	Human and Economic
Biological and Ecological	$1/ \Sigma(1+1/j + 1/k)$	$j/ \Sigma(j + 1 + 1/m)$	$k/ \Sigma(k + m + 1)$
Physical	$(1/j)/ \Sigma(1+1/j + 1/k)$	$1/ \Sigma(j + 1 + 1/m)$	$m/ \Sigma(k + m + 1)$
Human and Economic	$(1/k)/ \Sigma(1+1/j + 1/k)$	$(1/m)/ \Sigma(j + 1 + 1/m)$	$1/ \Sigma(k + m + 1)$
Sum	1	1	1

The weights were then computed by averaging the responses for each row and multiplying by 100.

In order to determine if this approach is acceptable, the consistency ratio for each matrix has to be calculated. If the consistency ratio (CR) is less than 0.10 or 10%, the matrix is consistent and no further work needs to be done (Saaty, 1980; Saaty and Vargas, 1982; Saaty and Kearns, 1985; Saaty, 1986; Triantaphyllou and Mann, 1995; Rao, 2013). The consistency ratio is calculated by:

$$CR = \frac{consistency\ index}{random\ index} \qquad 5.7$$

Where:

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad 5.8$$

$$\lambda_{max} = maximum\ eigenvalue\ of\ the\ row \qquad 5.9$$

$$n = number\ of\ indicators \qquad 5.10$$

And RI is given by Saaty (1980) as:

Table 5.27 Random Index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

(Saaty, 1980)

For a more in-depth view of the AHP and its derivation, please refer to The Analytic Hierarchy Process (Saaty, 1980), Fundamentals of Decision Making with the Analytic Hierarchy Process (Saaty, e. 5, 2013), or Axiomatic Foundation of the Analytic Hierarcy Process in Management Science vol. 32, no. 7 (Saaty, July 1986).

AHP is especially useful for weighting the indicators in each management protocol for multiple reasons:

1. AHP is a “highly regarded and widely used decision making method” (Rao, 2013) and “has broken through the academic community to be widely used by practitioners” (Ishizaka and Labib, 2011). Some studies that have used AHP for decision making include designing a transport system for the Sudan (Saaty, 1977),

effectively transferring technology to less developed countries (Ramanujam and Saaty, 1981), "use in integrated manufacturing (Putrus, 1990), in the evaluation of technology investment decisions (Boucher and McStravic, 1991), in flexible manufacturing systems (Wabalickis, 1988) layout design (Cambron and Evans, 1991), and also in other engineering problems (Wang and Raz, 1991)" (Triantaphyllou and Mann, 1995), evaluation of statistical expert systems in social science research (Hwang, 1990), setting priorities for agricultural biotechnology research (Braunschweig, 2000), identification of groundwater recharge zones (Kaliraj, et al., 2013), and water quality assessments through shrimp (Carbajal-Hernández, et al., 2013) to name a few.

2. "The AHP does not require that judgments be consistent or even transitive" (Saaty, 1986). The process described above can be applied if the consistency ratio is less than or equal to 10%. However, AHP can still be applied if the CR is greater than 10%. In order to do this, there are two approaches: the eigenvalue/eigenvector approach and the geometric mean approach. For the eigenvalue/eigenvector approach, the eigenvalue for the inconsistent matrix are computed and used in the matrix instead of the given responses. For the geometric mean approach, the geometric mean of each row is computed and used to find the weights (Saaty, 1980).
3. This approach presents a conceptually simple method of dealing with complex decisions (Saaty 1986; Ishizaka and Labib, 2011).
4. The process presents a way to allow individual results to be synthesized into a group response. If there are multiple respondents in a study (as is the case with

this study), AHP provides a way to synthesize the respondents answers into one comparison matrix. Saaty (1986) proposed that “when a group uses the AHP, their judgments can be combined […] by applying the geometric mean to the judgments” in order to compute one input (e.g. Saaty, 1980; Aczel and Saaty, 1983; Saaty and Kearns, 1985). O’Learly, however recommended synthesizing results using a consensus vote on judgments or priorities (1993). Ishizaka and Labib recommends that a “consensus vote is used when we have a synergistic group and not a collection of individuals” (2011).

5. The AHP has “the ability to provide measures of consistency of preferences” (Rao, 2013) through the consistency ratio.

However, the AHP is not without its flaws. Some of the problems with the AHP include:

1. How the decision maker quantifies their choices during the survey (Triantaphyllou and Mann, 1995). This is a problem with pairwise comparisons as qualitative results will be converted into quantitative results through the AHP.
2. The decision maker can become fatigued during the survey if they are presented with too many options. In 1956, Miller performed psychological experiments that showed that individuals are unable to simultaneously compare more than seven options at one time (plus or minus two). To prevent this from becoming a problem, the PI creating the survey should take care to limit the options (indicators, in this experiment) to 7±2.
3. The AHP assumes “structural dependence of the criteria on the number of alternatives and on their priorities. As a result, when alternatives are scaled

through paired comparisons, adding a new alternative can change the relative ranking of the old ones" (Saaty, 1986). As a result, criteria cannot be added or taken away from a survey without the weights changing and the entire study having to be redone.

4. For the AHP to result in valid results, knowledgeable individuals (see "experts") need to participate in the pairwise comparisons (Saaty, 1986). This is a problem as experts can be difficult to identify, and even after they are identified there may not be many experts in the field the PI is studying.

The AHP was applied in this research to rank (for each management protocol) both the indicator groups and the indicators in order of importance for classifying nearshore coastal and estuarine environments for IEA, CMSP, and EBM. In addition to the pariwise comparisons for the AHP, the management protocol experts were also asked to rank temporal and spatial scales in order from most important to least important for each indicator and to answer additional questions pertaining to the survey (Appendix B.1). The temporal and spatial scales were ranked in hopes that the most important scales for each indicator could be identified and in order to construct a figure (similar to Figure 3.1) for each management protocol.

All of the results from the survey were agglomerated and the indicators were ranked for importance. These agglomerated results were used to construct an estuarine classification system (Chapter 8) that classifies estuaries based not only upon their biological, ecological, and physical characteristics, but also upon their human and economic characteristics as well.

The results of the AHP, scale study, and additional questions are shown and discussed in the following sections.

5.3.2 Integrated Ecosystem Assessment

Figure 5.4 displays the indicator group weights for IEA based upon expert elicitation. The biological and ecological indicators have the highest weight at 44%, followed by the physical indicators at 31%, and then the human and economic indicators at 25%.

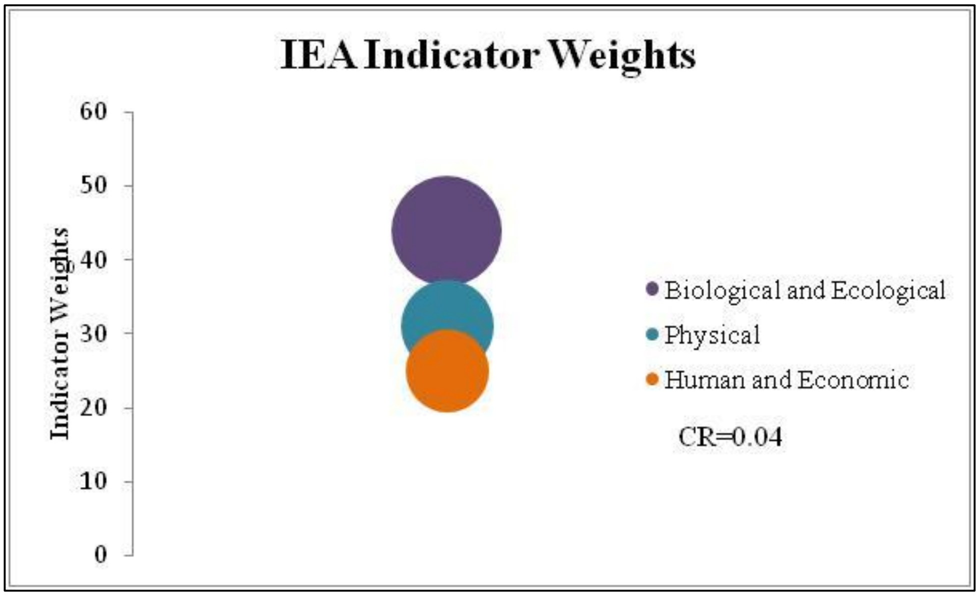


Figure 5.4 IEA Indicator Group Weights Based on Expert Elicitation

From these results, it can be concluded that for IEA to be successfully implemented in estuarine ecosystems, experts believe that sub-ecosystems need to be identified based on biological and ecological features first, then physical features, then human and economic features.

The consistency ratio (CR) of 0.04 or 4% indicates that the results are consistent and fall well below the acceptable CR of 10%.

5.3.2.1 Biological and Ecological Indicators

Figure 5.5 shows the indicator weights for the biological and ecological indicators from expert elicitation using the AHP process. It is important to note that the sum of the indicator weights is 100%. The CR for these indicators is 2%, which is within the range of acceptable CR values.

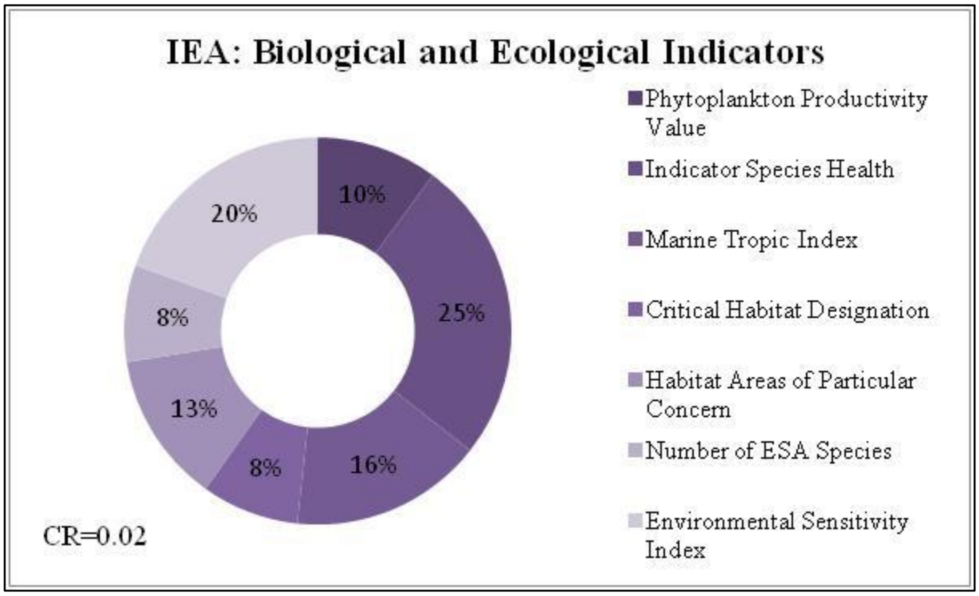


Figure 5.5 IEA: Biological and Ecological Indicators Weights

5.3.2.2 Physical Indicators

Figures 5.6, 5.7, and 5.8 show the results for the physical indicators and sub-indicators based upon expert elicitation and the AHP.

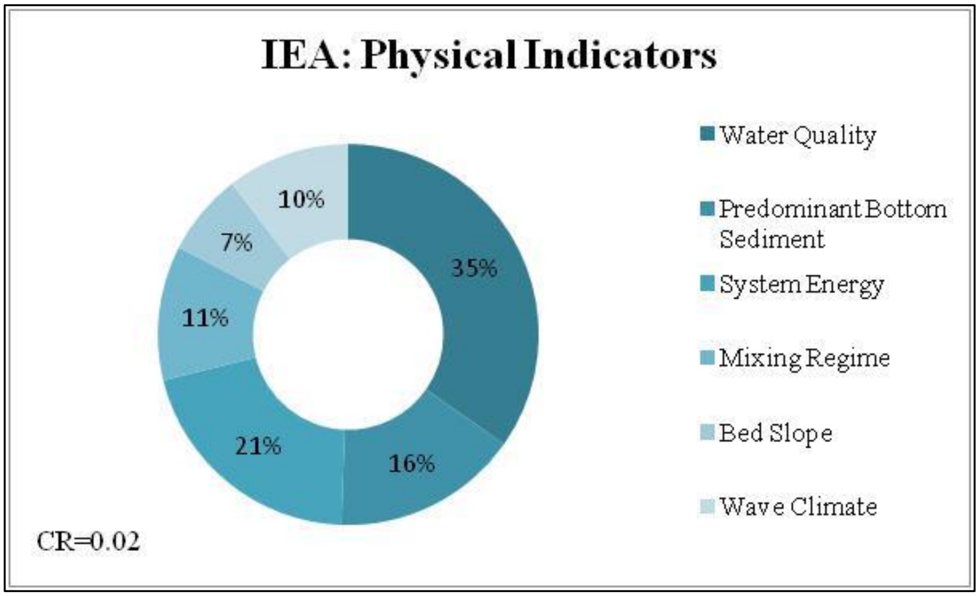


Figure 5.6 IEA: Physical Indicators Weights

The CR for the IEA Physical Indicators is 2% which is within the acceptable range for the AHP.

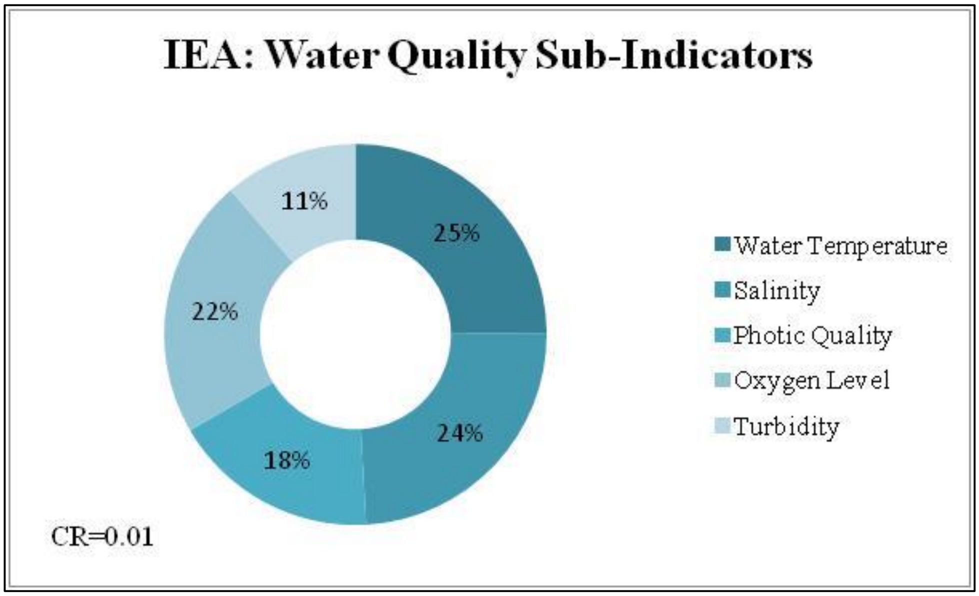


Figure 5.7 IEA: Water Quality Sub-Indicators Weights

The CR for the water quality sub-indicators is 1%, well within the acceptable range.

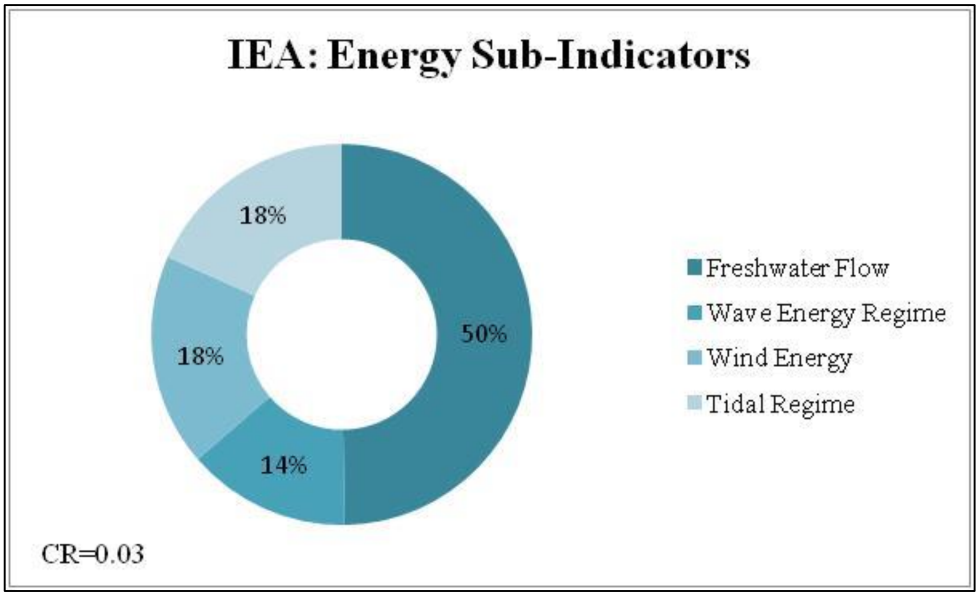


Figure 5.8 IEA: Energy Sub-Indicators Weights

Of this group of results, the energy sub-indicator weights have the highest CR at 3%; however, this is still well within the acceptable range.

5.3.2.3 Human and Economic Indicators

Figures 5.9 and 5.10 show the weights of the human and economic indicators group and its sub-indicators.

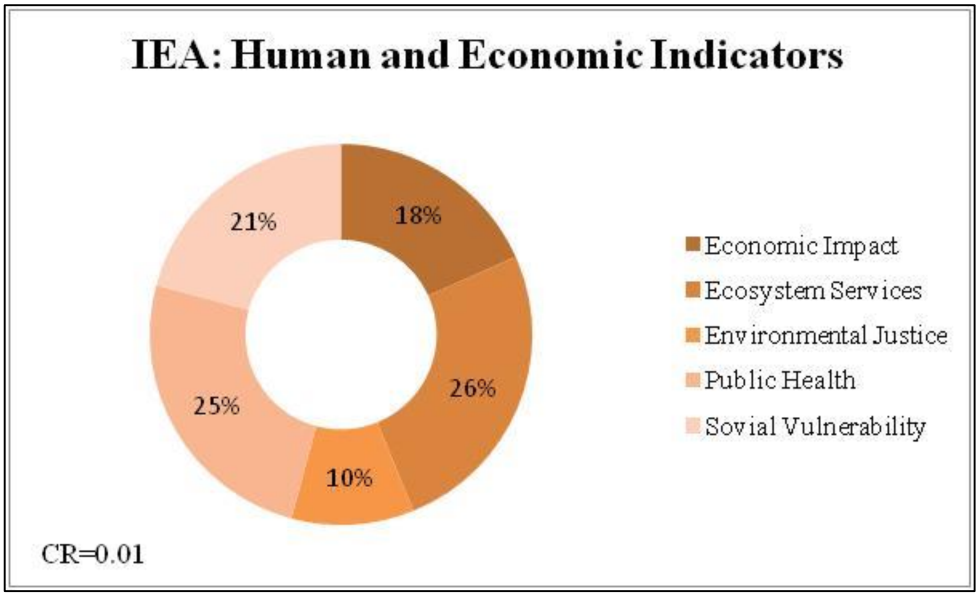


Figure 5.9 IEA: Human and Economic Indicators Weights

The CR for the weights calculated using the AHP for the human and economic indicators is 1%.

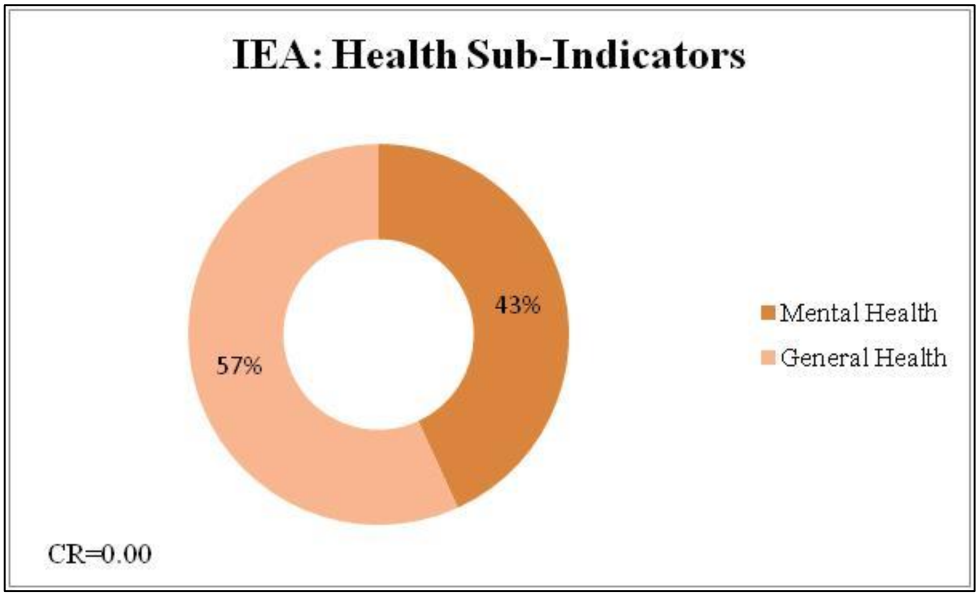


Figure 5.10 IEA: Health Sub-Indicators Weights

The health sub-indicators have a consistency ratio of 0%, which is expected as there are only two sub-indicators in this group.

5.3.2.4 Spatial and Temporal Scales

As discussed previously, identifying the proper spatial and temporal scales at which to model the ecosystem and execute the management plan are imperative in successfully creating and implementing a management plan to restore, preserve, and protect estuarine ecosystems.

As part of the management survey, experts were requested to rank different spatial and temporal scales in order of their importance for each indicator (but not sub-indicator) in the framework.

The answers were synthesized, and Figure 5.11 shows the most important temporal and spatial scales for each indicator as identified through expert elicitation. It is important to note that an indicator can have multiple “most important’’ temporal and/or spatial scales as in the case of phytoplankton productivity values.

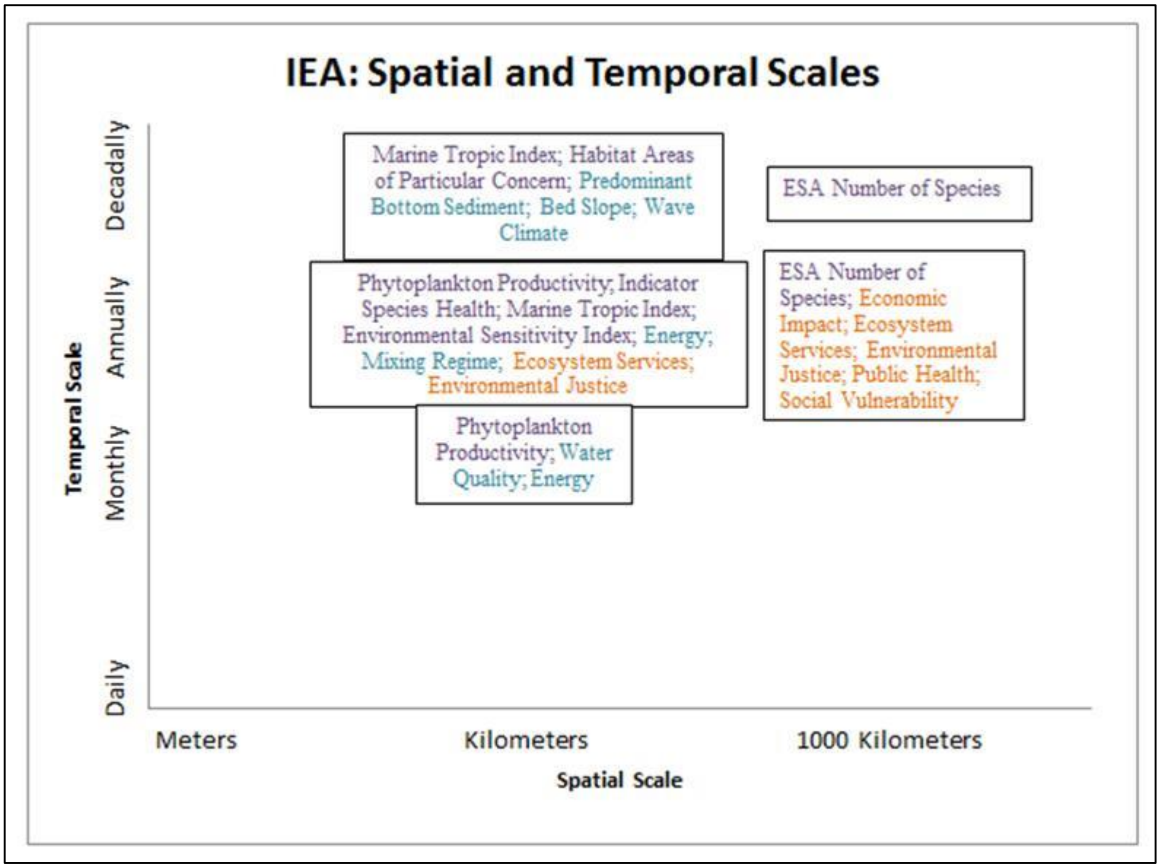


Figure 5.11 IEA: Important Spatial and Temporal Scales Based on Expert Elicitation

5.3.2.5 Additional Survey Results

Additional information was collected about the survey respondents and the results are listed in Table 5.35.

Table 5.28 IEA: Additional Survey Results

Average Experience (years)	10.75
Least Experience (years)	5
Most Experience (years)	16
Number of Respondents	4

Other information about the respondents cannot be released due to human research constraints.

As part of the survey, respondents were asked to list any additional parameters they felt should be included or considered in the framework. Their answers are listed below:

- Availability of effective regional governance structure.

As there is no way to incorporate this into the framework, it has not been added. Additionally, this is a constraint when actually creating and implementing the plan and not necessarily important for identifying sub-ecosystems.

5.3.3 Coastal and Marine Spatial Planning

Figure 5.12 shows the indicator group weights based upon expert elicitation and the AHP. The biological and ecological indicators received a weight of 42%, the physical indicators received a weight of 38%, and the human and economic indicators received a weight of 20%.

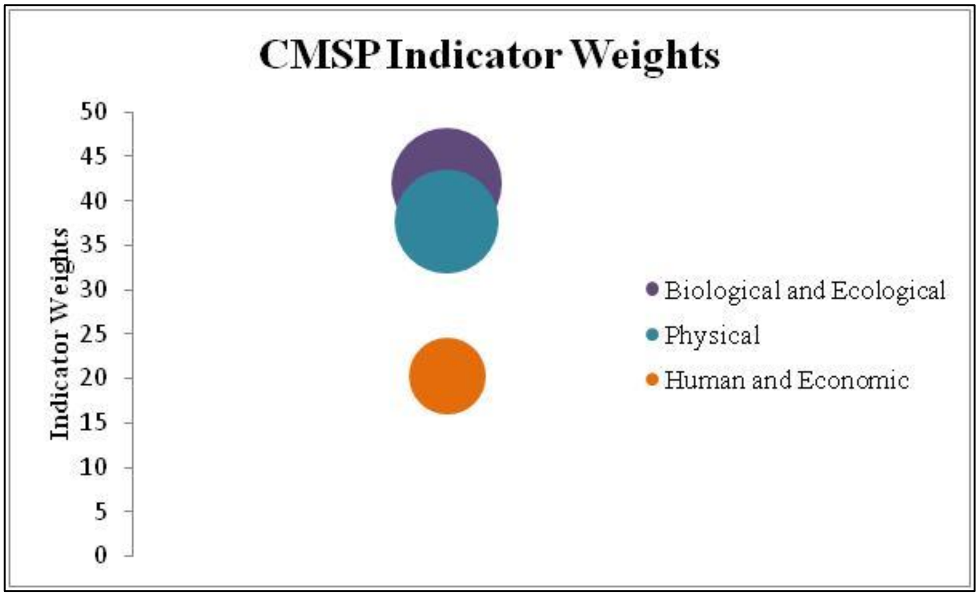


Figure 5.12 CMSP: Indicator Group Weights Based on Expert Elicitation

5.3.3.1 Biological and Ecological Indicators

Figure 5.13 shows the indicator weights for the biological and ecological group.

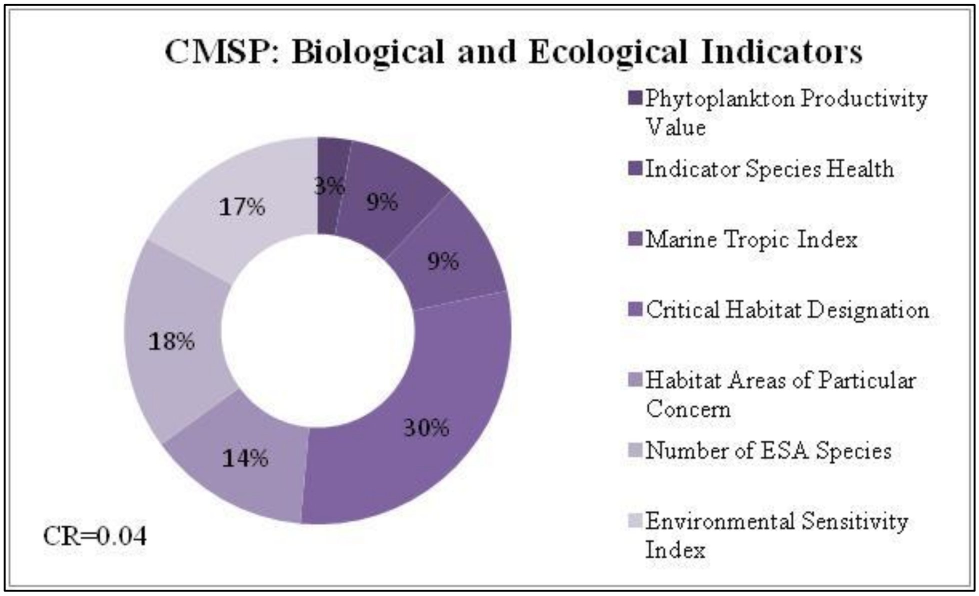


Figure 5.13 CMSP: Biological and Ecological Indicators Weights

5.3.3.2 Physical Indicators

Figures 5.14, 5.15, and 5.16 shows the indicator and sub-indicator weights and consistency ratios for the physical indicator group.

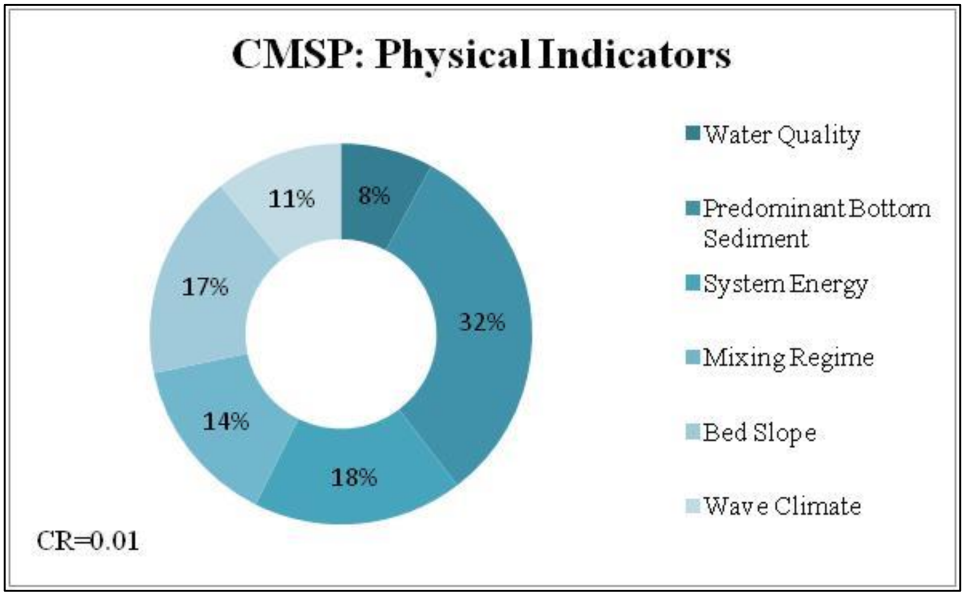


Figure 5.14 CMSP: Physical Indicators Weights

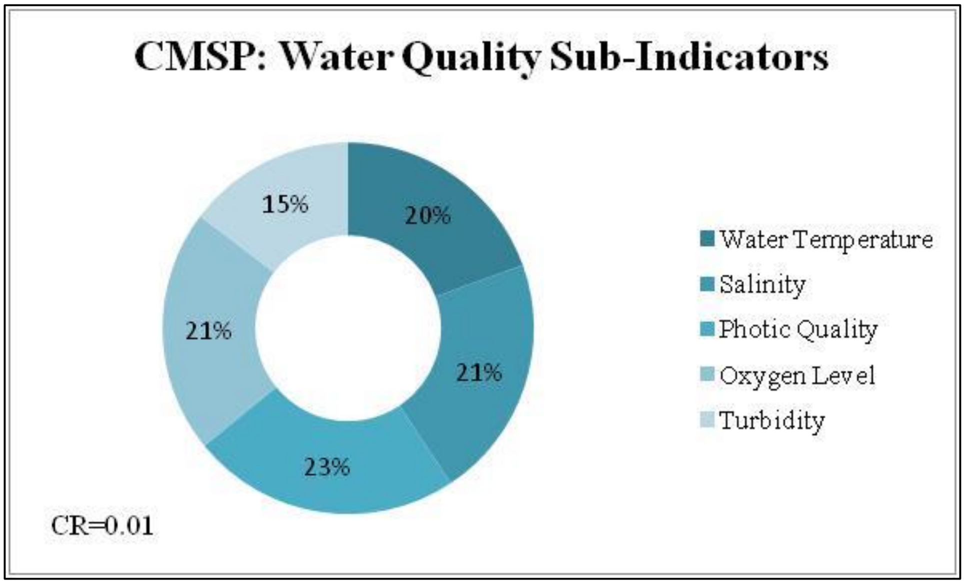


Figure 5.15 CMSP: Water Quality Sub-Indicator Weights

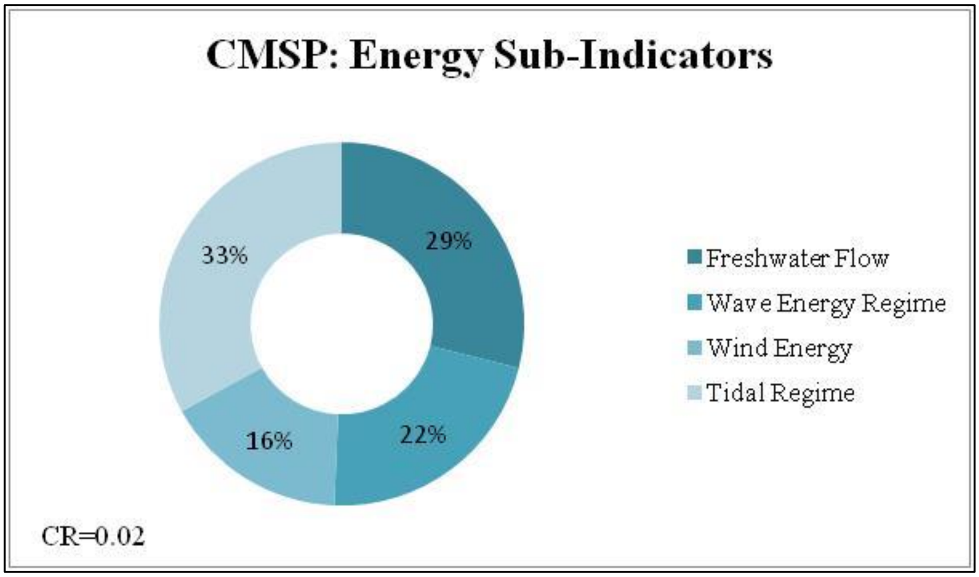


Figure 5.16 CMSP: Energy Sub-Indicator Weights

5.3.3.3 Human and Economic Indicators

Figures 5.17 and 5.18 display the weights and CRs for the human and economic indicators and sub-indicators.

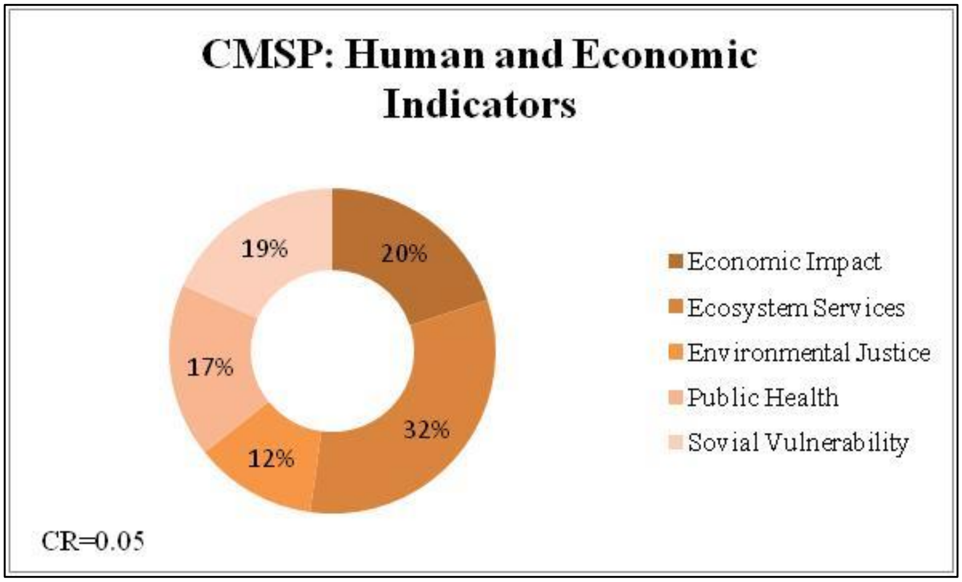


Figure 5.17 CMSP: Human and Economic Indicator Weights

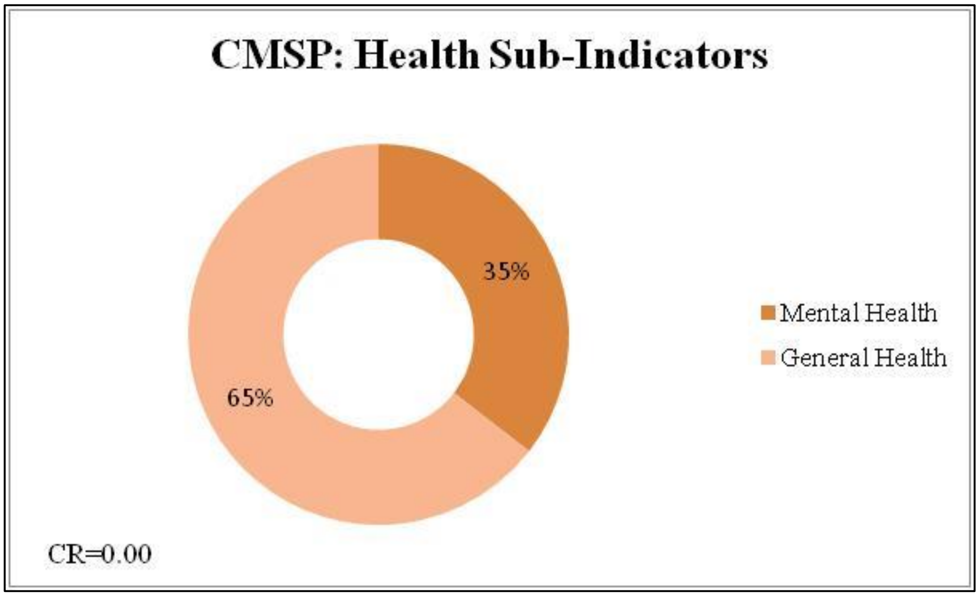


Figure 5.18 CMSP: Health Sub-Indicator Weights

5.3.3.4 Spatial and Temporal Scales

Figure 5.19 displays the important spatial and temporal scales for each indicator for CMSP according to expert elicitation.

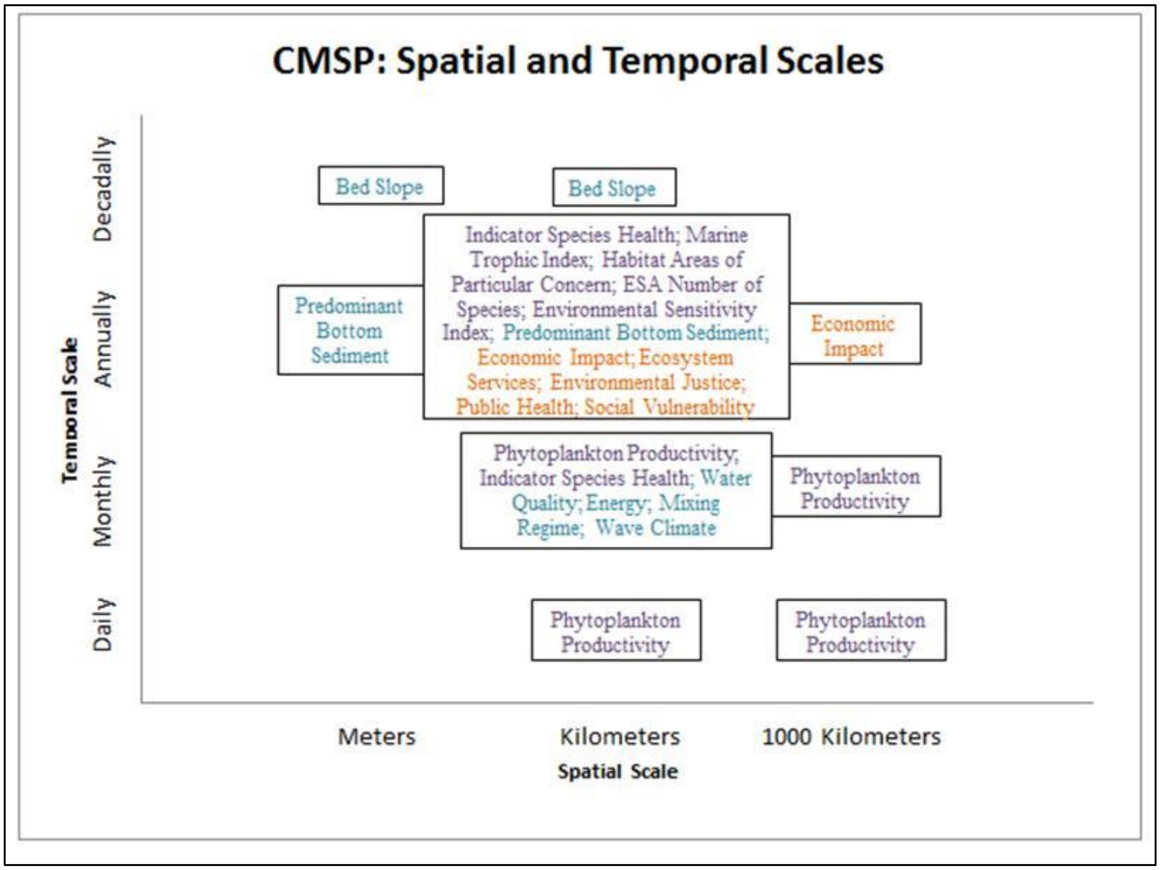


Figure 5.19 CMSP: Important Spatial and Temporal Scales Based on Expert Elicitation

5.3.3.5 Additional Survey Results

Table 5.29 shows demographics for the CMSP survey respondents.

Table 5.29 CMSP: Additional Survey Results

Average Experience (years)	22
Least Experience (years)	10
Most Experience (years)	40
Number of Respondents	3

As with the IEA survey, the CMSP experts were asked what additional parameters needed to be considered. Their responses are listed below.

- Overall capacity: ability of key agencies to commit good people to the task.
- Funds to make this happen.
- Availability of baseline data.
- Existing political boundaries.
- Existing regional management boundaries.
- Location of littoral zones.

While having funds and good people to commit to any task is always a problem – after all, we do not have unlimited funds or people! – there is no way to account for this in the framework.

As CMSP comes under the direction of the federal government, existing political boundaries are ignored, except for existing international boundaries. This is mostly due to the fact that ecosystems do not pay any heed to jurisdictional boundaries, and as such, it may be necessary to cross state lines to identify an entire sub-ecosystem. As CMS plans will be created and their implementation overseen on a federal level, state boundaries are not a concern.

The recognition of existing regional management boundaries is discussed in chapter 5.2.3 titled as "managed areas". The respondent did not know that recognizing existing management boundaries was already accounted for the in framework as it was not part of the survey.

Identifying the location of littoral zones typically falls under the purview of the United States Army Corps of Engineers who have created regional sediment management plans. It is recommended that the regional sediment management plans be taken into consideration when creating and implementing any sort of ecosystem-based management plan.

5.3.4 Ecosystem Based Management

Indicator group weights for EBM are shown in Figure 5.20. The results show that out of all of the management protocols, experts weight the indicator groups almost equivalently for EBM with the biological and ecological group being assigned a weight of 36%, the physical group having a weight of 31%, and the human and economic group having a weight of 31%.

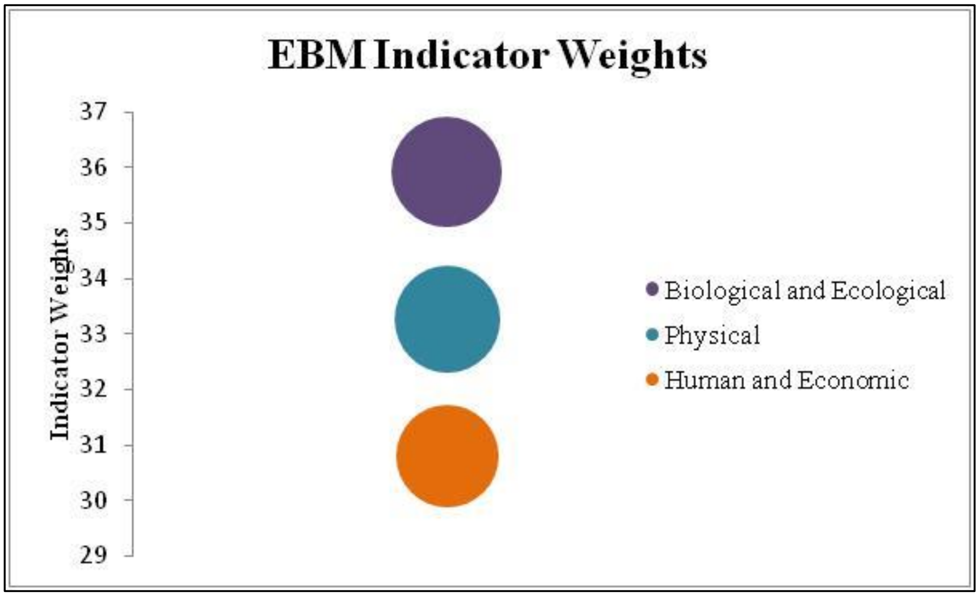


Figure 5.20 CMSP: Indicator Group Weights Based on Expert Elicitation

5.3.4.1 Biological and Ecological Indicators

Indicator weights and the CR for the biological and ecological indicators are shown in Figure 5.21.

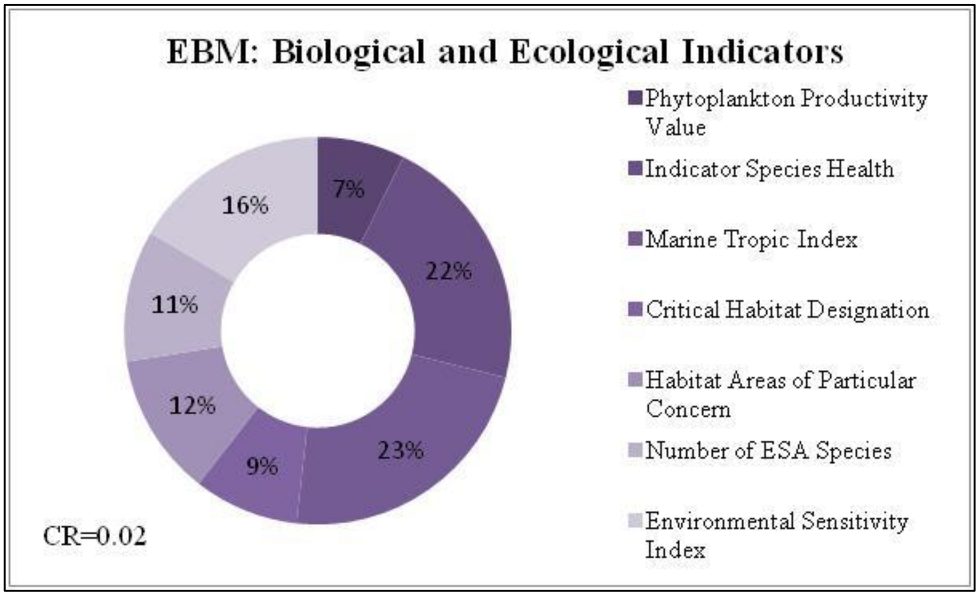


Figure 5.21 EBM: Biological and Ecological Indicators Weighting

5.3.4.2 Physical Indicators

Figures 5.22, 5.23, and 5.24 show the indicator and sub-indicator weights and CR for the physical group.

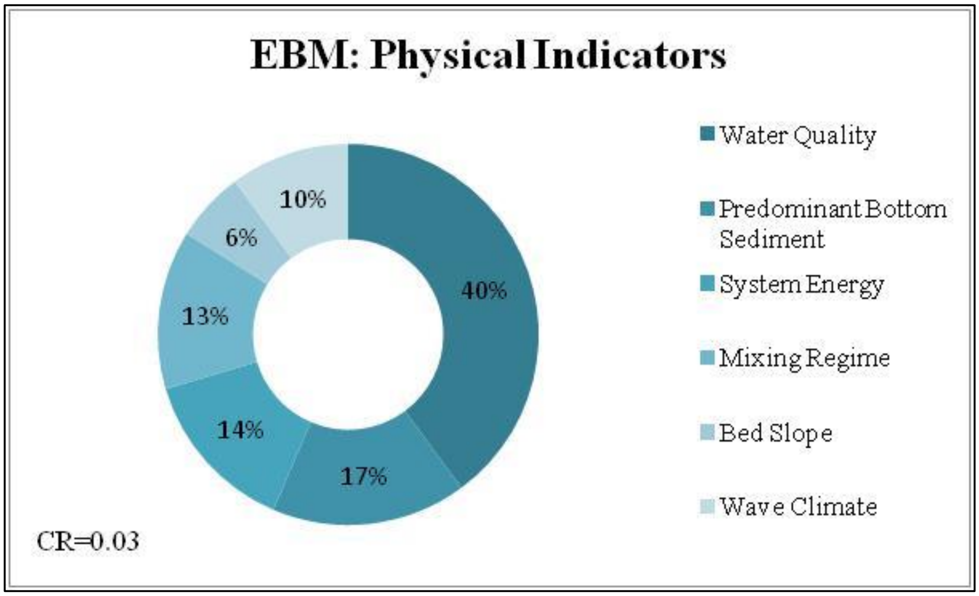


Figure 5.22 EBM: Physical Indicators Weights

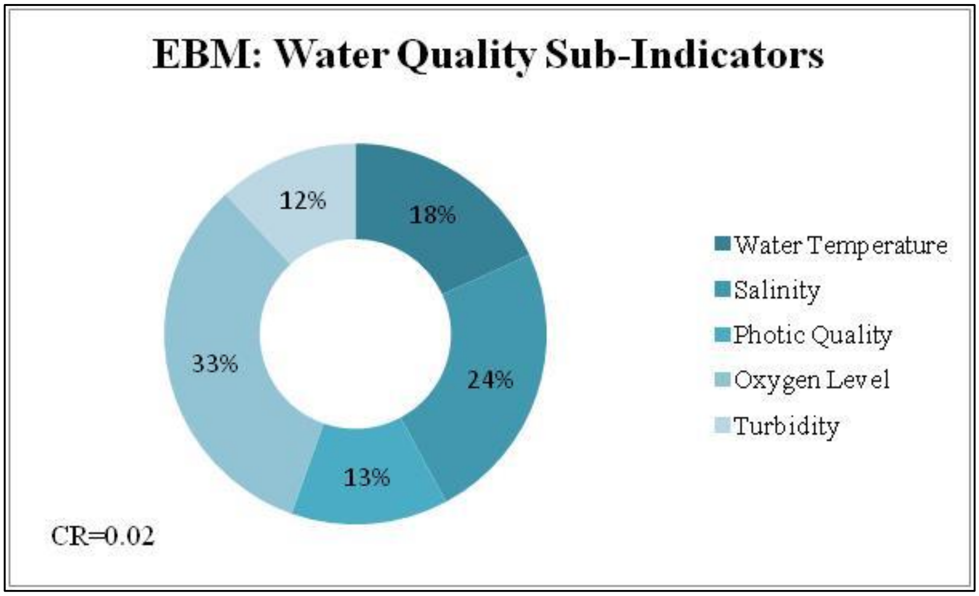


Figure 5.23 EBM: Water Quality Sub-Indicator Weights

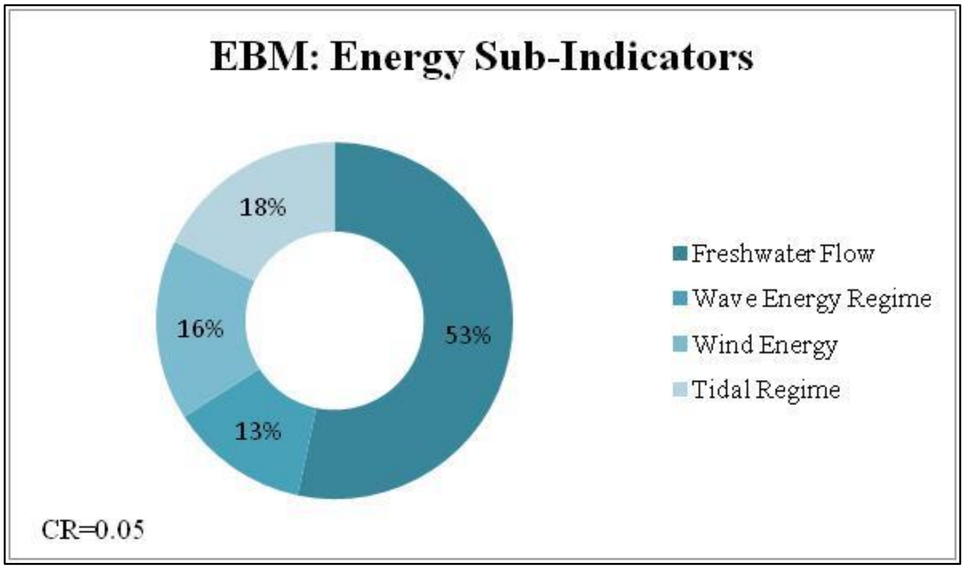


Figure 5.24 EBM: Energy Sub-Indicator Weights

5.3.4.3 Human and Economic Indicators

Figures 5.25 and 5.26 display the CR and indicator weights for the human and economic indicators group.

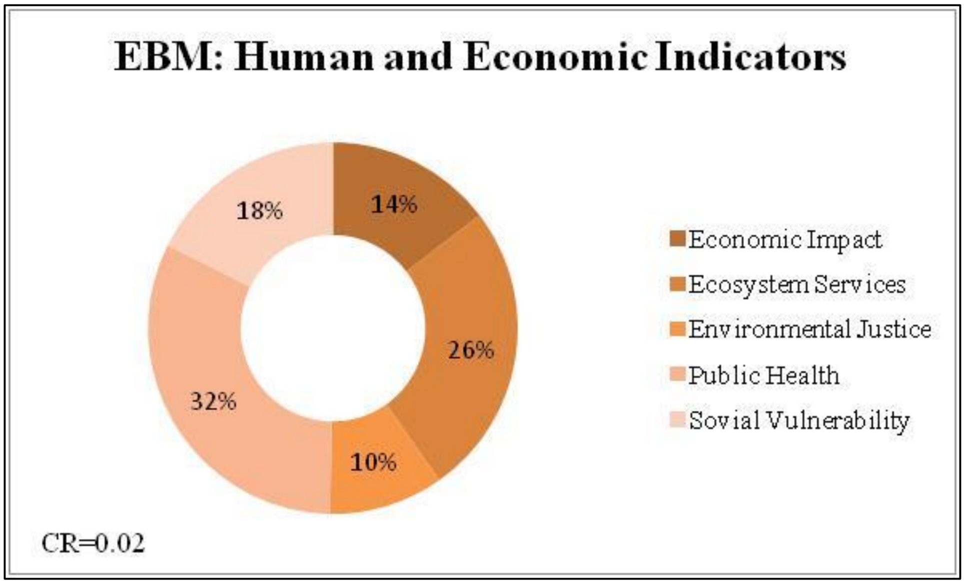


Figure 5.25 EBM: Human and Economic Indicators Weights

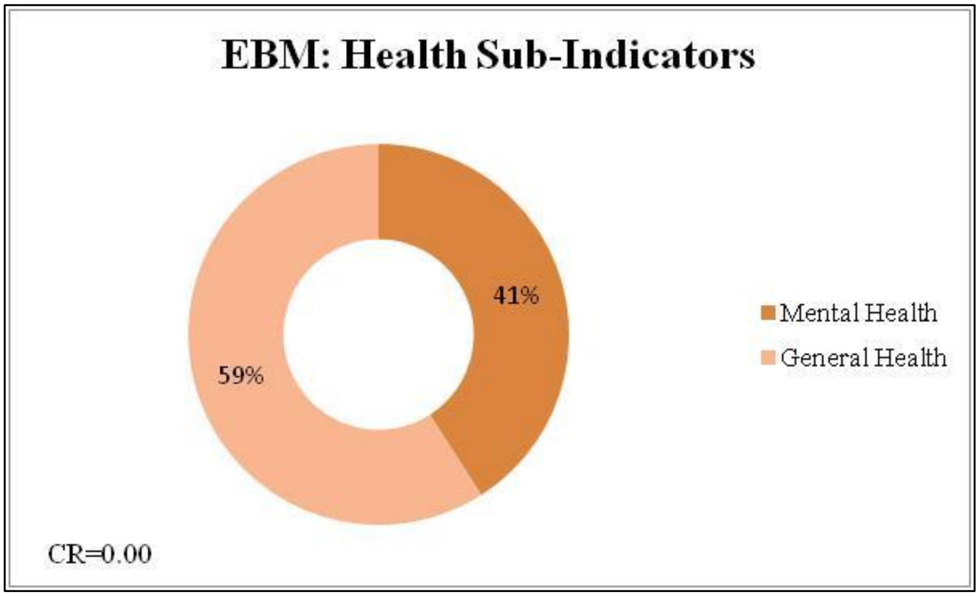


Figure 5.26 EBM: Health Sub-Indicators Weights

5.3.4.4 Spatial and Temporal Scales

Figure 5.27 shows the most important spatial and temporal scales for each indicator as identified through expert elicitation.

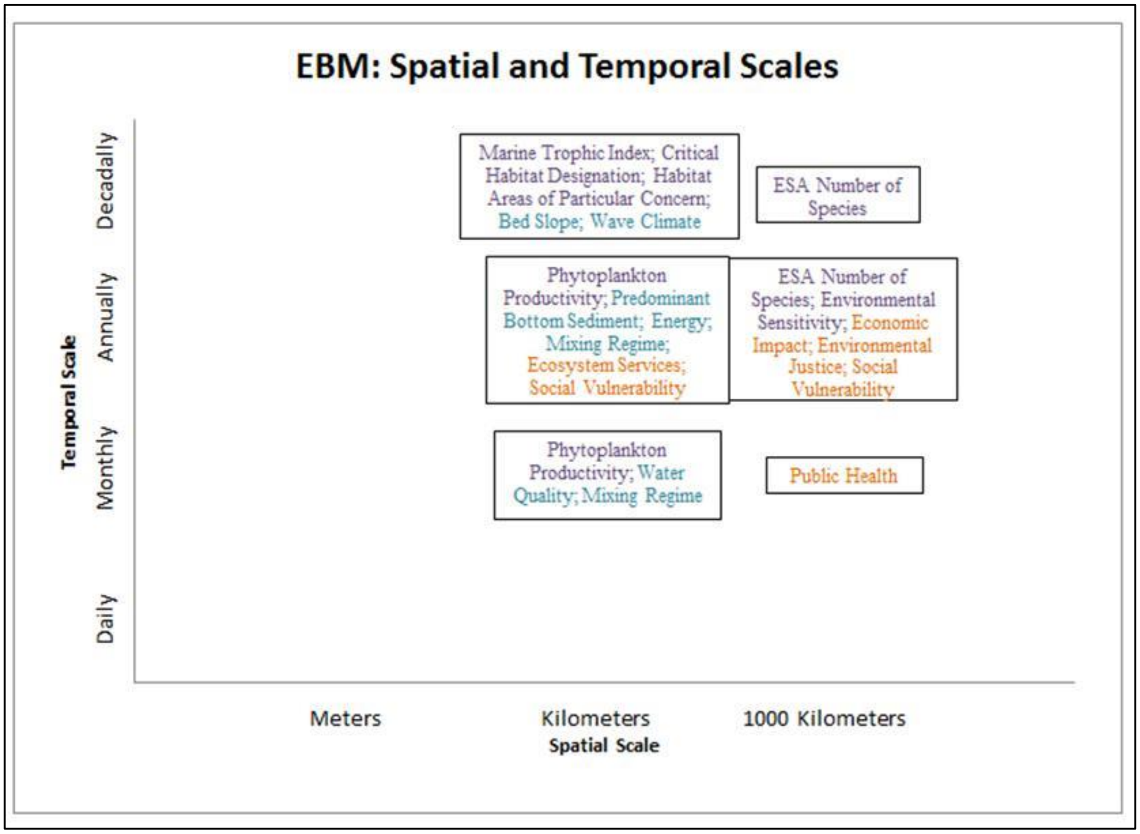


Figure 5.27 EBM: Important Spatial and Temporal Scales for Indicators Based on Expert Elicitation

5.3.4.5 Additional Survey Results

Table 5.30 displays demographic data about the EBM survey respondents.

Table 5.30 EBM: Additional Survey Results

Average Experience (years)	15
Least Experience (years)	7
Most Experience (years)	23
Number of Respondents	3

None of the EBM expert survey respondents listed any additional parameters they believe should be considered in the framework.

5.3.5 Conclusions from AHP

The results from the expert elicitation and the AHP displayed above are very interesting and show the differences between the different management protocols as to what is viewed as "more important" (demonstrated by a higher weight) and also the scales at which the indicators are most important, as this changes for every protocol.

Table 5.31 shows a summary of the indicator group weights that were calculated using the AHP.

Table 5.31 Indicator Group Weights Based on Expert Elicitation

	IEA	**CMSP**	**EBM**
Biological and Ecological	44	42	36
Physical	31	38	33
Human and Economic	25	20	31

From Table 5.38 it can be seen that while none of the management protocols place the same weight on the different indicator groups, IEA and CMSP produce similar results. The experts for EBM answered the survey in such a way that the indicator groups are weighted roughly equivalent to each other.

The differences in the management protocols are very interesting to note, especially as IEA and EBM are used in conjunction with each other for many federally-created management plans.

CHAPTER VI

INITIAL DEVELOPMENT AND ITERATION OF THE FRAMEWORK WITH APPLICATION TO PERDIDO AND GALVESTON BAYS

6.1 Introduction

As noted in Chapter 2, properly identifying the scale at which an area needs to be managed is important, but also very difficult. As such, the work presented in this chapter is intended to lay the foundation for a framework that can be used to identify sub-ecosystems within LMEs for management purposes. The indicators matrix (Chapter 4) along with the management protocols matrix (Chapter 5) will be applied to two sites (Perdido Bay and Galveston Bay) at multiple grid sizes. The purpose of using multiple grid sizes is to identify how changes in scale affect the classification scheme.

The framework development sites of Perdido Bay and Galveston Bay were chosen because they share many characteristics but differ substantially in size, facilitating identification of the scale at which sub-ecosystems can be differentiated for ecosystems of varying sizes. Of the sites used for the development and validation of the framework, Perdido Bay is by far the smallest site by surface area; Galveston Bay, on the other hand is close in size to both Mobile Bay and Barataria Bay, but much smaller than Mississippi Sound. The intent in using these sites is to draw conclusions about the appropriate grid size to use in the framework based upon the ecosystem being sub-divided. By choosing the largest site, Mississippi Sound, as a validation site, the conclusions drawn from developing the framework are able to be tested.

6.2 Method

In order to apply the framework to the development sites, the following steps were taken:

1. Using ArcMap 10.1, a shapefile consisting of a polygon of each estuary oultine used was created using the Basemap "Oceans" to identify the sites.
2. The estuary shapefile was assigned to the USA Contiguous Albers Equal Area Conic USGS coordinate system which is associated with the geographic coordinate system of GCS North American 1983.
3. The shapefile was gridded with polygons using the "fishnet" tool in ArcGIS. However, the polygon fishnet created took the shape of a box; the fishnet layer was intersected with the estuary shapfile layer (both are polygons) to create a polygon shapefile of the grid representing the shape of the estuary.
4. Step 3 was repeated for multiple grid sizes (4 kilometer squares, 2 kilometer squares, and 1 kilometer square) for each estuary used.
5. To populate the grids, the gridded shapefile and multiple data layers were added to ArcMap. The data layers (previously downloaded from multiple sources including the Gulf of Mexico Data Atlas) were turned on one at a time. Starting with the 1 kilometer square grid boxes, data were manually transcribed from each data layer to the attributes table in ArcMap via Excel workbooks. Since the grids are based upon the same starting point, the grids overlay each other (i.e. a 2 kilometer square grid is composed of four 1

kilometer square grids, etc.). To simplify the process, the indicators for each box were manually transcribed for the smallest grid size (in this case, 1 kilometer square). For the next grid size (i.e. 2 kilometer squares), the average of the values located in the four boxes associated with the smaller grid size was used. This was to: 1. Reduce human error in transcribing the data and 2. Reduce the excessive workload the manual transcription induced.

6. The indicator weights (described and detailed in Chapter 5) were then used to determine the weighted indicator value. As each management protocol (Chapter 2) has different associated weights, each estuary at each grid size resulted in four different weighted indicator tables: one for original values without weights, one for IEA, one for CMSP, and one for EBM. While these numbers are needed in ArcMap, it is much easier to work with these numbers in Excel; as such, the majority of this work was done within Excel before the numbers were transferred to ArcMap.
7. When the tables for the weighted indicators associated with the management protocols were populated, the FIDs (the numbers used within ArcMap to identify the different grid boxes) and the weighted indicators were clustered using multi-variant agglomerative hierarchy clustering using Matlab R2011a. This code not only finds the natural clusters within the data, but also plots a dendrogram of the cluster hierarchy. The dendrogram was used to identify multiple levels of clusters.
8. The data were then imported into Microsoft Excel and pivot tables were created to summarize the data. The pivot tables were used alongside the

dendrograms to determine how many clusters reasonably described each system. The pivot tables were also used to compare the total number of FIDs (or boxes) in each cluster group. This is useful as the data can be easily viewed to determine how much influence the different management protocol weights exert on both the number of clusters and the number of FIDs per cluster. The determination of the number of clusters to display on a map was a judgment-based decision using natural jinks in the data. The cluster number where the number of FIDs in the cluster stopped changing significantly was located on the pivot table. The corresponding dendrogram was then viewed and the number of natural clusters in the dendrogram was noted and the number of clusters identified was mapped.

9. After the number of clusters to be visualized was decided and the FIDs were associated with a cluster number, the associated cluster number for each FID was imported into ArcMap in the attributes table using the editor tool.
10. The color ramp of the polygons in ArcMap was changed so that one color was associated with each cluster. It is much easier to view the clusters and locate them by doing this. When applied to a system for the purposes of identifying sub-estuaries for management, the clustered map of each estuary can be displayed so that estuarine experts can determine if the cluster separation is appropriate and are different enough to justify different management plans.

For the purpose of the development and iteration of the framework, the data were analyzed to determine how sensitive the clusters are to changes within the data. In order to perform a sensitivity analysis, the data within the indicators matrix for Perdido Bay were increased by an order of magnitude and then the data were then re-clustered to determine how the clusters changed. The results from this analysis are discussed below.

6.3 Cluster Pivot Tables

Pivot tables are a data summarization tool that allow the display of large quantities of data in a concise format. For this work, the pivot tables were used to show how many FIDs are associated with different clusters. They were used to determine the changes in how many FIDs are associated with each cluster group between the original data sets and those created for the sensitivity analysis. The pivot tables are, however, unable to be used to determine which FIDs are associated with each cluster. It is important to note that the "cluster group" in the pivot tables are arbitrary and can be renamed as wanted; the cluster group numbers were assigned as a way to differentiate the different clusters. The number itself does not tell where the cluster is located, nor does it have any bearing on the number of FIDs in a cluster. In the pivot tables below, the number in each box displays the number of FIDs per cluster group ("Number of Clusters"). Three pivot tables are shown below for emphasis: the Perdido 1 km^2 grid without indicator weights (Figure 6.2), the Perdido 1 km^2 grid without indicator weights for sensitivity analysis (Figure 6.3), and the Galveston 1 km^2 grid without indicator (Figure 6.4). The remaining pivot tables for each grid size and management protocol for both Galveston and Perdido Bays are shown in Appendix F.

Table 6.1 Perdido: 1 km^2 Grid

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	276										276
3	1	236	39								276
4	1	38	1	236							276
5	1	37	1	1	236						276
6	1	235	1	37	1	1					276
7	8	227	1	1	37	1	1				276
8	1	226	8	1	1	37	1	1			276
9	2	224	1	8	1	1	37	1	1		276
10	9	28	2	224	1	8	1	1	1	1	276

Table 6.2 Perdido: 1 km^2 Grid; Sensitivity Analysis

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	276										276
3	1	236	39								276
4	1	38	1	236							276
5	1	37	1	1	236						276
6	1	235	1	37	1	1					276
7	8	227	1	1	37	1	1				276
8	1	226	8	1	1	37	1	1			276
9	2	224	1	8	1	1	37	1	1		276
10	9	28	2	224	1	8	1	1	1	1	276

Table 6.3 Galveston: 1 km^2 Grid

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	2295										2295
3	4	2289	2								2295
4	28	2261	4	2							2295
5	126	2135	28	4	2						2295
6	1	2134	126	28	4	2					2295
7	2127	7	1	126	28	4	2				2295
8	2	2	2127	7	1	126	28	2			2295
9	1	6	2	2	2127	1	126	28	2		2295
10	4	2	1	2	2	2127	1	126	28	2	2295

From the Perdido Bay pivot tables (Tables 6.2, 6.3, E1.1-E1.22, and E2.1-E2.11), it can be seen that there is little to no variation between the number of FIDs per cluster in the original and sensitivity analysis files. For Perdido Bay with a grid size of one kilometer square, differences only appear when dealing with the indicators matrices for CMSP and IEA; however, the differences do not occur until the number of clusters is set to seven or higher and even then, the variation between the original file and the file for sensitivity analysis is minimal. For the two kilometer square grid size in Perdido Bay, the only differences are noted for CMSP when the number of grids is set to six or higher. As with the variation for the smaller grid size, this variation is minimal. No difference was noted when looking at the number of FIDs per cluster with the four kilometer square grid size.

As the sensitivity analysis for Perdido Bay yielded no significant difference in cluster results it is thought that the data are not sensitive to a uniform increase in magnitude of the indicator value, thus a sensitivity analysis for Galveston Bay was determined to be unnecessary.

6.4 Dendrograms

Dendrograms are a type of tree diagram that are used to show cluster arrangements produced by hierarchical clustering. The script for the cluster analysis generated not only a file that associated FIDs with a cluster number, but a dendrogram as well. Dendrograms are used in correlation analysis to show how closely correlated two objects are. For the purposes of this work, each FID started as an individual “cluster”. Clusters that are closely related based upon indicator value were then clustered at a higher level cluster; this method continues until one cluster encompassing all of the FIDs remains.

In the MATLAB script, the number of clusters to be in the output files was specified to be 2, 3, 4, 5, 6, 7, 8, 9, and 10. Based upon the data used in the framework and the size of the system, more than 10 clusters produced extraneous results.

For the dendrograms shown, the y-axis is the Euclidean distance, or the distance between the clusters and the x-axis is the Box ID number. Matlab was unable to run the cluster analysis using an FID number equal to zero; as such, box identification numbers were assigned to each box using the equation:

$$Box\ ID\ Number = FID + 1 \tag{6.1}$$

Figures 6.1-6.3, F1.1-F1.22, and F2.1-F2.11 show the dendrograms for Galveston Bay and Perdido Bay and its sensitivity analysis.

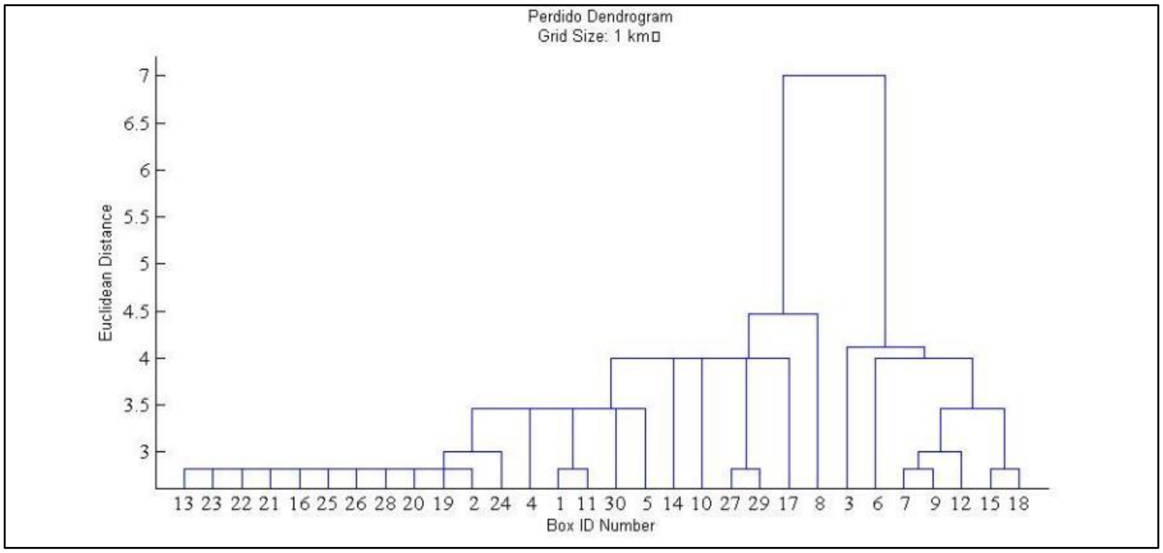


Figure 6.1 Perdido Cluster Dendrogram; Grid Size 1 km^2

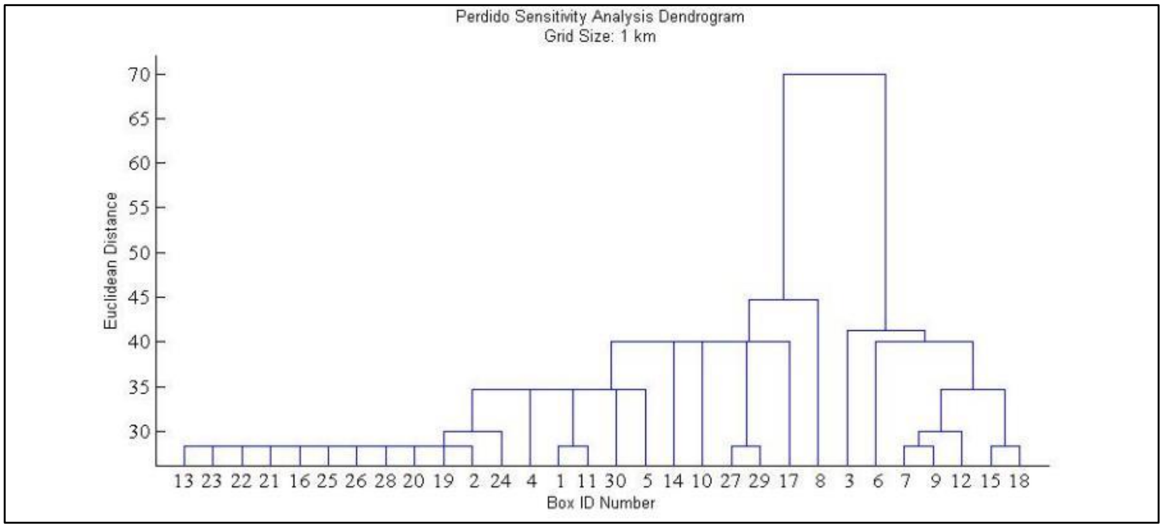


Figure 6.2 Perdido Cluster Dendrogram for Sensitivity Analysis; Grid Size 1 km^2

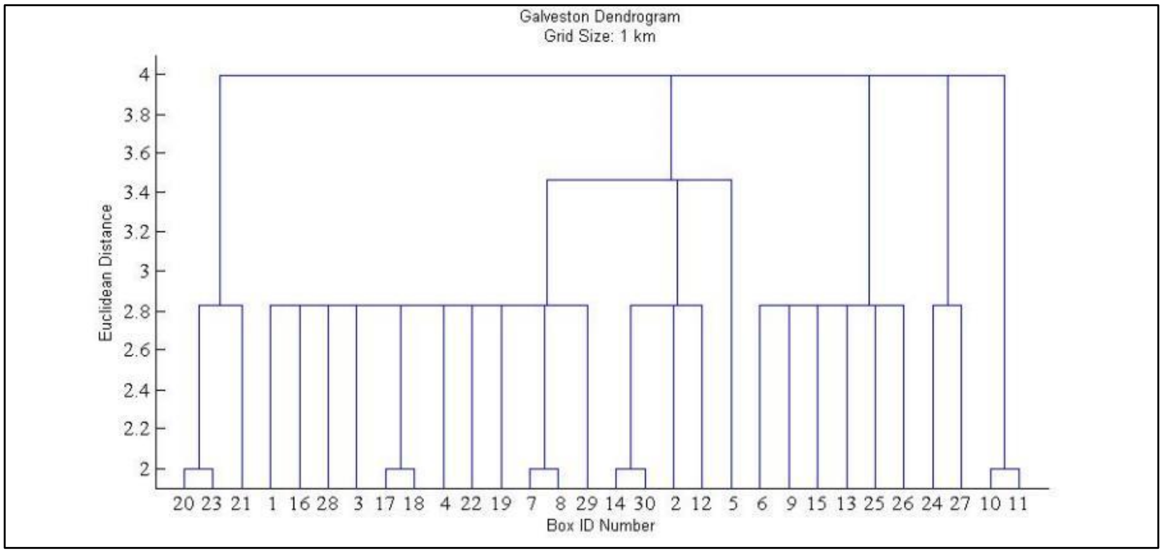


Figure 6.3 Galveston Cluster Dendrogram; Grid Size 1 km^2

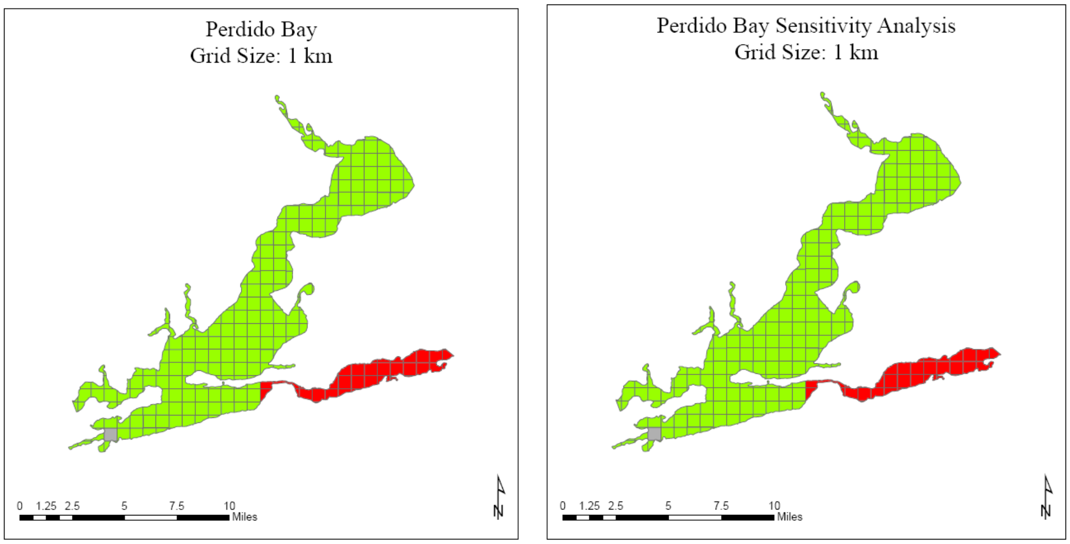
The dendrograms can be used (along with the pivot tables) to determine how many clusters are needed. While the pivot tables show the number of FIDs per cluster at each level, the dendrogram visually displays how these clusters are made. The natural breaks and clusters within the data can be seen in the dendrogram which is essential in determining how many sub-ecosystems (or clusters) to break a larger ecosystem into.

When viewing Figures 6.1-6.24, the dendrogram for the original Perdido data are above the dendrograms for the sensitivity analysis of Perdido Bay. The differences between the original data and the sensitivity analysis were noted when looking at the pivot tables. However, the pivot tables were only able to display the number of FIDs per cluster; the dendrograms, on the other hand are able to give more insight into how the differences within the clusters occur relative to the FIDs. The dendrograms re-affirm that while the clusters changed between the original data and the sensitivity analysis data on the lower levels, the clusters groups appear to have the same shape when looking at the higher-level clusters.

6.5 Cartographic Display

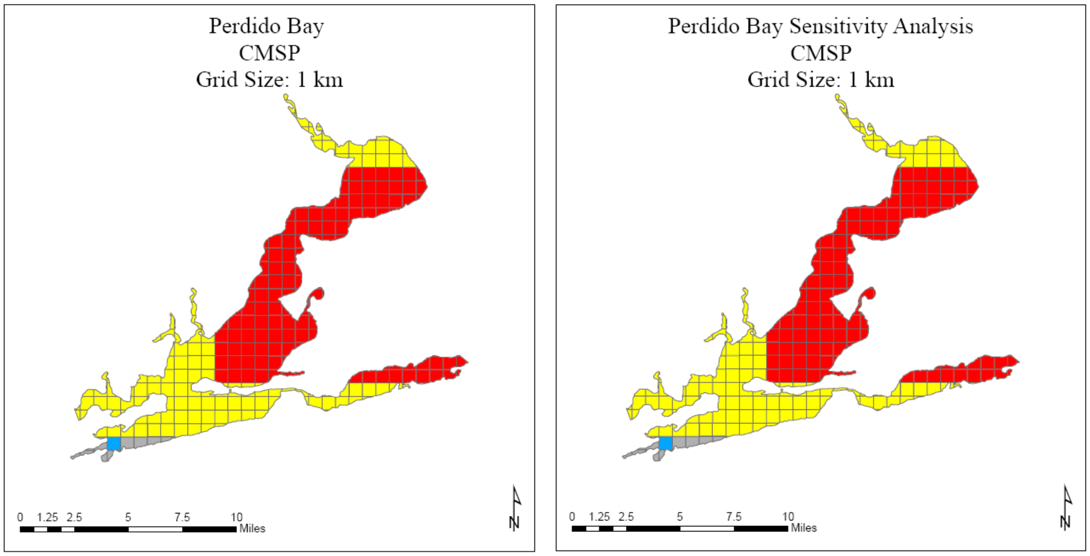
While the pivot tables can tell how many FIDs are in each cluster and the dendrograms can show the hierarchy of the clusters, visualizing the data allow for the location of clusters within the estuarine system; in order to do this, ArcMap 10.1 was used. The number of clusters for each system was based on the pivot tables and dendrograms. The extended MATLAB output that related FID to cluster number was then translated into ArcMap and the clusters were visualized by changing the color ramp display so that each cluster was associated with an individual color; Figures 6.4-6.15 and 6.16-6.21 show the clusters that were identified for Perdido Bay and Galveston Bay, respectively, through this work.

6.5.1 Perdido Bay Results


Perdido Bay
Grid Size: 1 km

Perdido Bay Sensitivity Analysis
Grid Size: 1 km

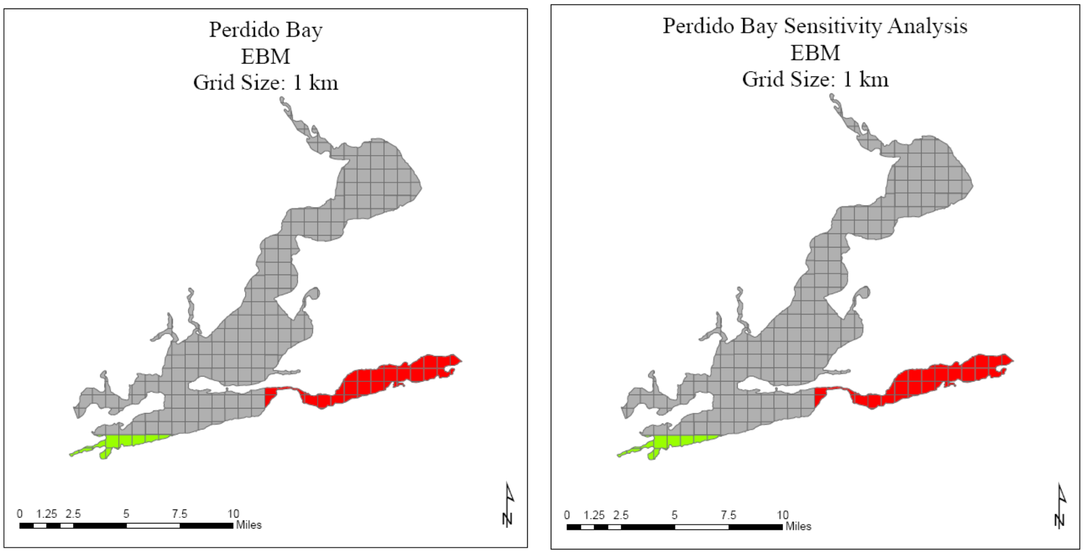
Figure 6.4 Perdido Bay using 1 km^2 grid size: (l) original data; (r) sensitivity analysis



Perdido Bay
CMSP
Grid Size: 1 km

Perdido Bay Sensitivity Analysis
CMSP
Grid Size: 1 km

Figure 6.5 Perdido Bay using 1 km^2 grid size for CMSP weights: (l) original data; (r) sensitivity analysis



Perdido Bay
EBM
Grid Size: 1 km

Perdido Bay Sensitivity Analysis
EBM
Grid Size: 1 km

Figure 6.6 Perdido Bay using 1 km^2 grid size for EBM: (l) original data; (r) sensitivity analysis

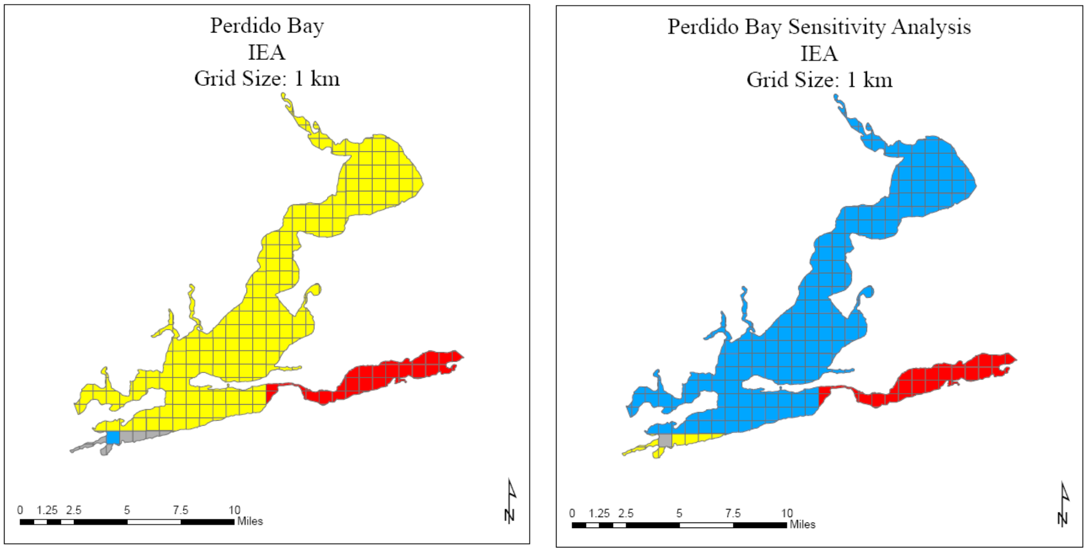


Figure 6.7 Perdido Bay using 1 km^2 grid size for IEA: (l) original data; (r) sensitivity analysis

Figures 6.4 through 6.7 show the results from the application of the framework by applying it on a one kilometer square grid to Perdido Bay. The maps on the left are of the original data and the maps on the right are of the sensitivity analysis of the same application. The maps for the original data (Figure 6.4) and EBM (Figure 6.6) are shown using three clusters while CMSP and IEA are shown with four clusters. Using the side-by-side comparison, it can be seen that the maps produced by the original data and the maps produced by the sensitivity analysis are identical except in the case of Figure 6.7. However, upon further inspection, it is seen that the difference between these maps is solely in the color used to represent the clusters. This indicates that the cluster number is different; however the FIDs within the clusters themselves are the same. This shows that the cluster number can vary, but the results will be the same when visualized.

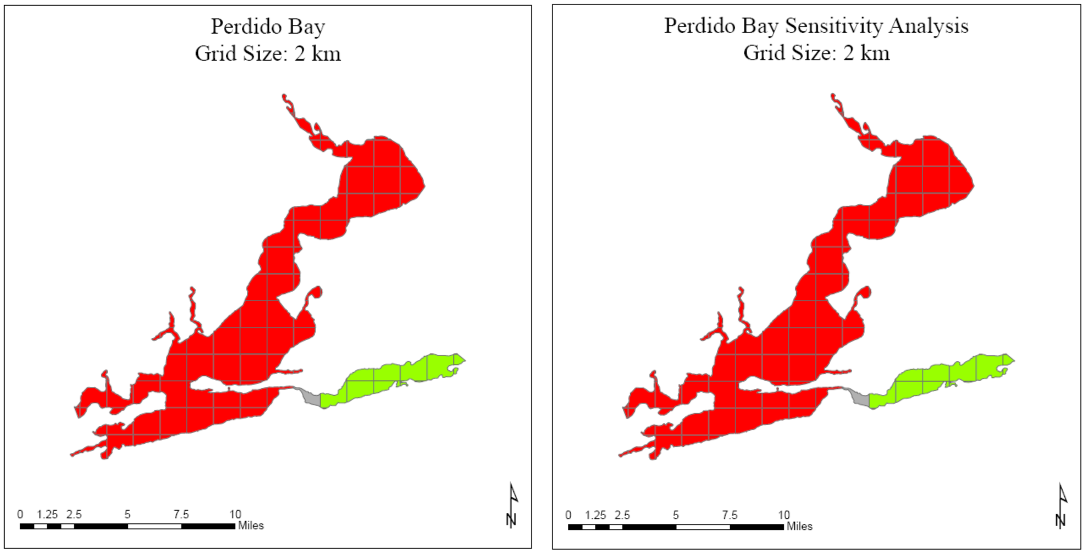


Figure 6.8 Perdido Bay using 2 km^2 grid size: (l) original data; (r) sensitivity analysis

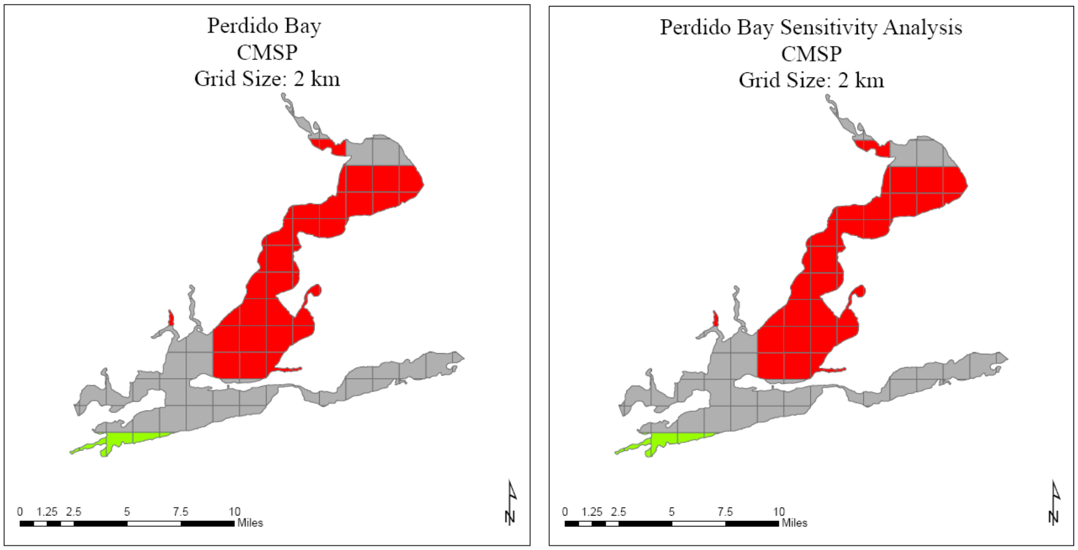


Figure 6.9 Perdido Bay using 2 km^2 grid size: for CMSP (l) original data; (r) sensitivity analysis

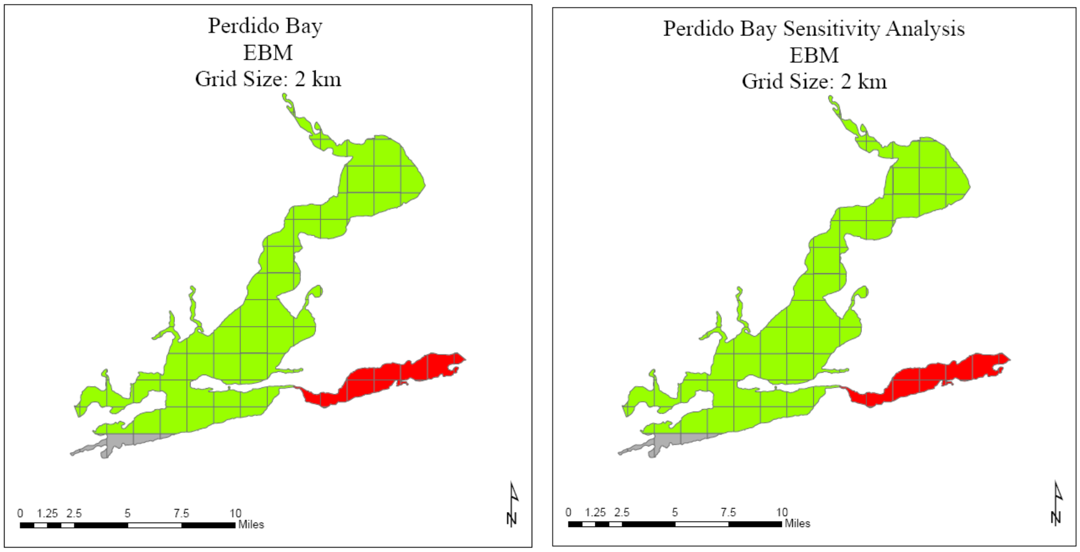


Figure 6.10 Perdido Bay using 2 km^2 grid size for EBM: (l) original data; (r) sensitivity analysis

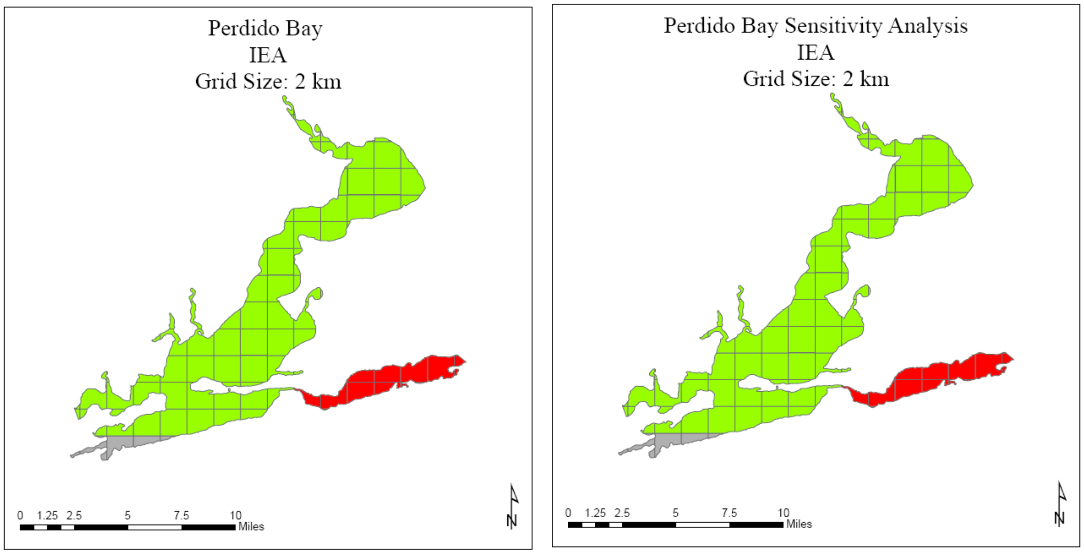


Figure 6.11 Perdido Bay using 2 km^2 grid size for IEA: (l) original data; (r) sensitivity analysis

Figures 6.8 through 6.11 show the results from the application of the framework by applying it on a two kilometer square grid to Perdido Bay. As with the maps for the one kilometer square grid, the maps on the left are of the original data and the maps on the right are of the sensitivity analysis of the same application. All of the maps are shown with three clusters. The maps for EBM (Figure 6.10) and IEA (Figure 6.11) are identical and show a high congruency to the results produced by the original data (Figure 6.8) while the results produced by CMSP (Figure 6.9) are noticeably different. This is likely due to differences in the weights between the different indicators.

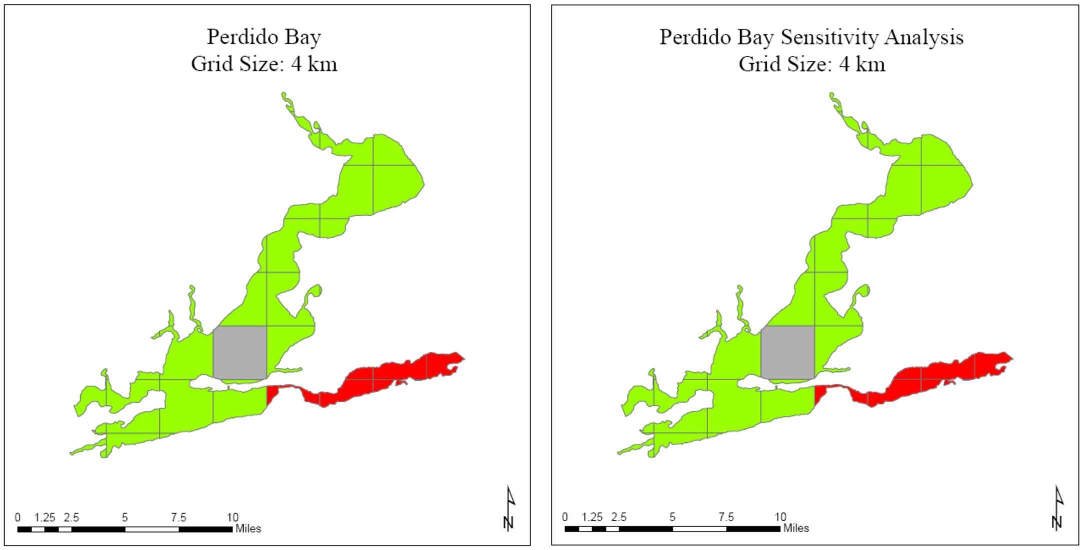
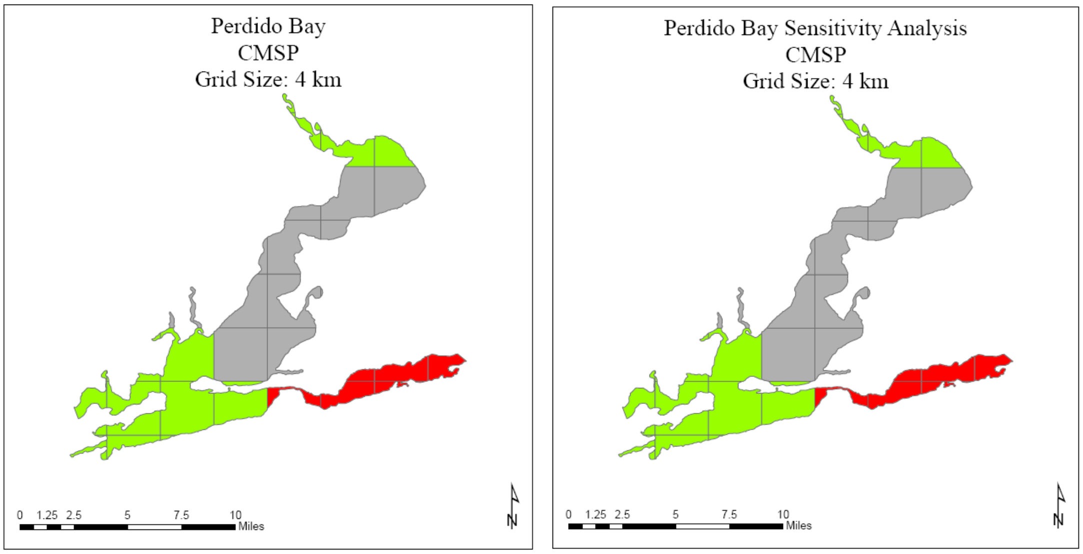
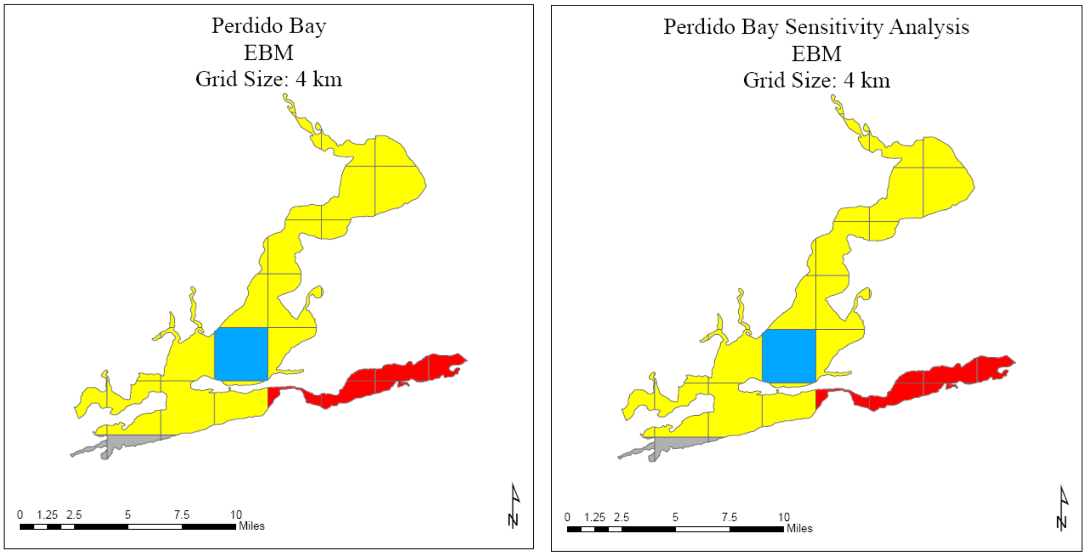


Figure 6.12 Perdido Bay using 4 km^2 grid size: (l) original data; (r) sensitivity analysis


Perdido Bay
CMSP
Grid Size: 4 km

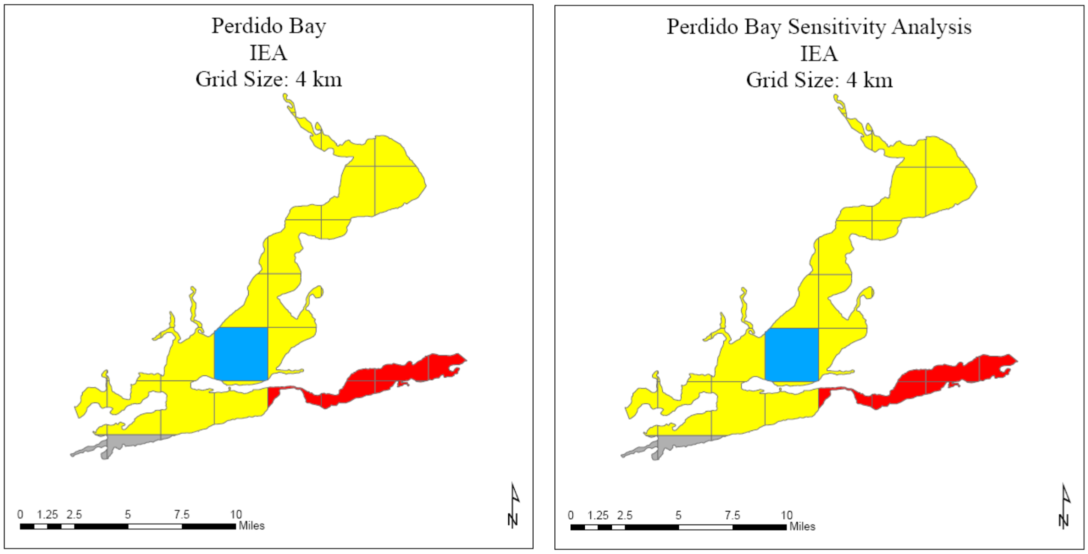
Perdido Bay Sensitivity Analysis
CMSP
Grid Size: 4 km

Figure 6.13 Perdido Bay using 4 km^2 grid size for CMSP: (l) original data; (r) sensitivity analysis


Perdido Bay
EBM
Grid Size: 4 km

Perdido Bay Sensitivity Analysis
EBM
Grid Size: 4 km

Figure 6.14 Perdido Bay using 4 km^2 grid size for EBM: (l) original data; (r) sensitivity analysis


Perdido Bay
IEA
Grid Size: 4 km

Perdido Bay Sensitivity Analysis
IEA
Grid Size: 4 km

Figure 6.15 Perdido Bay using 4 km^2 grid size for IEA: (l) original data; (r) sensitivity analysis

Figures 6.12 through 6.15 show the results from the application of the framework by applying it on a four kilometer square grid to Perdido Bay. As with the maps for the one kilometer square grid, the maps on the left are of the original data and the maps on the right are of the sensitivity analysis of the same application. The results for the original data (Figure 6.12) and CMSP (Figure 6.13) are shown with three clusters while the results for EBM (Figure 6.14) and IEA (Figure 6.15) are shown with four clusters. As with the results using a two kilometer square gird size, the results from EBM and IEA are identical and very similar to the results for the original data. The results using the indicator weights assigned for CMSP are noticeably different. Once again, this can be attributed to the different indicator weights placing different importance on different indicators.

6.5.2 Galveston Bay Results

Figures 6.16 through 6.21 show the results of the Galveston Bay analysis using various grid sizes for the different management protocols.

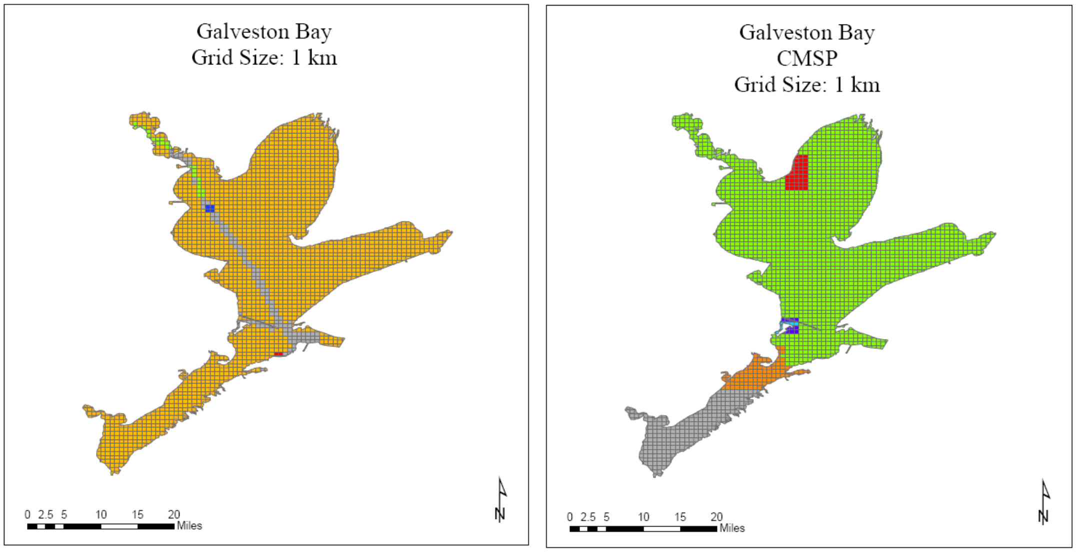


Figure 6.16 Galveston Bay using 1 km^2 grid size: (l) original data; (r) CMSP

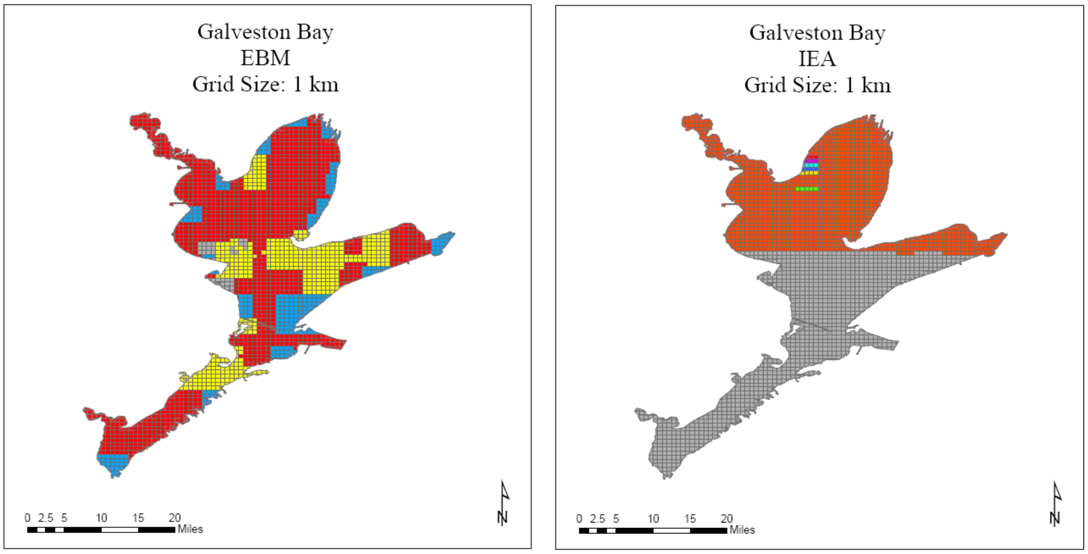
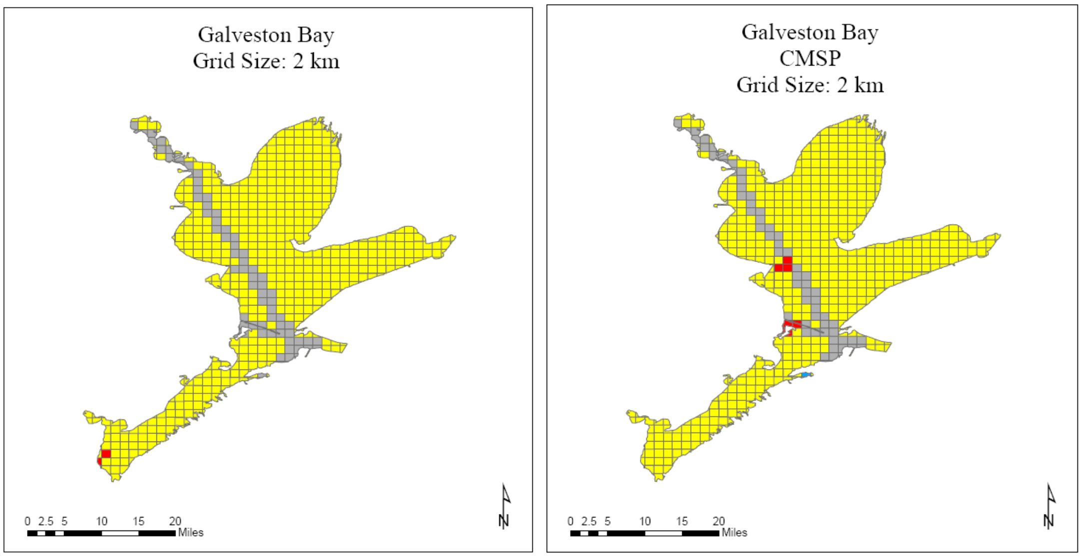


Figure 6.17 Galveston Bay using 1 km^2 grid size: (l) EBM; (r) IEA

Figures 6.16 and 6.17 show the results when the framework was applied to Galveston Bay using a one kilometer square grid size. The results for the original data, CMSP, and IEA are shown using five clusters while the results for EBM are shown with four. The results are not expected based upon the input data as the input data for Galveston Bay are generally consistent throughout the system. Differences in the predominant bottom sediment are seen in the EBM results, which may be responsible for creating the map shown. It was expected that the Houston Ship Channel would be identified as a separate cluster on the maps; however, the only map that shows the channel at this resolution is the original data.


Galveston Bay
Grid Size: 2 km

Galveston Bay
CMSP
Grid Size: 2 km

Figure 6.18 Galveston Bay using 2 km^2 grid size: (l) original data; (r) CMSP

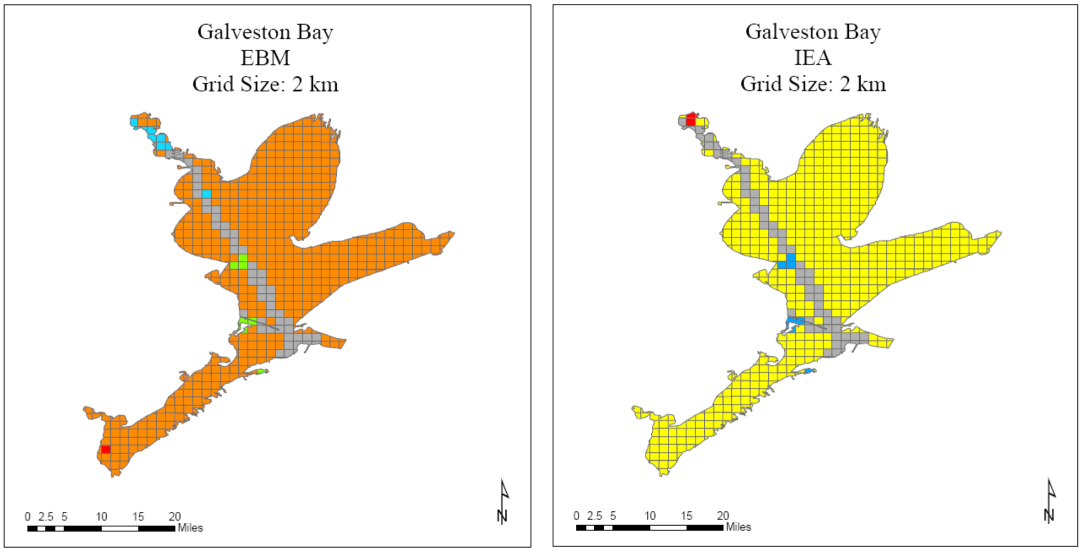


Figure 6.19 Galveston Bay using 2 km^2 grid size: (l) EBM; (r) IEA

Figures 6.18 and 6.19 show the results when the framework was applied to Galveston Bay using a two kilometer square grid size. The results for the original data and IEA are shown with three clusters and are very similar. The results from CMSP are shown with four clusters and has a strong resemblance to the results from the original data and IEA. The results from EBM are shown using five clusters which also has a remarkable similarity to the rest of the results. The results from all of the maps shows that the Galveston Bay Shipping Channel is identified as its own cluster.

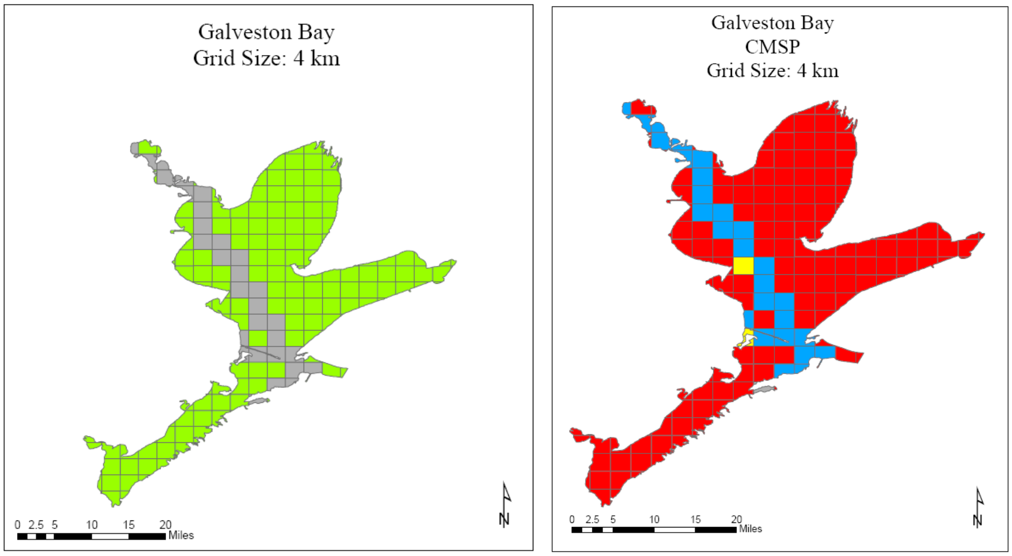


Figure 6.20 Galveston Bay using 4 km^2 grid size: (l) original data; (r) CMSP

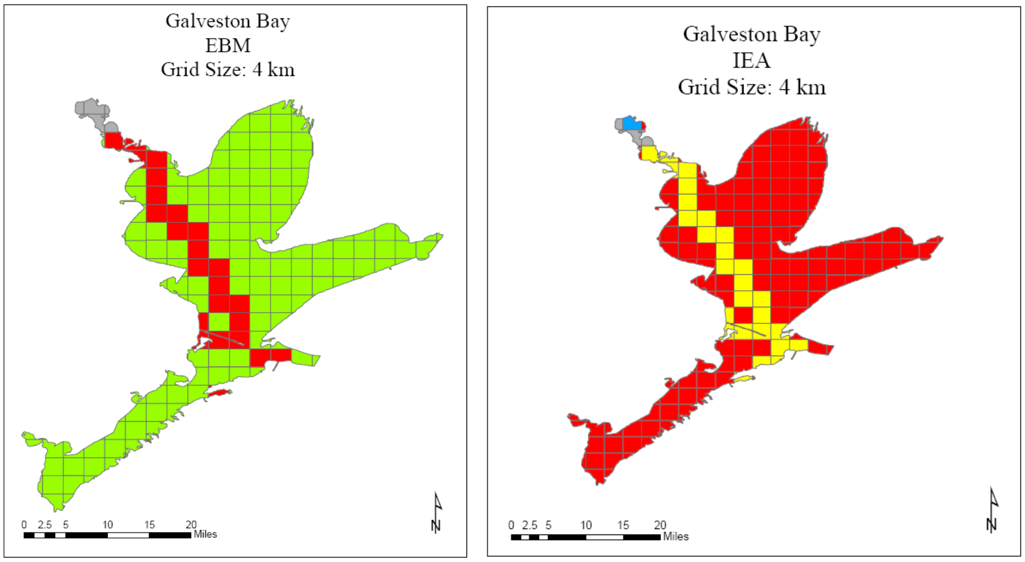


Figure 6.21 Galveston Bay using 4 km^2 grid size: (l) EBM; (r) IEA

The results from applying the framework to Galveston Bay using a four kilometer square grid size are show in Figures 6.20 and 6.21. The original data is displayed using two clusters, the CMSP and EBM results are displayed with three clusters, and the IEA results are displayed with four clusters. The results are similar across the board; the main difference being which cluster the top of the Houston Shipping Channel is placed into. As with the results from the two kilometer square results, the navigation channel is identified as its own cluster in this iteration of the framework application.

6.6 Conclusions and Changes to the Framework

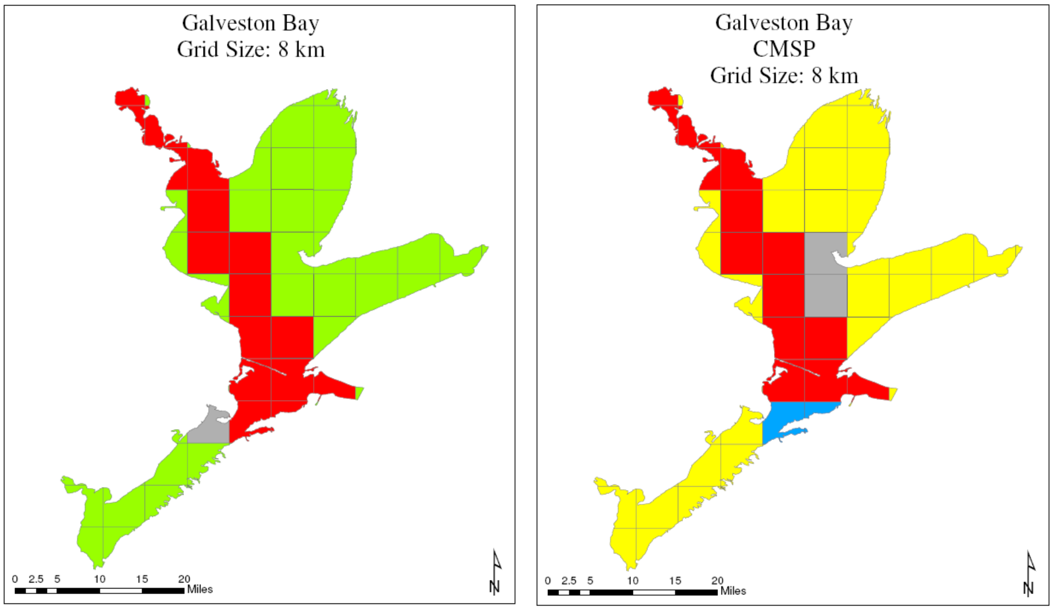
Multiple conclusions can be drawn from the results above and are:

1. As suspected from examining both the pivot tables and the dendrograms, when visually displayed using ArcMap 10.1, the clusters identified by the MATLAB script were exactly the same for the original data and the corresponding data used for the sensitivity analysis. The purpose of this small sensitivity analysis was to determine if larger differences between indicator values would affect the results. A full sensitivity analysis is beyond the scope of this work, but the results from the small sensitivity analysis show that the cluster data are not sensitive to changing the input indicator values by an order of magnitude. While the indicator weights (Ch. 5.3) are meant to weight the importance of the indicators for different management protocols, weighting the data can also be seen as a sensitivity analysis. The results show that while the indicator weights do change the results, the changes seen in the maps are smaller than expected based solely on the differences in the indicator weights.
2. As also seen from the pivot tables, the multi-variable hierarchical clustering shows that for queries resulting in three or more clusters, there is always at least one cluster that is populated with only one FID. After further review of the data

for the FID that produces its own cluster, it was determined that the data in these boxes are different than the data in the surrounding areas, and in some cases, different from data in any other boxes within the system – for example, the blue box in Figure 6. 14-6.15 (for Perdido Bay), is identified as FID 9. FID 9 has the same values as FID 8 (located west) except in the photic quality column (where FID 8 is “moderately turbid” and FID 9 is “seasonally photic”) and the turbidity column (where FID 8 is “disphotic” and FID 9 is “aphotic”). The values displayed for FID 8 are true of FID 10 (located east), FID 4 (located south), and FID 12 (located north). However, as the grid sizes are so small in comparison with a large marine ecosystem, and due to the fact that while the data are different, the data are not significantly different, these boxes can be manually added to another established cluster within the system whose data is similar.

3. For Perdido Bay, the results for each management protocol are fundamentally the same when displayed on maps regardless of the grid size used. The largest difference is the location of the one-box cluster. The high congruence between the results regardless of the grid size suggests that all of the grid sizes used in this work are valid when applying this framework to a system the size of Perdido Bay. This result could also suggest that Perdido Bay is unusual in some way which allows for similar results being produced regardless of the spatial resolution used.

For Galveston Bay, the visualization of the clusters shows a high degree of similarity between the two kilometer square grid and four kilometer square grid results. The results for the one kilometer square grid, however, are inconsistent with rest of the Galveston Bay results. In order to determine the appropriate scale(s) at which this framework can be applied to a system the size of Galveston Bay, and since it was determined that a one kilometer square gird size was extraneous, a grid size of eight kilometer squares was created and the method described earlier in the chapter was followed. The results from applying the framework using an eight kilometer square grid to Galveston Bay are shown below in pivot tables (Appendix H, Tables H1-H4), dendrograms (Appendix H, Figures H1-H4), and using GIS displays (Figures 6.22 and 6.23).


Galveston Bay
Grid Size: 8 km

Galveston Bay
CMSP
Grid Size: 8 km

Figure 6.22 Galveston Bay using 8 km^2 grid size: (l) original data; (r) CMSP

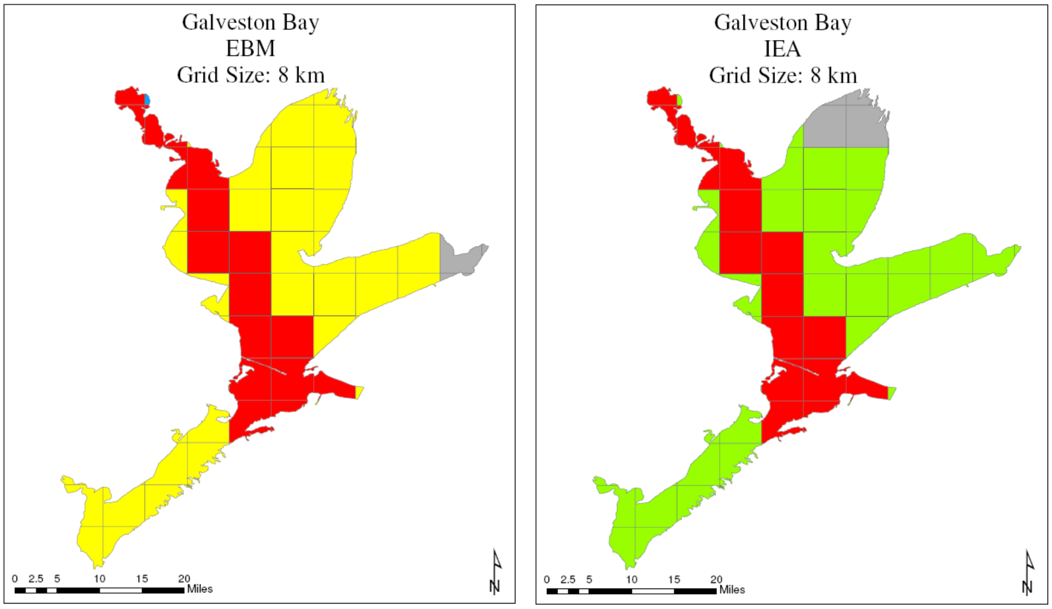


Figure 6.23 Galveston Bay using 8 km^2 grid size: (l) EBM; (r) IEA

When looking at the results from the application of the framework to Galveston Bay at all spatial resolutions, the following conclusions can be drawn:

1. Cluster similarities are consistent between the two, four, and eight kilometer square grid sizes with slight variations caused by the number of clusters identified and the grid size used in the analysis.

2. For smaller grid sizes in this system, the clusters produced from the un-weighted data create maps that are similar to the IEA results whereas CMSP and EBM produce similar maps.

3. All grid sizes used in this work with the exception of the one kilometer square grid size for CMSP, EBM, and IEA recognize and separate the boxes

that contain the Houston Ship Channel. These boxes are separated from the rest of the estuary and constitute their own cluster.

4. The results from the two, four, and eight kilometer square grids show remarkable similarities; when applying this method to Perdido Bay, the data used in the indicators matrix supports the results of the maps created. The areas separated using cluster analysis are significantly different in regards to the indicators in the grid boxes.

The application of this framework for each system used in this work shows that the very different weights used for the indicators associated with the different management protocols produce similar results when viewed in a visual display. While the weights (Chapter 5) for the different management protocols are substantially different and show that management schemes place emphasis on different indicators, these differences do not result in substantially different results when clustering the data. Increasing the weights by an order of magnitude, as with the sensitivity analysis, yielded no noticeable differences in the results.

CHAPTER VII

VALIDATION OF FRAMEWORK VIA APPLICATION TO BARATARIA BAY, MISSISSIPPI SOUND, AND MOBILE BAY

After the framework was tweaked through its application to Perdido Bay and Galveston Bay, it was applied to Barataria Bay, Mississippi Sound, and Mobile Bay for validation. The purpose of this validation is: 1) to determine if the framework, as it currently stands, is applicable to multiple sites of varying longitudes in the Northern Gulf of Mexico, 2) to determine if the conclusions of scale that were drawn in Chapter 6 are valid when applied to additional sites of varying sizes, and 3) to suggest improvements that can be made to the framework through additional work.

The method described in Chapter 6 was followed when the framework was applied to the three validation sites. The difference between the method created in Chapter 6 and the method applied for this chapter is that for the validation of the framework, grid sizes of two, four, and eight kilometer squares were used. As with applying the framework to Perdido and Galveston Bays, the indicators matrix was completed for smallest grid size (in this instance, two kilometer squares); the grid boxes from the smaller grid sizes were averaged to populate the indicators matrix for the larger grid sizes. This method is used to reduce error caused by human judgment when estimating the values for the indicators in each grid box and to ensure equivalence in the indicator values across the different spatial scales for the same general area.

Pivot tables and dendrograms (in Appendix I and Appendix J, respectively) were used to determine how many clusters the data divided into for visual displays. As with the iteration sites, only one visual display is shown for each site, management protocol, and spatial size combination; the maps are shown in Figures 7.1 – 7.20.

7.1 Barataria Bay Results

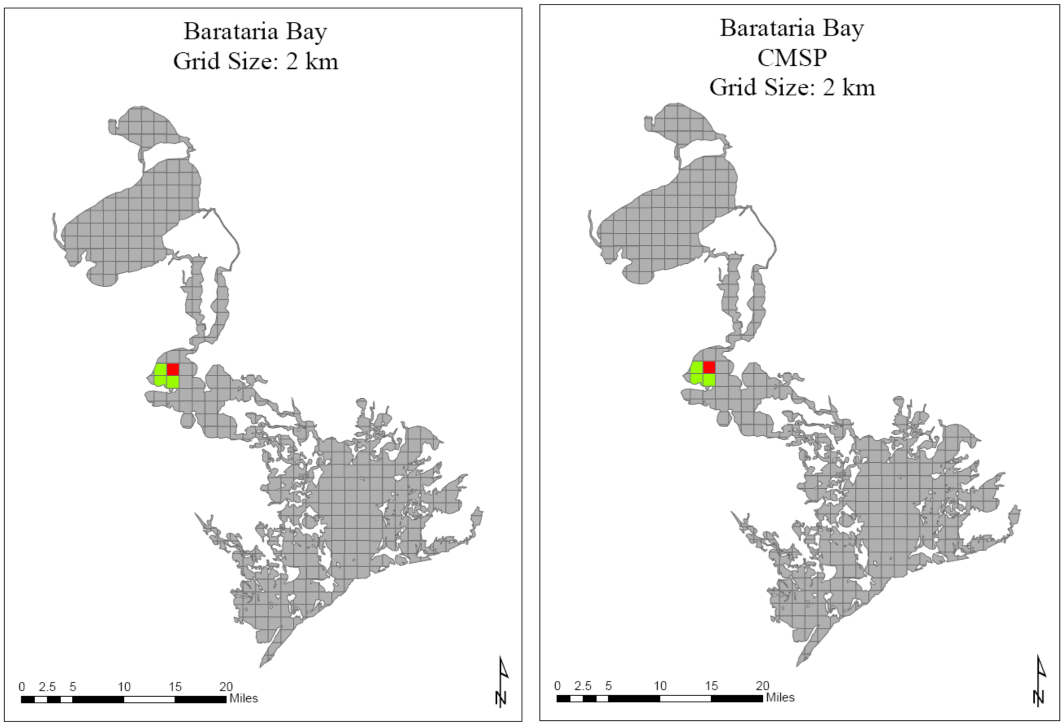


Figure 7.1 Barataria Bay using 2 km^2 grid size: (l) original data; (r) CMSP

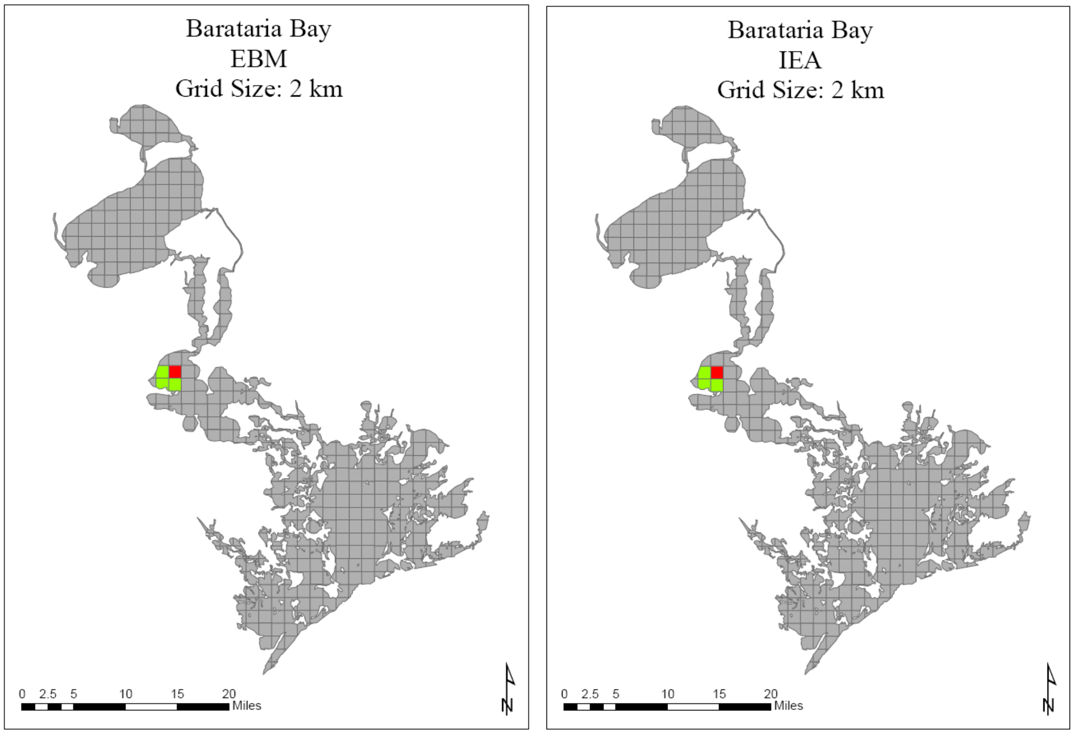


Figure 7.2 Barataria Bay using 2 km^2 grid size: (l) EBM; (r) IEA

Figures 7.1 and 7.2 above show the maps created from visualizing the clustered boxes based upon multi-variable cluster analysis of the indicators matrix for each management protocol. For each map, only the results using three clusters are shown. It was decided to display only three clusters per map based upon the results output by Matlab. After further review of the data, it was seen that the four boxes that do not fall into the main cluster are similar in indicator value to the area surrounding them. As a result, the results imply that the entire system can be treated the same under any of the management protocols.

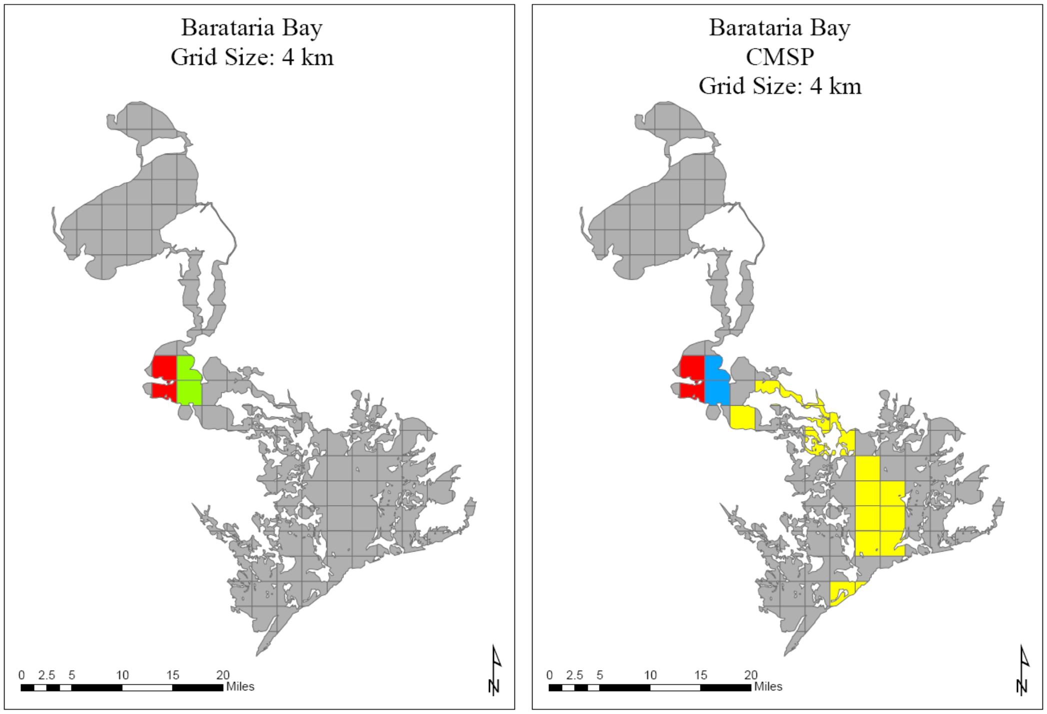


Figure 7.3 Barataria Bay using 4 km^2 grid size: (l) original data; (r) CMSP

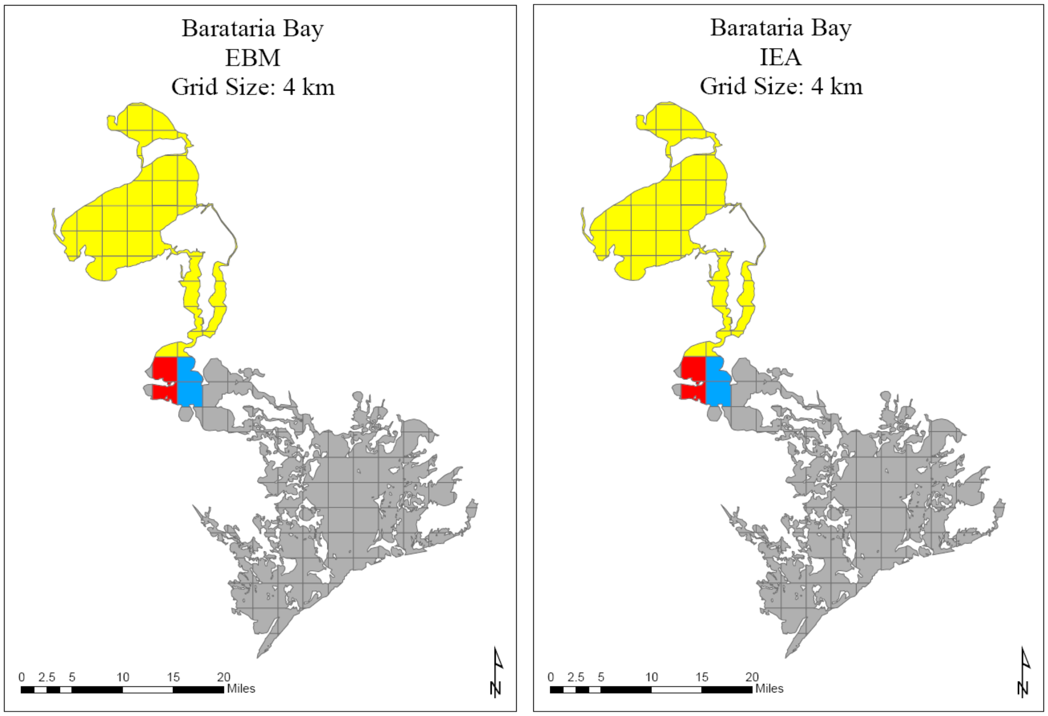


Figure 7.4 Barataria Bay using 4 km^2 grid size: (l) EBM; (r) IEA

Figures 7.3 and 7.4 shows the results obtained through applying the framework to Barataria using a four kilometer square grid size. As with the results from the two kilometer square grid size, these results display four boxes that are identified as different clusters (represented by red and green in 7.3 (l) and red and blue in 7.3 (r) and 7.4). As these boxes are in the same location for the higher order grid as they are in the lower order grid, and because it was decided that the data are not significant enough to necessitate separating these from the main cluster, it is recommended that these boxes be incorporated into the main cluster. The results for the data without indicator weights are the same as for the two kilometer square results; the results for obtained using CMSP, EBM, and IEA weights are different. In Figure 7.4 it can be seen that the results produced are the same and that the upper half of Barataria Bay is in a different cluster than the lower half. This is expected as the upper half is influenced significantly by freshwater inflow and has virtually no saltwater intrusion while the lower half is comprised either of brackish or saltwater thus resulting in a different ecosystem.

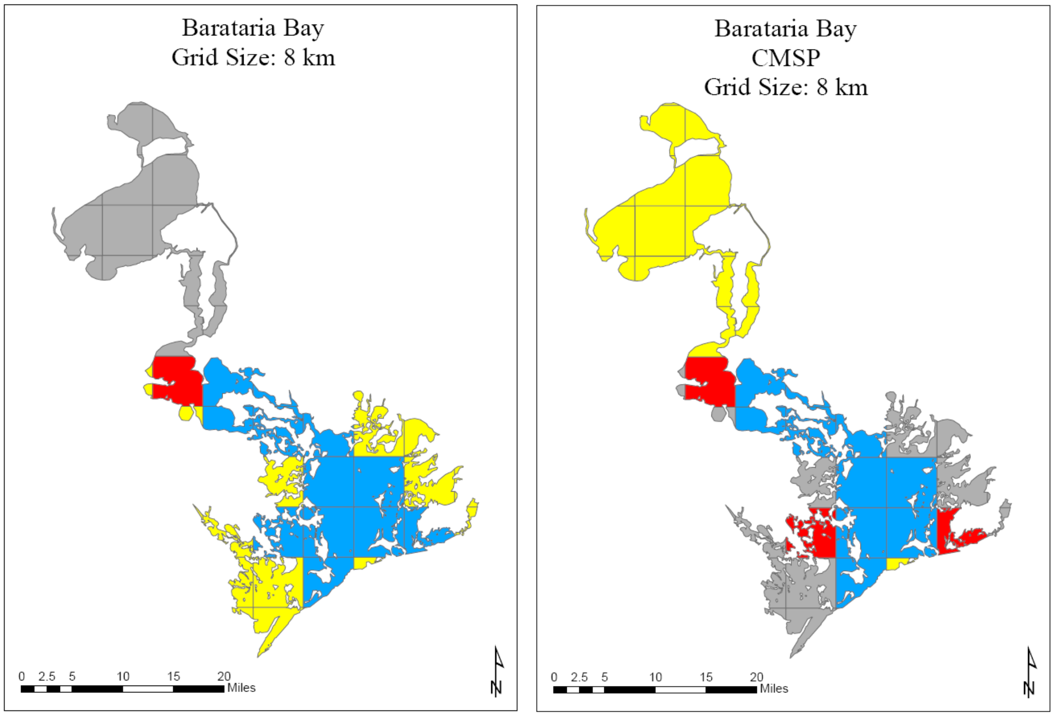


Figure 7.5 Barataria Bay using 8 km^2 grid size: (l) original data; (r) CMSP

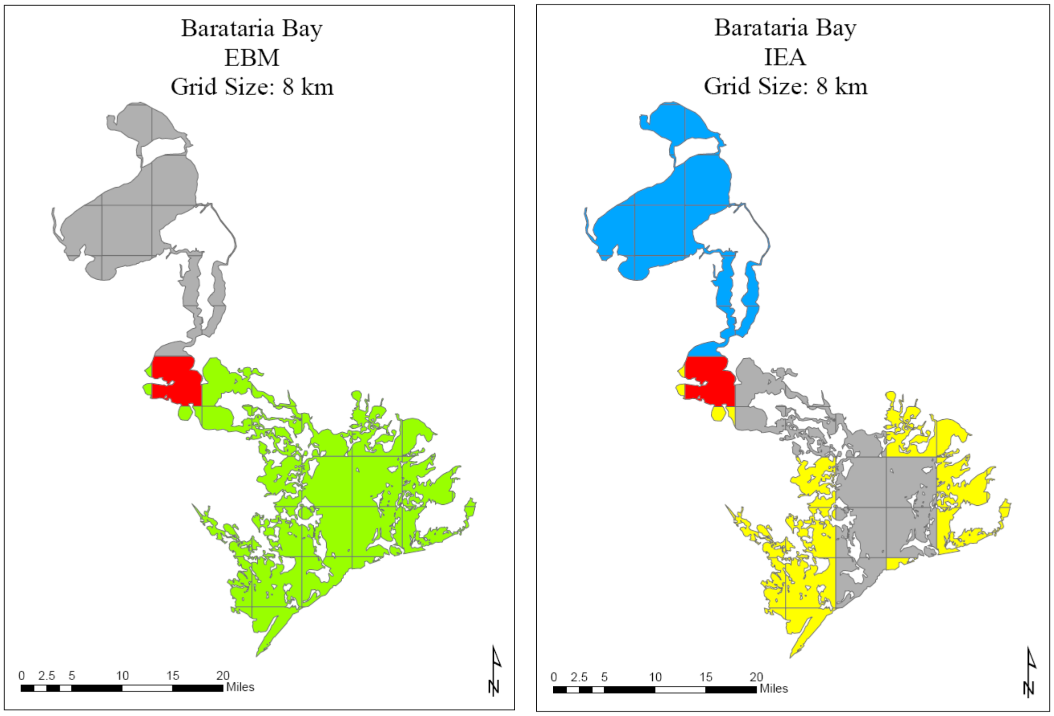


Figure 7.6 Barataria Bay using 8 km^2 grid size: (l) EBM; (r) IEA

Figures 7.5 and 7.6 show the results of applying the framework using an eight kilometer square grid size to Barataria Bay. As with the two and four kilometer square grid sizes, there is a box (represented in red on all of the maps) that is identified as a different cluster that was previously decided to be mixed in with the main cluster. The results from the original data, CMSP, and IEA all identify four clusters while only three clusters are identified using the EBM weights. Not only do the results from the original data, CMSP weights, and IEA weights result in the same number of clusters, but when displayed on a map, the mapped results are nearly identical. It is important to note that some of the clusters, while being identified as similar, are not physically touching each other or are separated by another cluster. This is important as it shows that the clusters are identified strictly upon indicator values and not upon physical location.

All of the results using the eight kilometer square grid show that Lake Salvador (located at the top of the system) is different from the rest of the system, which is expected. The results from the original data, CMSP, and IEA show that the outer fringes of the bay are different from the middle of the bay. This result is not unexpected as the fringes are comprised of more marsh areas while the center is more open water. Even though the results using the EBM weights are different from the rest of the results, it does not mean that the results are not valid; it simply means that EBM places emphasis on different indicators which causes different results.

7.2 Mississippi Sound Results

Figures 7.7-7.18 show the maps produced through applying this framework to Mississippi Sound.

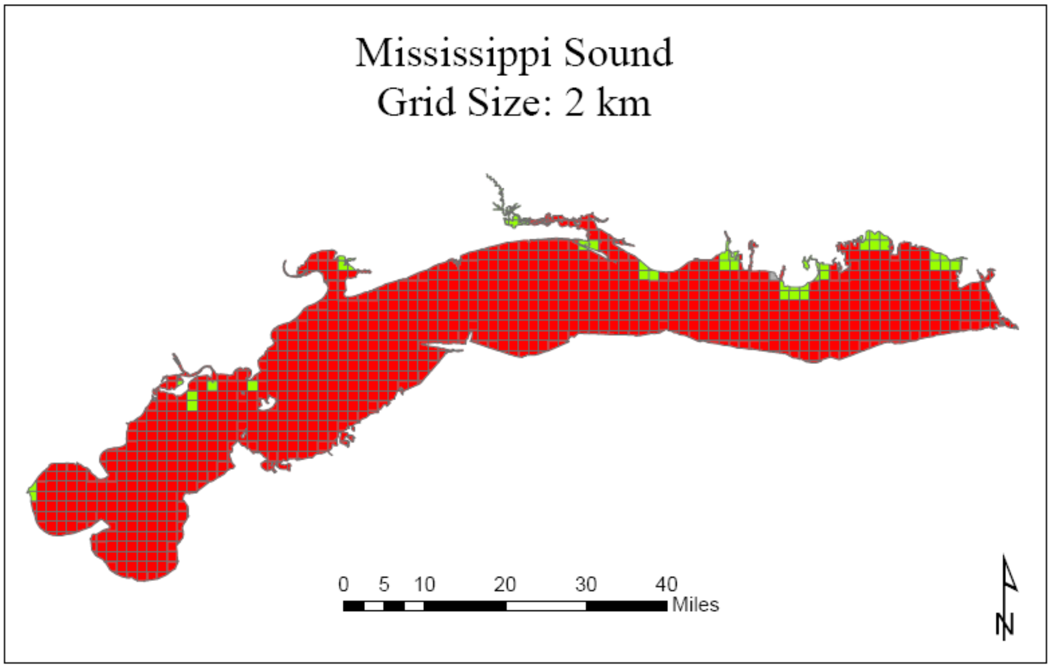


Figure 7.7 Mississippi Sound using 2 km^2 grid size: original data

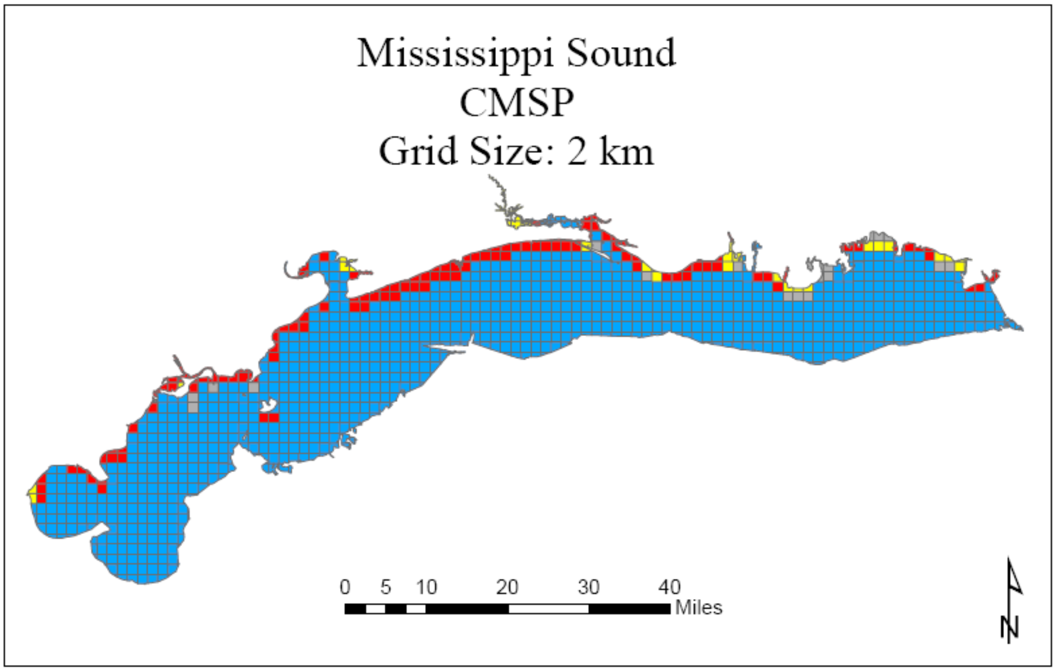


Figure 7.8 Mississippi Sound using 2 km^2 grid size: CMSP

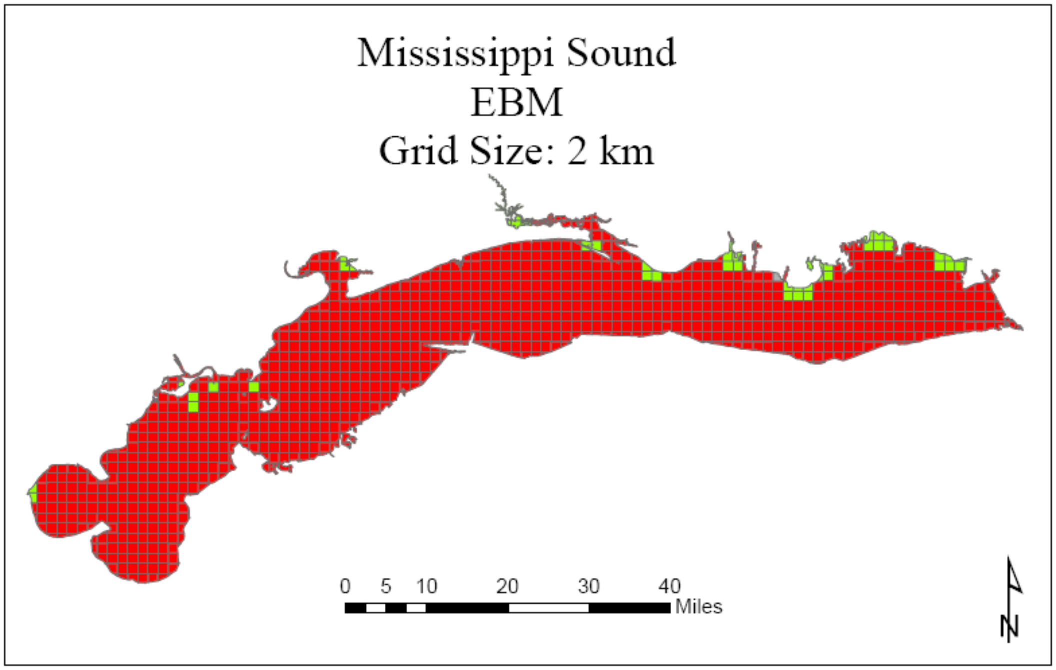


Figure 7.9 Mississippi Sound using 2 km^2 grid size: EBM

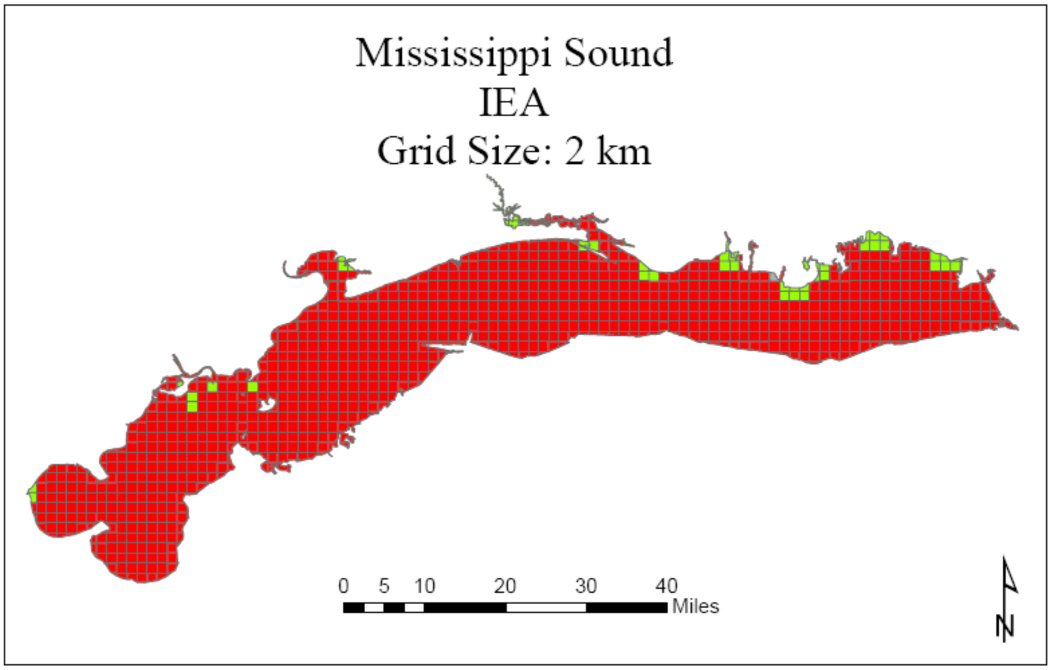


Figure 7.10 Mississippi Sound using 2 km^2 grid size: IEA

Figures 7.7-7.10 show the results from applying the framework using a two kilometer square grid to Mississippi Sound. The results for the original data, EBM, and IEA are shown with two different clusters while the results for CMSP are shown with three clusters. The results produced are very similar between the different management protocols. Even though the CMSP results show one cluster more than the other results, the cluster represented in yellow (Figure 7.8) is very similar to the cluster represented in green for Figures 7.7, 7.9, and 7.10. The additional cluster in Figure 7.8 (represented by red) is located nearshore. This area is different from the rest of the Sound as it is shallower and has lower chlorophyll a levels than the rest of the Sound; due to the weights for EBM, this difference is represented as a cluster.

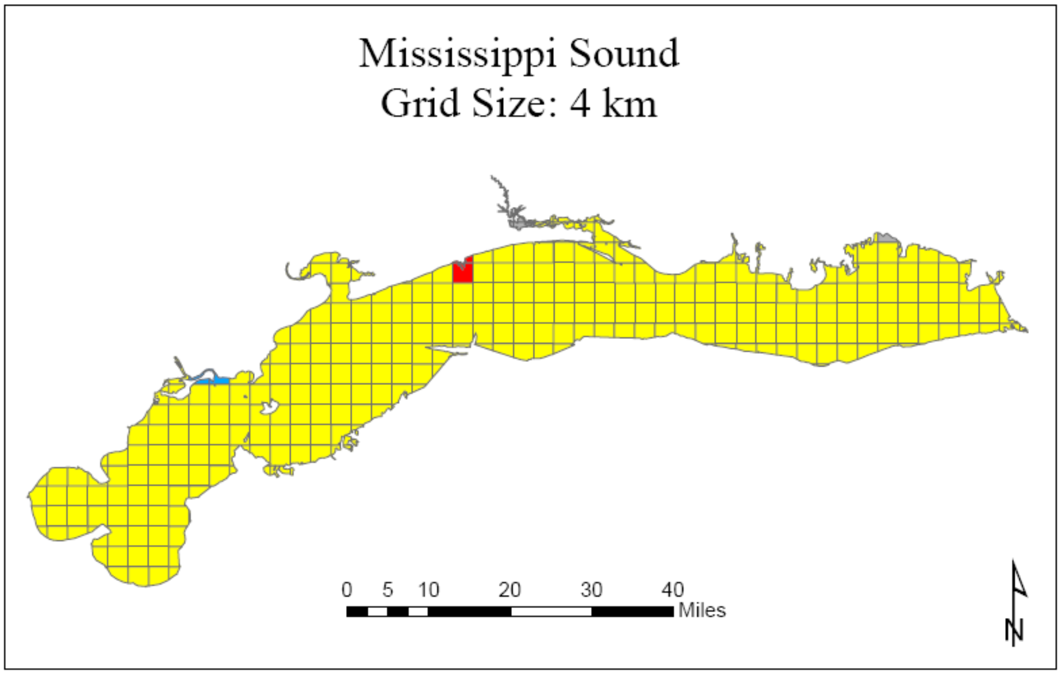


Figure 7.11 Mississippi Sound using 4 km^2 grid size: original data

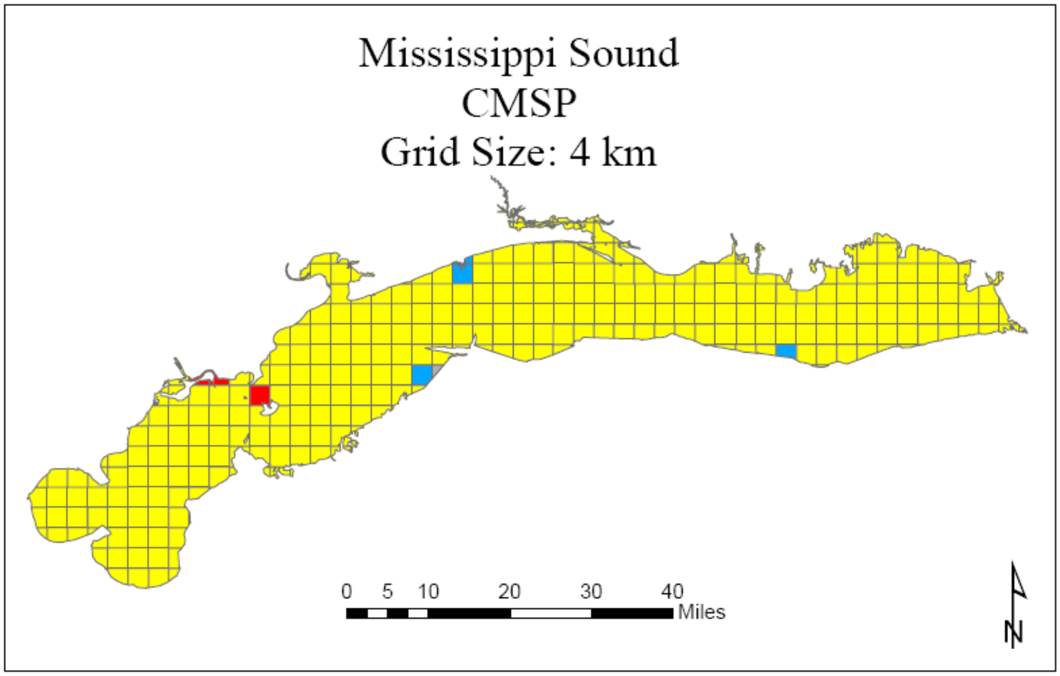


Figure 7.12 Mississippi Sound using 4 km^2 grid size: CMSP

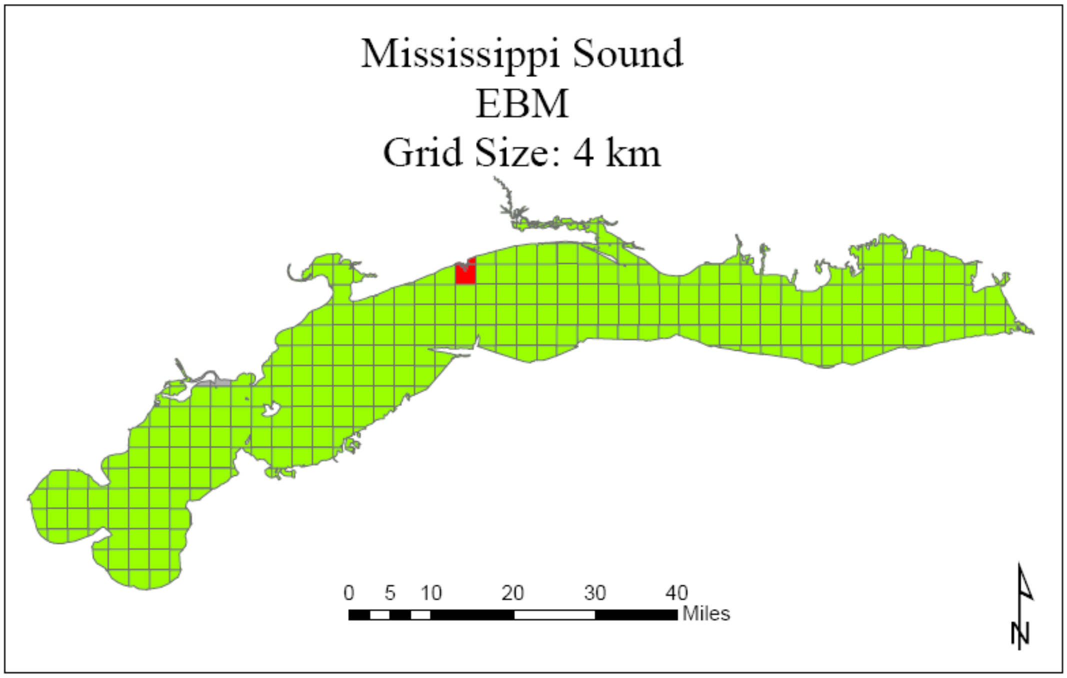


Figure 7.13 Mississippi Sound using 4 km^2 grid size: EBM

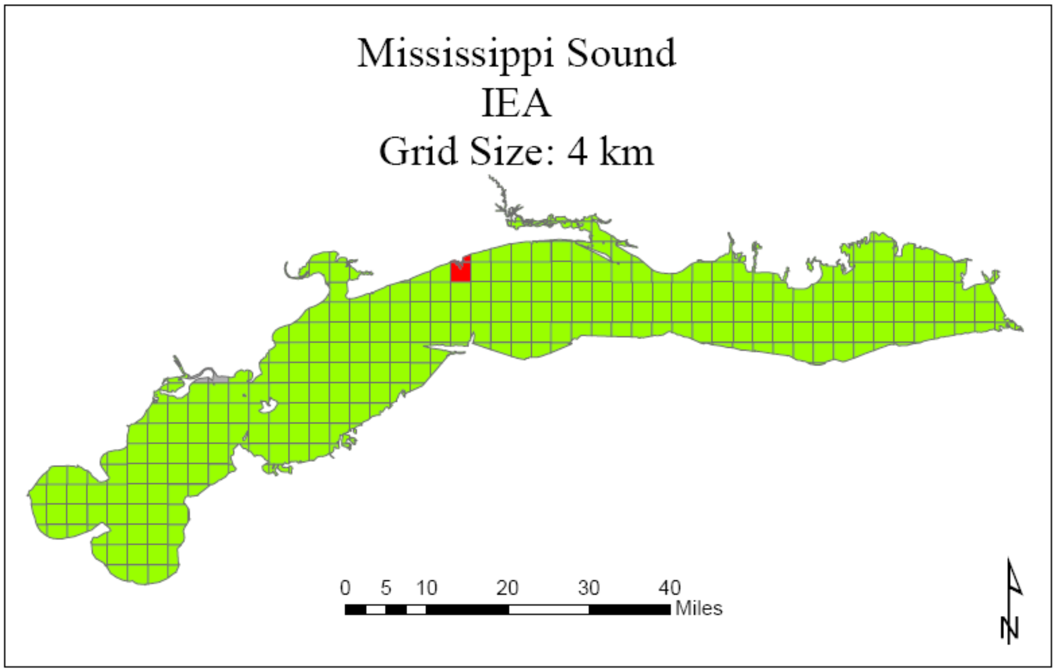


Figure 7.14 Mississippi Sound using 4 km^2 grid size: IEA

The application of the framework using a four kilometer square grid size is shown in Figures 7.11-7.14. Once again, the maps for the original data, EBM, and IEA are shown in the same number of clusters (two) and the results from CMSP have an additional cluster. The results are similar to the results presented in Figures 7.7-7.10 where most of the Mississippi Sound is identified as one cluster (representing a near homogeneous ecosystem using the indicators); however, the cluster identified in the nearshore area using the two kilometer square grid size is not present in the four kilometer square grid size. This is most likely due to the fact that this area was so small in the two kilometer square grid size that when looking at the data using a larger scale, these differences were not observable.

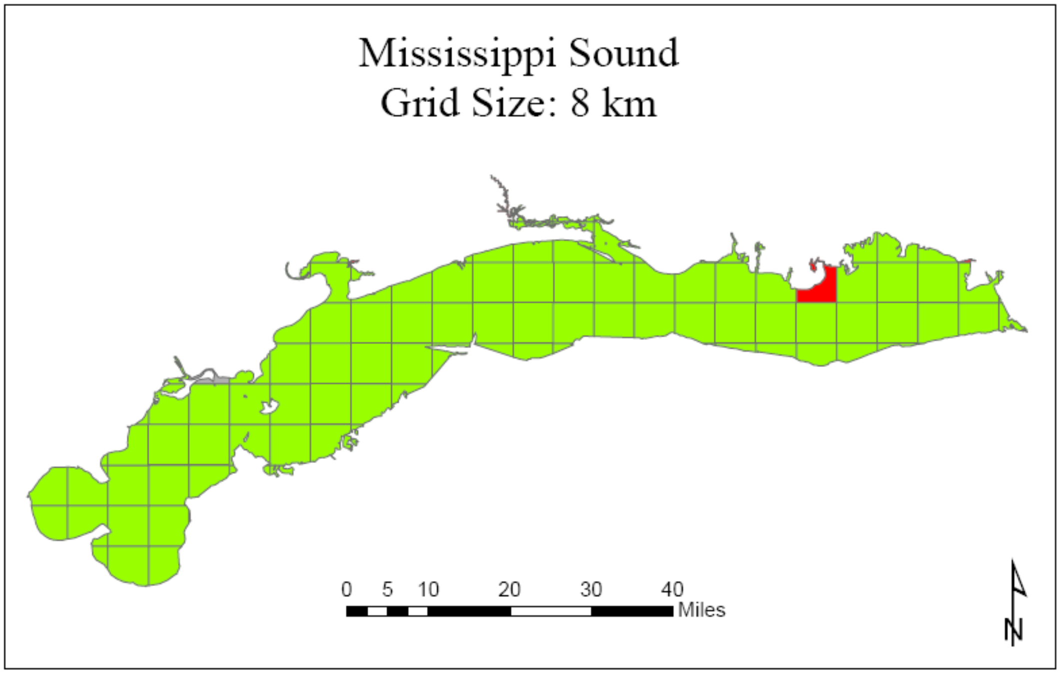


Figure 7.15 Mississippi Sound using 8 km^2 grid size

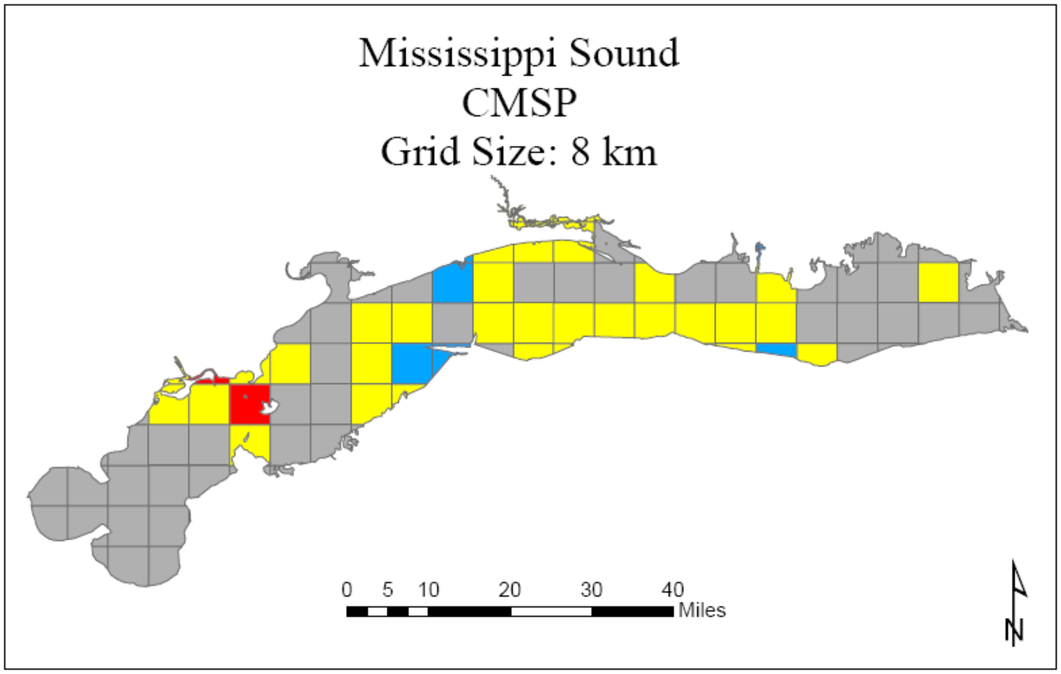


Figure 7.16 Mississippi Sound using 8 km^2 grid size: CMSP

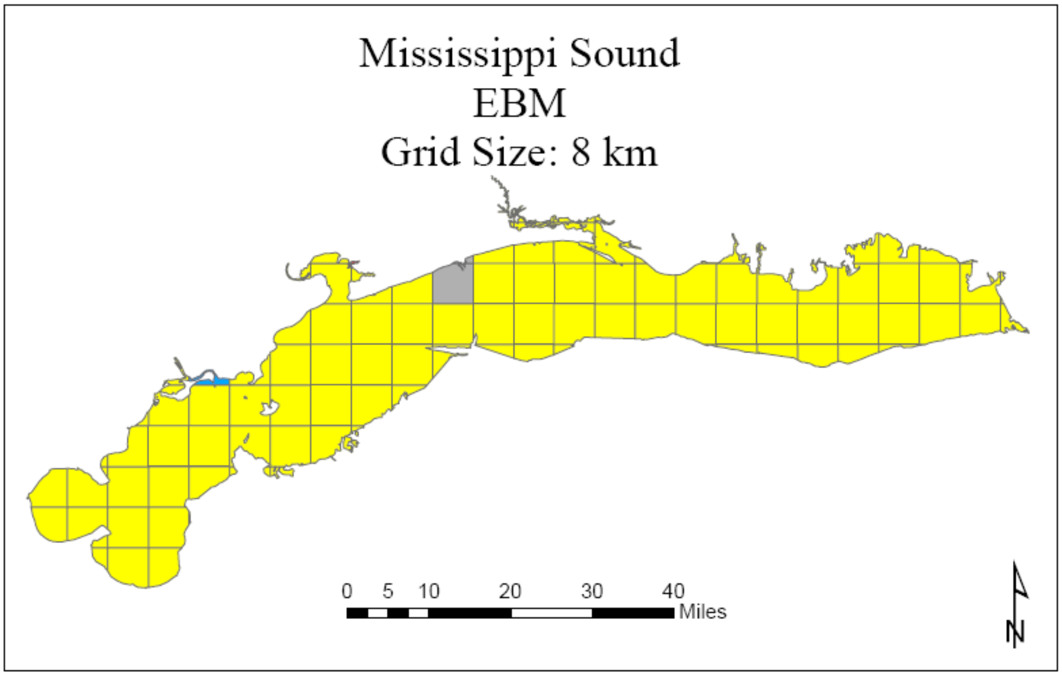


Figure 7.17 Mississippi Sound using 8 km^2 grid size: EBM

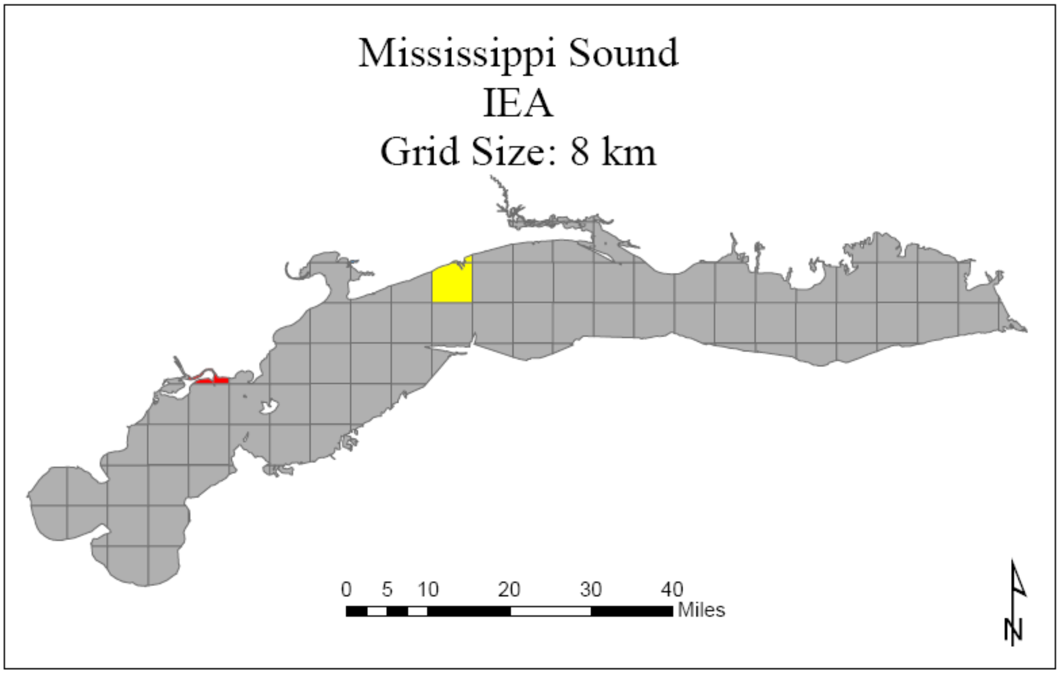


Figure 7.18 Mississippi Sound using 8 km^2 grid size: IEA

Figures 7.15-7.18 display the maps created by applying the framework using an eight kilometer square grid size. The results for the original data, EBM, and IEA are shown using three clusters and the results for CMSP are shown in four clusters. As with the other grid sizes, the results for EBM and IEA are similar to each other and are almost identical while the results using the original data vary slightly from EBM and IEA. The results produced using the weights for CMSP are substantially different from the other management protocols using this grid size, as well as the results produced using CMSP weights at smaller grid sizes. As with the results from Barataria Bay, these differences come about as a result of the different weights used to rank the indicators. When looking back at the input data to try to determine why the results for CMSP at this grid size are so different from each other, it was discovered that these areas have vastly different turbidity values and sediment types than the rest of the system; however, due to the indicator weights used, these differences were never dissimilar enough to produce different clusters under EBM and IEA.

7.3 Mobile Bay Results

The results produced by applying the framework to Mobile Bay are seen in Figures 7.19-7.24.

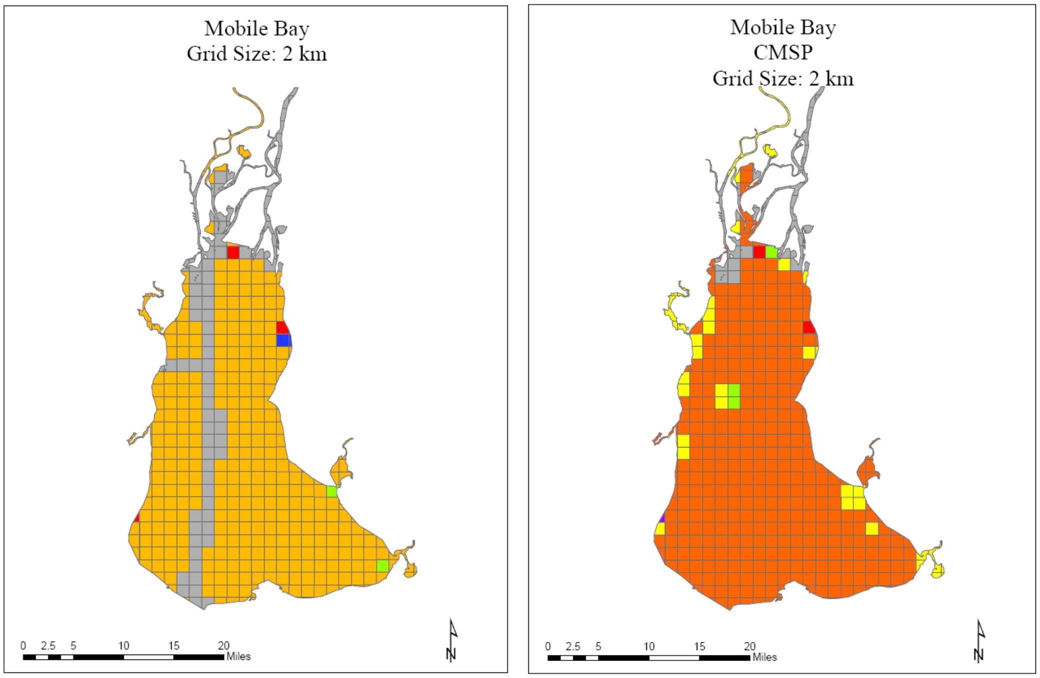


Figure 7.19 Mobile Bay using 2 km^2 grid size: (l) original data; (r) CMSP

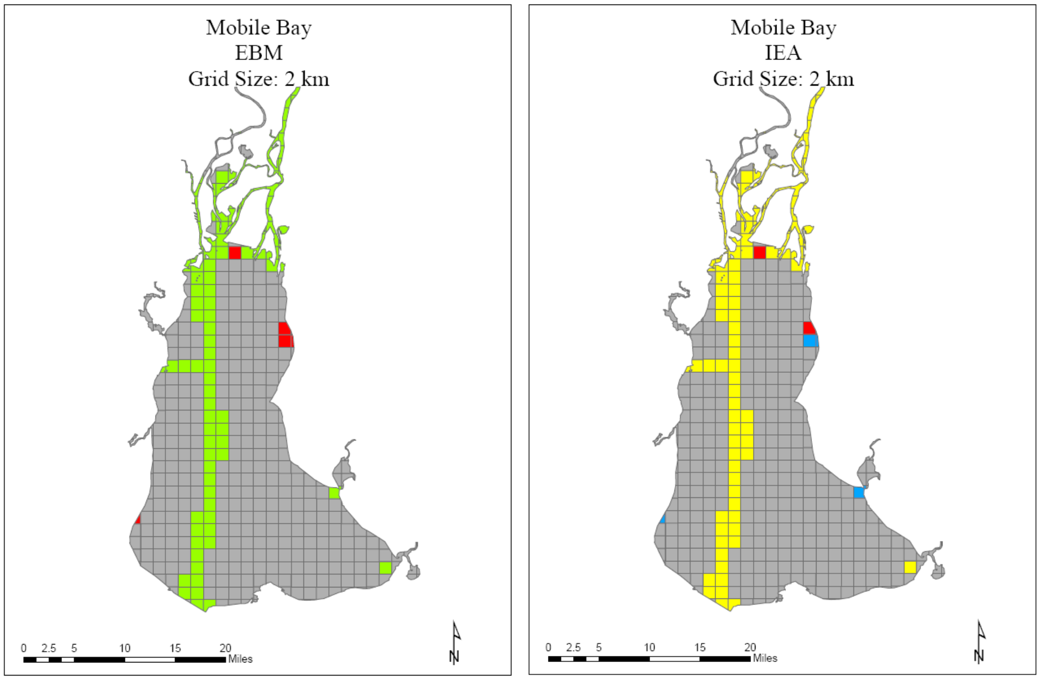


Figure 7.20 Mobile Bay using 2 km^2 grid size: (l) EBM; (r) IEA

Figures 7.19 and 7.20 show the results for Mobile Bay using a two kilometer square grid size. The results for the original data and CMSP show five clusters and the results for EBM and IEA are shown using three clusters. In the results for the original data, EBM, and IEA, the navigation channel running through Mobile Bay is shown as its own cluster. Most of the Five Rivers system north of the main estuary is included in the cluster that contains the navigation channel, most probably due to the bed slope in these areas being similar. The results for CMSP do not separate the navigation channel in the estuary into its own cluster.

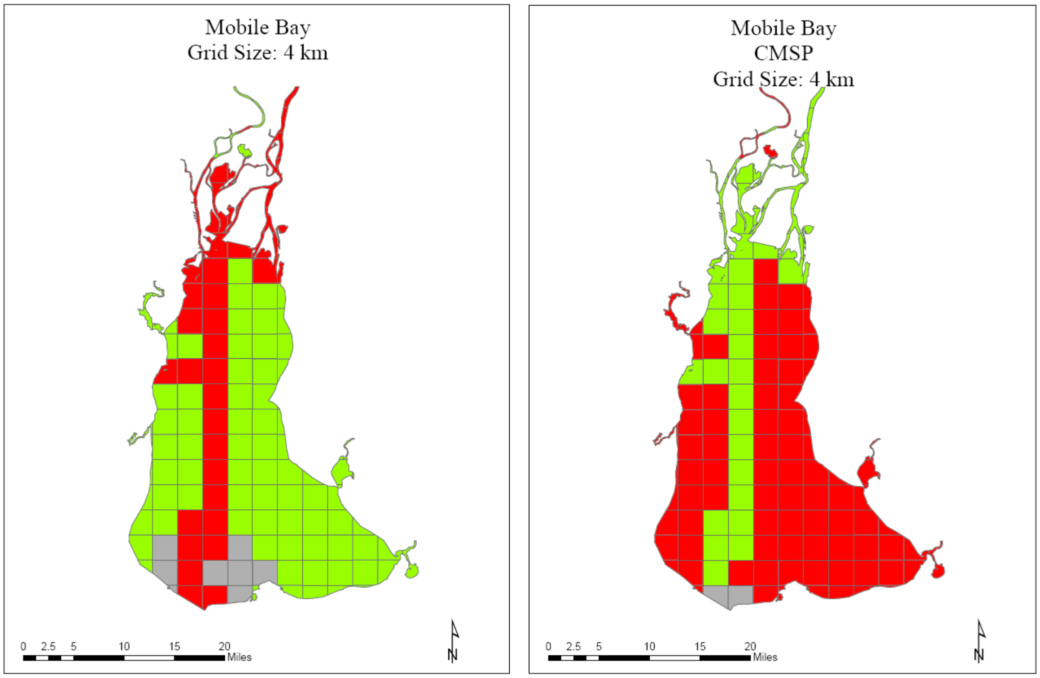


Figure 7.21 Mobile Bay using 4 km^2 grid size: (l) original data; (r) CMSP

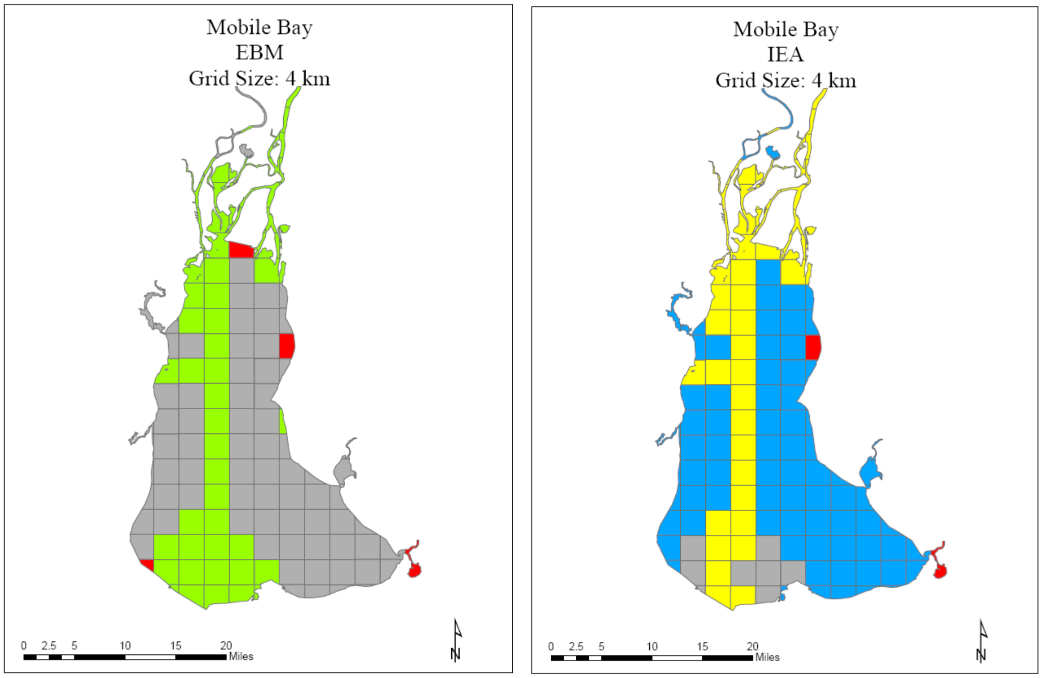
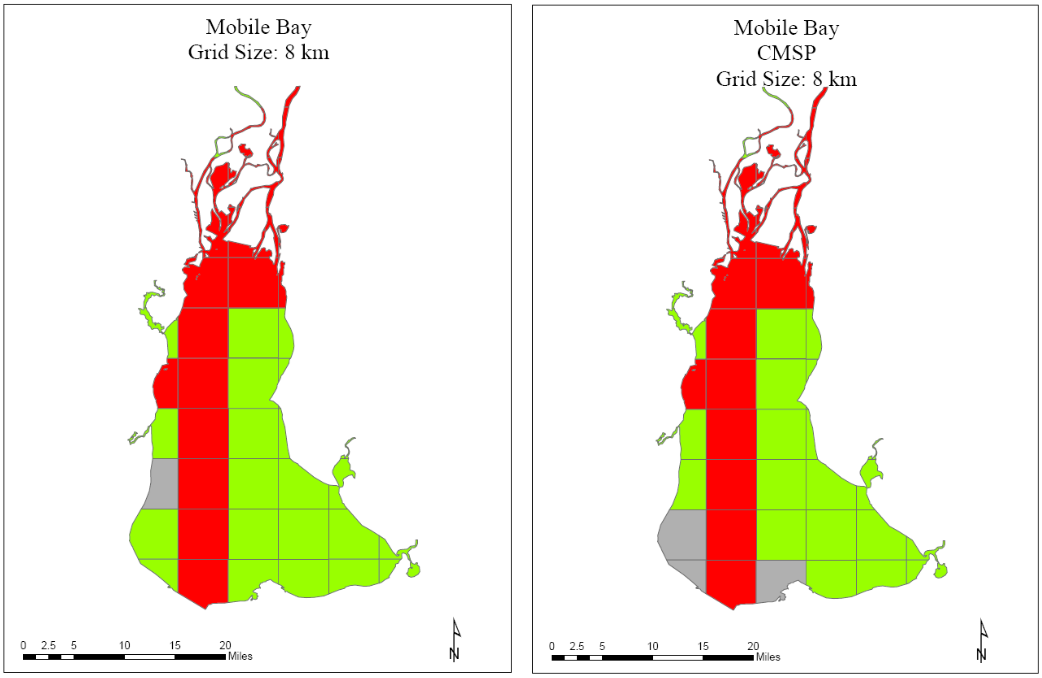


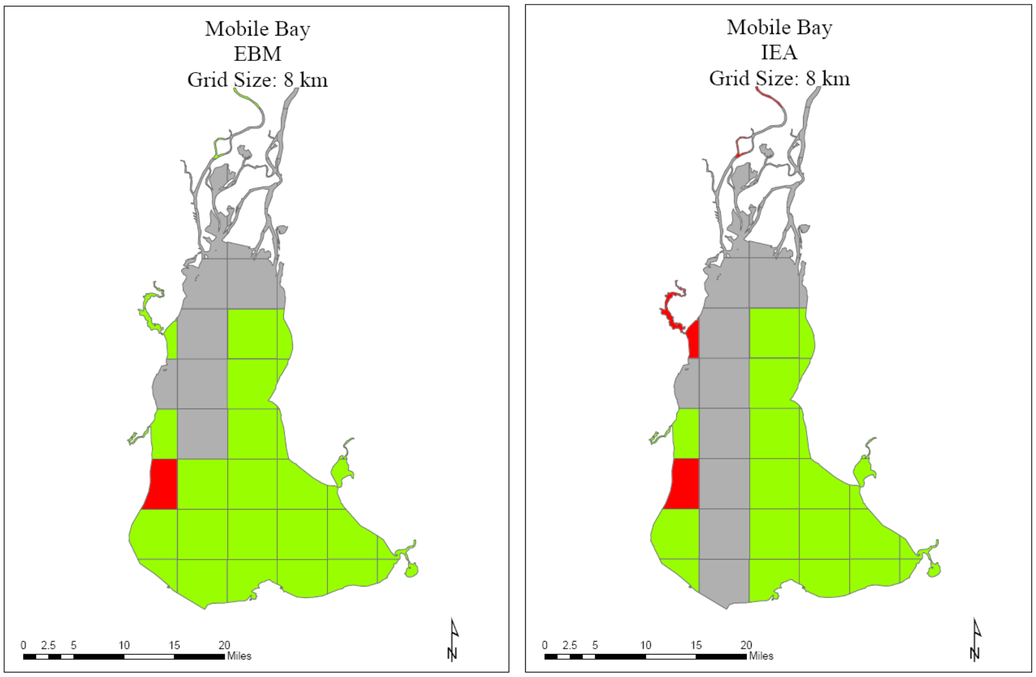
Figure 7.22 Mobile Bay using 4 km^2 grid size: (l) EBM; (r) IEA

The results found by applying the framework to Mobile Bay using a four kilometer square grid size are shown in Figures 7. 21 and 7.22. The maps for the original data and IEA are produced using four clusters whereas the maps for CMSP and EBM are produced with three clusters. In all four displays, the navigation channel is separated into its own cluster and combined with most of the Five Rivers system. In the map for the original data and IEA the area around the mouth of the estuary into the Gulf of Mexico is a separate cluster. This is most likely due to the differences in data at this location – most notably salinity and mixing. In the map for EBM, this area is in the cluster with the navigation channel while for CMSP, the area is much smaller than it is for any of the other management protocols. As discussed previously, these differences can be attributed to the different indicator weights.


Mobile Bay
Grid Size: 8 km

Mobile Bay
CMSP
Grid Size: 8 km

Figure 7.23 Mobile Bay using 8 km^2 grid size: (l) original data; (r) CMSP


Mobile Bay
EBM
Grid Size: 8 km

Mobile Bay
IEA
Grid Size: 8 km

Figure 7.24 Mobile Bay using 8 km^2 grid size: (l) EBM; (r) IEA

Figures 7.23 and 7.24 show the results from applying the framework using an eight kilometer square grid size. All of the results are shown with three clusters. The maps produced by the original data, CMSP, and IEA show the entire navigation channel and most of the Five Rivers system as a cluster; the EBM results show only the northern most part of the navigation channel and the riverine system as its own cluster.

7.4 Conclusions

The following conclusions can be drawn from this part of the work:

1. As suggested when using Galveston Bay to develop the framework, the larger grid sizes appear to do a better job of identifying clusters than the smaller grid sizes for larger systems. This is, more than likely, due to the fact that the larger grid size allows the important data to be seen but does not allow the framework to be overwhelmed by a large amount of data. However, as an objective criterion has not been developed to determine which spatial resolution produces the best result, it is important to choose the scale at which the management plan needs to be developed. It is important to keep in mind that different spatial scales are good for different purposes; as such, when applying the framework, the final use of applying the framework should be considered through the application.
2. As with Galveston Bay, when the framework was applied to Mobile Bay, the navigation channel was separated into a cluster that was different from the rest of the estuary. This is important to note as the navigation channel will need to be managed under a different management plan than the rest of the estuary due to the necessity of dredging the channel. The navigation channels within the Mississippi Sound were not identified and separated into a discrete cluster. This is seemingly

due to the fact that the Sound is deeper, in general, than the other estuaries used in this work and therefore produces a much less significant bed slope than the navigation channels within Mobile and Galveston Bays.

3. There are subtle differences between the displays for each estuary within the same grid size that are caused by the indicator weights for the different management protocols. As noted in Chapter 6, even though the indicator weights for the different management protocols are very different, the maps produced using these weights are remarkably similar. While the weights (Chapter 5) for the different management protocols are substantially different and show that management schemes place emphasis on different indicators, these differences do not result in substantially different results when clustering the data except in the case of Barataria Bay and Mississippi Sound kilometer grid size. It appears as if this is due to the fact that these systems are more homogeneous, indicator data-wise, than the other systems used in this work. As a result, the clusters mapped are different based upon a few key indicators. If the weights for these indicators are substantially different enough, the clusters produced will be different.

CHAPTER VIII

ESTUARINE CLASSIFICATION SYSTEM

Traditionally, estuaries have been classified based upon their salinity (Chapter 5.3.1.2), geomorphology (Chapter 5.2.2.7.3), and water circulation (Chapter 5.2.2.4). The report Classification of California Estuaries Based on Natural Closure Patterns: Template for Restoration and Management (Southern California Coastal Water Research Project 2010) presented a classification system “based on the geophysical processes that formed and hence govern the behavior of estuaries in southern California” and bases classification of estuaries on “geologic origins, exposure to littoral processes, and watershed size and runoff” to support coastal restoration goals. For example, under this classification system San Diego Bay is classified as a progradational (S1) coastal setting; west high exposure; large, low gradient (W1) watershed size; inherited space (P1) formation process; with a proportion in closure state of emergent bars at low tide (S 0.2) and deep water openings (O 0.6) (2010)

In 2012 the Federal Geographic Data Committee (FDGC) Marine and Coastal Spatial Data Subcommittee released FGDC-STD-018-2012: Coastal and Marine Ecological Classification Standard (CMECS) that aims to classify “waters from the head of tide or inland incursion of ocean salinity to the splash zone of the coasts to the deepest portions of the oceans and deep waters of the Great Lakes” (2012). CMECS characterizes environments based on two “settings” (the aquatic setting and the biogeographic setting) and four “components” (water column, geoform, substrate, and biotic) and their subcomponents (FDGC, 2012). While CMECS describes the ecological, biological, and physical attributes of an estuary – and other coastal and marine areas, too – it does not address the human and economic attributes of the system. For example, Key West, Florida is classified as follows under CMECS: Biogeographic setting: tropical Atlantic realm, tropical Northwestern Atlantic province, Floridian Ecoregion; aquatic setting: marine system, marine nearshore subsystem, marine nearshore subtidal tidal zone; water column component: marine nearshore lower water column layer, euhaline water, water; geoform component: passive continental margin tectonic setting, barrier, biogenic geoform origin, shallow/mesophotic coral reef of patch coral reef type for level 1 geoform, lagoon with aggregate patch coral reef for level 2 geoform; substrate component; biogenic substrate origin, coral substrate class, coral reef substrate subclass, sand veneer layering modifier; biotic component: benthic biota setting, reef biota class, shallow/mesophotic coral reef biota subclass, massive coral reef group, and massive *Montastrea* reef community (FGDC, 2012). In none of the settings are human or economic attributes of the system described.

Including human and economic characteristics – on top of biological, ecological, and physical characteristics – is important when classifying an estuarine system for two main reasons:

1. Humans greatly influence what happens within an estuarine system through land development, dredging, fishing, etc. and are affected by the system through ecosystem services and flooding(see Ch. 5.1.3) (e.g. UNEP GPA, 2006; McLeod and Leslie, 2009; EBM TN, 2010; NOAA CSC, 2011).

2. Human and economic drivers (as well as the ecological, biological, and physical settings) must be used to formulate effective management measures for estuarine ecosystem health.

The proposed estuarine classification system detailed here seeks to effectively classify estuarine ecosystems based upon biological and ecological characteristics, physical characteristics, and human and economic characteristics.

8.1 Development of Classification System

Expert elicitation was used for the initial development of the classification system. Experts in integrated ecosystem assessment (IEA), coastal and marine spatial planning (CMSP), and ecosystem based management (EBM) were asked to answer a survey (Available in Appendix A) to indicate the “most important” indicators (Ch. 5.2) when identifying sub-ecosystems within large marine ecosystems (LMEs). The survey results from the experts were synthesized and weights for each indicator group and each indicator (Ch. 5.2) were calculated using the analytic hierarchy process (AHP) (Ch. 5.3).

From the AHP, it is seen that the higher the weight of an indicator group or individual indicator, the more significant it is when describing the ecosystem. Figure 8.1 shows the indicator group weights and Figure 8.2 shows the overall indicator weights while Figures 8.3, 8.4, and 8.5 shows the indicator weights for each indicator within their respective groups based upon expert elicitation.

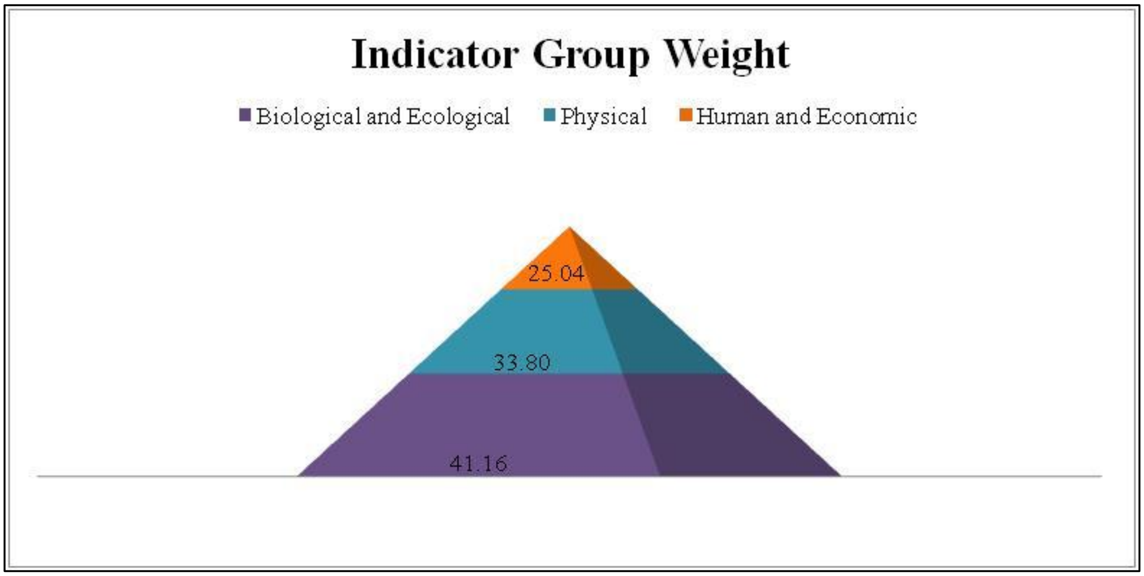


Figure 8.1 Indicator Group Weight Based on Expert Elicitation

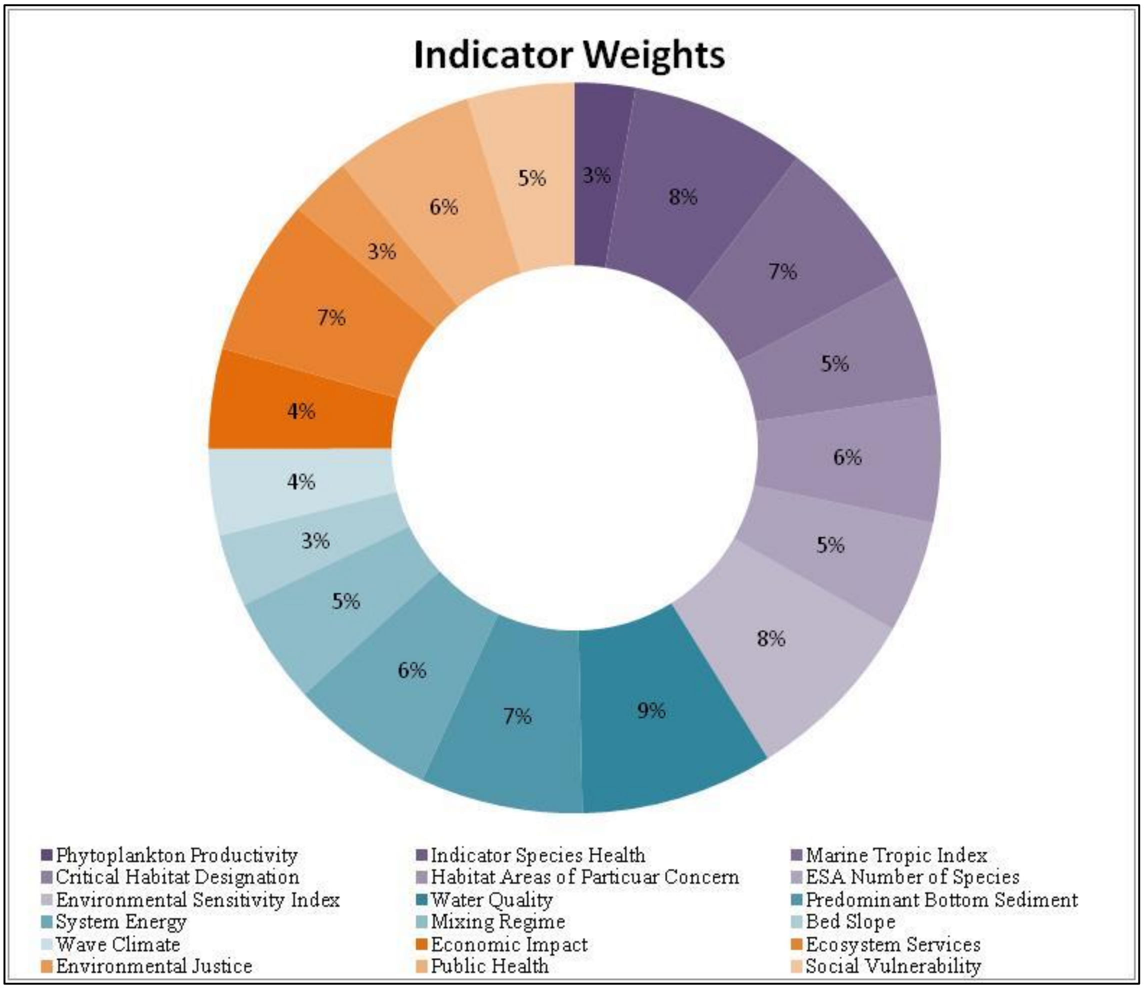


Figure 8.2 Overall Indicator Weights Based on Expert Elicitation

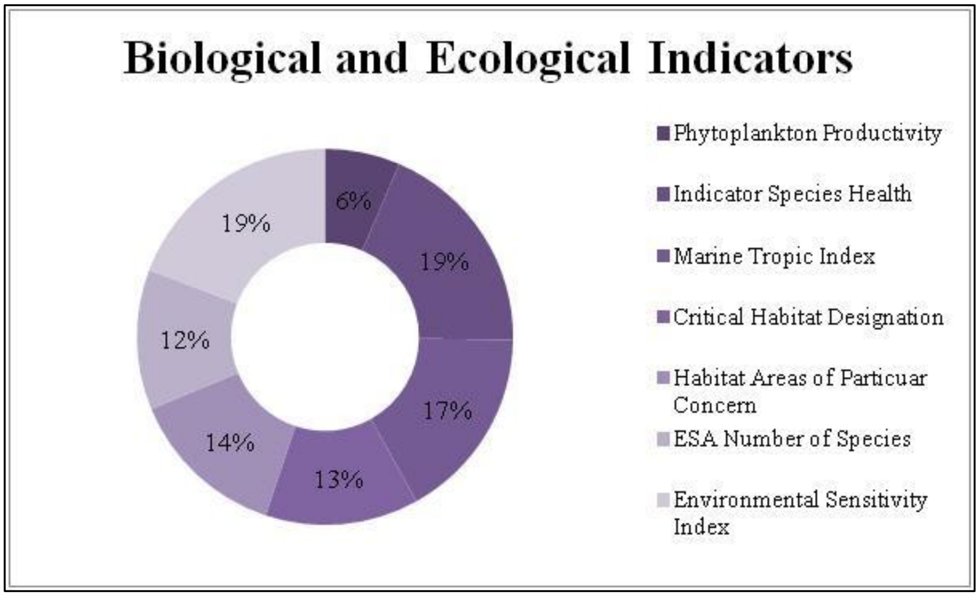


Figure 8.3 Biological and Ecological Indicator Weights Based on Expert Elicitation

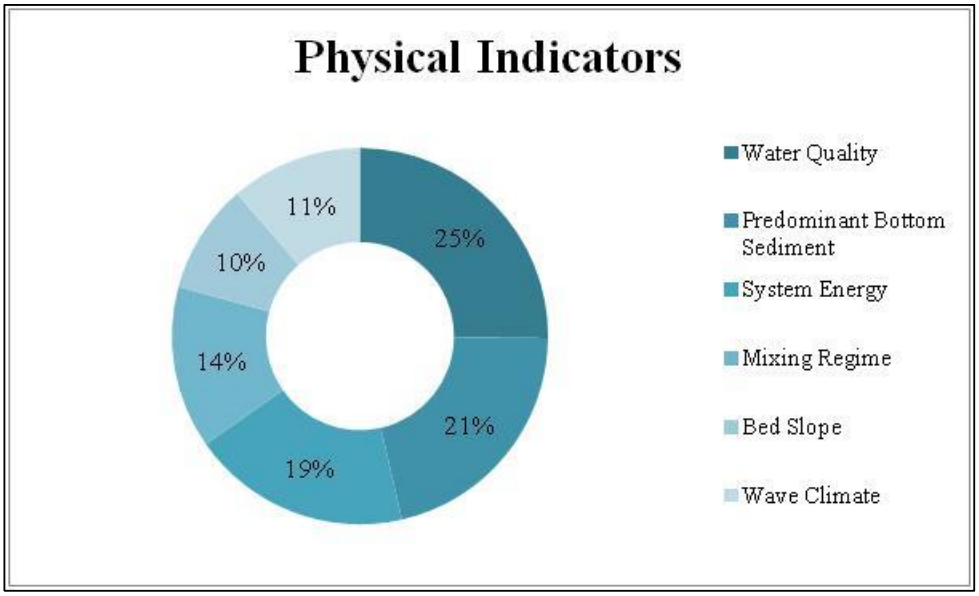


Figure 8.4 Physical Indicator Weights Based on Expert Elicitation

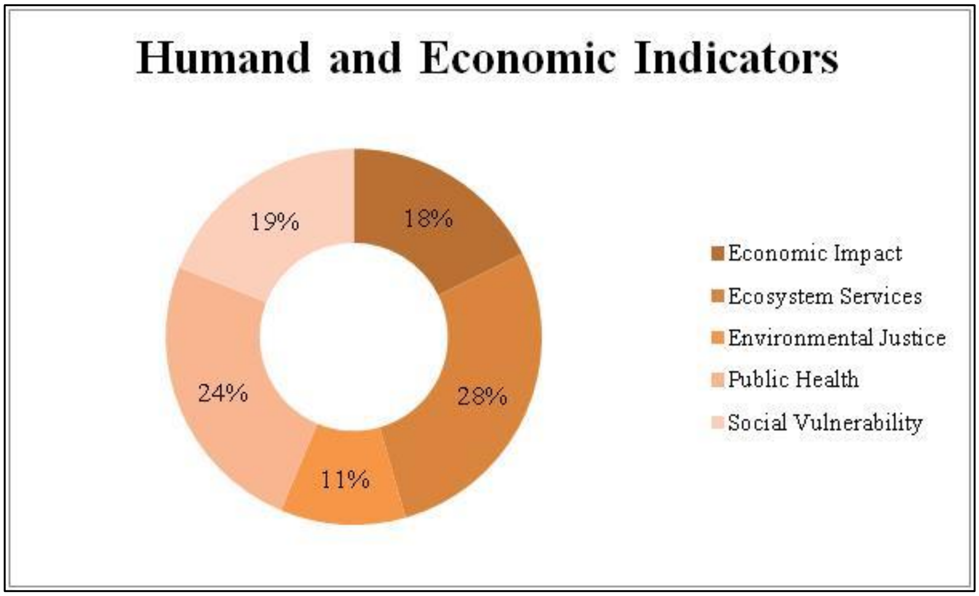


Figure 8.5 Human and Economic Indicator Weights Based on Expert Elicitation

From Figure 8.1, it can be seen that the biological and ecological indicator group needs to be the first level classification for estuarine systems as it achieved a weight of 41%. Figure 8.3 shows that, of the indicators in this group, the significance in describing an estuarine ecosystem ranks the indicators as: indicator species health and environmental sensitivity index (19%), marine trophic index (17%), habitat areas of particular concern (14%), critical habitat designation (13%), number of species listed under the ESA (12%), and phytoplankton productivity value (6%).

The second level classification should be based upon the physical indicators (34%) in the following order: water quality (25%), predominant bottom sediment type (21%), system energy (19%), mixing regime (14%), wave climate (11%), and bed slope (10%).

The final level of classification is based upon human and economic characteristics of the ecosystem (25%) in the following order: ecosystem services (28%), public health (24%), social vulnerability (19%), economic impact (18%), and environmental justice (11%).

A more in-depth description of each level of the classification system is given below.

8.1.1 First Level Classification: Biological and Ecological Characteristics

The indicators used to identify sub-ecosystems for a first level classification are:

- Indicator species health
- Environmental sensitivity index
- Marine trophic index
- Habitat areas of particular concern
- Critical habitat designation
- Number of species listed under the ESA, and
- Phytoplankton productivity value.

The first sub-level classification will be based upon indicator species health (Chapter 5.2.1.2). To classify an estuarine system upon indicator species health, the same approach as described in Chapter 5.2.1.2 will be taken. To determine the trend of each indicator species, historical data will be used. For time series data, the overall trend (in regards to total area, number of species present, etc.) will be determined based upon the indicator species being used. Based upon this trend, each indicator species will be designated as very poor, poor, moderate, good, or very good according to the rankings described in Table 5.9. The designation of the overall indicator species trend will lead to a classification of the ecosystem based upon indicator species health, described in Table 8.1.

Table 8.1 Indicator Species Health (Level 1, Sub-Classification 1)

Indicator Species Trend (%)	**Designation**	**Classification**
< -60	Very Poor	Extreme Degradation
-60 to -20	Poor	Degrading
-20% to 20%	Moderate	Steady
20% to 60%	Good	Improving
>60%	Very Good	Extreme Improvement

The indicator species used will vary for each estuarine system. Multiple indicators species from different genera or families were used in this work to try to represent multiple aspects of the ecosystem.

The second sub-level classification will be re-labeled as “sensitive areas” and be based upon environmental sensitivity index (ch. 5.2.1.7), habitat areas of particular concern (ch. 5.2.1.6), and critical habitat designations (ch. 5.2.1.5) as they all describe sensitive areas that are essential for protection. The total surface area of the estuary designated as a sensitive area (e.g. environmental sensitivity index, habitat areas of particular concern, and/or critical habitat designations) will be calculated for the sub-classification level. Sensitive areas that overlap (i.e. are classified as both habitat areas of particular concern and critical habitats) will only be included once (in other words, no double or triple counting). The sensitive area classification will be based upon the percent of the total estuarine area designated as “sensitive” (Table 8.2).

Table 8.2 Sensitive Areas (Level 1, Sub-Classification 2)

Sensitive Area Classification	**Total Estuary Area Designated as Sensitive (%)**
Slightly Sensitive	0 to < 20
Modestly Sensitive	20 to < 40
Moderately Sensitive	40 to < 60
Highly Sensitive	60 to < 80
Extremely Sensitive	≥ 80

The third sub-level classification will be based upon the number of species listed under the ESA (ch. 5.2.1.6). An endangered species is a species classified under the Endangered Species Act of 1973 as a plant or animal that is in danger of extinction in the foreseeable future. Designated as threatened or endangered species by the Fish and Wildlife Service and the National Marine Fisheries Service and approved by Congress, these species are added to the endangered and threatened species list and programs are put into place for the protection of the species to prevent its extinction. The number of both threatened and endangered species that can be found in each estuary will be used to classify an area. While it would be ideal to compare the number of threatened or endangered species to the total number of species in the estuary, it is extremely difficult to locate the total number of species living in the system – if a number can even be found at all! As such, the total number of threatened and endangered species will be noted in the classification system.

The fourth and final sub-level classification will be based upon phytoplankton productivity value (ch. 5.2.1.1). Phytoplankton productivity values are measured based upon the level of chlorophyll a in the water column. Each estuary will be described as oligotriphic, mesotrophic, or eutrophic depending upon the chlorophyll a levels (measured in μg/L) in the water column and will be classified as in Table 8.3.

Table 8.3 Trophic Classification (Level 1, Sub-Level 4)

Trophic Classification	**Chlorophyll a (μg/L)**
Oligotrophic	< 5
Mesotrophic	5 to < 50
Eutrophic	≥ 50

The five year seasonal mean, as estimated using satellite imagery, is reported by NOAA's Gulf of Mexico Data Atlas (n.d.). The value that will be used for classifying the systems given (Ch. 8.5) will be from the season with the highest Chlorophyll a concentrations.

The marine trophic index (ch. 5.2.1.3) will not be used in the estuarine classification system as it describes the interactions between fisheries and marine ecosystems (Biodiversity Indicators Partnerships, 2010) and are only available for LMEs and the EEZ. As such, the marine trophic index can be used to differentiate different ecosystem from each other, but is not necessarily useful in characterizing an ecosystem.

8.1.2 Second Level Classification: Physical Characteristics

The physical indicators used to differentiate between sub-ecosystems are:

- Water quality
- Predominant bottom sediment type
- System energy
- Mixing regime

- Wave climate, and
- Bed slope

The first sub-level classification for physical characteristics is based upon water quality (ch. 5.2.2.1) classified by water temperature, salinity, photic quality and turbidity (optical classification), and oxygen level. The mixing regime (Ch. 5.2.2.4) will be noted with the salinity component. All of the values for the water quality sub-classifiers will be noted on a monthly or seasonal basis depending upon data availability.

Estuaries will first be classified by water temperature (in °C) (Ch. 5.2.2.1.1). The highest mean temperature for each estuary will be used in the classification of that estuary as warmer water temperatures can lead to conditions that affect other aspects of water quality such as decreased dissolved oxygen and increased eutrophication. Table 8.4 shows the temperature classification based upon average temperature and was modified from Table 5.12.

Table 8.4 Temperature Classification (Level 2, Sub-Level 1.1)

Temperature Classification	Mean Temperature (°C)
Frozen/Superchilled	≤ 0
Cold	0 to < 10
Temperate	10 to < 20
Warm	20 to < 30
Hot	≥ 30

The second classification under water quality is salinity which includes both the average seasonal salinity (in psu) (Ch. 5.2.2.1.2) and the mixing regime (stratified, partially mixed, or well mixed based upon Simmon's Number) (Ch. 5.2.2.4). Table 8.5

shows the salinity classifications for estuaries as amended from Tables 5.13 and 5.23. This classification system does not account for seasonal variations in salinity and mixing regimes.

Table 8.5 Salinity Classification (Level 2, Sub-Level 1.2)

Salinity Regime	**Salinity (psu)**	**Mixing Regime**	**Simmon's Number**
Oligohaline	0 to 5	Stratified	≥ 1
		Partially Mixed	0.2 to 0.5
		Well Mixed	< 0.1
Mesohaline	5 to 18	Stratified	≥ 1
		Partially Mixed	0.2 to 0.5
		Well Mixed	< 0.1
Lower Polyhaline	18 to 25	Stratified	≥ 1
		Partially Mixed	0.2 to 0.5
		Well Mixed	< 0.1
Upper Polyhaline	25 to 30	Stratified	≥ 1
		Partially Mixed	0.2 to 0.5
		Well Mixed	< 0.1
Euhaline	≥ 30	Stratified	≥ 1
		Partially Mixed	0.2 to 0.5
		Well Mixed	< 0.1

The water quality sub-classification is then classified by photic quality (ch. 5.2.2.1.3) and turbidity (ch. 5.2.2.1.5) together. The photic quality will be classified as aphotic, dysphotic, photic, or seasonally photic. This classification will be determined by comparing seasonal euphotic depths (in meters) and the depth of the estuary. The turbidity will be classified as extremely turbid, highly turbid, moderately turbid, clear, and extremely clear. Table 8.6 shows the photic and turbidity classifications (renamed "optical classification").

Table 8.6 Optical Classification (Level 2, Sub-Level 1.3)

Turbidity Classification	**Euphotic Depth (m)**	**Photic Classification**	**Light Penetration (% depth)**
Extremely Turbid	< 1	Aphotic	0
		Dysphotic	< 2
		Photic	> 2
		Seasonally Photic	Varies by season
Highly Turbid	1 to < 2	Aphotic	0
		Dysphotic	< 2
		Photic	> 2
		Seasonally Photic	Varies by season
Moderately Turbid	2 to < 5	Aphotic	0
		Dysphotic	< 2
		Photic	> 2
		Seasonally Photic	Varies by season
Clear	5 to < 20	Aphotic	0
		Dysphotic	< 2
		Photic	> 2
		Seasonally Photic	Varies by season
Extremely Clear	≥ 20	Aphotic	0
		Dysphotic	< 2
		Photic	> 2
		Seasonally Photic	Varies by season

The final sub-classification of water quality is one of the most important classifications: oxygen level (ch. 5.2.2.1.4). The oxic classification is based upon dissolved oxygen concentration (mg/L) of the estuary. The seasonal or monthly average will be used from the season or month that produces the lowest dissolved oxygen concentration in the estuary. Table 8.7 shows the oxic classification.

Table 8.7 Oxic Classification (Level 2, Sub-Level 1.4)

Oxic Classification	Dissolved Oxygen Concentration (mg/L)
Anoxic	0 to < 0.1
Severely Hypoxic	0.1 to < 2
Hypoxic	2 to < 4
Oxic	4 to < 8
Highly Oxic	8 to < 12
Hyperoxic	≥ 12

The second sub-level classification is predominant bottom sediment type of the estuary (ch. 5.2.2.2). The predominant bottom sediment in each estuary will be classified as mud, sand, rock, or gravel depending upon the grain size diameter of the sediment. As sediment changes throughout an estuary, a sub-dominant bottom sediment classification can also be noted, if wished. The predominant sediment classification will be noted as the sediment that covers the largest percent of the estuary. The sub-dominant sediment classification is the sediment that occurs second most often in an estuary. Table 8.8 shows the sediment classifications (based on grain size diameter in millimeters). Table 8.8 can also be used to determine the sub-dominant bottom sediment classification.

Table 8.8 Sediment Classification (Level 2, Sub-Level 2)

Sediment Classification	Grain Size Diameter (mm)
Mud	< 0.063
Sand	0.063 to 2
Gravel	> 2 to 256
Rock	> 256

The third sub-level classification is based on system energy (ch. 5.2.2.3) from four sources: freshwater inflow, wave energy, wind energy, and tidal energy. Wave climate (ch. 5.2.2.6) will be incorporated with the wave energy component.

The first sub-classification of system energy is based upon freshwater inflow (ch. 5.2.2.3.1). The freshwater inflow impact will be determined based upon the amount of freshwater that enters the system during a tidal cycle compared with the tidal prism (the amount of salt water that enters the estuary over one tidal cycle). The month in which the most freshwater enters the system will be used for classification. Table 8.9 shows the freshwater flow impact classifications.

Table 8.9 Freshwater Flow Impact Classification (Level 2, Sub-Level 3.1)

Freshwater Flow Impact	**Ratio of Freshwater to Tidal Prism (%)**
Slight	0 to 20
Low	> 20 to 40
Moderate	> 40 to 60
High	> 60 to 80
Complete	> 80

The second sub-level classification of system energy is based upon wave energy (ch. 5.2.2.3.2) and wave climate (ch. 5.2.2.6) (renamed “wave impact”). Wave energy is expressed as wave amplitude (proportional to the square root of energy) in meters and wave climate tells how exposed an estuary is to waves and where they are propagated. Table 8.10 shows the wave impact classifications.

Table 8.10 Wave Impact Classification (Level 2, Sub-Level 3.2)

Wave Energy Classification	**Wave Amplitude (m)**	**Wave Climate Classification**
Quiescent	< 0.1	Fully Exposed
		Partially Exposed
		Locally Generated
Very Low Energy	0.1 to < 0.25	Fully Exposed
		Partially Exposed
		Locally Generated
Low Energy	0.25 to < 1	Fully Exposed
		Partially Exposed
		Locally Generated
Moderate Energy	1 to < 2	Fully Exposed
		Partially Exposed
		Locally Generated
Moderately High Energy	2 to < 4	Fully Exposed
		Partially Exposed
		Locally Generated
High Energy	4 to < 8	Fully Exposed
		Partially Exposed
		Locally Generated
Very High Energy	≥ 8	Fully Exposed
		Partially Exposed
		Locally Generated

The third system energy sub-classification is based upon wind energy (ch. 5.2.2.3.3) expressed as velocity in meters per second. The season that produces the highest wind speeds on average will be used in classification. Table 8.11 shows the wind energy classification which is based upon the Beaufort scale and amended from Table 5.21.

Table 8.11 Wind Energy Classification (Level 2, Sub-Level 3.3)

Wind Impact Classification	Wind Velocity (m/s)
Calm	< 0.3
Light	0.3 to < 3
Gentle	3 to < 5
Moderate	5 to < 8
Fresh	8 to < 11
Strong	11 to < 14
High	14 to < 17
Severe	≥ 17

The final sub-classification of system energy is based upon tidal energy (ch. 5.2.2.3.4) as expressed by the mean wave amplitude in meters. Table 8.12 shows the tidal energy classification. The "microtidal" and "mesotidal" classifications have been further broken down to further classify estuaries with small wave amplitudes as most estuaries fall in these categories.

Table 8.12 Tidal Energy Classification (Level 2, Sub-Level 3.4)

Tidal Energy Classification		Wave Amplitude (m)
Microtidal	Slight	0 to < 1
	Ample	1 to < 2
Mesotidal	Slight	2 to < 3
	Ample	3 to < 4
Macrotidal		4 to < 6
Hypertidal		≥ 6

The fourth and final sub-level of classification will be based upon bed slope (ch. 5.2.2.5). The bed slope is exemplified in the depth change of the estuary from one location to another. The average bed slope of the estuary will be calculated and used to classify the estuary. Table 8.13 shows the bed slope classifications for estuaries.

Table 8.13 Bed Slope Classification (Level 2, Sub-Level 4)

Bed Slope Classification	Slope (%)
Horizontal	< 20
Mild	20 to < 40
Critical	40 to < 60
Steep	60 to < 80
Adverse	≥ 80

8.1.3 Third Level Classification: Human and Economic Characteristics

The final level of classification for estuarine ecosystems will be upon human and economic characteristics based on the human and economic group indicators (ch. 5.2.3).

The first sub-level classification will be labeled "economy" and will combine the ecosystem services (ch. 5.2.3.2) and economic impact (ch. 5.2.3.1) indicators. To classify an estuary by economic impact, data from NOAA's ENOW Explorer from 2009 (economic impact) and Kidlow et al. (2009) (ecosystem services) will be used. The average non-market value for each state will be calculated and then added to the GDP for that state as obtained from the ENOW Explorer for 2009 and the percent of the total GDP obtained from the non-market value will be calculated for the ecosystem services impact. To calculate the economic impact, the aggregated trend data for all of the counties bordering the waterbody will be compiled using ENOW 2009 data to yield an average trend for the entire system. Then, using the state-level aggregated data, the percent each sector-indicator combination contributes to the state government will be calculated. For multi-state estuaries, this process will be followed for the counties bordering the estuary for each state individually. After the aggregated data for the counties surrounding the waterbody are calculated, the weighted average of the results for each waterbody will be calculated and used in the framework. Ranges for the percent each waterbody contributes to the state economically (Table 5.25) and for the percent non-market value contribute to the state were developed (Table 5.27). These tables were used to create Table 8.14 which shows the economic classifications for estuaries based upon ecosystem services and economic impact.

Table 8.14 Economic Classification (Level 3, Sub-Level 1)

Economic Impact	**Contribution to State Economics (%)**	**Ecosystem Services**	**Contribution to State Economics (%)**
Slight	0 to < 20	Slight	0 to < 20
		Light	20 to < 40
		Moderate	40 to < 60
		High	60 to < 80
		Complete	≥ 80
Light	20 to < 40	Slight	0 to < 20
		Light	20 to < 40
		Moderate	40 to < 60
		High	60 to < 80
		Complete	≥ 80
Moderate	40 to < 60	Slight	0 to < 20
		Light	20 to < 40
		Moderate	40 to < 60
		High	60 to < 80
		Complete	≥ 80
High	60 to < 80	Slight	0 to < 20
		Light	20 to < 40
		Moderate	40 to < 60
		High	60 to < 80
		Complete	≥ 80
Complete	≥ 80	Slight	0 to < 20
		Light	20 to < 40
		Moderate	40 to < 60
		High	60 to < 80
		Complete	≥ 80

The second sub-level of classification will be based upon public health (ch. 5.2.3.4) which includes information about general health (ch. 5.2.3.4.2) and mental health (ch. 5.2.3.4.1). Data for the mental and general health status of the overall population in a state are not available. However, the mental health and general health of children between the ages of two and seventeen is recorded every year by the Annie E. Casey Foundation's "Kids Count". Kids Count "is a national and state-by-state effort to track the well-being of children in the United States" (2012). The mental and general health scores will be averaged across the counties bordering the estuary and used in the classification system. Table 8.14 shows the general health classifications based upon mental health classifications (Table 5.29) and general health classifications (Table 5.30).

Table 8.15 Public Health Classification (Level 3, Sub-Level 2)

General Health Classification	**Ranking**	**Mental Health Classification**	**Percent of Children having One or More Emotional, Behavioral, or Developmental Condition**
Above Average	1 to 16	Low	12 to 14
		Medium Low	14 to 16
		Medium High	17
		High	18 to 20
Average	17 to 33	Low	12 to 14
		Medium Low	14 to 16
		Medium High	17
		High	18 to 20
Below Average	34 to 50	Low	12 to 14
		Medium Low	14 to 16
		Medium High	17
		High	18 to 20

The third sub-level of classification will describe the social vulnerability to environmental hazards (ch. 5.2.3.5) of the terrestrial area adjacent to the estuary. The Social Vulnerability Index (SoVI) developed by the University of South Carolina quantifies how vulnerable a population is to environmental hazards. SoVI scores are generated by county and then a national percentile is calculated for each county and the counties are ranked based on of their national percentile. The average national percentile for counties surrounding an estuary will be calculated and that value will be used to classify the social vulnerability of an estuary. Social vulnerability classifications have been established and are shown in Table 8.15; these classifications have been based upon Table 5.31 and upon SoVI (University of South Carolina, 2012).

Table 8.16 Social Vulnerability Classification (Level 3, Sub-Level 3)

Social Vulnerability Classification	SoVI National Percentile
High	Upper 20%
Medium	Middle 60%
Low	Lower 20%

The final sub-level of classification will be based upon environmental justice (ch. 5.2.3.3) scores of the counties immediately adjacent to the estuary. For estuarine classification, the environmental justice ratios calculated for toxic chemicals with relation to poverty will be used as obtained through GoodGuide's Scorecard. The average ratio for the estuary will be calculated based upon the individual county scores reported for counties bordering the estuary. Classifications of the environmental justice ratio are shown in Table 8.16 and based upon Table 5.28.

Table 8.17 Environmental Justice Classification (Level 3, Sub-Level 4)

Environmental Justice Classification	Environmental Justice Ratio
Equal	1
Slightly Disproportionate	> 1 to 1.20
Mildly Disproportionate	> 1.20 to 1.40
Severely Disproportionate	> 1.40 to 1.60
Extremely Disproportionate	> 1.60

8.2 Application of Estuarine Classification System to Sites

To demonstrate how to apply the estuarine classification system to an estuary, the classification system will be used to classify five estuarine systems: Barataria Bay, Louisiana; Galveston Bay, Texas; Mississippi Sound, Mississippi; Mobile Bay, Alabama; and Perdido Bay, Florida.

Table 8.18 Barataria Bay Estuarine Classification

Indicator	Classification	Data Source(s)
Level 1: Biological and Ecological		
Indicator Species Health	**Extreme Improvement**	USGS; BTNEP
Sensitive Areas	**Slightly Sensitive**	GoM Data Atlas; Marine Cadastre
ESA	**9**	BTNEP
Phytoplankton Productivity	**Mesotrophic**	GoM Data Atlas
Level 2: Physical		
Water Quality: Temperature	**Hot**	GoM Data Atlas
Water Quality: Salinity	**Upper Polyhaline; Partially Mixed**	GoM Data Atlas
Water Quality: Optical	**Clear; Seasonally Photic**	GoM Data Atlas
Water Quality: DO	**Oxic**	LADEQ, 2008
Predominant Bottom Sediment	**Mud**	GoM Data Atlas
Energy: Freshwater	**Complete**	Swenson et al., 1998; Swenson et al, 2006; Swenson and Welsh
Energy: Wave Impact	**Low energy, locally generated**	McAnally et al (2012)
Energy: Wind	**Moderate**	GoM Data Atlas
Energy: Tide	**Micro-tidal, slight**	McAnally et al (2012)
Bed Slope	**Mild**	GoM Data Atlas
Level 3: Human and Economic		
Economy	**GDP: slight; Ecosystem Services: slight**	ENOW; Bureau of Labor and Statistics; Bureau of Economic Analysis
Public Health	**General Health: below average; Mental Health: high**	The Annie E. Casey Foundation
Social Vulnerability	**Medium**	The University of South Carolina
Environmental Justice	**Extremely Disproportionate**	Scorecard

Table 8.19 Galveston Bay Estuarine Classification

Indicator	Classification	Data Source(s)
Level 1: Biological and Ecological		
Indicator Species Health	**Improving**	USGS; GBEP
Sensitive Areas	**Slightly Sensitive**	GoM Data Atlas; Marine Cadastre
ESA	**9**	USFWS
Phytoplankton Productivity	**Mesotrophic**	GoM Data Atlas
Level 2: Physical		
Water Quality: Temperature	**Warm**	GoM Data Atlas
Water Quality: Salinity	**Upper Polyhaline, mixed**	GoM Data Atlas
Water Quality: Optical	**Moderately Turbid, Seasonally photic**	GoM Data Atlas
Water Quality: DO	**Oxic**	GBEP
Predominant Bottom Sediment	**Mud**	GoM Data Atlas
Energy: Freshwater	**Low**	USGS; Corps of Engineers
Energy: Wave Impact	**Low energy, locally generated**	McAnally et al (2012)
Energy: Wind	**Moderate**	GoM Data Atlas
Energy: Tide	**Micro-tidal, slight**	McAnally et al (2012)
Bed Slope	**Mild**	GoM Data Atlas
Level 3: Human and Economic		
Economy	**GDP: slight; Ecosystem Services: slight**	ENOW; Bureau of Labor and Statistics; Bureau of Economic Analysis
Public Health	**General Health: below average; Mental Health: low**	The Annie E. Casey Foundation
Social Vulnerability	**Low**	The University of South Carolina
Environmental Justice	**Slightly Disproportionate**	Scorecard

Table 8.20 Mississippi Sound Estuarine Classification

Indicator	Classification	Data Source(s)
Level 1: Biological and Ecological		
Indicator Species Health	**Steady**	USGS; GBEP
Sensitive Areas	**Extremely Sensitive**	GoM Data Atlas; Marine Cadastre
ESA	**20**	USFWS
Phytoplankton Productivity	**Mesotrophic**	GoM Data Atlas
Level 2: Physical		
Water Quality: Temperature	**Warm**	GoM Data Atlas
Water Quality: Salinity	**Upper Polyhaline; Partially Mixed**	GoM Data Atlas
Water Quality: Optical	**Clear; Photic**	GoM Data Atlas
Water Quality: DO	**Oxic**	EPA and MSDEQ, 2005
Predominant Bottom Sediment	**Dominant: Mud; Sub-dominant: Sand and Rock**	GoM Data Atlas
Energy: Freshwater	**Slight**	Kjerfve, 1986; Byrnes and Berlinghoff, 2011; McAnally et al, 2012
Energy: Wave Impact	**Low energy, locally generated**	McAnally et al (2012)
Energy: Wind	**Moderate**	GoM Data Atlas
Energy: Tide	**Micro-tidal, slight**	McAnally et al (2012)
Bed Slope	**Mild**	GoM Data Atlas
Level 3: Human and Economic		
Economy	**GDP: slight; Ecosystem Services: slight**	ENOW; Bureau of Labor and Statistics; Bureau of Economic Analysis
Public Health	**General Health: below average; Mental Health: medium low**	The Annie E. Casey Foundation
Social Vulnerability	**Medium**	The University of South Carolina
Environmental Justice	**Slightly Disproportionate**	Scorecard

Table 8.21 Mobile Bay Estuarine Classification

Indicator	Classification	Data Source(s)
Level 1: Biological and Ecological		
Indicator Species Health	**Degrading**	USGS; MBEP
Sensitive Areas	**Slightly Sensitive**	GoM Data Atlas; Marine Cadastre
ESA	**17**	USFWS
Phytoplankton Productivity	**Mesotrophic**	GoM Data Atlas
Level 2: Physical		
Water Quality: Temperature	**Warm**	GoM Data Atlas
Water Quality: Salinity	**Upper Polyhaline; Partially Mixed**	GoM Data Atlas
Water Quality: Optical	**Moderately Turbid; Seasonally Photic**	GoM Data Atlas
Water Quality: DO	**Oxic**	NOAA, 1997
Predominant Bottom Sediment	**Dominant: Mud; Sub-dominant: sand**	GoM Data Atlas
Energy: Freshwater	**Slight**	HRI, 2002c; Davis, Jr. and Fitzgerald, 2004
Energy: Wave Impact	**Low Energy, locally generated**	McAnally et al (2012)
Energy: Wind	**Moderate**	GoM Data Atlas
Energy: Tide	**Micro-tidal, slight**	McAnally et al (2012)
Bed Slope	**Mild**	GoM Data Atlas
Level 3: Human and Economic		
Economy	**GDP: slight; Ecosystem Services: slight**	ENOW; Bureau of Labor and Statistics; Bureau of Economic Analysis
Public Health	**General Health: below average; Mental Health: high**	The Annie E. Casey Foundation
Social Vulnerability	**Medium**	The University of South Carolina
Environmental Justice	**Slightly Disproportionate**	Scorecard

Table 8.22 Perdido Bay Estuarine Classification

Indicator	Classification	Data Source(s)
Level 1: Biological and Ecological		
Indicator Species Health	**Degrading**	USGS
Sensitive Areas	**Slightly Sensitive**	GoM Data Atlas; Marine Cadastre
ESA	**24**	USFWS
Phytoplankton Productivity	**Mesotrophic**	GoM Data Atlas
Level 2: Physical		
Water Quality: Temperature	**Warm**	GoM Data Atlas
Water Quality: Salinity	**Lower Polyhaline, stratified**	GoM Data Atlas
Water Quality: Optical	**Clear, photic**	GoM Data Atlas
Water Quality: DO	**Oxic**	Sigsby, 2012
Predominant Bottom Sediment	**Dominant: Mud; Subdominant: Sand**	GoM Data Atlas
Energy: Freshwater	**Complete**	USGS; Seabergh and Thomas (2002)
Energy: Wave Impact	**Quiescent, locally generated**	McAnally et al (2012)
Energy: Wind	**Moderate**	GoM Data Atlas
Energy: Tide	**Micro-tidal, slight**	McAnally et al (2012)
Bed Slope	**Mild**	GoM Data Atlas
Level 3: Human and Economic		
Economy	**GDP: slight; Ecosystem services: n/a**	ENOW; Bureau of Labor and Statistics; Bureau of Economic Analysis
Public Health	**General Health: below average; Mental health: medium-high**	The Annie E. Casey Foundation
Social Vulnerability	**Medium-Low**	The University of South Carolina
Environmental Justice	**Equal**	Scorecard

CHAPTER IX

CONCLUSIONS

Based upon the work shown in Chapters 6 and 7, the creation of the framework, while still in its infancy, is promising and can, in fact, identify sub-ecosystems within larger systems based upon the management indicators used.

9.1 Conclusions

From the work done in this dissertation, the following conclusions can be drawn regarding the methods used and the results of the research:

9.1.1 Methods

1. For the development of the indicator weights, expert elicitation was used; while this method is an acceptable form of data mining, it does have its strengths and weaknesses. One of the strengths of expert elicitation is it allows experts across the spectrum to weigh in on the issues at hand and can serve to introduce previously unthought-of aspects of the research due to the different views and opinions presented by the experts. However, the use of expert elicitation presents a dimension of human error and unpredictability into the research thus decreasing the chance of reproducing the exact values used in the research. If special attention is not paid when selecting the experts, the researcher can unknowingly

stack the experts so the results yield biased results. Another problem with expert elicitation is defining what an expert is.

In an effort to increase the strengths of expert elicitation and decrease the weaknesses for this research, experts were identified as those who: 1) work in ecosystem based management (EBM), coastal and marine spatial planning (CMSP), or integrated ecosystem assessment (IEA) either creating and implementing plans for different large marine ecosystems (LMEs) or helping draft legislation using their technical background for EBM, 2) have worked in their field for a minimum of 5 years, 3) have multiple publications concerning EBM, CMSP, or IEA, and 4) work in the United States of America. Experts were also chosen based upon their field of study (e.g. economists, biologists, fisheries management experts, etc. were included) and their location (participants from five LMEs were surveyed) in order to diversify the results.

An important aspect of expert elicitation is ensuring that the expert feels comfortable and unthreatened when answering the survey or questionnaire. If the expert feels as if the results of the survey can harm their personal or professional life, he or she may answer the survey in a manner which does not accurately reflect his or her expert judgment. In order to try to reduce the probability of this occurring, extreme care was taken to protect the experts used in this work through following the protocols and techniques set forth by Mississippi State University's Office of Research Compliance through the Institutional Research Board (IRB).

2. The Analytic Hierarchy Process (AHP) was used to create weights for the different indicators in the indicators matrix based upon expert elicitation. As with

expert elicitation, the AHP has both strengths and weaknesses. The largest strength of the AHP is that this approach presents a simple method of dealing with complex decisions and is that it is a "highly regarded and widely used decision making method" (Rao, 2013) and "has broken through the academic community to be widely used by practitioners" (Ishizaka and Labib, 2011). Multiple studies in various fields have used AHP for decision making and priority setting (Chapter 5.3). Another strength of AHP is that the judgments used do not have to be consistent between experts. Unlike other methods, AHP also allows individual results to be synthesized into a single group response by allowing multiple survey respondents results to be compiled into one comparison matrix. AHP also has a built-in function that reviews the consistency of the results with each other. This is useful when determining if the results are valid and can be used.

However, the AHP has its flaws. Triantaphyllou and Mann noted that problems may arise from converting qualitative survey results into quantitative results (1995). Another problem is that the survey respondent may become fatigued if presented with too many options through a long survey. The AHP also does not adapt well to adding additional parameters after the survey has begun. As such, the researcher must know what needs to be included before the survey begins, which is not always the case especially during the initial stages of new research. The largest weakness of the AHP is that in order to produce valid results, experts need to participate in the survey. As previously stated, the identification of experts and subsequent expert agreement to participate in the survey may be difficult to obtain.

A flaw in using AHP and expert elicitation is that the survey answers may vary based upon the questions asked, how the questions are presented, and the order in which the options are presented.

3. The framework created through this research is also not without its strengths and weaknesses. For the purposes of this research, only indicators with publically available data were used. This is both a strength and a weakness. The strength is that the results can be replicated by anybody with access to a computer and the federal sites the data were obtained through. A weakness of this, though, is that fact that indicators that should probably be used to describe a system were not included in the framework if data were not available. An example of this is the concentration of particular chemicals in a system such as mercury, nitrogen, phosphates, and sulfates/sulfites. Another weakness of this is that only quantitative data can be used in this work while some descriptors of the system rely upon qualitative data.

   A weakness of using a quantitative approach to describe a system is that not only do the data have to be available, but the data have to exist. To select the indicators for this work, the first step was to identify all of the potential indicators that could be used to describe an ecosystem using literature review and expert elicitation. The next step was to identify if data were publically accessible. Indicators without publically accessible data were eliminated after this step. After reviewing the remaining indicators, it was seen that many the human and economic indicator group was sparsely populated. However, human activity has a strong impact on coastal and estuarine uses and needed to be incorporated into the framework. Locating human and economic data took a long time, and ultimately, those data that were used were not ideal.. As a result, the framework is not as robust as it could be were more data available.

A strength of the framework, however, is that there are relatively few indicators – only three indicator groups are used and throughout those groups, only twenty-six indicators or sub-indicators are used. The benefit of this is that a large amount of data is not necessary in order to apply the framework. A weakness, however, is that between these twenty-six indicators and sub-indicators, the ecosystem may not be adequately described.

9.1.2 Results

1. Based upon the written descriptions of EBM, IEA, and CMSP, some experts in these management protocols hold that EBM and IEA are, essentially, the same thing with different names while CMSP is different from either EBM or IEA. Some practitioners agree with this assessment and have stated that EBM and IEA are implemented together when managing an ecosystem while CMSP is implemented separately from either EBM or IEA. However, the results from applying AHP to the expert survey results do not weight the indicators in such a way that this assertion is upheld. The table below synthesizes the indicator group weights for each management protocol.

Table 9.1 Synthesis of Survey Results

	IEA	CMSP	EBM	All Results
Biological and Ecological	44	42	36	41
Physical	31	38	33	34
Human and Economic	25	20	31	25

From Table 9.1 it is seen that, based upon the weights calculated through AHP using expert elicitation, IEA and CMSP are more closely related to each other than either of them is to EBM. As a consequence, the results obtained through this aspect of the research do not, in fact, align with the stated descriptions of the management protocols.

2. While Table 9.1 shows that the different management protocols place different values on the indicator groups, the visual displays created by applying the framework to Perdido Bay, Galveston Bay, and Mobile Bay do not yield significantly different displays for the different protocols; however, the differences created by the varying indicator weights were more noticeable when mapping the clusters in Barataria Bay and Mississippi Sound. This may be due to the fact that Perdido, Galveston, and Mobile Bays are less homogeneous systems than Barataria Bay and Mississippi Sound relative to the indicators used. As a result, in Barataria Bay and Mississippi Sound, the differences between the management protocols are seen since one or two indicators change the clusters, thus one or two indicator weights influence the results.

Even though the weights calculated for the management protocols vary significantly based upon the protocol used, for systems that were not highly homogeneous in indicator data values, the different weights did not produce substantially different cluster maps. However, for mostly homogeneous sites with regard to indicator data value, the indicator weights did substantially change the results.

3. When applying the framework to the smallest system, Perdido Bay, the results for each management protocol are fundamentally the same when displayed on maps regardless of the grid size used. The high congruence between the results regardless of the grid size suggests that all of the grid sizes used in this work are valid when applying this framework to a system the size of Perdido Bay.

   For Galveston Bay, the visualization of the clusters shows a high degree of similarity between the two kilometer square grid and four kilometer square grid results. The results for the one kilometer square grid, however, are inconsistent with rest of the Galveston Bay results. When the framework was applied to Galveston Bay using an eight kilometer square grid size, the larger grid size does a more consistent job of identifying similar cluster results to the two and four kilometer square grids than the one kilometer square grid size. This is, more than likely, due to the fact that the larger grid size allows the overall data trends to be seen.

   However, it is essential to remember that different scales are good for different purposes, so the final spatial resolution selected to apply the framework at needs to be determined based upon what the results will be used for as well as the system characteristics.

There are subtle differences between the displays for Barataria Bay, Mississippi Sound, and Mobile Bay within the same grid size that are caused by the indicator weights for the different management protocols.

From this examination, it can be concluded that in order to identify appropriate sub-regions within estuaries using the developed framework, a larger grid size produces more consistent results across different grid sizes for a larger system while all of the grid sizes used for the smallest system produce consistent results. It is important to note that for the smallest system, Perdido Bay, that all of the grid sizes used (one kilometer square, two kilometer squares, and four kilometer squares) produced nearly identical results and thus any of these grid sizes can be used. For the remaining systems, the two kilometer square, four kilometer square, and eight kilometer square grid sizes also produced nearly the same results for the same management protocol with a few exceptions. One of these exceptions is the application of the framework to Mississippi Sound using the eight kilometer square grid size for CMSP which is very different than the results obtained by applying the framework at smaller grid sizes using the CMSP indicator weights. The input values were checked and it was determined that the map produced did yield usable clusters for management purposes.

4. Clusters can be identified as similar to each other based upon data values and not upon physical location which could be useful in identifying similar ecosystems that are not located adjacent to each other.
5. The framework does a good job of identifying the navigation channels in shallower estuaries and creating a cluster that is made up of the channel itself.

As with Galveston Bay, when the framework was applied to Mobile Bay, the navigation channel was separated into a cluster that was different from the rest of the estuary. This is important to note as the navigation channel will need to be managed under a different management plan than the rest of the estuary due to the necessity of dredging the channel. The navigation channels within the Mississippi Sound were not identified and separated into a discrete cluster. This is most likely due to the fact that the Sound is deeper, in general, than the other estuaries used in this work and thus the channels are typically smaller and therefore produce a much less significant bed slope than the navigation channels within Mobile and Galveston Bays.

6. While a preliminary sensitivity analysis was run for Perdido Bay by increasing the indicator values by an order of magnitude, the analysis simply shows that the framework is not susceptible to this perturbation of input data; however, additional sensitivity analysis needs to be run to determine how changes to the indicator values result in different clusters within the data.

9.2 Recommendations for Future Research

In order to further enhance the development of this framework and for the purpose of continuing to develop understanding of ecosystem based management of coastal areas, the following recommendations are suggested:

1. To enhance and strengthen the results obtained through expert elicitation for this research, future research should focus on expanding the survey to additional experts. This can be done on multiple fronts: a) increasing the expert participation within individual LMEs in the United States, b) ensuring that experts

from all LMEs in the U.S. participate in the survey, c) increasing the number of institutions that have participants in the survey (federal vs. state, public vs. private, universities, etc.), and d) increasing the background/career diversity of participants in the survey.

2. During the use of AHP when synthesizing multiple expert results into one input, all of the expert judgments were weighted the same regardless of the expert's professional background. Additional research can be conducted to determine how the indicator weights would change based upon professional judgment if each expert were assigned a weight for each indicator group. For instance, if the expert responding to the survey were an expert in biological processes, his or her responses for the biological and ecological indicator group would have a higher priority over a respondent who has a background in economics.
3. In order to strengthen the results obtained through AHP and expert elicitation, creating and conducting multiple versions of the same survey can be used to determine how much the presentation and order of the questions and available responses affects the results. This analysis can be useful in determining how influenced the survey respondent is by distractions introduced through the actual look and presentation of the survey.
4. Continue updating and expanding the framework indicators as new research and data become available. However, if new indicators are added to the framework, this would necessitate performing additional expert elicitation as well as re-calculating the indicator weights for the different management protocols. Also

look at including extraordinary events – such as hurricane storm surge – into the framework.

5. Perform more rigorous sensitivity analysis for the framework in order to determine differences due to changing the indicator values, reversing the indicator value ramps, and other perturbations in the indicator values.
6. Apply the framework to additional estuaries within the Gulf of Mexico as well as estuaries in other large marine ecosystems to continue refining the framework.
7. Apply of the framework to multiple sites at the same time. While it appears as if the framework is successful in identifying sub-regions within the estuaries it was applied to, the next step would be to see how the framework handles this approach to multiple sites at the same time. As an example, if the framework were applied to Barataria Bay, Mississippi Sound, and Mobile Bay all at the same time using the same shapefile, how would the framework react, what clusters could be identified, and how does the application change the conclusions drawn about scale.
8. Continue applying the framework to sites with increasingly larger spatial scales to determine at what spatial scale the results become unusable. As an example, what would the results be if the grid size of sixteen kilometer squares was used on Mississippi Sound?
9. Apply the framework to different sites using different temporal scales and data from different seasons. For the application of the framework for this research, the season that produced the worst possible case (i.e. highest salinity, lowest dissolved oxygen levels, etc.) were used. The framework can be applied to a

system using data from different seasons to see the seasonal variations in the subsystems identified. This would help managers better understand the system and seasonal variations within the system and could lead to the production of more efficient management plans for the system.

10. Reduce human error caused by visual judgment when transferring data from the basemaps obtained through federal agencies to the gridded estuary shapefile by creating programs that can automatically populate the indicators matrix for the estuaries. This would require in-depth knowledge of programming and artificial intelligence, but would streamline the process and allow the framework to be used more efficiently and effectively at multiple different levels from individual estuaries up to LMEs.
11. Develop objective criterion to determine what spatial scale the framework needs to be applied at based upon what the results will be used for (e.g. identifying subregions within an individual wetland in order to create a wetland management plan vs. identifying sub-regions for the purpose of creating a state-by-state coastal health report card).

REFERENCES

Aczel, J. and T.L. Saaty. 1983. Procedures for Synthesizing Ratio Judgments. Journal of Mathematical Psychology 27.1: 93-102.

American Heritage Dictionary. 1994. Model. P.G. Evenson and J.M. Patwell, eds. 3rd Ed. Brantwell Doubleday Dell Publishing Group, Inc. New York, NY.

American Society of Civil Engineers Manual of Practice 110. Sedimentation Engineering: Processes, Measurements, Modeling, and Practice. Ed. Marcelo H. Garcia. ASCE: Reston, Virginia.

Annie E. Casey Foundation. 2013. Kids County Data Center. Available online at: [http://datacenter.kidscount.org/].

Apitz, S.E. 2011. Conceptualizing the role of sediment in sustaining ecosystem services: sediment-ecosystem regional assessment (SEcoRA). Science of the Total Environment, 415: 9-30.

Associated Press. 26 January 2013. Pipeline to carry sediment to Barataria Basin. Available online at: [http://www.wbrz.com/news/pipeline-to-carry-sediment-to-barataria-basin].

Atwood, T.B., T.N. Wiegner, and R.A. MacKenzie. 2011. Effects of hydrological forcing on the structure of a tropical estuarine food web. Oikos, 121: 277-289.

Australian Environmental Protection Authority. 2007. Community Estuarine Monitoring Manual. Environmental Protection Authority; Adelaide, Australia.

Bakter, D., I. de la Torre, R. Costanza, P. Swedeen, J. Day, R. Boumans, and K. Bagstad. 2010. Gaining ground – wetlands, hurricanes, and the economy: the value of restoring the Mississippi River Delta. Earth Economics. Tacoma, Washington.

Barataria-Terrebonne National Estuary Program. June 1996. Comprehensive Conservation Management Plan.

Barataria-Terrebonne National Estuary Program. 2008. Use Attaniability Analysis: An Ecoregion Approach to Dissolved Oxygen Criteria Development. Barataria-Terrebonne National Estuary Program. Thibodaus, Louisiana.

Barataria-Terrebonne National Estuary Program. No date. What is BTNEP? Found online. Available at: [http://www.btnep.org/BTNEP/about/whatisBTNEP.aspx].

Barras, J., S. Beville, D. Britsch, S. Hartley, S. Hawes, J. Johnston, P. Kemp, Q. Kinler, A. Martucci, J. Porthouse, D. Reed, K. Roy, S. Sapkota, and J. Suhayda. 2003. Historical and Projected Coastal Louisiana Land Changes: 1978-2050, Open File Report. USGS.

Battelle Memorial Institute. 2013. *Coastal and Marine Spatial Planning: Advancement Training*. Course notes for the Gulf of Mexico Region. 4-7 March 2013. Five Rivers Delta Center, Mobile, Alabama.

Baya, E.E., L.S. Yokel, C.A. Pinyerd III, E.C. Blancher, S.A. Sklenar, and W.C. Isphording. 1998. Preliminary Characterization of Water Quality of the Mobile Bay National Estuary Program (MBNEP) Study Area.

Biodiversity Indicators Partnership. 2010. Marine Trophic Index. Indicator Factsheet 4.1.1. Sea Around Us Project. University of British Columbia Fisheries Center.

Blumberg, A.F., Q. Ahsan, H. Li, I.D. Kaluarachchi, and J.K. Lewis. 2001. Circulation, Sediment, and Water Quality Modeling in the Northern Gulf of Mexico. World Water and Environmental Resources Congress. 20-24 May 2001, Orlando, Florida.

Borja, A., I. Galparsors, O. Solaun, I. Muxika, E.M. Tello, A. Uriarte, and V. Valencia. 2006. The European Water Framework Directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status. *Estuarine, Coastal, and Shelf Science,* 66. p. 84-96.

Boucher, T.O. and E.L. McStraic. 1991. Multi-attribute Evaluation Within a Present Value Framework and its Relation to the Analytic Hierarchy Process. The Engineering Economist, 37:55-71.

Bowen, R.E., and C. Riley. 2003. Socio-economic indicators and integrated coastal management. *Ocean and Coastal Management,* 46. p. 299-312.

Braun, D. and R. Neugarten. 2005. Mobile-Tensaw River Delta, Alabama: Hydrological Modifications Impact Study. The Nature Conservancy. Arlington, Virginia.

Braunschewig, T. 2000. Priority Setting in Agricultural Biotechnology Research: Supporting Public Decisions in Developing Countries with the Analytic Hierarchy Process. ISNAR Research Report No. 16. The Hague: International Service for National Agricultural Research.

Bricker, S., B. Longstaff, W. Dennison, A. Jones, K. Boicourt, C. Wicks, and J. Woerner. 2007. Effects of Nutrient Enrichment in the Nation's Estuaries: A Decade of Change. NOAA Coastal Ocean Program Decision Analysis Series No. 26. National Centers for Coastal Ocean Science, Silver Spring, MD.

Bricker, S.B., B. Longstaff, W. Dennison, A. Jones, K. Boicourt, C. Wicks, and J. Woerner. 2008. Effects of nutrient enrichment in the nation's estuaries: a decade of change. Harmful Algae, 8(1): 21-32.

Brown, S. and J. Lehrter. 2012. Water Quality: Assessment of Current Situation. For MBNEP/CCMP Development.

Bulger, A.J., B.P. Hayden, M.E. Monaco, D.M. Nelson, and M G. McCormick-Ray. 1993. Biologically-Based Estuarine Salinity Zones Derived from Multi-Variate Analysis. Estuaries, 16(2): 311-322.

Burbeck, S. 2007. Complexity and the Evolution of Computing: Biological Principles for Managing Evolving Systems. TII/Vanguard Conference on Complexity. Los Angeles.

Bureau of Ocean Energy Management. No date. Multipurpose Marine Cadastre, Active Oil and Gas Leases. Found online. Available at: [http://www.marinecadastre.gov/Data/default.aspx].

Bureau of Ocean Energy Management. No date(b). Multipurpose Marine Cadastre, Active Renewable Energy Leases. Found online. Available at: [http://www.marinecadastre.gov/Data/default.aspx].

Byrnes, M.R. and J.L. Berlinghoff. 2011. Gulf Regional Sediment Management Master Plan: Case Study Compilation.

Byrnes, M.R., J.L. Berlinghoff, and S.F. Griffee. 2013. Sediment Dynamics in Mobile Bay, Alabama: Development of an Operational Sediment Budget (Final Report).

Camanho, A.S., J. Hora, M.B. Gaspar, and M.M. Oliveria. 2010. A bibliographic survey of applications of the DPSIR Framework to coastal zones. *FEUP/IPIMAR Report of Project PRESPO.* pp. 19.

Cambron, K.E. and G.W. Evans. 1991. Layout Design Using the Analytic Hierarchy Process. Computers and IE 20: 221-229.

Cao, M., S. Marshall, and K. Gregson. 1996. Global Carbon Exchange and Methane Emissions from Natural Wetlands: Application of a process-based model. Journal of Geophysical Research: Atmospheres 101(D9): 14399-14414.

Carabajal-Herdández, J.J., L.P. Sánchez-Fernández, L.A. Villa-Vargas, J.A. carrasco-Ochoa, and J.F. Martínez-Trinidad. 2013. Water quality assessment in shrimp culture using an analytical hierarchical process. Ecological Indicators 29: 148-158.

Cave, R.R., L. Ledoux, K. Turner, T. Jickells, J.E. Andrews, and H. Davies. 2003. The Humber catchment and its coastal area: from UK to European perspectives. *The Science of the Total Environment,* 314-316. p. 31-52.

Center for Coastal Monitoring and Assessment. no date. Barataria Bay.

Chambers, G. 2001. Professional Development Programme: Coastal Infrastructure Design, Construction, and Maintenance. A Course in Coastal Zone/Island Systems Management. Chapter 4: Coastal Hazards and Vulnerability.

Chapra, S.C. 1997. *Surface Water-Quality Modeling.* Waveland Press, Inc. Long Grove, Illinois.

Chernock, R.L., P.A. Boone, and R.L. Lipp. 1974. The Environment of Offshore and Estuarine Alabama. Geological Survey of Alabama, Information Series, 51.

Christensen, N.L., A.M. Bartuska, J.H. Brown, S. Carpenter, C. D'Antonio, R. Francis, J.F. Franklin, J.A. MacMahon, R.F. Noss, D.J. Parsons, C.H. Peterson, M.G. Turner, and R.G. Woodmansee. 1996. The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. Ecological Applications 6(3): 665-691.

Coastwide Reference Monitoring System. Available online at: [http://www.lacoast.gov/crms2/Home.aspx].

Commonwealth of Australia House of Representatives. 5 June 1975. *Commonwealth Parliamentary Debates*, p. 3424-3436.

Cordi, J.A., M.A. Meylan, and W.C. Isphording. 2003. Metal distribution and metal site partitioning, Mobile Bay surface sediments. Transactions of the Gulf Coast Association of Geological Societies, 53: 145-159.

Cucker, F. and S. Smale. 2007. Emergent Behavior in Flocks. IEEE Transactions on Automatic Control 52.5: 852-862.

Daily, G.C., S. Alexander, P.R. Ehrlich, L. Goulder, J. Lubchenco, P.A. Matson, H.A. Mooney, S. Postel, S.H. Schneider, D. Tilman, G.M. Woodwell. 1997. Ecosystem Services: Benefits Provided to Human Societies by Natural Ecosystems. Ecology, 2: 1-16.

Dalrymple, R.A. and W. W. Thompson. 1976. Study of equilibrium beach profiles. *Proceedings 15th Coastal Engineering Conference,* Vol 2. American Society of Civil Engineers, 1,277-1,296.

Davis, Jr., R.A., and D.M. Fitzgerald. 2004. *Beaches and Coasts*. Blackwell Publishing, Malden, Massachusetts.

Day, J.W., D.F. Boesch, E.J. Clairain, G.P. Kemp, S.B. Laska, W.J. Mitsch, K. Orth, H. Mashiqui, D.J. Reed, L. Shabman, C.A. Simenstad, B.J. Streever, R.R. Twilley, C.C. Watson, J.T. Wells, and J.F. Whigham. 2007. Restoration of the Mississippi Delta: Lessons from Hurricanes Katrina and Rita. Science 315(5819): 1679-1684.

DeLaune, R.D., J.A. Nyman, and W.H. Patrick, Jr. 1994. Peat collapse, ponding and wetland loss in a rapidly submerging coastal marsh. Journal of Coastal Research, 10(4): 1021-1030.

DeLaune, R.D., J.H. Whitcomb, W.H. Patrick, Jr., J.H. Pardue, and S.R. Pezeshki. 1989. Accretion and canal impact in a rapidly subsiding wetland. Estuaries, 12(4): 247-259.

Department of Defense. No date. Multipurpose Marine Cadastre, Danger Zones and Restricted Areas. Found online. Available at: [http://www.marinecadastre.gov/Data/default.aspx].

Department of Energy. 2010. Offshore Wind Energy Permitting: A Survey of U.S. Project Developers. PNNL-20024. Prepared by F.B. van Cleve and A.E. Copping.

Douvere, F. 2008. *The importance of marine spatial planning in advancing ecosystem-based sea use management.* Marine Policy 32.5: 762-771.

Dyson, G.B. 1998. *Darwin Among the Machines: The Evolution of Global Intelligence*. Perseus Books Group.

Ecosystem-Based Management Tools Network. 2010. About Ecosystem-Based Management (EBM). Available online at: [http://www.ebmtools.org/about_ebm.html].

EBM Tools. 2010. Ecosystem-based management schematic. Available online: http://www.ebmtools.org/sites/natureserve/files/imce/schematic_for_website_0213_1.jpg

EEA. 1995. Europe’s Environment: the Dobris Assessment. European Environment Agency, Copenhagen.

Engineering Research and Development Center. June 1989. Coastal Engineering Technical Note: Application of Movable-Bed Physical Models to Predict Storm-Induced Erosion. CETN-II-18.

Ehler, E., and F. Douvere. 2009. *Marine Spatial Planning: A Step-by-Step Approach Toward Ecosystem-Based Management*. Intergovernmental Oceanographic Commission and Man and the Biosphere Programme. IOC Manual and Guides (pdf, 9.14 MB), No. 53, IOCAM Dosier No. 6, Paris, UNESCO.

Escambia County Board of County Commissioners. 2010. Habitat Conservation Plan: A Plan for the Protection of the Perdido Key Beach Mouse, Sea Turtles, and Piping Plovers on Perdido Key, Florida.

Federal Geographic Data Committee. 2012. Coastal and Marine Ecological Classification Standard, June 2012. FGDC-STD-018-2012.

Ferreira, J.G., A.M. Nobre, T.C. Simas, M.C. Silva, A. Newton, S.B. Bricker, W.J. Wolff, P.E. Stacey, and A. Sequeira. 2006. A Methodology for Defining Homogeneous Water Bodies in Estuaries – Application to the Transitional Systems of the EU Water Framework Directive. Estuarine, Coastal, and Shelf Science, 66(3-4): 468-482.

Financial Dictionary. 2013. Collateralized Debt Obligation. Found online. Available at: [http://www.investinganswers.com/financial-dictionary/bonds/collateralized-debt-obligation-cdo-2123].

Florida Department of Environmental Protection. 2011. Perdido River and Bay Watershed. Florida's Water Ours to Protect. Available online at: [http://www.protectingourwater.org/watersheds/maps/perdido/].

Florida Department of Environmental Protection. October 2012. Site-Specific Information in Support of Establishing Numeric Nutrient Criteria for Perdido Bay

French, R.H., J.J. Cooper, and S. Vigg. 1982. Secchi Disc Relationships. Water Resources Bulletin: American Water Resources Association, 18(1): 121-123.

Galveston Bay Estuary Program. 2011. The State of the Bay: A characterization of the Galveston Bay ecosystem, 3rd ed.

Galveston Bay National Estuary Program. April 1995. The Galveston Bay Plan: The Comprehensive Conservation and Management Plan for the Galveston Bay Ecosystem. GBNEP-49.

Galveston Bay National Estuary Program. October 2007. Galveston Bay Estuary Program. Found online. Available at: [http://www.gbep.state.tx.us/].

Galveston Bay National Estuary Program. 2002. The State of the Bay: A Characterization of the Galveston Bay Ecosystem, 2nd Edition. GBEP-T7.

Geotechnology Research Institute. May 2005. Galveston Bay Indicators Project: Final Report.

Gerbersdorf, S.U., H. Hollert, M. Brinkmann, S. Wieprecht, H. Schüttrumpf, and W. Manz. Anthropogenic pollutants affect ecosystem services of freshwater sediments: the need for a “triad plus x” approach. Journal of Soils and Sediments, Section 4: Sediment-Ecology Interactions: Position Paper.

Glenn, T.H. 2012. The Mexican Gulf Coast on Mobile Bay and Mississippi Sound, Illustrated. General Books, LLC. Memphis, TN.

Great Barrier Reef Marine Park Authority. May 2004. *Great Barrier Reef Marine Park Zoning Plan 2003.* Australian Government, Townsville, Queensland, Australia.

Grimm, V. and C. Wissel. 1997. Babel, or the ecological stability discussions: an inventory and analysis of terminology and a guide for avoiding confusion. Oecologia 109 (3). p. 323-334.

Grubbs, J.W. and J.R. Pittman. 1997. Application of Acoustical Methods for Estimating Water Flow and Constituent Loads in Perdido Bay, Florida. USGS Water-Resources Investigation Report 97-4101.

Gulf of Mexico Research Initiative Research Board. 25 April 2011. *Request for Proposals: Selection of Research Consortia.*

Halpern, B.S., K.L. McLeod, A.A. Rosenberg, and L.B. Crowder. 2008. Managing for Cumulative Impacts in Ecosystem-Based Management through Ocean Zoning. Ocean and Coastal Management, v. 51.

Hansen, D.V. and M. Rattray Jr. 1966. New Dimensions in Estuary Classification. Limnology and Oceanography, 11(3): 319-326.

Harris, G. 2007. Seeking Sustainability in an Age of Complexity. Cambridge University Press, Cambridge, UK.

Harte Research Institute. October 2002. Barataria Bay. Found online. Available at: [http://www.gulfbase.org/bay/view.php?bid=barataria].

Harte Research Institute. October 2002b. Mississippi Sound. Found online. Available at: [http://www.gulfbase.org/bay/view.php?bid=mississippi1].

Harte Research Institute. October 2002c. Mobile Bay. Found online. Available at: [http://www.gulfbase.org/bay/view.php?bid=mobile].

Harte Research Institute. December 2011. Gulf of Mexico Report Card. Presented at the Summit 2011: State of the Gulf of Mexico in Houston, Texas. December 4-8, 2011.

Harte Research Institute. 2012. GecoServ Gulf of Mexico Ecosystem Services Valuation Database. Available online at: [http://www.gecoserv.org].

Haufler, J.B., T. Crow, and D. Wilcove. 1999. Scale Considerations for ecosystem management. Ecological Stewardship: A common reference for ecosystem management in Cheng, A.S. and S.E. Daniels. 2003. Examining the Interactions between Geographic Scale and Ways of Knowing in Ecosystem Management: A Case Study of Place-Based Collaborative Planning.

Heck, K., D. Byron, and S. Alexander. 2011. Florida Seagrass Integrated Mapping and Monitoring Program: Summary Report for Perdido Bay. Yarbro and Carlson, Eds.

Henriques, S., M.P. Pais, M.J. Costa, and H. Cabral. 2008. Development of a fish-based multimetric index to assess the ecological quality of marine habitats: The Marine Fish Index. *Marine Pollution Bulletin,* 56. p. 1913-1934.

Holier, N.R., D.W. Mason, R.M. Dawson, T. Simons, and M.C. Wooten. 1989. Reestablishment of the Perdido Key Beach Mouse (Peromyscus polionotus trissyllepsis) on Gulf Islands National Seashore. Conservation Biology 3(4): 397-404.

Hudson, R.Y., F.A. Herrmann, R.A. Sager, R.W. Whalin, G.H. Keulegan, C.E. Chatham, and L.Z. Hales. 1979. “Coastal Hydraulic Models” Special Report No. 5, U.S. Army Corps of Engineers Engineering Research and Development Center, Vicksburg, MS.

Hughes, S.A. 2003. CHL Precision Flow Table – Description and Applications. ERDC/CHL CETN-IV-55.

Hughes, S.A. and J. Cohen. 2006. Half Moon Bay, Grays Harbor, Washington: Movable-Bed Physical Model Study. ERDC Coastal and Hydraulics Laboratory. ERCD/CHL TR-06-15.

Hummell, R.L. 1996. Holocene Geologic History of the West Alabama Inner Continental Shelf, Alabama. Geological Survey of Alabama. Circular, 189.

Hutchings, R. and L. Yokel. 2000. Mobile Bay National Estuary Program Monitoring Plan.

Hwang. 1990. An Application of the Analytic Hierarchy Process to the Evaluation of Statistical Expert Systems for Social Science Research. Mississippi State University Libraries (a dissertation).

Ippen, A.T., Ed. Eagleson, P S., R G. Dean, C L. Bretschneider, F Raichlen, D.R. F. Harleman, J.W. Johnson, A.T. Ippen, G.H. Keulegan, and H.B. Simmons, Authors. *Estuary and Coastline Hydrodynamics*. Iowa Institute of Hydraulic Research, The University of Iowa, Iowa City, Iowa: McGraw-Hill, 1966.

Isphording, WC., F.D. Imsand, and R.B. Jackson. 1996. Fluvial sediment characteristics of the Mobile River Delta. Transactions of the Gulf Coast Association of Geological Societies, 46: 185-191.

Ishizaka, A. and A. Labib. 2011. Review of the main developments in the analytic hierarchy process. Expert Systems with Applications, 38(11): 14336-14345.

Jones, J.S. and S. Ganey, 2010. Building the Legal and Institutional Framework. In K. McLeod and H. Leslie, eds., Ecosystem-based Management for the Oceans. Washington, D.C.: Island Press.

Kaliraj, S., N. Chandrasekar, and N.S. Magesh. 2013. Identification of potential groundwater recharge zones in Vaigai upper basin, Tamil Nadu, using GIS-based analytical hierarchical process (AHP) technique. Arabian Journal of Geosciences. 2013: 1-17.

Karageorgis, A.P., V. Kapsimalis, A. Kontogianni, M. Skourtos, K.R. Turner, and W. Salomons. 2006. Impacts of 100-Year Human Interventions on the Deltaic Coastal Zone of the Inner Thermaikos Gulf (Greece): A DPSIR Framework Analysis. *Environmental Management,* 38(2). p. 304-315.

Kelble, Chris. no date. MARine Ecosystem goal Setting (MARES).

Kelble, C., D. Loomis, P. Ortner, J. Lorenz, W. Nuttle, P. Fletcher, and many more. no date. An Integrated Conceptual Ecosystem Model for the southwest Florida shelf: Results and products from MARine and Estuarine goal setting (MARES).

Kildow, J.T., C.S. Colgan, and L. Pendleton. 2009. The Changing Coastal and Ocean Economies of the United States Gulf of Mexico. In: J.C. Cato (ed.) Gulf of Mexico Origin, Waters, and Biota, Volume II: Ocean and Coastal Economy. Texas A&M University Press. College Station, Texas.

Kirschenfeld, T., R.K. Turpin, and L.R. Hadley. 2006. Seagrass Status and Trends in the Northern Gulf of Mexico: 1940-2002: Perdido Bay.

Kjerfve, B. 1980. Measurement and Analysis of Water Current, Temperature, Salinity, and Density. In: Estuarine hydrography and sedimentation. K.H. Dyer (ed). Cambridge University Press. Cambridge.

Kjerfve, B. 1986. Comparative oceanography of coastal lagoons. In: *Estuarine Variability* (D.A. Wolfe, ed.). Academic Press, New York.

Kolker, A.S., M.A. Allison, and F. Marcantonio. no date. Spatial and Temporal Variability in Sediment Accumulation Rates in Barataria Bay and the Development of a Regional Subsidence Map. CREST Final Technical Report.

Kristensen, P. 2004. The DPSIR Framework. National Environmental Research Institute, Department of Policy Analysis. Nairobi, Kenya.

Lawrence, D., R. Kenchington, and S. Woodley. 2002. *The Great Barrier Reef: Finding the Right Balance.* Melbourne University Press, Victoria, Australia.

Levin, P.S., M.J. Fogarty, G.C. Matlock, and M. Ernst. 2008. *Integrated Ecosystem Assessments*. U.S. Department of Commerce, NOAA Technical Memo. NMFS-NWFSC-92.

Levin, P.S., M.J. Fogarty, S.A Murawski, and D. Fluharty. 2009. *Integrated Ecosystem Assessments: Developing the Scientific Basis for Ecosystem-Based Management of the Ocean.* PLoS Biol 7(1): e1000014.dio:10.1371/journal.pbio.1000014.

Li, H. 2010. Concepts and Applications of Water Transport Time Scales for Coastal Inlet Systems. ERDC/CHL CHETN-IV-77.

Lindsay, R.W. and J. Zhang. 2005. The Thinning of Arctic Sea Ice, 1988-2003: Have We Passed a Tipping Point? American Meterological Society 18: 4879-4894.

Lotka, A.J. 1956. Elements of Mathematical Biology. Dover Publications, New York.

Louisiana Coast. no date. Coastal Wetlands Planning, Protection and Restoration Act: The Barataria Basin. Available online at: [http://lacoast.gov/new/About/Basin_data/ba/Default.aspx#dynamics].

Lubchenco, J. 2010. Lessons from the Ice Bear. *Ecosystem-Based Management for the Oceans*. K. McLeod and H. Leslie, Eds. p. xi-xiv.

Lubchenco, J. and L.A. Petes. 2009. The Interconnected Biosphere: Science at the Ocean's Tipping Point. Oceanography 23(2): 115-129.

Martin, J.L. and S.C. McCutcheon. 1999. *Hydrodynamics and Transport for Water Quality Modeling.* CRC Press.

Martin, J.L. 2011. Class notes from Water Quality Modeling II. Mississippi State University. Spring semester 2011.

Martin, J.L. 2012. Class notes from Surface Water Quality Modeling. Mississippi State University. Spring semester 2012.

McAnally, W.H. 2010. Class notes from Sedimentation Engineering. Mississippi State University. Fall semester 2010.

McAnally, W.H. 2011. Class notes from Tidal Hydraulics. Mississippi State University. Spring semester 2011.

McAnally, W.H., J. Cebrian, R. Fulford, E. Swenson, C. Carollo, J. Harding, J. Larigue, S. Milroy, J. Cartwright, S. Welsh, B. Allee, B. Christiaen, and J.S. Ziegler. August 2012. Ecosystem Approach to Management for the Northern Gulf of Mexico. Northern Gulf Institute, Stennis Space Center, Mississippi.

McClure, M., and Ruckelshaus, M. 2007. *Collaborative Science: Moving ecosystem-based management forward in Puget Sound.* Fisheries 32: 458.

McLeod, K. and H. Leslie. 2009. *Ecosystem-Based Management for the Oceans.* Island Press, Washington, D.C.

McLeod, K.L., J. Lubchenco, S.R. Palumbi, and A.A. Rosenberg. 2005. *Scientific consensus statement on marine ecosystem-based management.* The Communication Partnership for Science and the Sea (COMPASS). Signed by 221 academic scientists and policy experts with relevant expertise. Available online: http://www.compassonline.org/pdf_files/EBM_Consensus_Statement_v12.pdf

McLusky, D.S. 1993. Marine and Estuarine Gradients – An Overview. Netherlands Journal of Aquatic Ecology, 27(2-4): 489-493.

McMahon, G., S.M. Gregonis, S.W. Waltman, J.M. Omernik, T.D. Thorson, J.A. Freeouf, A.H. Rorick, and J.E. Keys. 2001. Developing a spatial framework of common ecological regions for the conterminous United States. Environmental Management 28(3): 293-316.

Melosi, M.V. and J.A. Pratt. 2007. *Energy metropolis: an environmental history of Houston and the Gulf Coast*. University of Pittsburgh Press, Pittsburgh, Pennsylvania.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-Being: Synthesis. Island Press. Washington, D.C.

Miller, G.A. 1956. The Magical Number Seven Plus or Minus Two: Some Limits on Our Capacity for Processing Information. Psychological Review, 63: 81-97.

Miller, G.T. and S.E. Spoolman. 2011. Living in the Environment, 17th Edition. Brooks/Cole, CENGAGE Learning, Boston.

Millonas, M.M. 1992. A connectionist type model of self-organized foraging and emergent behavior in ant swarms. Journal of Theoretical Biology 159(4): 529-552.

Mobile Bay National Estuary Program. 2002. Comprehensive Conservation and Management Plan, Volume I – A Call to Action. Mobile Bay National Estuary Program. Mobile, Alabama.

Mobile Bay National Estuary Program. 2010. Found online. Available at: [http://www.mobilebaynep.com

Mobile Bay National Estuary Program. 2012. Respect the Connect: The Comprehensive Conservation Management Plan for Baldwin and Mobile Counties, Alabama: 2013-2018 DRAFT.

Moncreiff, C.A. 2002. Seagrass Status and Trands in the Northern Gulf of Mexico: 1940-2002 (Mississippi Sound and the Gulf Islands).

Moreira, M.H., H. Queiroga, M.M. Machado, and M.R. Cunha. 1993. Environmental Gradients in a Southern Europe Estuarine System: Ria de Aveiro, Portugal Implications for Soft Bottom Macrofauna Colonization. Netherlands Journal of Aquatic Ecology, 27(2-4): 465-482.

National Ocean Economics Program. 2012. Environmental and Recreational (Non-Market) Values – Value Estimates for the U.S. Available online at: [http://www.oceaneconomics.org/nonmarket/valEstim.asp].

National Oceanic and Atmospheric Administration. No date. NOAA's Integrated Ecosystem Assessment Program. Found online. Available at: http://www.st.nmfs.noaa.gov/iea/index.html

National Oceanic and Atmospheric Administration. No date (b). *Coastal and Marine Spatial Planning and Integrated Ecosystem Assessments.* NOAA Presentation.

National Oceanic and Atmospheric Administration. No date (c). NOS Estuarine Bathymetry, Mississippi Sound, MS/LA/AL (G170). Found online. Available at: [http://estuarinebathymetry.noaa.gov/bathy_htmls/G170.html].

National Oceanic and Atmospheric Administration. 1985. National Estuarine Inventory – Data Atlas Volume I: Physical and Hydrologic Characteristics.

National Oceanic and Atmospheric Administration. 1997. NOAA's Estuarine Eutrophication Survey, Vol. 4: Gulf of Mexico Region. NOAA, Office of Ocean Resources and Assessment. Silver Spring, Maryland.

National Oceanic and Atmospheric Administration. 2009. FY-2012-2014 Strategic Investment Question, Integrated Ecosystem Assessments: A synthesis and quantative analysis of information on relevant physical, chemical, ecological, and human processes in relation to specified ecosystem management objectives.

National Oceanic and Atmospheric Administration. 2011a. *Clarifying the Relationship among Ecosystem Based Management; Integrated Ecosystem Assessments; and Coastal and Marine Spatial Planning: NOAA Response to SAB/ESMWG Letter of April 5, 2010.*

National Oceanic and Atmospheric Administration. 2011b. *NOAA Response to the SAB-ESMWG Recommendations on Guidelines for NOAA's Integrated Ecosystem Assessment Program.*

National Oceanic and Atmospheric Administration. 2011c. NOAA's State of the Coast: Vulnerability of our Nation's Coasts to Sea Level Rise. Available online at: [http://stateofthecoast.noaa.gov/vulnerability/welcome.html].

National Oceanic and Atmospheric Administration. 2012. Monitoring Estuaries. Available online at: [http://oceanservice.noaa.gov/education/tutorial_estuaries/est10_monitor.html].

National Oceanic and Atmospheric Administration. 2013. Large Marine Ecosystems. Found online. Available at: [http://www.lme.noaa.gov/index.php?option=com_content&view=article&id=47&Itemid=28].

National Oceanic and Atmospheric Administration, Coastal Services Center. No date. Multipurpose Marine Cadastre, Critical Habitat Designations. Found online. Available at: [http://www.marinecadastre.gov/Data/default.aspx].

National Oceanic and Atmospheric Administration Coastal Services Center. 2011. Ecosystem-Based Management: What Makes It A Success?. Available online at: [http://www.csc.noaa.gov/magazine/2011/06/article2.html]

National Oceanic and Atmospheric Administration Coastal Services Center Digital Coast. no date. ENOW Explorer. Available online at: [http://www.csc.noaa.gov/digitalcoast/tools/enow].

National Oceanic and Atmospheric Administration, Economics: National Ocean Watch. no date. ENOW Explorer. Available online at: [http://www.csc.noaa.gov/enow/explorer/].

National Oceanic and Atmospheric Administration, Environmental Response Management Application. 2011. *ERMA Gulf Response*. Found online. Available at: http://gomex.erma.noaa.gov/erma.html#x=-88.25810&y=27.03211&z=6&layers=5723

National Oceanic and Atmospheric Administration Gulf of Mexico Data Atlas. no date. Gulf of Mexico Data Atlas. Available online at: [http://www.ncddc.noaa.gov/website/DataAtlas/atlas.htm#].

National Oceanic and Atmospheric Administration, National Marine Fisheries Service. No date. Multipurpose Marine Cadastre, Habitat Areas of Particular Concern. Found online. Available at: [http://www.marinecadastre.gov/Data/default.aspx].

National Oceanic and Atmospheric Administration Storm Prediction Center. Beaufort Wind Scale. Available online at: [http://www.spc.noaa.gov/faq/tornado/beaufort.html].

National Oceanic and Atmospheric Administration, Ocean Service Education. 2008. Classifying Estuaries By Geology. Found online. Available at: [http://oceanservice.noaa.gov/education/kits/estuaries/estuaries04_geology.html].

National Oceanic and Atmospheric Administration, Office of Response and Restoration. 2012. Environmental Sensitivity Index (ESI) Maps. Found online. Available at: [http://response.restoration.noaa.gov/esi].

National Oceanic and Atmospheric Administration, Ocean Service Education. 2008. Estuaries: Classifying Estuaries by Water Circulation. Available online at: [http://oceanservice.noaa.gov/education/kits/estuaries/estuaries05_circulation.html].

National Ocean Council. 2011. Coastal and Marine Spatial Planning: Public Comments Received 1/24/2011-4/29/2011.

National Ocean Service. 11 January 2013. NOS & Coastal Ecosystem Science. Found online. Available at: [http://oceanservice.noaa.gov/ecosystems/coastalecosci/]

National Ocean Service, Center for Coastal Monitoring and Assessment. No date. Mobile Bay. Found online. Available at: [http://ccma.nos.noaa.gov/stressors/pollution/eutrophication/eutrocards/mobile.pdf].

National Park Service. 2012. Jean Lafitte National Historical Park and Preserve, Louisiana. Found online. Available at: [http://www.nps.gov/jela/index.htm].

National Park Service. 2012b. Gulf Islands National Seashore, Florida and Mississippi. Found online. Available at: [http://www.nps.gov/guis/index.htm].

National Research Council. 2012. Approaches for Ecosystem Services Valuation for the Gulf of Mexico after the Deepwater Horizon Oil Spill: Interim Report. NRC Committee on the Effects of the Deepwater Horizon Mississippi Canyon-252 Oil Spill on Ecosystem Services in the Gulf of Mexico. National Academies Press. Washington, D.C.

NERI. 1997. Integrated Environmental Assessment on Eutrophication, A Pilot Study, Technical Report No. 207. Ministry of Environment and Energy, National Environmental Research Institute. ISBN 87-7772-347-3.

Niedoroda, A.W. 1992. Perdido Bay System Nutrient Loading Study. Environmental Science & Engineering, Inc. Report to the Florida Department of Environmental Regulation.

Niedoroda, A. 2010. Perdido Bay Physical Oceanography (presentation) Development of Numeric Criteria in Florida Estuaries and Coastal Waters Meetings of Marine Numeric Nutrient Criteria Technical Advisory Committee meeting in Pensacola, Florida 10 February 2010. Available online at: [http://www.dep.state.fl.us/water/wqssp/nutrients/estuarine.htm].

Noble, M.A., W.W. Schroeder, W.J. Wiseman Jr., H.F. Ryan, and G. Gelfenbaum. 1996. Subtidal Circulation Patterns in a Shallow, Highly Stratified Estuary: Mobile Bay, Alabama. Journal of Geophysical Research, Vol. 101, No.C11, P.25,689-25,703.

Northern Gulf Institute. No date. *NGI IEA/EAM Context*. NGI presentation.

Norton, B.G. and R.E. Ulanowicz. 1992. Scale and Biodiversity Policy: A Hierarchical Approach. AMBIO: A Journal of the Human Environment 21(3): 244-249.

Noss, R.F. 1990. Indicators for Monitoring Biodiversity: A Hierarchical Approach. Conservation Biology 4(4): 355-364.

Nuttle, W., J. Ault, J. Fourqurean, G. Johns, C. Kelble, D. Lee, B. Leeworthy, D. Lirman, D. Loomis, and J. Lorenz. no date. Integrating Human Dimensions into Goals for Ecosystem Management in the Florida Keys: Experience from the MARES Project.

OECD. 1991. Environmental Indicators, a Preliminary Set. OEDC, Paris.

OECD. 1993. OECD core set of indicators for environmental performance reviews. OECD Environmental Directorate Monographs. No. 83.

Ojeda-Martinez, C., F.G. Casalduero, J.T. Bayle-Sempere, C.B. Cebrian, C. Valle, J.L. Sanchez-Lizaso, A. Forcada, P. Sanchez-Jerez, P. Martin-Sosa, J.M Falcon, F. Salas, M. Graziano, R. Chemello, B. Stobart, P. Cartagena, A. Perez-Ruzafa, F. Vandeperre, E. Rochel, S. Planes, and A. Brito. 2009. A conceptual framework for the integral management of marine protected areas. Ocean and Coastal Management 52: 89-101.

Oliver, J.F. (ed.). 2005. Encyclopedia of World Climatology (Encyclopedia of Earth Sciences Series). Springer. New York.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Assoication of American Geographers 77(1): 118-125.

Omernik J.M., S.S. Chapman, R.A. Lillie, and R.T. Dumke. 2000. Ecoregions of Wisconsin. Transactions of the Wisconsin Academy of Sciences, Arts, and Letters 88:77-103.

Orton, P.M., W.R. McGillis, and C.J. Zappa. 2010. Sea Breeze Forcing of Estuary Turbulence and Air-water CO_2 Exchange. Geophysical Research Letters, 37(13).

O’Learly, D. 1993. Determining Differences in Expert Judgment: Implications for Knowledge Acquisition and Validation. Decision Sciences, 24: 395-408.

O’Neill, R.V., D.L. DeAngelis, J.B. Waide, and T.F.H. Allen. 1986. A hierarchical concept of ecosystems. Princeton University Press, Princeton, New Jersey, USA.

Paine, J.G., and R.A. Morton. 1986. Historical shoreline changes in Trinity, Galveston, West and East Bays, Texas Gulf Coast. Austin, Texas: The University of Texas at Austin, Bureau of Economic Geology, Geology Circular 86-3.

Paulic, M., R. Wieckowicz, K. Sanders, T. McClenahan, T. Seal, A. Dorsett, B. Ruth, S. Alexander, and C. Bunch. 2006. Water Quality Status Report: Perdido River and Bay. Florida Department of Environmental Protection Division of Water Resource Management.

Pendleton, L. 2008. Understanding the Economics of the Coast: An Introduction to This Volume. In: L.H. Pendleton (ed.) The Economic and Market Value of Coasts and Estuaries: What’s at Stake? Restore America’s Estuaries. Arlington, Virginia.

Petraitis, P.S. and S.R. Dudgeon. 2004. Detection of alternative stable states in marine communities. Journal of Experimental Marine Biology and Ecology 300: 343-371.

Petraitis, P.S. and R.E. Latham. 1999. The importance of scale in testing the origins of alternative community states. Ecology 80 (2). p. 429-442.

Phillips, J.D. no date. A Sediment Budget for Galveston Bay. University of Kentucky.

Putrus, P. 1990. Accounting for Intangibles in Integrated Manufacturing (nonfinancial justification based on the Analytic Hierarchy Process). Information Strategy, 6: 25-30.

Queensland Transport and the Great Barrier Reef Marine Park Authority. August 2000. *Oil Spill Risk Assessment for the Coastal Waters of Queensland and the Great Barrier Reef Marine Park.* Queensland Transport, Brisbane, Queensland, Australia.

Ramanujam, V. and T.L. Saaty. 1981. Technological choice in less developed countries. Technological Forecasting and Social Change 19: 81-98.

Rao, R.V. 2013. Improved Multiple Attribute Decision Making Methods. *Decision Making in the Manufacturing Environment Using Graph Theory and Fuzzy Multiple Attribute Decision Making Methods*, Springer Series in Advanced Manufacturing. Springer-Verlag London.

Raven, P.H., R.F. Evert, and S.E. Eichhorn. 2012. Biology of Plants, 8th Ed. W.H. Freeman Publishers. New York.

Rapport, D. and A. Friend. 1970. Towards a Comprehensive Framework for Environmental Statistics: a Stress-Response Approach. Statistics Canada Catalogue 11-510. Minister of Supply and Services Canada, Ottawa.

Reed, D.J. 2002. Sea-level rise and coastal marsh sustainability: geological and ecological factors in the Mississippi delta plain. Geomorphology 48: 233-243.

Rosenberg, A.A. and P.A. Sandifer. 2010. What do managers need? *Ecosystem-Based Management for the Oceans.* K. McLeod and H. Leslie, Eds. p. 13-30.

Saaty, T.L. 1977. Scenarios and Priorities in Transport Planning: Application to the Sudan. Transportation Research 11: 343-350.

Saaty, T.L. 1980. *The Analytic Hierarchy Process*. McGraw-Hill, New York.

Saaty, T.L. 1986. Axiomatic Foundation of the Analytic Hierarchy Process. Management Science 32.7: 841-855.

Saaty, T.L. and K.P. Kearns. 1985. *Analytical Planning: The Organization of Systems.* International Series in Modern Applied Mathematics and Computer Science 7. Pergamon Press, New York.

Saaty, T.L. and L.G. Vargas. 1983. *The Logic of Priorities: Applications in Business, Energy, Health, and Transportation*. Kluwer Boston, Inc. Hingham, Massachusetts.

Schaffer, J.D., R.A. Caruana, and L.J. Eshelman. 1990. Using genetic search to exploit the emergent behavior of neural networks. Physica D: Nonlinear Phenomena 42(1-3): 244-248.

Schroeder, W.W., J.L.W. Cowan, J.R. Pennock, S.A. Luker, and W.J. Wiseman, Jr. 1998. Response of resource excavations in Mobile Bay, Alabama, to extreme forcing. Estuaries, 21(4A): 652-657.

Schwarts, M. (ed.) 2005. Encyclopedia of Coastal Science: 1st Ed. Springer-Verlag. New York.

Scorecard. 2011. Environmental Justice: Distribution of Environmental Burdens. Available online at: [http://scorecard.goodguide.com/community/ej-hotspots.tcl].

Seabergh, W.C. and L.J. Thomas. December 2002. Weir Jetties at Coastal Inlets: Part 2, Case Studies. ERDC/CHL, CHETN-IV-54.

Sheavly, S.B. and H.G. Marshall. 1989. Phytoplankton and Water Quality Relationships Within the Euphotic Zone of Lake Trashmore, Virginia: A Borrow Pit Lake. Castanea, 54(3): 153-163.

Showalter, S. and L.C. Schiavinato. 2003. Marine Protected Areas in the Gulf of Mexico: A Survey. National Sea Grant College Program. MASGP 03-019.

Sigsby, N.J. 2013. Sedimentation processes of Perdido Bay. Mississippi State University Libraries (a thesis).

Silver, N. 2012. *The Signal and the Noise.* The Penguin Press. New York.

Slocombe, D.S. 1998. Defining Goals and Criteria for Ecosystem-Based Management. Environmental Management, v. 22, no. 4.

Smith, G.C., F.J. Saucier, and D. Straub. 2006. Response of the Lower St. Lawerence Estuary to External Forcing in Winter. Journal of Physical Oceanography, 36: 1485-1501.

Smith, J.M. 2010. Class notes from Coastal Engineering. Mississippi State University. Fall semester 2010.

Solomatine, D., L.M. See, and R.J. Abrahart. 2008. Data-Driven Modelling: Concepts, Approaches and Experiences. *Practial Hydroinformatics*, ch. 2. Computational Intelligence and Technological Developments in Water Applications. R.J. Abrahart, L.M. See and D.P. Solomatine, Eds. Springer-Verlag Berlin Heidelberg.

South Central Eco Institute. no date. How Water Quality Indicators Work: Summary of Water Quality Indicators.

Southern California Coastal Water Research Project. 2010. Technical Report 619: Classification of California Estuaries Based on Natural Closure Patterns: Templates for Restoration and Management.

Stevens Jr., H.H., J.F. Ficke, and G.F. Smoot. Techniques of Water-Resources Investigations of the United States Geological Survey.

Stewart. 2005. Tropical Storm Katrina: ZCZC MIATCDAT2 ALL, TTAA00 KNHC DDHHMM. Available online at: [http://www.nhc.noaa.gov/archive/2005/dis/all22005.discus.005.shtml?].

Svarstad, H., L.K. Petersen, D. Rothman, H. Sipel, and F. Watzold. 2008. *Discursive biases of the environmental research framework DPSIR*. Land Use Policy 25. p. 116-125.

Swenson, E.M. and R.E. Turner. 1998. *Past, Present, and Probably Future Saalinity Variations in the Barataria Estuary System.* Final Report to the Coastal Restoarion Division of the Louisiana Department of Natural Resources, coastal ecology division. Baton Rouge, Louisiana.

Swenson, E.M., J.E. Cable, B. Fry, D. Justic, A. Das, G. Snedden, and C. Swarzenski. 2006. Estuarine flushing times influenced by freshwater diversions. In: Coastal Hydrology Processes (Eds. V.P> Singh and Y.J. Xu).

Swenson, E. and S. Welsh. no date. Integrated Ecosystem Assessment for Barataria Basin, Louisiana.

Texas A&M University. no date. Galveston Bay. Available online at: [http://www.tamug.edu/phytoplankton/Research/Galveston_Bay.html].

Tornqvist, T.E., D.J. Wallace, J.E.A. Storms, J. Wallinga, R.L van Dam, M. Blaauw, M.S. Derksen, C.J.W. Klerks, C. Meijneken, and E.M.A. Snijders. 2008. Mississippi Delta subsidence primarily caused by compaction of Holocene strata. Nature Geoscience, 1(3): 173-176.

Triantaphyllou, E. and S.H. Mann. 1995. Using the Analytic Hierarchy Process for Decision Making in Engineering Applications: Some Challenges. International Journal of Industrial Engineering: Applications and Practice 2.1: 35-44.

Troussellier, M., P. Got, M. Bouvy, M. M'Boup, R. Arfi, F. Lebihan, P. Monfort, D. Corbin, and C. Bernard. 2004. Water Quality and Health Status of the Senegal River Estuary. Marine Pollution Bulletin, 48(9-10): 852-862.

Turner, R.E. 1997. Wetland loss in the northern Gulf of Mexico: multiple working hypotheses. Estuaries, 20(1): 1-13.

United Nations Educational, Scientific, and Cultural Organization. 1981. The Practical Salinity Scale 1978 and the International Equation of State of Seawater 1980. Appendix I, Tenth Report of the Joint Panel on Oceanographic Tables and Standards. Paris: UNESCO. UNESCO Technical Papers in Marine Science No. 36. As referenced in FGDC, 2012.

United Nation's Environmental Program, Global Program of Action for the Protection of the Marine Environment from Land-based Activities. 2006. Ecosystem-based Management: Markers for Assessing Progress. Grafisch Centrum Mijdrecht. The Netherlands.

United States Department of Commerce Census Bureau. 2002. State and County QuickFacts. Available online at: [http://quickfacts.census.gov/qfd/states/28000.html].

United States Department of Commerce Census Bureau. 2010. State and County QuickFacts. Available online at: [http://quickfacts.census.gov/qfd/index.html].

United States Environmental Protection Agency. 1999. Importance of Turbidity. EPA Guidance Manual: Turbidity Provisions.

United States Environmental Protection Agency. 2005. Water Quality Study of Bays in Coastal Mississippi Water Quality Report. Project #05-0926.

United States Environmental Protection Agency. 2007b. National Estuary Program Coastal Condition Report: Mobile Bay national Estuary Program.

United States Environmental Protection Agency. 2007. Gulf of Mexico National Estuary Program Coastal Condition, Barataria-Terrebonne National Estuary Program.

United States Environmental Protection Agency. May 2010. Mobile Bay National Estuary Program. Found online. Available at: [http://www.epa.gov/owow_keep/estuaries/pivot/2008mobile_bay.html].

United States Environmental Protection Agency. October 2012. National Estuary Program Overview. Found online. Available at: [http://water.epa.gov/type/oceb/nep/index.cfm].

United States Environmental Protection Agency. 2012. Water: Monitoring & Assessment: 5.5 Turbidity. Found online. Available at: [http://water.epa.gov/type/rsl/monitoring/vms55.cfm].

United States Environmental Protection Agency. 2012b. Western Ecology Division. Found online. Available at: [http://www.epa.gov/wed/pages/ecoregions.htm].

United States Fish and Wildlife Service. September 2011. Mississippi Sandhill Crane National Wildlife Refuge. Found online. Available at: [http://www.fws.gov/mississippisandhillcrane/].

United States Fish and Wildlife Service. 2013. Endangered Species. Available online at: [http://www.fws.gov/endangered/].

United States Fish and Wildlife Service. No date. Grand Bay National Wildlife Refuge. Found online. Available at: [http://www.fws.gov/grandbay/].

United States Fish and Wildlife Service, Southeast Region. No date. Perdido Key Beach Mouse: 5-year Review: Summary and Evaluation. Panama City, Florida

United States Geological Survey Gulf of Mexico Program. 2006. Seagrass Status and Trends in the Northern Gulf of Mexico: 1940-2002. Scientific Investigations Report 2006-5287. U.S. Environmental Protection Agency 855-R-04-003.

University of Michigan. No date. Fisheries Learning on the Web: Water Clarity. Found online. Available at: [http://www.miseagrant.umich.edu/flow/U2/U2-L4_clarity.html].

University of South Carolina. 2012. Social Vulnerability Index for the United States: 2006-2010. Available online at: [http://webra.cas.sc.edu/hvri/products/sovi.aspx].

van Waveren, R.H., S. Groot, H. Scholten, F.C. van Greer, J.H.M. Wösten, R.D. Koeze, and J.J. Noort. 2005. Good Modelling Practice Handbook. STOWA Report 99-05. Utrecht, RWS-RIZA. Lelystad, The Netherlands.

Venice System. 1959. The Venice System for the Classification of Marine Waters According to salinity. Archivio Oceanographic Limnology, 9: 243-245.

Wabalickis, R.N. 1988. Justification of FMS with the Analytic Hierarchy Process. Journal of Manufacturing Systems, 17: 175-182.

Walker, G. The Tipping Point of the Iceberg. Nature, Vol. 441: 802-805. Nature Publishing Group.

Wall, D.H. 2004. Sustaining biodiversity and ecosystem services in soils and sediments. The Scientific Committee on Problems of the Environment (SCOPE). SCOPE 64. Island Press. Washington, D.C.

Wang, L. and T. Raz. 1991. Analytic Hierarchy Process Based on Data Flow Problem. Computers and IE, 20: 355-365.

Ward, G.M., P.M. Harris, and A.K. Ward. 2005. Gulf Coast rivers of the southeastern United States. In: *Rivers of North America.* A.C. Benke and C.E. Cushing (eds.). Elsevier Academic Press. Burlington, Massachusetts.

Warnock, J.E. 1950. Hydraulic similitude. *Engineering Hydraulics.* H. Rouse [ed.], 136-176. Wiley and Sons, New York.

Whitfield, A.K. 1992. A Characterization of South African Estuarine Systems. Taylor and Francis. United Kingdom.

White House Council on Environmental Policy. 2010. *Final Recommendations of the Ocean Policy Task Force.* White House Press, Washington, D.C.

Winter, M. 2009. Barataria Basin: Potential Large Scale Mitigation Projects. USACE Hurrican and Storm Damage Risk Reduction System Mitigation Workshop.

Xin, P., C. Robinson, L. Ling, D.A. Barry, and R. Bakhyar. 2010. Effects of Wave Forcing on a Subterranean Estuary. Water Resources Research, 46.

Yoskowitz, D., C. Carollo, J. Beseres-Pollack, K. Welder, C. Santos, and J. Francis. 2012. Assessment of Changing Ecosystem Services Provided by Marsh Habitat in the Galveston Bay Region. Harte Research Institute. Corpus Chrisit, Texas.

Zhao, H., Q. Chen, N.D. Walker, Q. Zheng, and H.L. Macintyre. 2011. A study of sediment transport in a shallow estuary using MODIS imagery and particle tracking simulation. International Journal of Remote Sensing, 32(21): 6653-6671.

zu Ermgassen, P.S.E., M.D. Spalding, R.E. Grizzle, and R.D. Brumbaugh. 2012. Quantifying the Loss of a Marine Ecosystem Service: Filtration by the Eastern Oyster in US Estuaries. Estuaries and Coasts 36:36-43.

APPENDIX A

MANAGED AREAS IN THE NORTHERN GULF OF MEXICO

The following shows the marine protected areas in the Gulf of Mexico and designates them as federally managed areas, federal-state cooperatives, or state managed areas (Showalter and Schiavinato, 2003).

Alabama	
Bon Secour National Wildlife Refuge	Federally Managed
Mobile Bay National Estuary Program	Federal-State Cooperatives
Weeks Bay National Estuarine Research Reserve	Federal-State Cooperatives
Cat Island	State Managed
Gulf State Park	State Managed
Grand Bay Savanna Bioreserve	State Managed
Lillian Swamp	State Managed
Meaher State Park	State Managed
Mobile-Tensaw River Delta	State Managed
Orange Beach Maritime Forest	State Managed
South Mon Louis Island Salt Marsh	State Managed
Florida	
Cedar Key National Wildlife Refuge	Federally Managed
Chassahowitzka National Wildlife Refuge	Federally Managed
Crocodile National Wildlife Refuge	Federally Managed
Crystal River National Wildlife Refuge	Federally Managed
Egmont Key National Wildlife Refuge	Federally Managed
Gulf Islands National Seashore	Federally Managed
Island Bay National Wildlife Refuge	Federally Managed
J.N. "Ding" Darling National Wildlife Refuge	Federally Managed
Lower Suwannee National Wildlife Refuge	Federally Managed
Matlacha Pass National Wildlife Refuge	Federally Managed
Pine Island National Wildlife Refuge	Federally Managed
Pinellas National Wildlife Refuge	Federally Managed
St. Marks National Wildlife Refuge	Federally Managed
St. Vincent National Wildlife Refuge	Federally Managed
Ten Thousand Islands National Wildlife Refuge	Federally Managed
Apalachicola National Estuarine Research Reserve	Federal-State Cooperatives
Charlotte Harbor National Estuary Program	Federal-State Cooperatives
Rookery Bay National Estuarine Research Reserve	Federal-State Cooperatives
Sarasota Bay National Estuary Program	Federal-State Cooperatives
Tampa Bay Estuary Program	Federal-State Cooperatives
Alligator Harbor Aquatic Preserve	State Managed
Apalachicola Bay Aquatic Preserve	State Managed

Big Bend Seagrasses Aquatic Preserve	State Managed
Boca Ciega Bay Aquatic Preserve	State Managed
Cape Haze Aquatic Preserve	State Managed
Cape Romano-Ten Thousand Islands Aquatic Preserve	State Managed
Charlotte Harbor State Buffer Preserve	State Managed
Cockroach Bay Aquatic Preserve	State Managed
Estero Bay Aquatic Preserve	State Managed
Estero Bay State Buffer Preserve	State Managed
Fort Pickens State Park Aquatic Preserve	State Managed
Gasparilla Sound-Charlotte Harbor Aquatic Preserve	State Managed
Lemon Bay Aquatic Preserve	State Managed
Matlacha Pass Aquatic Preserve	State Managed
Pine Island Sound Aquatic Preserve	State Managed
Pinellas County Aquatic Preserve	State Managed
Rocky Bayou Aquatic Preserve	State Managed
Rookery Bay Aquatic Preserve	State Managed
St. Andrews State Park Aquatic Preserve	State Managed
St. Joseph Bay Aquatic Preserve	State Managed
St. Joseph Bay State Buffer Preserve	State Managed
St. Martins Marsh Aquatic Preserve	State Managed
Terra Ceia Aquatic Preserve	State Managed
Yellow River Marsh Aquatic Preserve	State Managed
Louisiana	
Breton National Wildlife Refuge	Federally Managed
Bayou Sauvage National Wildlife Refuge	Federally Managed
Cameron Prarie National Wildlife Refuge	Federally Managed
Delta National Wildlife Refuge	Federally Managed
Sabine National Wildlife Refuge	Federally Managed
Shell Keys National Wildlife Refuge	Federally Managed
Barataria-Terrebone National Estuary Program	Federal-State Cooperatives
Atchafalaya Delta Wildlife Management Area	State Managed
Biloxi Wildlife Management Area	State Managed
Isles Dernieres Barrier Islands Refuge	State Managed
Marsh Island Wildlife Refuge	State Managed
Pass-a-Loutre Wildlife Management Area	State Managed
Pointe-au-Chenes Wildlife Management Area	State Managed
Rockefeller Wildlife Refuge	State Managed
Salvador Wildlife Management Area	State Managed
State Wildlife Refuge	State Managed
Timken Wildlife Management Area	State Managed

Wisner Wildlife Management Area	State Managed
Mississippi	
Grand Bay National Wildlife Refuge	Federally Managed
Gulf Islands National Seashore	Federally Managed
Sandhill Crane National Wildlife Refuge	Federally Managed
Grand Bay National Estuarine Research Reserve	Federal-State Cooperatives
Bayou La Croix Coastal Preserve	State Managed
Bayou Protage Coastal Preserve	State Managed
Bellefontaine Marsh Coastal Preserve	State Managed
Biloxi River Marshes Coastal Preserve	State Managed
Davis Bayou Coastal Preserve	State Managed
Deer Island Coastal Preserve	State Managed
Escatawpa River Marsh Coastal Preserve	State Managed
Grand Bay Savanna Coastal Preserve	State Managed
Grand Bayou Coastal Preserve	State Managed
Graveline Bay Coastal Preserve	State Managed
Hancock County Marsh Coastal Preserve	State Managed
Jourdan River Coastal Preserve	State Managed
Old Fort Bayou Coastal Preserve	State Managed
Pascagoula River Marsh Coastal Preserve	State Managed
Round Island Coastal Preserve	State Managed
Wolf River Marsh Coastal Preserve	State Managed
Texas	
Anahuac National Wildlife Refuge	Federally Managed
Aransas National Wildlife Refuge	Federally Managed
Big Boggy National Wildlife Refuge	Federally Managed
Brazoria National Wildlife Refuge	Federally Managed
Flow Garden Banks National Marine Sanctuary	Federally Managed
Laguna Atascosa National Wildlife Refuge	Federally Managed
McFaddin National Wildlife Refuge	Federally Managed
Moody National Wildlife Refuge	Federally Managed
Padre Island National Seashore	Federally Managed
San Bernard National Wildlife Refuge	Federally Managed
Texas Point National Wildlife Refuge	Federally Managed
Coastal Bend Bay National Estuary Program	Federal-State Cooperatives
Galveston Bay National Estuary Program	Federal-State Cooperatives
Armand Bay Coastal Preserve and Nature Center	State Managed
Atkinson Island Wildlife Management Area	State Managed
Boca Chica State Park	State Managed
Candy Cain Abshier Wildlife Management Area	State Managed

Christmas Bay Coastal Preserve	State Managed
D.R. Wintermann Wildlife Management Area	State Managed
Freeport Liberty Ship Reef Complex	State Managed
Galveston Island State Park	State Managed
Goose Island State Park	State Managed
Guadalupe Delta Wildlife Management Area	State Managed
J.D. Murphree Management Area	State Managed
Laguna Madre	State Managed
Lower Neches Wildlife Management Area	State Managed
Mad Island Wildlife Management Area	State Managed
Matagorda Island Wildlife Management Area and State Park	State Managed
Mustang Island State Park	State Managed
North Deer Island Sanctuary	State Managed
Peach Point Wildlife Management Area	State Managed
Redhead Pond Wildlife Management Area	State Managed
Sea Rime State Park	State Managed
South Bay Coastal Preserve	State Managed
Tony Houseman Wildlife Management Area	State Managed
Welder Flats Coastal Preserve	State Managed
Welder Flats Wildlife Management Area	State Managed

APPENDIX B

MANAGEMENT PROTOCOL EXPERT SURVEY

Management protocol expert survey

The analytical hierarchical process (AHP) was developed by Thomas Saaty in 1986. It is, simply put, a method that can be implemented to derive ratios from pair-wise comparisons. Table B.1 shows the Fundamental Scale.

Table B.1 The Fundamental Scale.

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one active over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit
Rationals	Rations arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix
1.1-1.9	For tied activities	When elements are close and nearby indistinguishable; moderate is 1.3 and extreme is 1.9

(Saaty, 1986)

The Fundamental Scale is a scale of absolute numbers used to assign numerical values to judgments made by comparing two elements with the smaller element used as the unit and the larger one assigned a value from this scale as a multiple of that unit (Saaty, 1986).

Each of the indicators that will be used in this work are listed and defined below. Pairs have been formed so that you can make comparisons for each set of indicators.

After the results from the survey are collected, the data will be analyzed and weights will be derived using the AHP developed by Saaty along with the survey results.

A copy of this document will be included in my dissertation as an appendix. However, only aggregate results will be published.

Biological and Ecological Indicators

The biological and ecological indicators are meant to characterize the health of the ecosystem. Components of this sub-matrix describe the growing environment for the flora and fauna, identifies areas of concern, and can tell of the overall health of the area using the health of indicator species. Seven biological and ecological indicators have been identified to describe the health of the system. These indicators are:

Phytoplankton productivity values

Based upon the CMECS classifications for productivity which was modified from the NOAA Estuarine Eutrophication Survey (1997), phytoplankton productivity values are measured based upon the level of chlorophyll a in the water column. Chlorophyll a is a form of chlorophyll that is used in photosynthesis by eukaryotes, cyanobacteria, and prochlorophytes (Raven et al., 2012). Chlorophyll a content in the water column reflects the productivity of the system and can indicate the balance and status of the system.

Coastal habitat: indicator species health

Indicator species health and trends will be used as a gauge of the overall habitat health of an area. Also known as sentinel organisms, indicator species' health and population trends are useful for monitoring the health of an ecosystem. Generally, an indicator species is chosen for two reasons: first, the species must convey meaningful information, and second, the species must be able to be reliably measured.

The trend of each indicator species will be designated as very poor, poor, moderate, good, or very good as an indicator of the future outlook each species has for a particular habitat based upon previous trends.

Marine trophic index

The marine trophic index (MTI) was established by the University of British Columbia's Fisheries Center to describe the complex interactions between fisheries and marine ecosystems (Biodiversity Indicators Partnership, 2010). The MTI of an ecosystem is calculated using "catch composition data collected by the Food and Agricultural Organization of the United Nations" (BIP, 2010).

The MTI for each country's exclusive economic zone (EEZ) and all LMEs were calculated from 1950 to 2011. The MTI expresses the trend of the diversity and abundance of different fish species high in the food chain.

Critical habitat designation

Under the ESA, critical habitat is defined as: "1. Specific areas within the geographical area occupied by the species at the time of listing, if they contain physical or biological features essential to conservation, and those features may require special management considerations or protection; and 2. Specific areas outside the geographical area occupied by the species if the agency determines that the area itself is essential for conservation" (NOAA Coastal Services Center in the Marine Cadastre, n.d.).

Based upon the total surface area designated as critical habitat, the amount of each grid square covered in critical habitat will be calculated and represented as a percent.

Habitat areas of particular concern

Habitat areas of particular concern are designated by NOAA National Marine Fisheries Service as "discrete subsets of Essential Fish Habitat that provide extremely important ecological function or are especially vulnerable to degradation" (NOAA National Marine Fisheries Service in Marine Cadastre, n.d.).

The total surface area of each grid square designated as a habitat area of particular concern (HAPC) will be used to determine the amount of HAPC located in each square as a percent.

Endangered species act: number of threatened and endangered species

The number of endangered and threatened species in a particular habitat can indicate the overall health of the habitat and surrounding area. As the amount of endangered and threatened species in an area increases, the more likely it is that irreversible changes are being made to the ecosystem. As such, both the number of threatened and endangered species that can be found in each area is noted so that management actions can be decided upon that will not harm these species.

Environmental sensitivity index

Environmental Sensitivity Index (ESI) maps provide a summary of coastal resources that are at risk from natural disasters and usually include information for at-risk resources such as biological resources, sensitive shorelines, and human resources (NOAA ORR, 2012).

Each state on the Gulf of Mexico has ESI maps; however it is important to note that the designations vary from state to state. As such, ESI maps will be reviewed to identify at-risk resources and sensitive shorelines as protecting these areas are essential in creating effective management plans.

Phytoplankton Productivity Value	9	7	5	3	1	3	5	Indicator Species Health
Phytoplankton Productivity Value	9	7	5	3	1	3	5	Marine Trophic Index
Phytoplankton Productivity Value	9	7	5	3	1	3	5	Critical Habitat Designation
Phytoplankton Productivity Value	9	7	5	3	1	3	5	Habitat Areas Of Particular Concern
Phytoplankton Productivity Value	9	7	5	3	1	3	5	ESA Number Of Species
Phytoplankton Productivity Value	9	7	5	3	1	3	5	Environmental Sensitivity Index
Indicator Species Health	9	7	5	3	1	3	5	Marine Trophic Index
Indicator Species Health	9	7	5	3	1	3	5	Critical Habitat Designation
Indicator Species Health	9	7	5	3	1	3	5	Habitat Areas Of Particular Concern
Indicator Species Health	9	7	5	3	1	3	5	ESA Number Of Species
Indicator Species Health	9	7	5	3	1	3	5	Environmental Sensitivity Index

Phytoplankton Productivity Value — 9 7 5 3 1 3 5 — Indicator Species Health

Phytoplankton Productivity Value — 9 7 5 3 1 3 5 — Marine Trophic Index

Phytoplankton Productivity Value — 9 7 5 3 1 3 5 — Critical Habitat Designation

Phytoplankton Productivity Value — 9 7 5 3 1 3 5 — Habitat Areas Of Particular Concern

Phytoplankton Productivity Value — 9 7 5 3 1 3 5 — ESA Number Of Species

Phytoplankton Productivity Value — 9 7 5 3 1 3 5 — Environmental Sensitivity Index

Indicator Species Health — 9 7 5 3 1 3 5 — Marine Trophic Index

Indicator Species Health — 9 7 5 3 1 3 5 — Critical Habitat Designation

Indicator Species Health — 9 7 5 3 1 3 5 — Habitat Areas Of Particular Concern

Indicator Species Health — 9 7 5 3 1 3 5 — ESA Number Of Species

Indicator Species Health — 9 7 5 3 1 3 5 — Environmental Sensitivity Index

Physical Indicators

The physical indicators are meant to describe the properties of the ecosystem from a purely descriptive perspective. Components of this sub-matrix can be used to describe the system – from the way it was originally formed to the processes that are currently influencing it. Six physical indicators and nine sub-indicators have been identified to adequately describe the properties of the system. These indicators are:

Water quality

Water quality refers the condition of water in an area. Multiple factors affect the water quality in an area, and as such, the water quality indicator will be described using six different sub-indicators:

Water temperature

Measured in °C

Salinity

Measured in psu

Photic quality

The photic quality of the water column refers to the depth of water that is exposed to sufficient light to allow photosynthesis to occur. Photic quality is highly variable and depends upon multiple factors including water column depth, turbidity, the angle of the sun, the season, and cloud cover.

The photic quality expresses light penetration adequacy for aquatic plants and animals.

Oxygen Level

Dissolved oxygen is measured in milligrams per liter (mg/L) which represents the milligrams of oxygen dissolved in a liter of water.

Turbidity

Turbidity is the measure of water clarity and is dependent upon the amount of suspended and dissolved solids in the water column. Turbidity values were established from CMECS which reports turbidity based on Secchi disk depth.

Predominant bottom sediment type

The predominant bottom sediment type is measured using the sediment grain size diameter, typically measured in millimeters or using the phi scale. A sediment classification (based on ASCE, 2007) will be determined based upon the grain size diameter or the phi value.

Energy

The energy in a system can have a tremendous effect on what happens within a system. Energy can be added to a system in a variety of ways. For this framework, four sub-indicators of energy have been identified: freshwater flow into the system, energy added to the system through waves, energy added to the system through wind, and energy added to the system through tidal exchanges.

Freshwater flow

The amount of freshwater that enters a system has a profound impact on the ecosystem in two main ways: the freshwater dilutes the salinity of the ecosystem which can cause a large change in the flora and fauna in the system, and the incoming flow can be the predominant forcing mechanism of the area contributing large amounts of energy to the system. To determine the impact of the freshwater flow on the system, the amount of freshwater that enters the system during one tidal cycle will be divided by the tidal prism. Different freshwater flow regimes have been established based upon this ratio and are: slight impact (0 to 20%), low impact (20 to 40%), moderate impact (40 to 60%), high impact (60 to 80%) and complete impact (≥80%).

Wave energy regime

Generally, as wave amplitude increases the energy supplied to the system increases as well. Different wave energy regimes have been established based upon wave amplitude and are: quiescent (<0.1 m), very low energy (0.1 to <0.25 m), low energy (0.25 to <1 m), moderate energy (1 to <2 m), moderately high energy (2 to <4 m), high energy (4 to <8 m), and very high energy (≥8 m).

Wind Energy

As the wind velocity of an area increases, so does the amount of energy within the system. The mean wind velocity over a tidal period in each area will be computed and ranked using the Beaufort scale. Each area will be assigned a Beaufort number and description depending upon the wind speed. The scale is: 0/calm (< 0.3 m/s), 1/light air (0.3-1.5 m/s), 2/light breeze (1.6 to 3.4 m/s), 3/gentle breeze (3.5 to 5.4 m/s), 4/moderate breeze (5.5 to 7.9 m/s), 5/fresh breeze (8.0 to 10.7 m/s), 6/strong breeze (10.8 to 13.8 m/s), 7/high wind (13.9 to 17.1 m/s), 8/gale (17.2 to 20.7 m/s), 9/strong gale (20.8 to 24.4 m/s), 10/storm (24.5 to 28.4 m/s), 11/violent storm (28.5 o 32.6 m/s), and 12/hurricane (≥32.7 m/s).

Tidal regime

The tidal regime of each area is based upon the mean tidal range in meters in each area. The classifications are: microtidal (<2 m), mesotidal (2 to < 4 m), macrotidal (4 to <6 m), an hypertidal (≥6 m).

Mixing regime

Mixing regimes have been identified based upon Simmons Number which is a ratio of the freshwater inflow during one tidal cycle to the tidal prism. The higher the Simmons Number, the more stratified the system is.

Bed slope

The mean bed slope of an area will be calculated using bathymetric information. As the mean depth will be recorded, having an indicator of the slope is important to indicate to the manager using the framework what is happening in the system

Wave climate

The wave climate refers to where the waves within the estuary are generated. There are three categories of wave climate: full exposure, partial exposure, and locally generated.

Water Quality	9	7	5	3	1	3	5	7	9	Predominant Bottom Sediment Type
Water Quality	9	7	5	3	1	3	5	7	9	Energy
Water Quality	9	7	5	3	1	3	5	7	9	Mixing Regime
Water Quality	9	7	5	3	1	3	5	7	9	Bed Slope
Water Quality	9	7	5	3	1	3	5	7	9	Wave Climate
Predominant Bottom Sediment Type	9	7	5	3	1	3	5	7	9	Energy
Predominant Bottom Sediment Type	9	7	5	3	1	3	5	7	9	Mixing Regime
Predominant Bottom Sediment Type	9	7	5	3	1	3	5	7	9	Bed Slope
Predominant Bottom Sediment Type	9	7	5	3	1	3	5	7	9	Wave Climate
Energy	9	7	5	3	1	3	5	7	9	Mixing Regime
Energy	9	7	5	3	1	3	5	7	9	Bed Slope

Energy 9 7 5 3 1 3 5 7 9 Wave Climate

Mixing Regime 9 7 5 3 1 3 5 7 9 Bed Slope

Mixing Regime 9 7 5 3 1 3 5 7 9 Wave Climate

Bed Slope 9 7 5 3 1 3 5 7 9 Wave Climate

Water Temperature 9 7 5 3 1 3 5 7 9 Salinity

Water Temperature 9 7 5 3 1 3 5 7 9 Photic Quality

Water Temperature 9 7 5 3 1 3 5 7 9 Oxygen Level

Water Temperature 9 7 5 3 1 3 5 7 9 Turbidity

Salinity 9 7 5 3 1 3 5 7 9 Photic Quality

Salinity 9 7 5 3 1 3 5 7 9 Oxygen Level

Salinity 9 7 5 3 1 3 5 7 9 Turbidity

Photic Quality	9	7	5	3	1	3	5	7	9	Oxygen Level
Photic Quality	9	7	5	3	1	3	5	7	9	Turbidity
Oxygen Level	9	7	5	3	1	3	5	7	9	Turbidity
Freshwater Flow	9	7	5	3	1	3	5	7	9	Wave Energy
Freshwater Flow	9	7	5	3	1	3	5	7	9	Wind Energy
Freshwater Flow	9	7	5	3	1	3	5	7	9	Tidal Regime
Wave Energy	9	7	5	3	1	3	5	7	9	Wind Energy
Wave Energy	9	7	5	3	1	3	5	7	9	Tidal Regime
Wind Energy	9	7	5	3	1	3	5	7	9	Tidal Regime

Human and Economic Indicators

The human and economic indicators are meant to define the relationships that exist between humans and the ecosystem. Components of this sub-matrix are used to detail human activities in the ecosystem, societal values placed upon the ecosystem, and the economic impact the ecosystem has on those living in the area. Five human and economic indicators and twenty six sub-indicators have been identified to describe the dependence humans have on the ecosystem. These indicators are:

Economic impact

NOAA's Coastal Services Center, the Bureau of Economic Analysis, and the Bureau of Labor Statistics have worked together to develop Economics: National Ocean Watch (ENOW) as a part of NOAA's Digital Coast. ENOW is a web-based service that "describes six economic sectors that depend on the oceans and Great Lakes: living resources, marine construction, marine transportation, offshore mineral resources, ship and boat building, and tourism and recreation

ENOW contains annual time-series data […] derived from the Bureau of Labor Statistics and the Bureau of Economic Analysis. Four economic indicators are provided: establishments, employment, wages, and gross domestic product" (NOAA, n.d.).

Since the waterbodies used in the development and validation of the framework contribute to the economies in multiple counties, the aggregated trend data for all of the counties bordering the waterbody will be compiled to yield an average trend for the entire system. Then, using the state-level aggregated data, the percent each sector-indicator combination contributes to the state government will be calculated. Ranges for the percent each waterbody contributes to the state economically were developed. Each sector-indicator combination will be designated a contribution level. There are 24 sector-indicator combinations:

Living resources/establishments

Living resources/employment

Living resources/wages

Living resources/GDP

Marine construction/establishments

Marine construction/employment

Marine construction/wages

Marine construction/GDP

Ship and boat building/establishments

Ship and boat building/employment

Ship and boat building/wages

Ship and boat building/GDP

Marine transportation/establishments

Marine transportation/employment

Marine transportation/wages

Marine transportation/GDP

Offshore mineral extraction/establishments

Offshore mineral extraction/employment

Offshore mineral extraction/wages

Offshore mineral extraction/GDP

Tourism and recreation/establishment

Tourism and recreation/employment

Tourism and recreation/wages

Tourism and recreation/GDP

Ecosystem services

Ecosystem services are non-monetary services an ecosystem provides to an area. In 2005, the Millennium Ecosystem Assessment (MEA) was published. The MEA is “an international assessment of the consequences of ecosystem change for human well-being” (Food and Agriculture Organization of the United Nations, 2010). The MEA defines ecosystem services as “all benefits that humans receive from ecosystems. These benefits can be direct or indirect, through the function of ecosystem processes that produce direct services […]” (FAO UN, 2010).

Environmental Justice

Defined in the Principles and Requirements for Federal Investments in Water Resources (March 2013), environmental justice is “the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respece to the development, implementation, and enforcement of environmental laws, regulations, and policies.” When implementing ecosystem-based management plans, care should be taken to avoid “disproportionate adverse effects on these communities” as stated in a Guidance Under the National Environmental Policy Act (59 Fed. Reg. 7629 (1994) and 42 USC §4321 et seq.).

Public Health

This refers to the overall quality of health and wellbeing in an area as reported by Kids Count, funded by the Annie E. Casey Foundation. Kids Count ® “is a national and state-by-state effort to track the well-being of children in the United States." Data from Kids Count ® is reported only for individuals under 18 years of age. This data was used as health data was not available for the general public. This indicator includes two sub-indicators: mental health indices and general health indices.

Mental Health

Mental health is a "state of well-being in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community," (World Health Organization, 2001). Mental health data in Kids Count ® refers to the percent of "children who have one or more emotional, behavioral, or developmental condition". This percent will be compared to the overall percent of children having conditions in the United States and will be reported for the waterbody in that state.

General Health

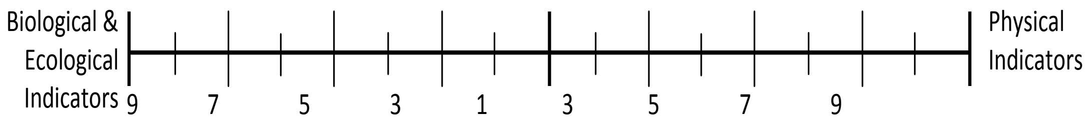
General health is a measure of the overall physical health and wellbeing of an individual. Kids Count ® ranks each state with an overall health rank where a high rank indicates a higher general health whereas a lower rank indicates poorer general health. The overall rank of a state will be reported for the waterbody in the state.

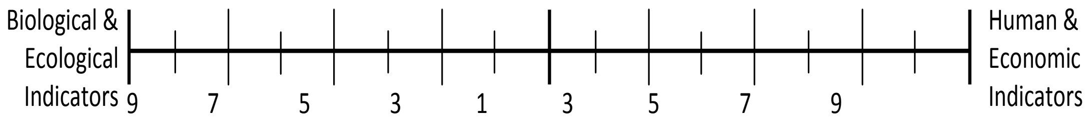
Social Vulnerability to Environmental Hazards

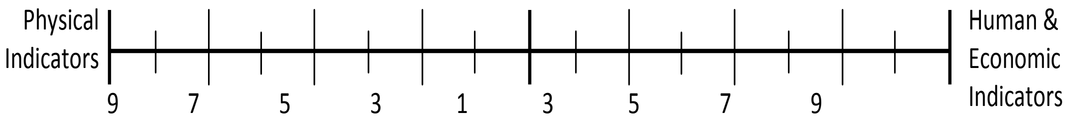
"The Social Vulnerability Index (SoVI®) 20006-10 measures the social vulnerability of U.S. Counties to environmental hazards. The index is a comparative metric that facilitates the examination of the differences in social vulnerability among counties. It graphically illustrates the geographic variation in social vulnerability. It shows where there is uneven capacity for preparedness and response and where resources might be used most effectively to reduce the pre-existing vulnerability. The index synthesizes 30 socioeconomic variables, which the research literature suggests contribute to reduction in a community's ability to prepare for, respond to, and recover from hazards. SoVI ® data sources include primarily those from the United States Census Bureau." (University of South Carolina, 2012).

As SoVI ® scores are generated by county and then a national percentile is calculated for each county, the average national percentile will be computed for the counties surrounding each waterbody and that value will be assigned to the waterbody.

Economic Impact	9	7	5	3	1	3	5	7	9	Ecosystem Services
Economic Impact	9	7	5	3	1	3	5	7	9	Environmental Justice
Economic Impact	9	7	5	3	1	3	5	7	9	Public Health
Economic Impact	9	7	5	3	1	3	5	7	9	Social Vulnerability
Ecosystem Services	9	7	5	3	1	3	5	7	9	Environmental Justice
Ecosystem Services	9	7	5	3	1	3	5	7	9	Public Health
Ecosystem Services	9	7	5	3	1	3	5	7	9	Social Vulnerability
Environmental Justice	9	7	5	3	1	3	5	7	9	Public Health
Environmental Justice	9	7	5	3	1	3	5	7	9	Social Vulnerability
Public Health	9	7	5	3	1	3	5	7	9	Social Vulnerability
Mental Health	9	7	5	3	1	3	5	7	9	General Health







For each of the parameters below, please rank the importance of each spatial scale. 1 indicates the least important and 4 indicates the most important.

Table B.2 Spatial Scale Survey

Parameter	**Meters**	**Kilometers**	**1000 km**	**More**
Phytoplankton Productivity				
Indicator Species Health				
Marine Trophic Index				
Critical Habitat Designation				
Habitat Areas of Particular Concern				
ESA Number of Species				
Environmental Sensitivity Index				
Water Quality				
Predominant Bottom Sediment Type				
Energy				
Mixing Regime				
Bed Slope				
Wave Climate				
Economic Impact				
Ecosystem Services				
Environmental Justice				
Public Health				
Social Vulnerability Index				

For each of the parameters below, please rank the importance of each temporal scale. 1 indicates the least important and 6 indicates the most important.

Table B.3 Temporal Scale Survey

Parameter	Daily	Monthly	Annually	Decadal	Centurial	More
Phytoplankton Productivity						
Indicator Species Health						
Marine Trophic Index						
Critical Habitat Designation						
Habitat Areas of Particular Concern						
ESA Number of Species						
Environmental Sensitivity Index						
Water Quality						
Predominant Bottom Sediment Type						
Energy						
Mixing Regime						
Bed Slope						
Wave Climate						
Economic Impact						
Ecosystem Services						
Environmental Justice						
Public Health						
Social Vulnerability Index						

Additional Questions:

When answering the questionnaire above, did you answer for CMSP, IEA, or EBM?

What LME do you work in?

How many years have you been working on EBM for aquatic environments?

How has your LME dealt with dividing its region to create and implement management plans?

In your opinion, what are some barriers to EBM?

In your opinion, are there any additional parameters that need to be considered in the development of this framework?

APPENDIX C

SPATIAL SCALE BOX AND WHISKER PLOTS

C.1 Integrated Ecosystem Assessment

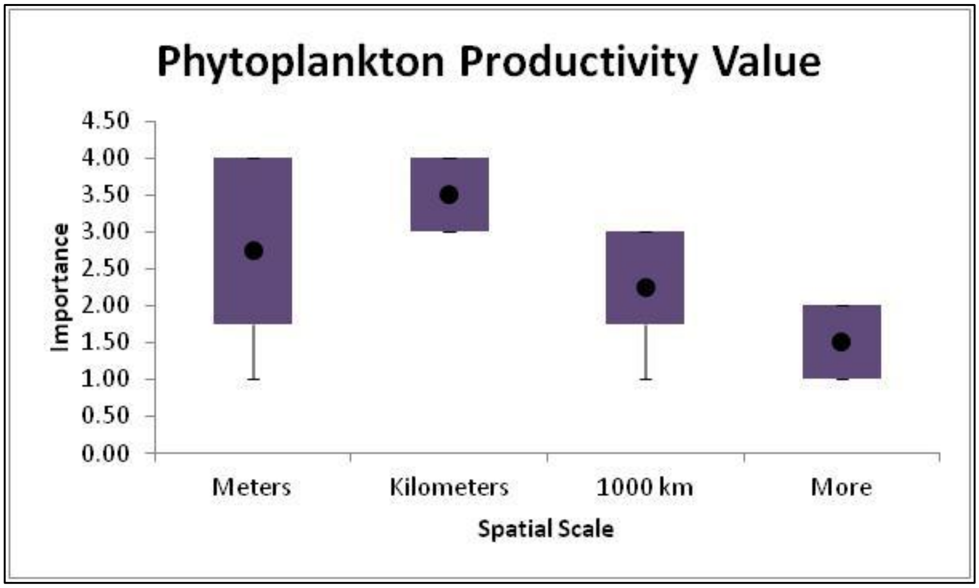


Figure C.1 IEA Spatial Scale: Phytoplankton Productivity Value

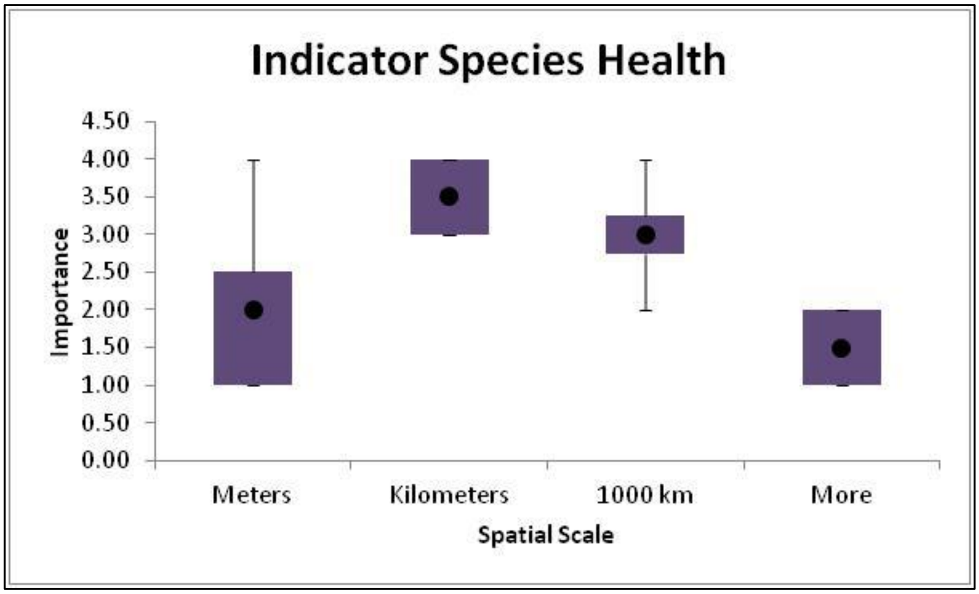


Figure C.2 IEA Spatial Scale: Indicator Species Health

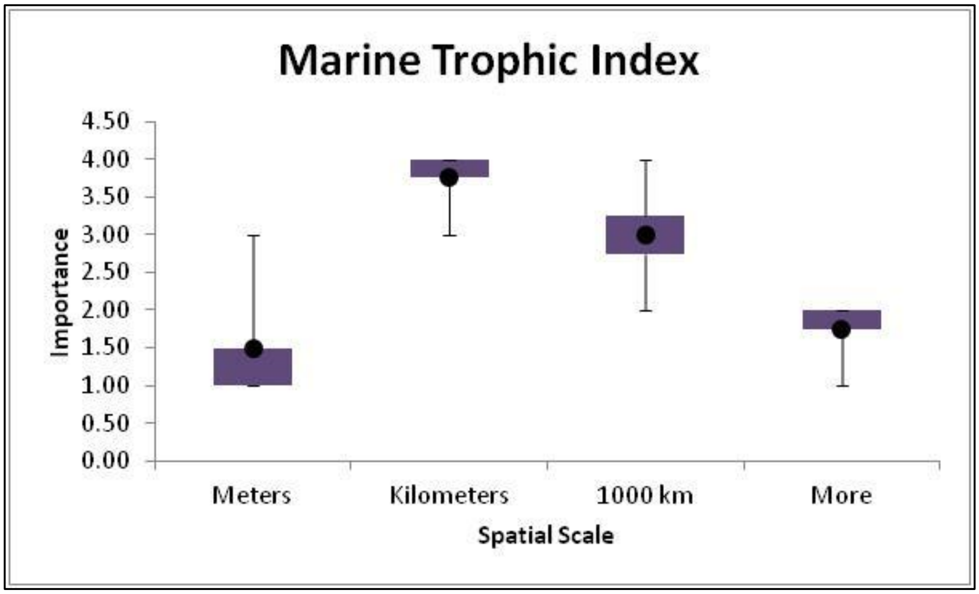


Figure C.3 IEA Spatial Scale: Marine Tropic Index

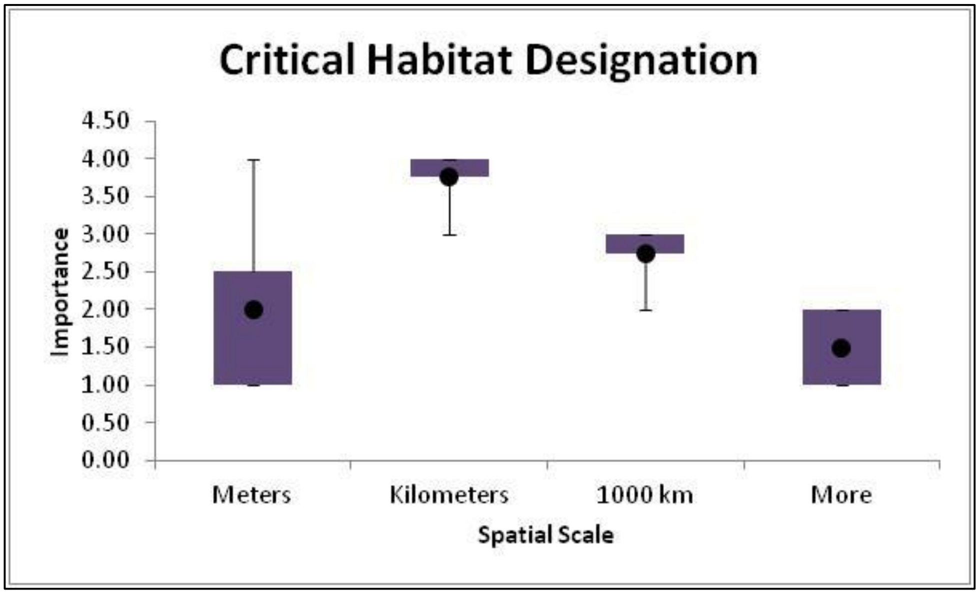


Figure C.4 IEA Spatial Scale: Critical Habitat Designation

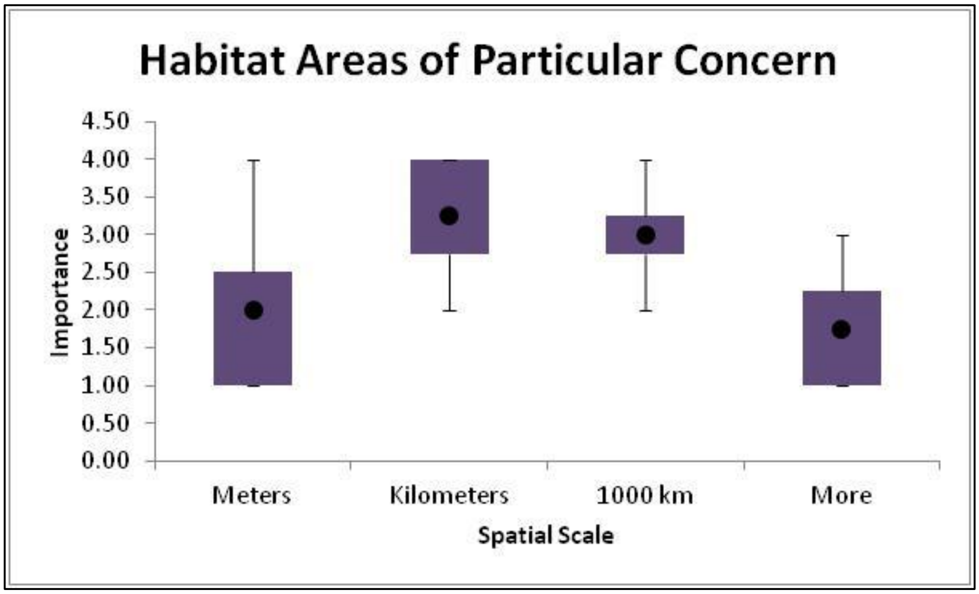


Figure C.5 IEA Spatial Scale: Habitat Areas of Particular Concern

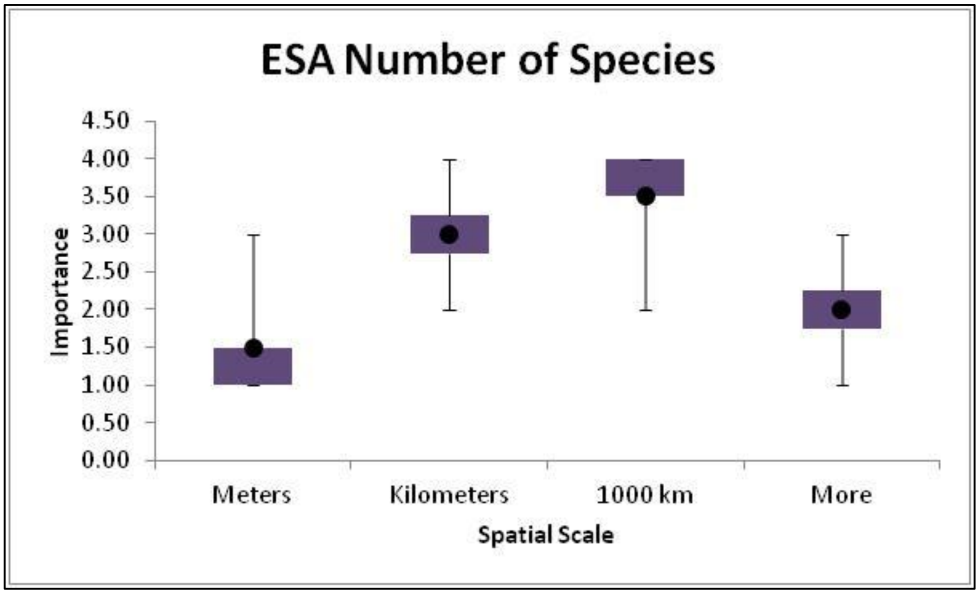


Figure C.6 IEA Spatial Scale: ESA Number of Species

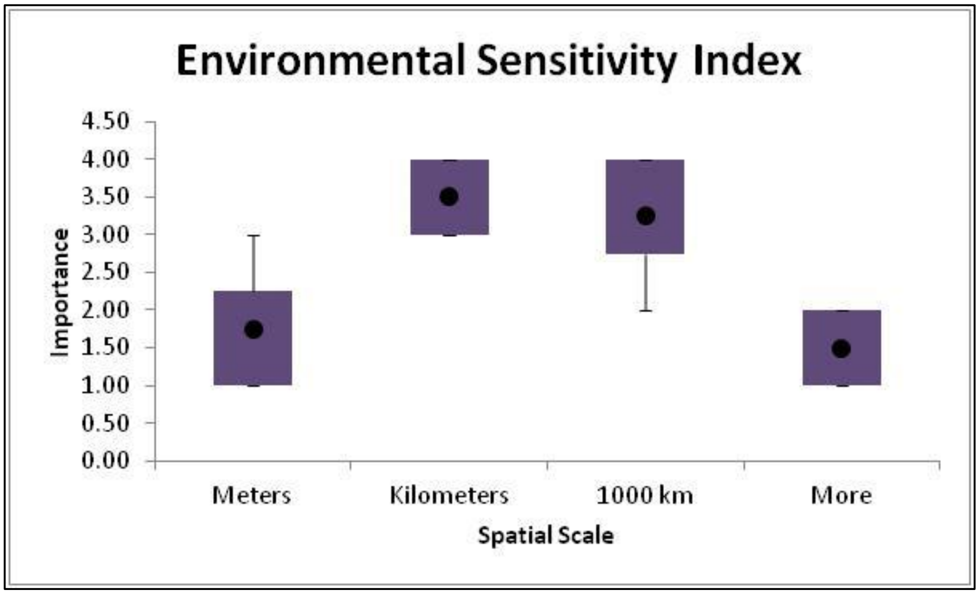


Figure C.7 IEA Spatial Scale: Environmental Sensitivity Index

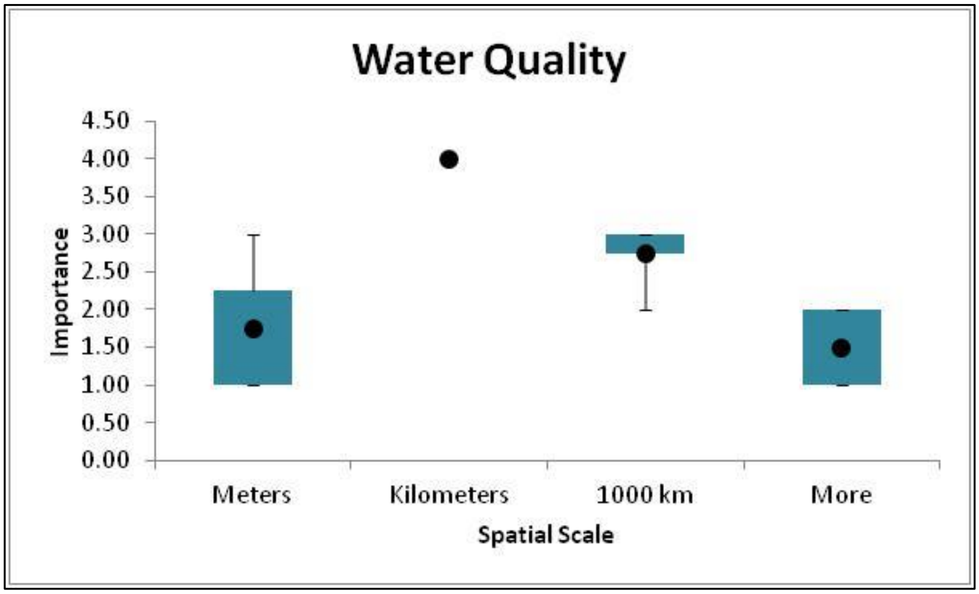


Figure C.8 IEA Spatial Scale: Water Quality

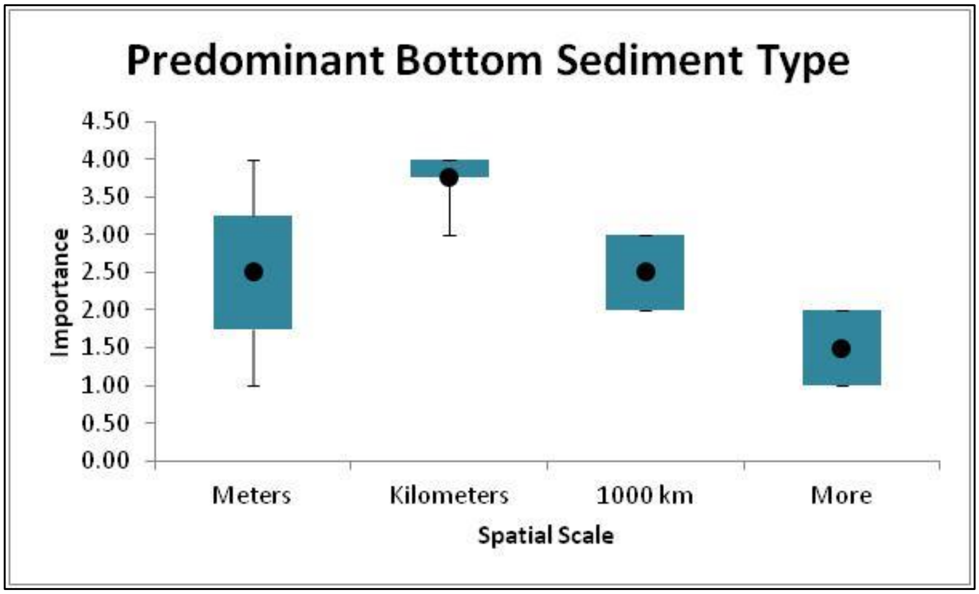


Figure C.9 IEA Spatial Scale: Predominant Bottom Sediment Type

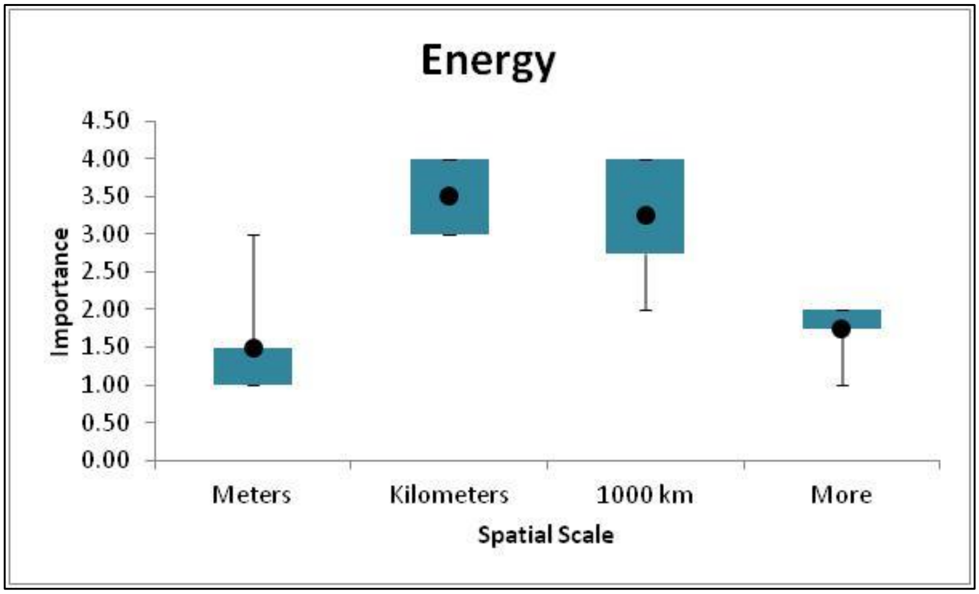


Figure C.10 IEA Spatial Scale: Energy

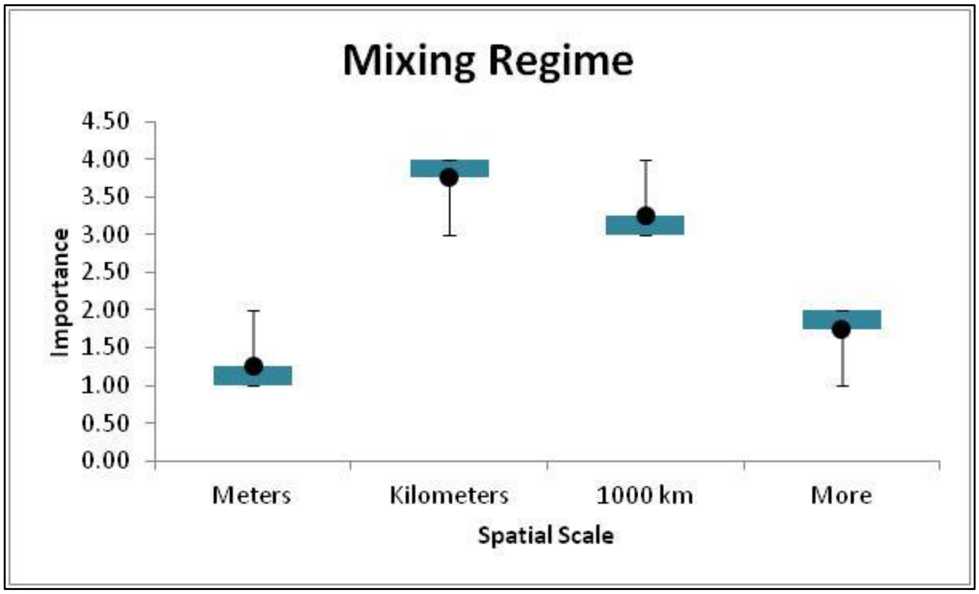


Figure C.11 IEA Spatial Scale: Mixing Regime

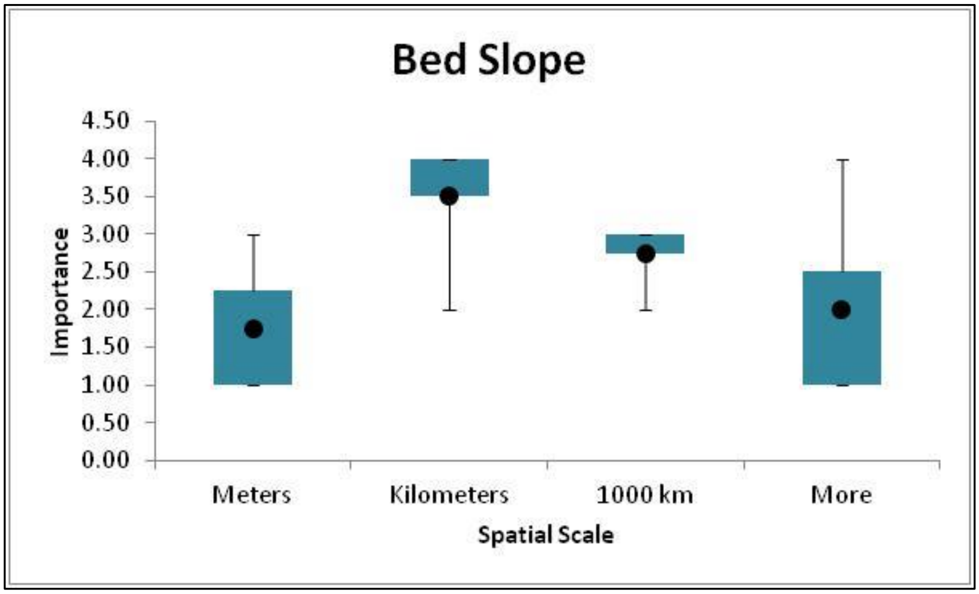


Figure C.12 IEA Spatial Scale: Bed Slope

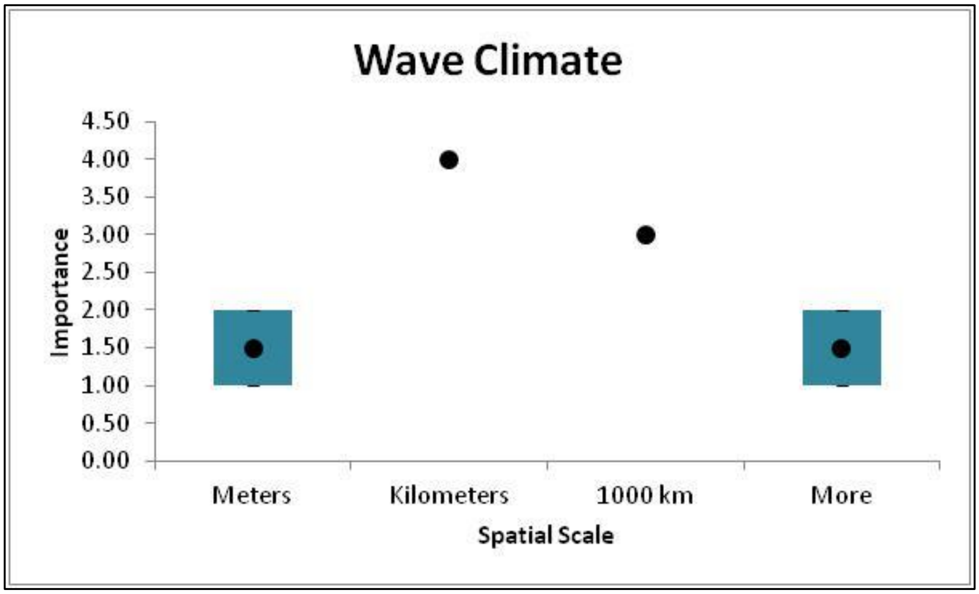


Figure C.13 IEA Spatial Scale: Wave Climate

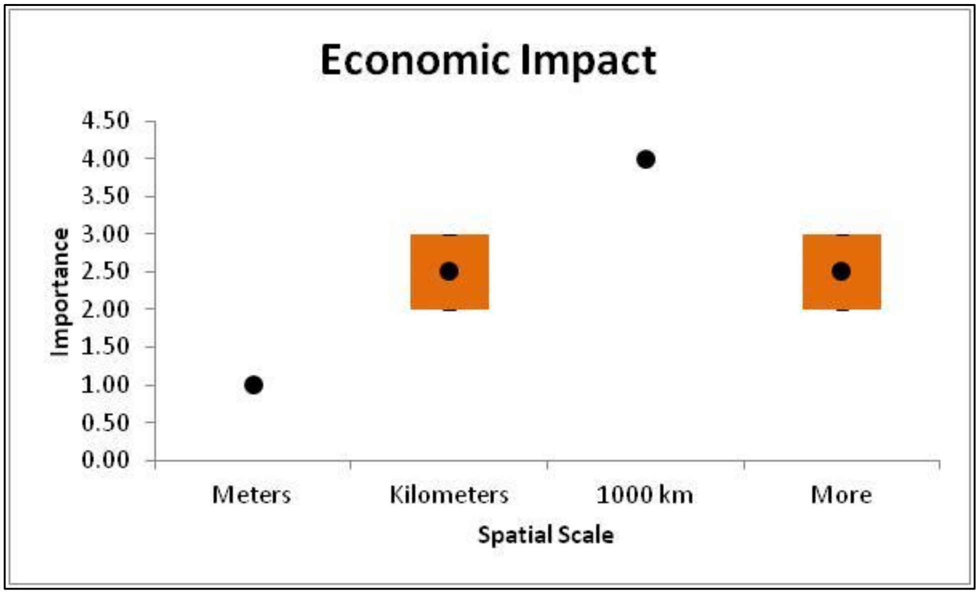


Figure C.14 IEA Spatial Scale: Economic Impact

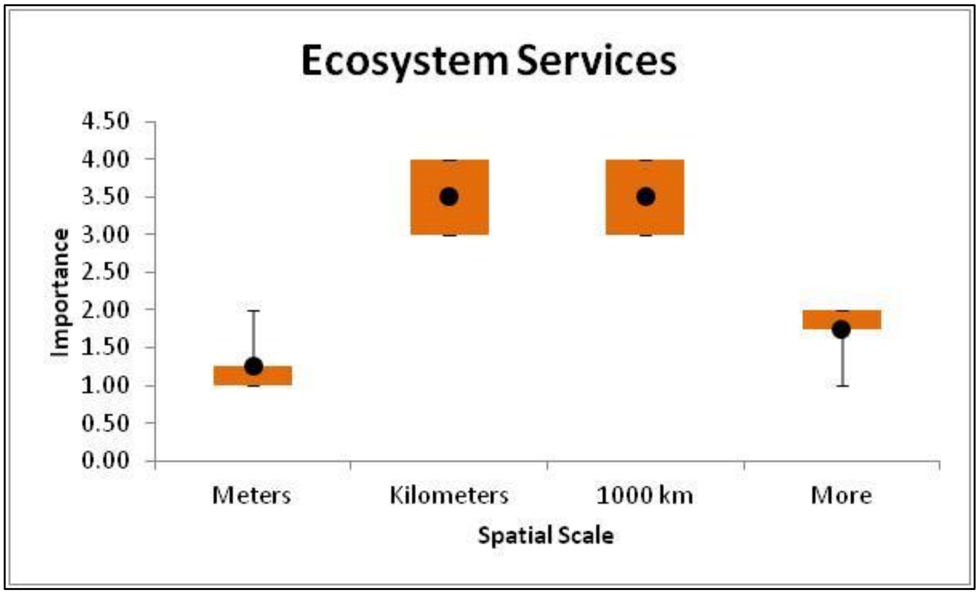


Figure C.15 IEA Spatial Scale: Ecosystem Services

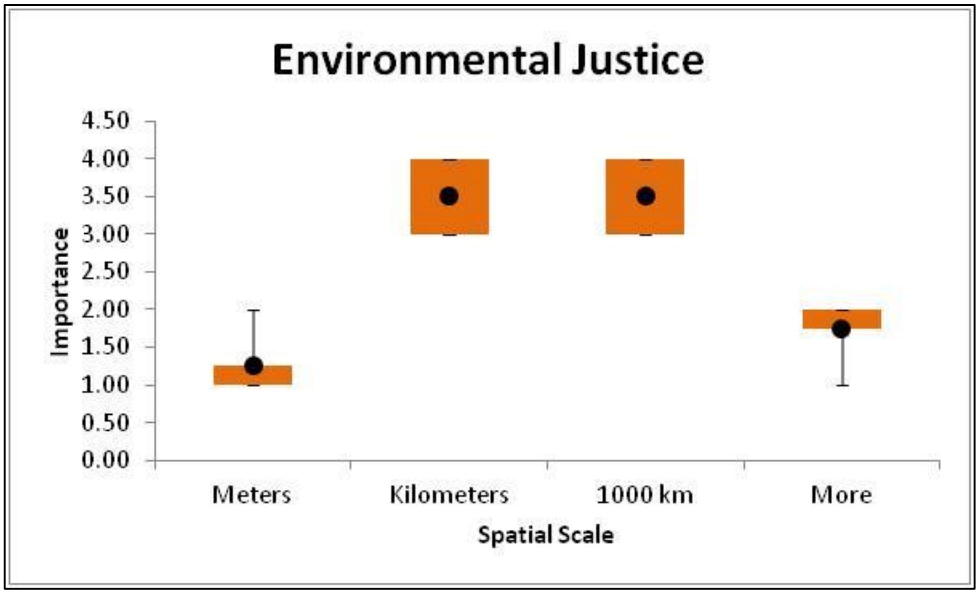


Figure C.16 IEA Spatial Scale: Environmental Justice

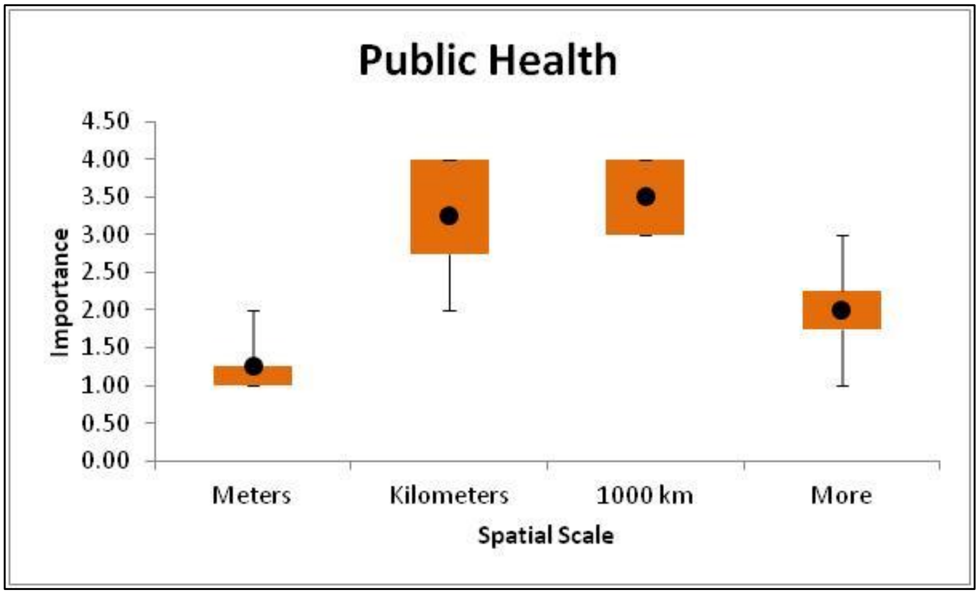


Figure C.17 IEA Spatial Scale: Public Health

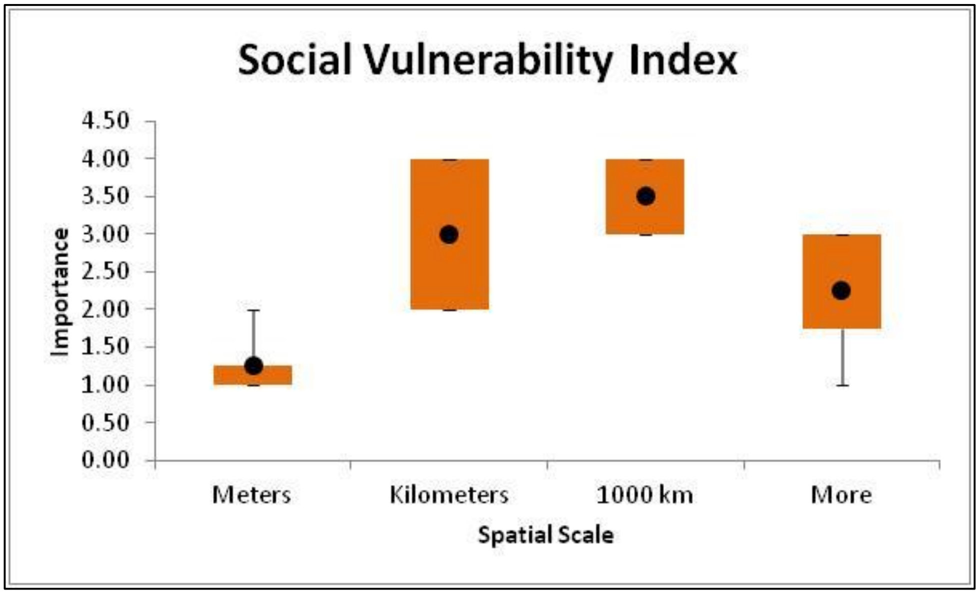


Figure C.18 IEA Spatial Scale: Social Vulnerability Index

C.2 Coastal and Marine Spatial Planning

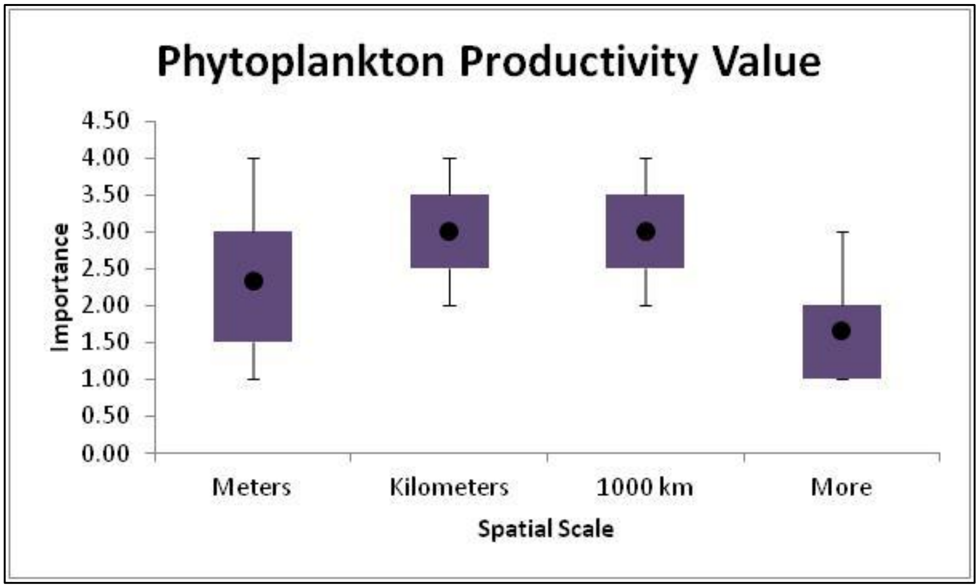


Figure C.19 CMSP Spatial Scale: Phytoplankton Productivity Value

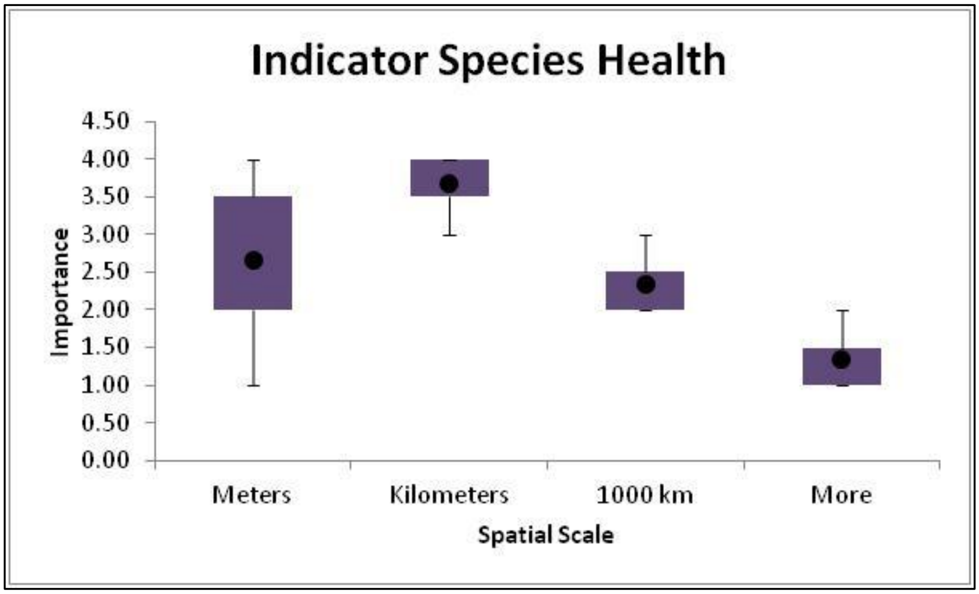


Figure C.20 CMSP Spatial Scale: Indicator Species Health

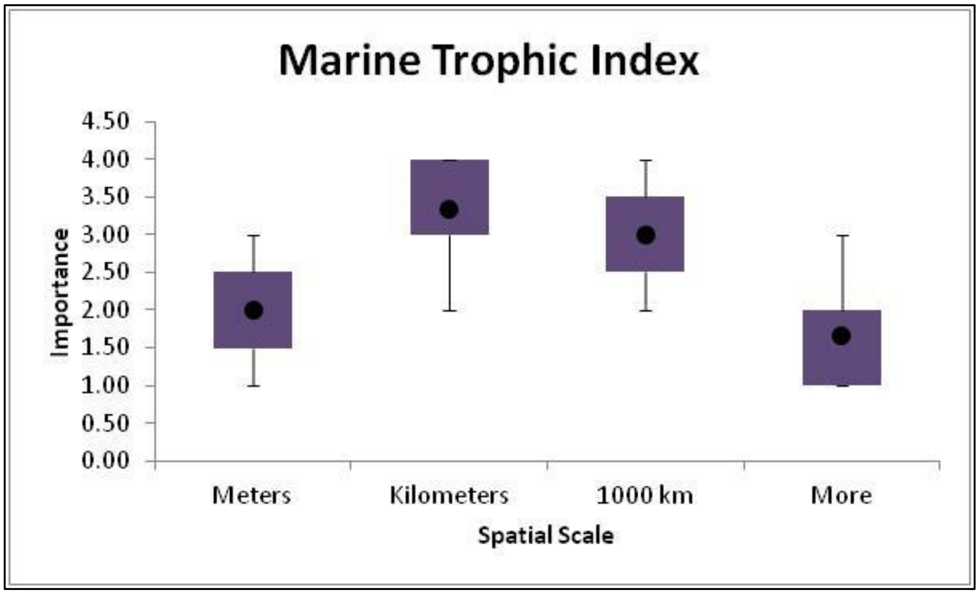


Figure C.21 CMSP Spatial Scale: Marine Trophic Index

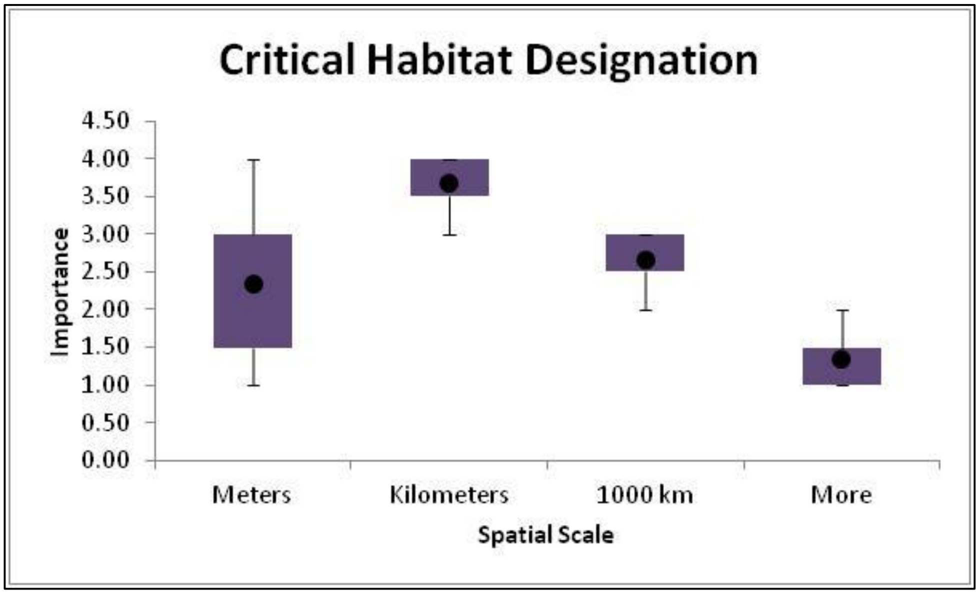


Figure C.22 CMSP Spatial Scale: Critical Habitat Designation

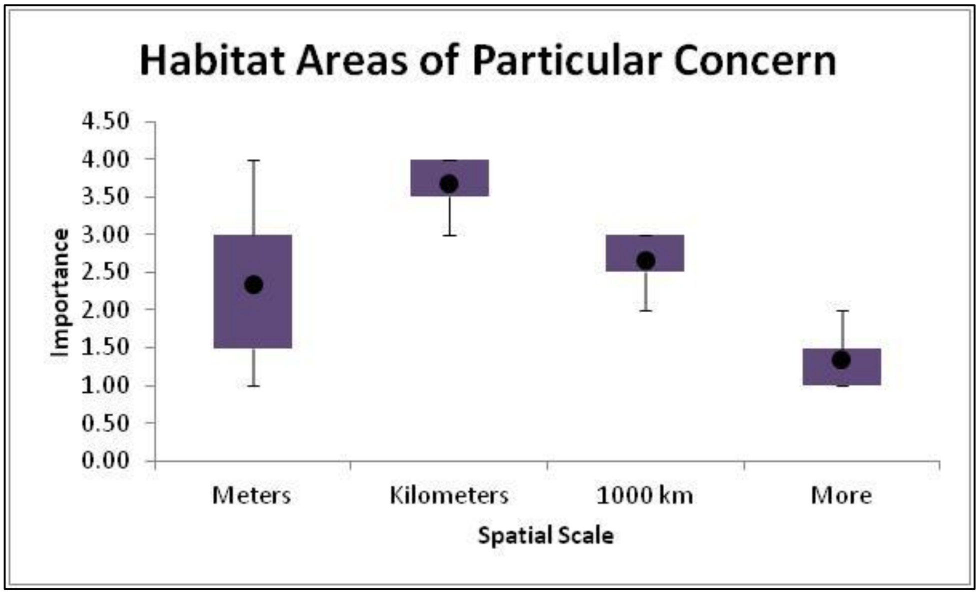


Figure C.23 CMSP Spatial Scale: Habitat Areas of Particular Concern

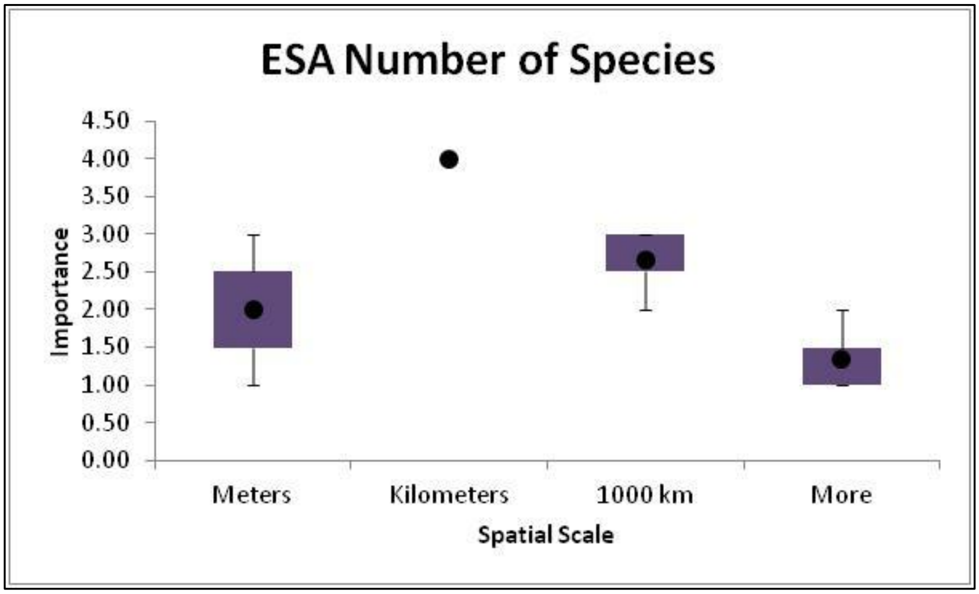


Figure C.24 CMSP Spatial Scale: ESA Number of Species

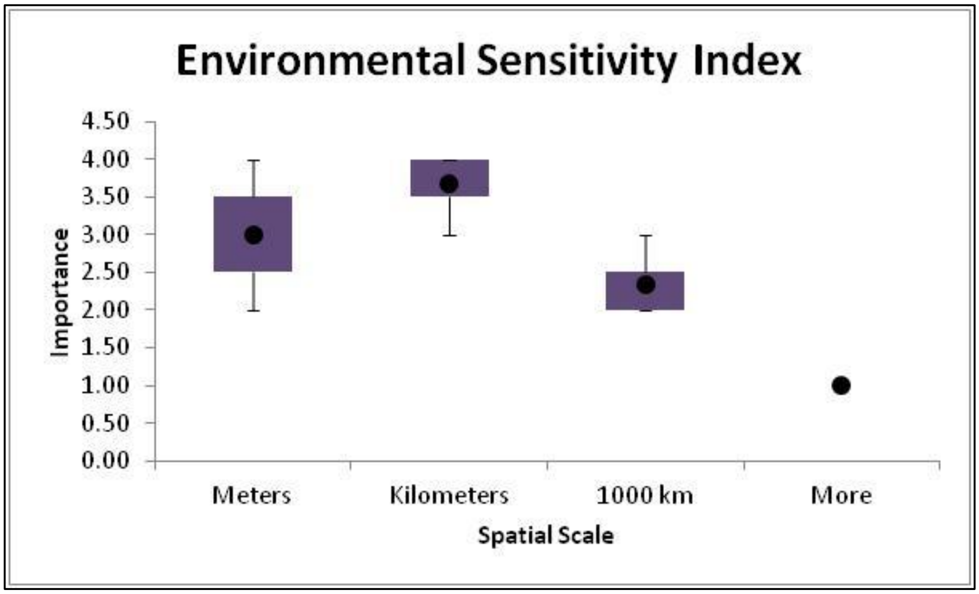


Figure C.25 CMSP Spatial Scale: Environmental Sensitivity Index

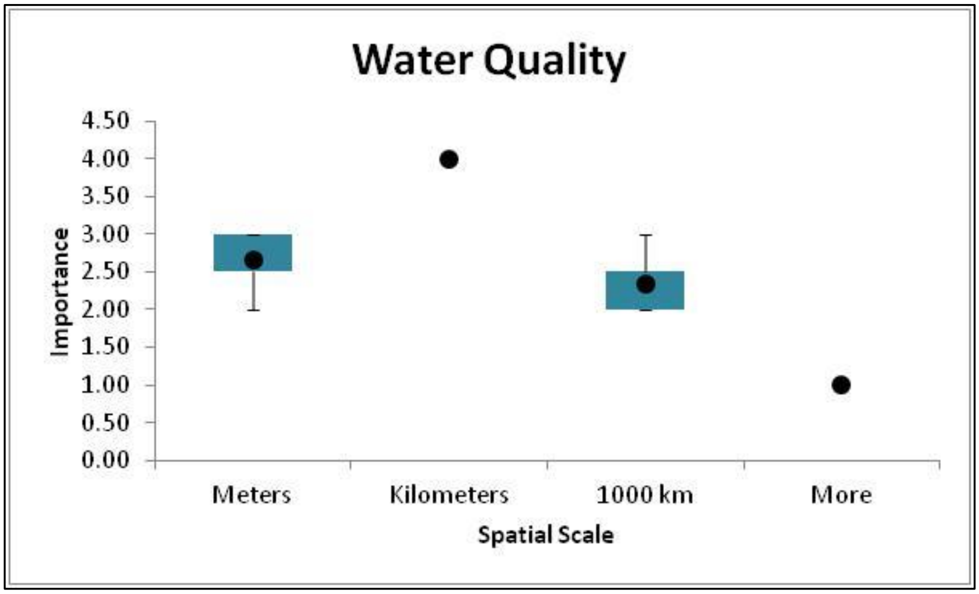


Figure C.26 CMSP Spatial Scale: Water Quality

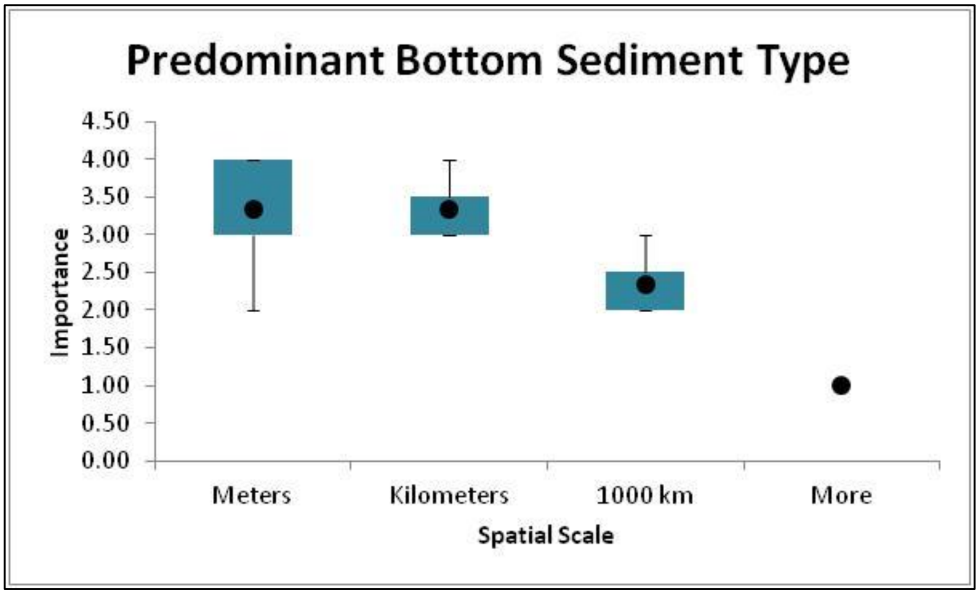


Figure C.27 CMSP Spatial Scale: Predominant Bottom Sediment Type

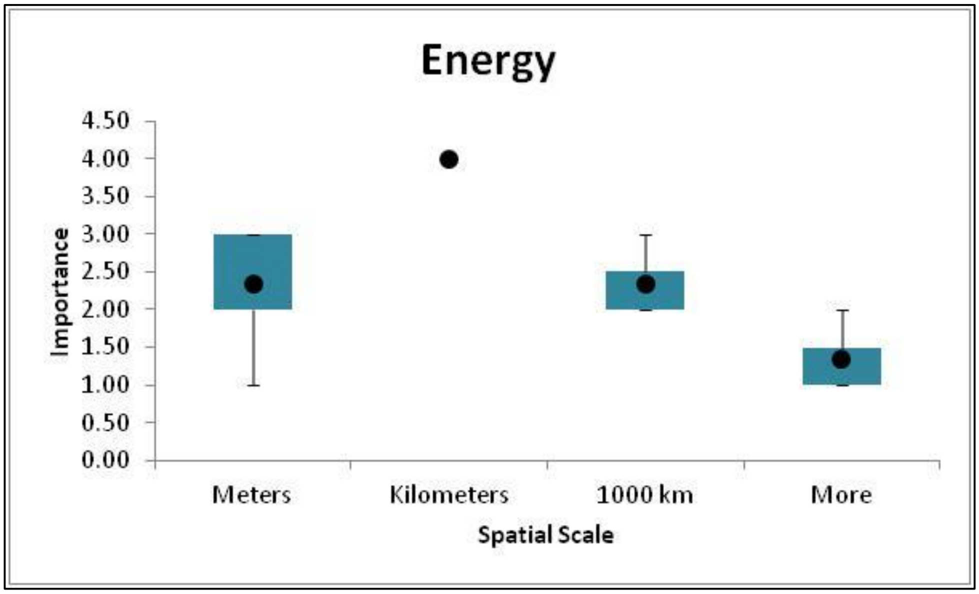


Figure C.28 CMSP Spatial Scale: Energy

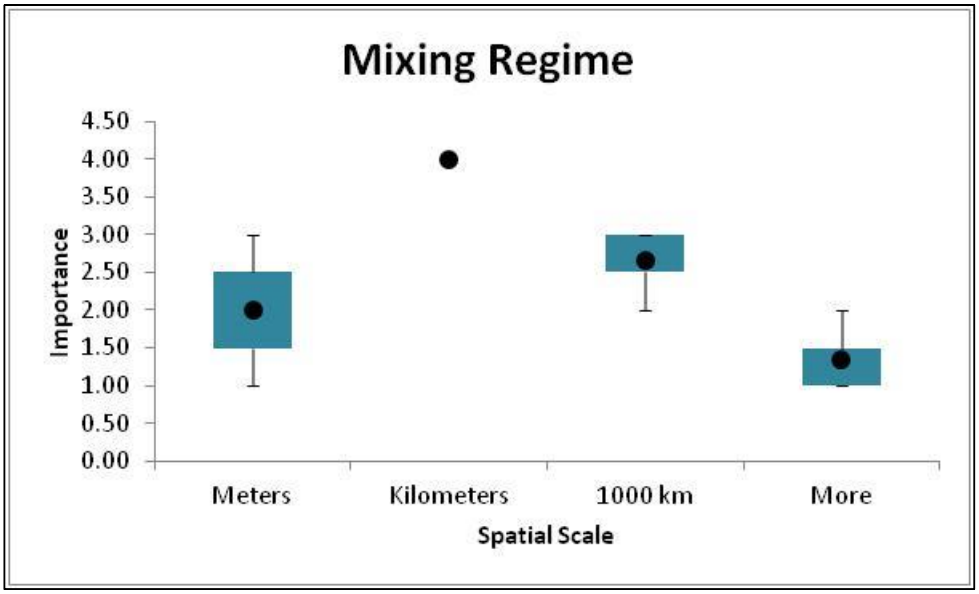


Figure C.29 CMSP Spatial Scale: Mixing Regime

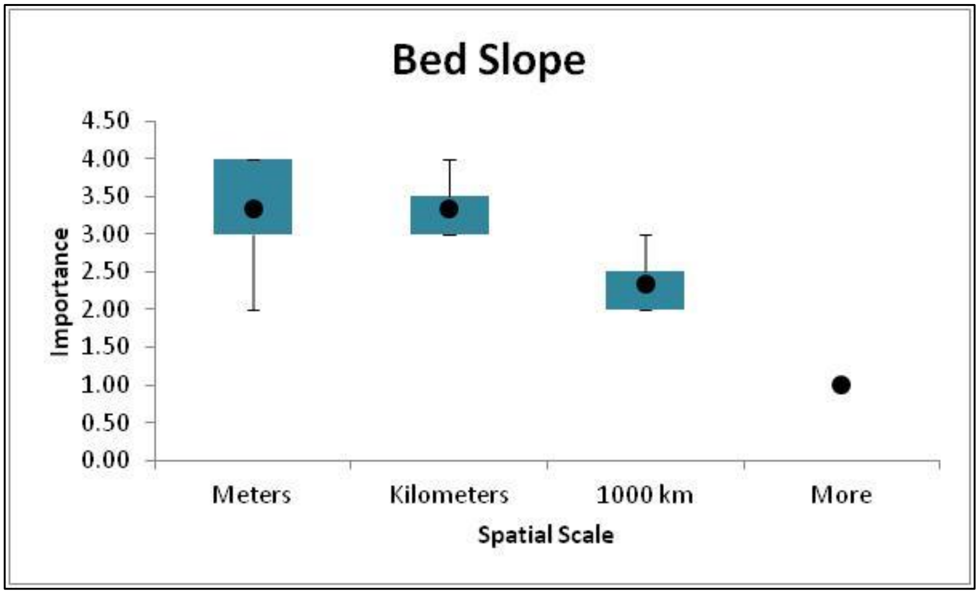


Figure C.30 CMSP Spatial Scale: Bed Slope

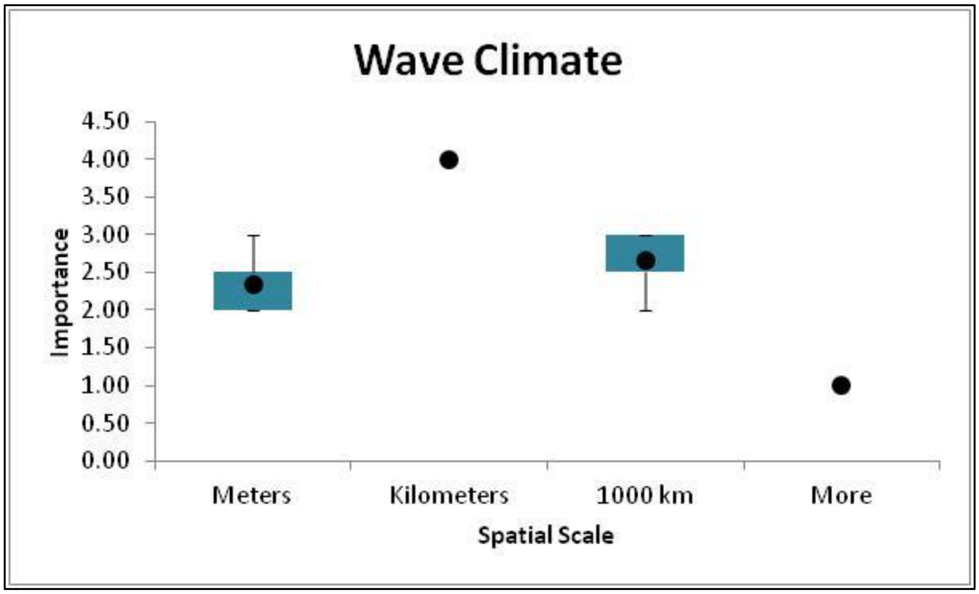


Figure C.31 CMSP Spatial Scale: Wave Climate

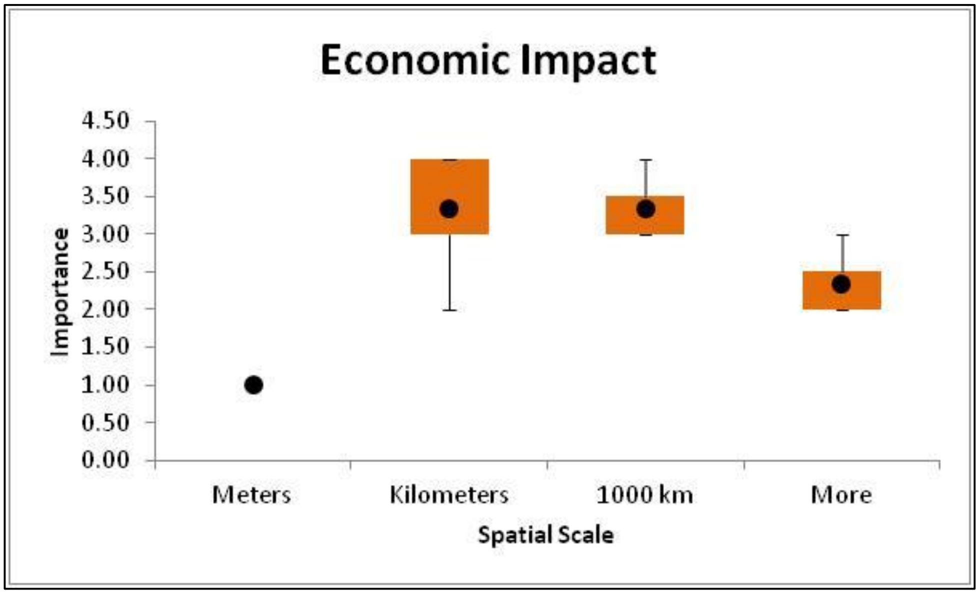


Figure C.32 CMSP Spatial Scale: Economic Impact

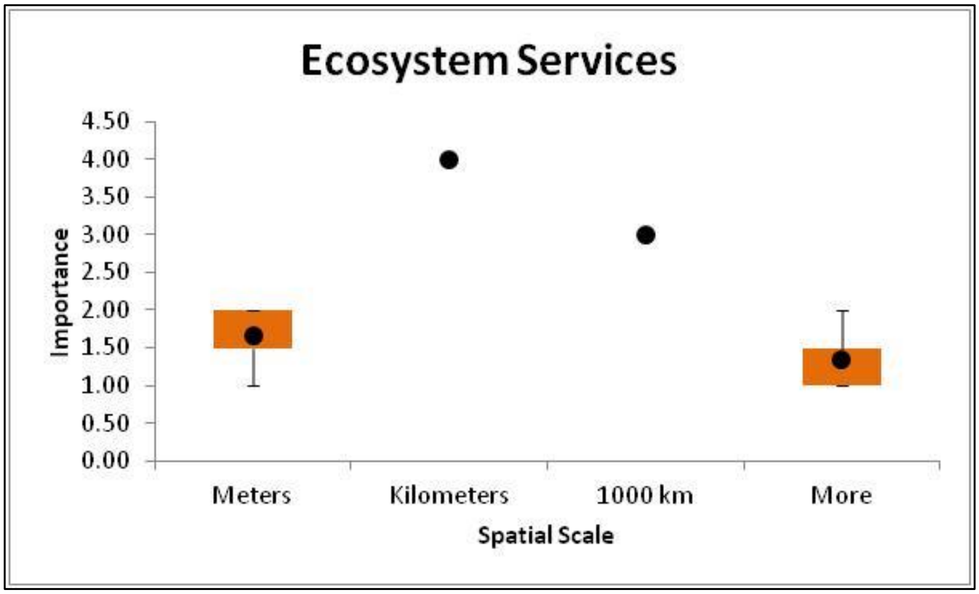


Figure C.33 CMSP Spatial Scale: Ecosystem Services

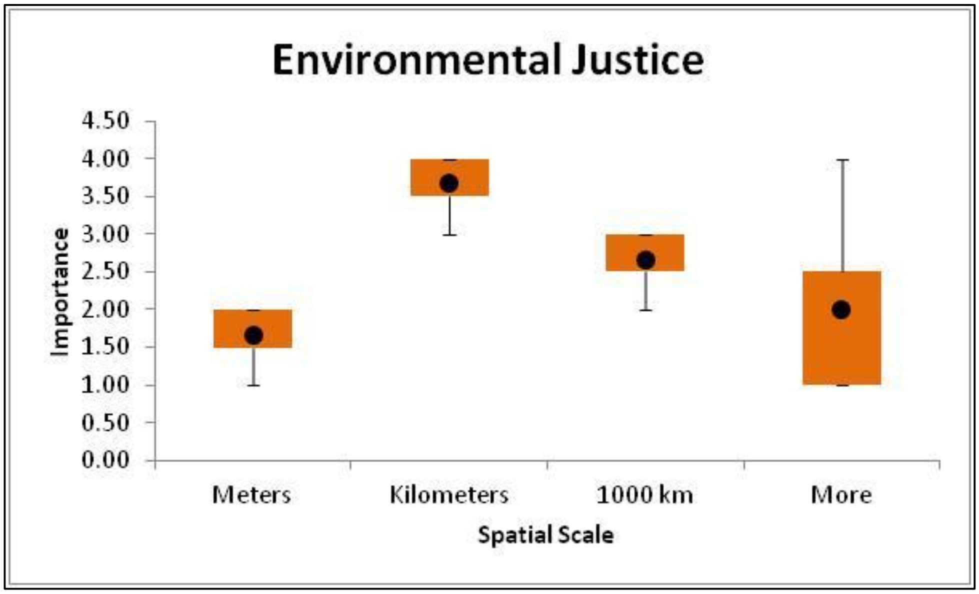


Figure C.34 CMSP Spatial Scale: Environmental Justice

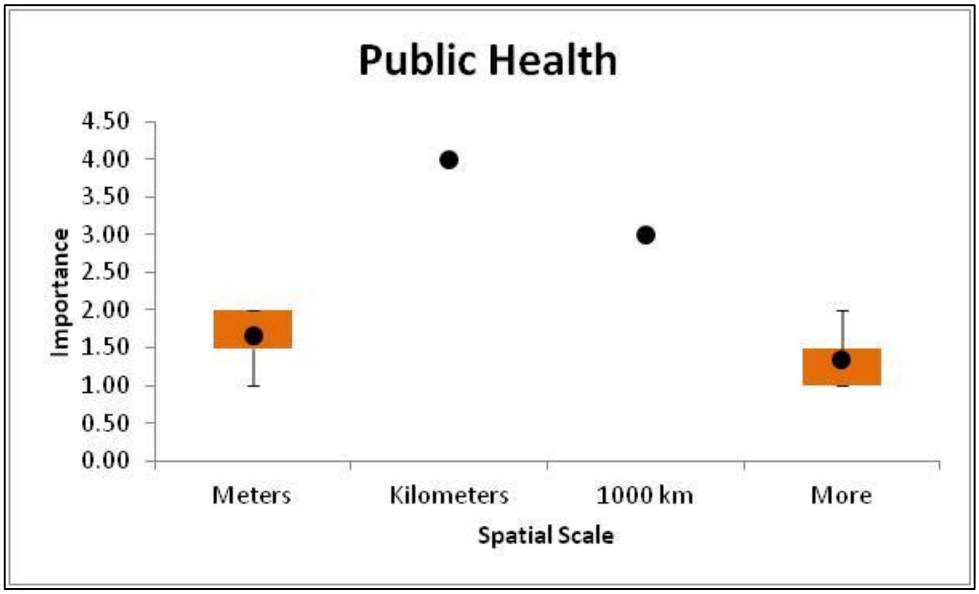


Figure C.35 CMSP Spatial Scale: Public Health

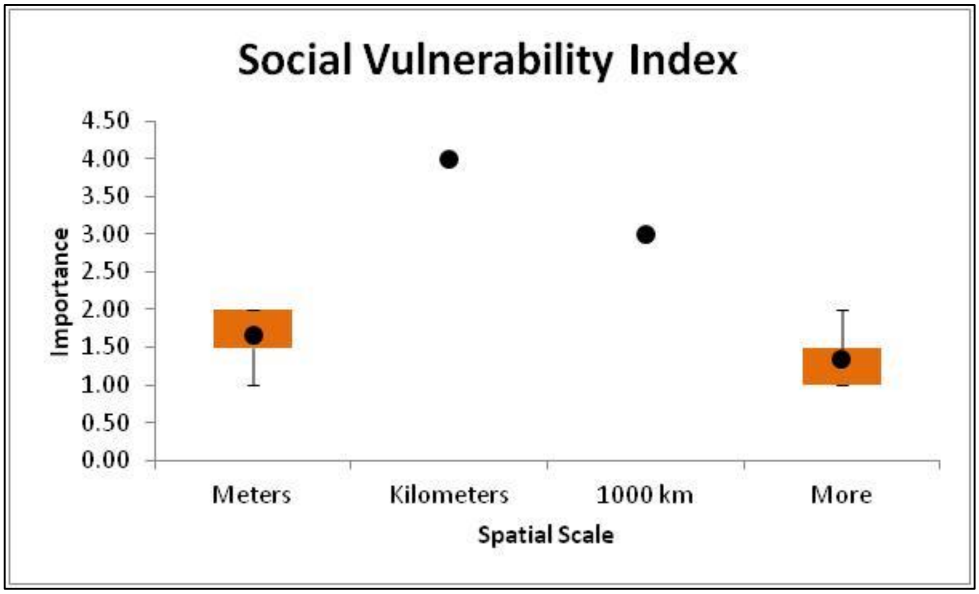


Figure C.36 CMSP Spatial Scale: Social Vulnerability Index

C.3 Ecosystem Based Management

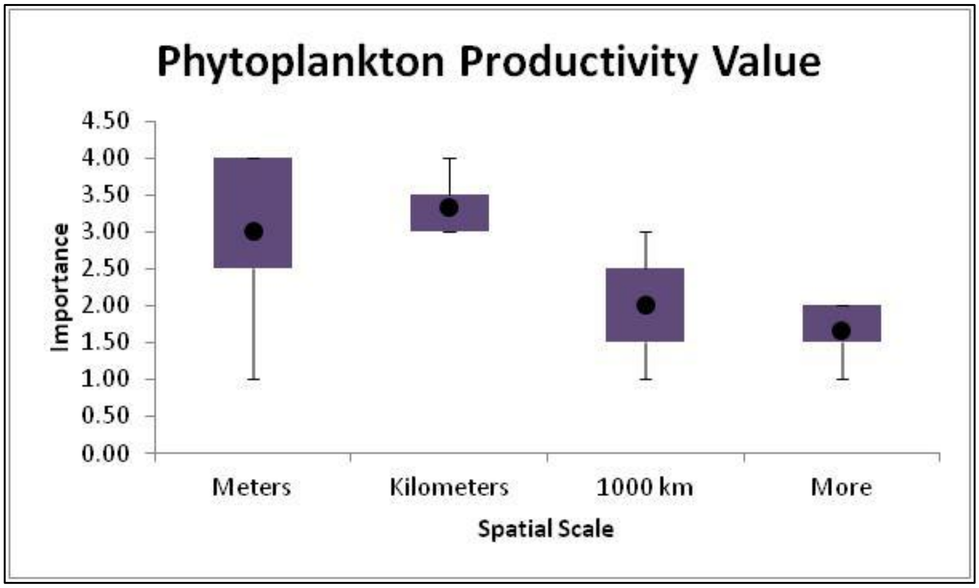


Figure C.37 EBM Spatial Scale: Phytoplankton Productivity Value

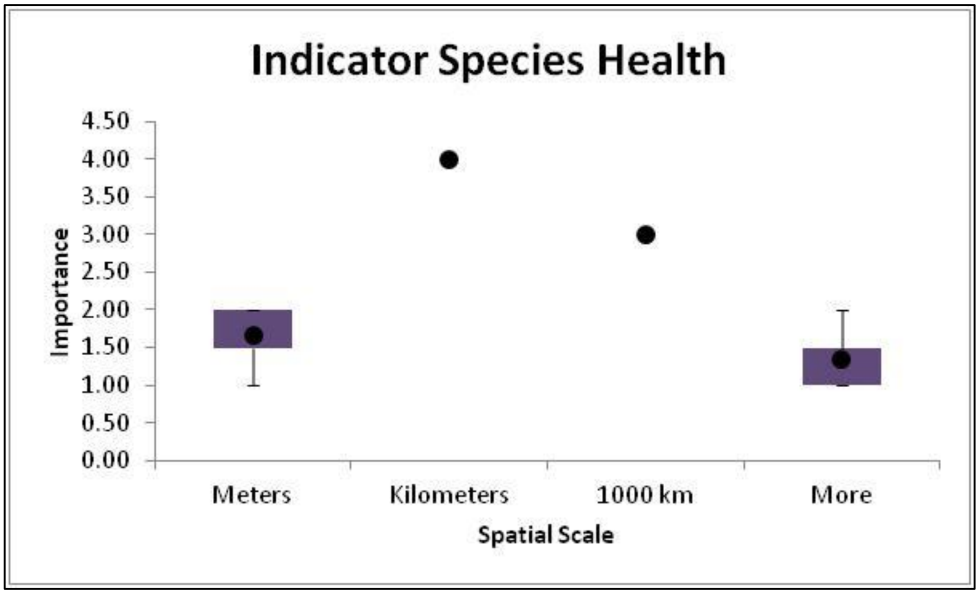


Figure C.38 EBM Spatial Scale: Indicator Species Health

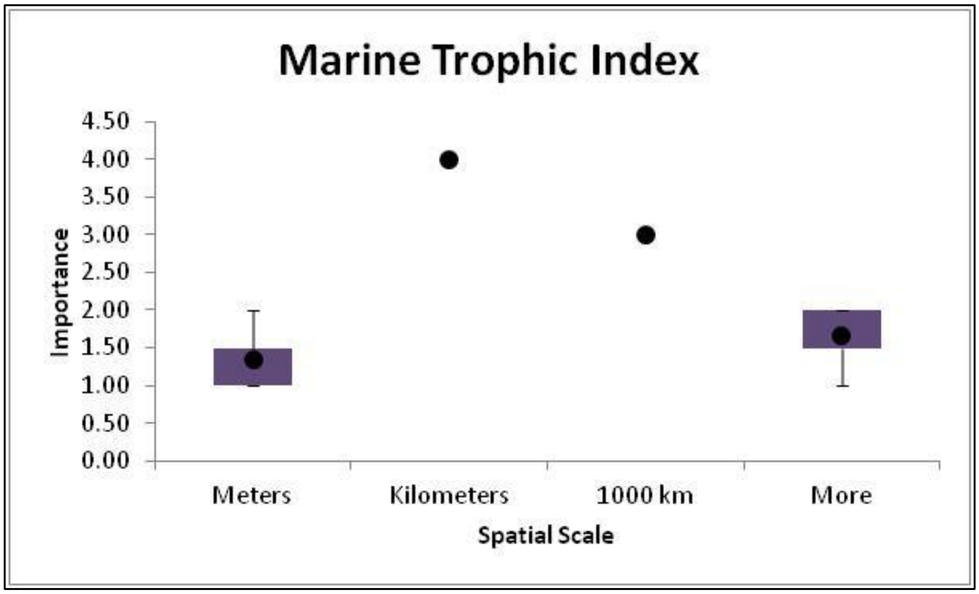


Figure C.39 EBM Spatial Scale: Marine Tropic Index

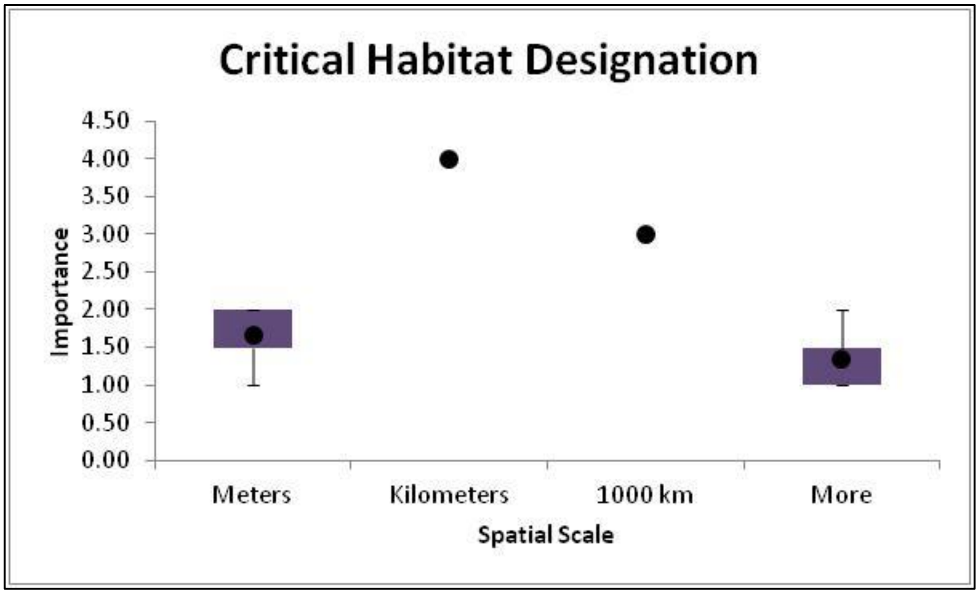


Figure C.40 EBM Spatial Scale: Critical Habitat Designation

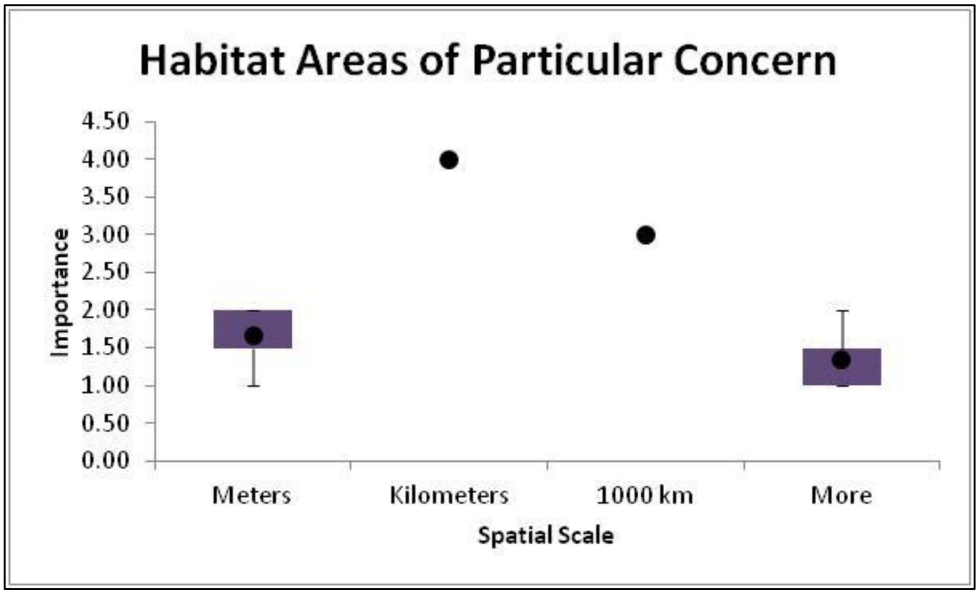


Figure C.41 EBM Spatial Scale: Habitat Areas of Particular Concern

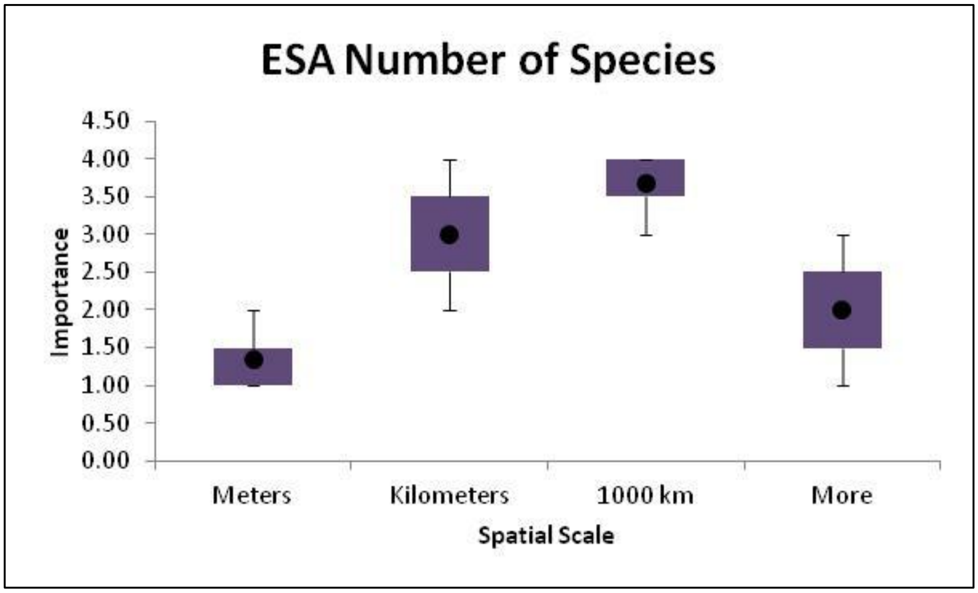


Figure C.42 EBM Spatial Scale: ESA Number of Species

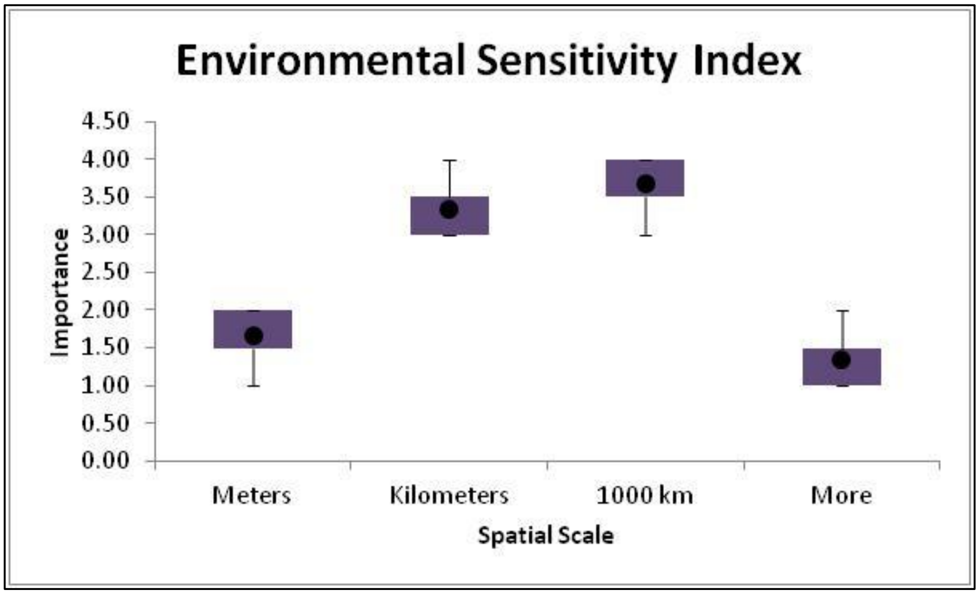


Figure C.43 EBM Spatial Scale: Environmental Sensitivity Index

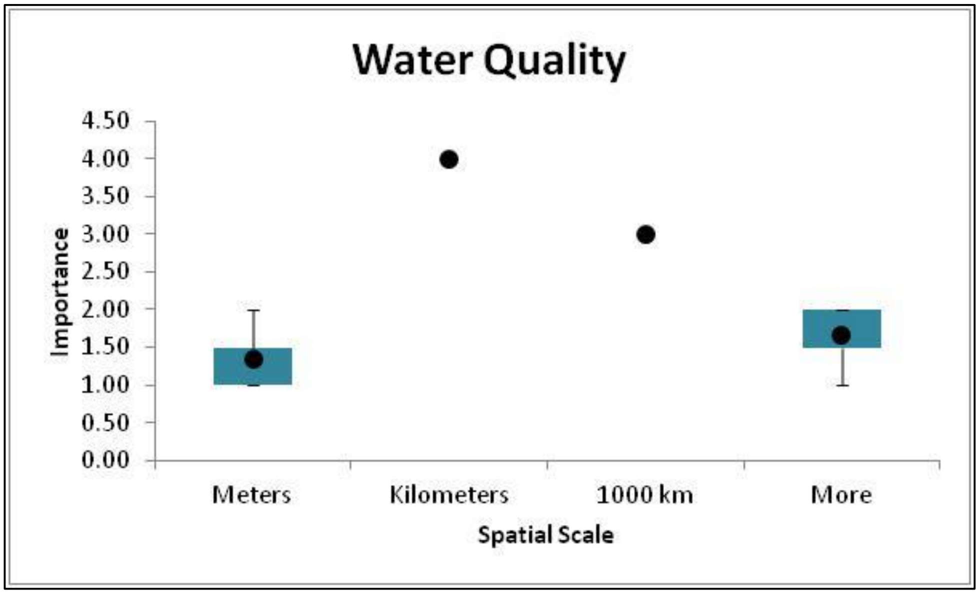


Figure C.44 EBM Spatial Scale: Water Quality

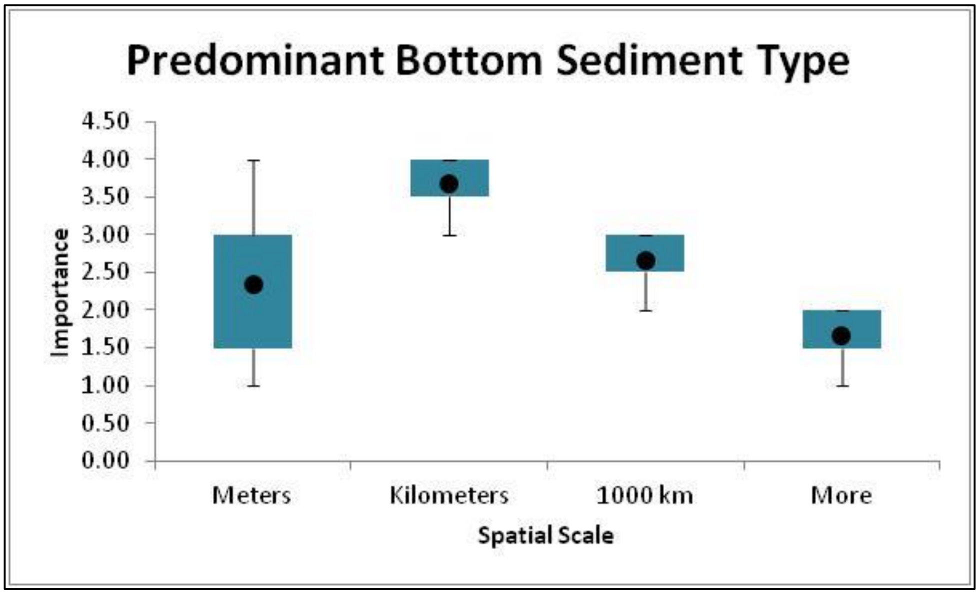


Figure C.45 EBM Spatial Scale: Predominant Bottom Sediment Type

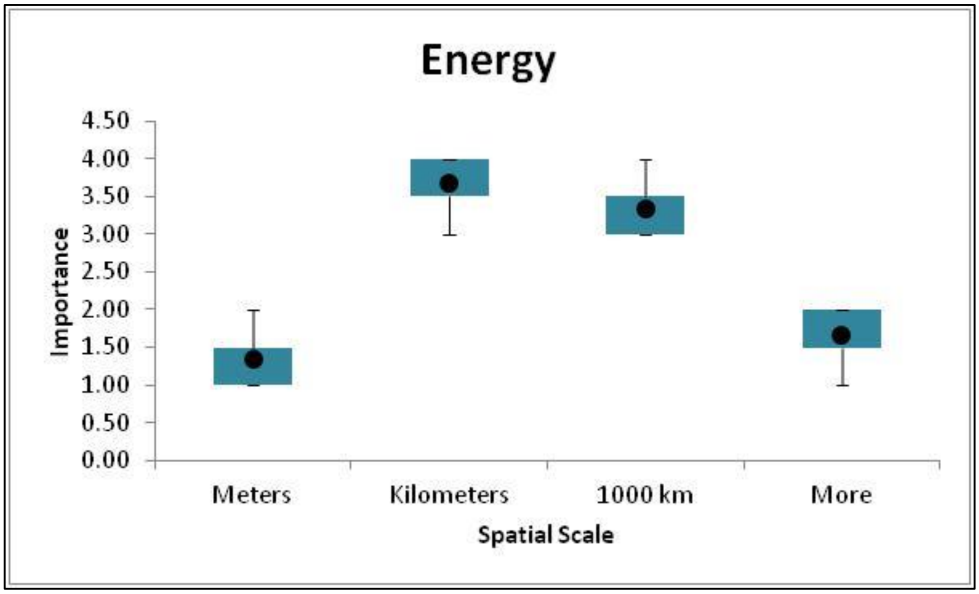


Figure C.46 EBM Spatial Scale: Energy

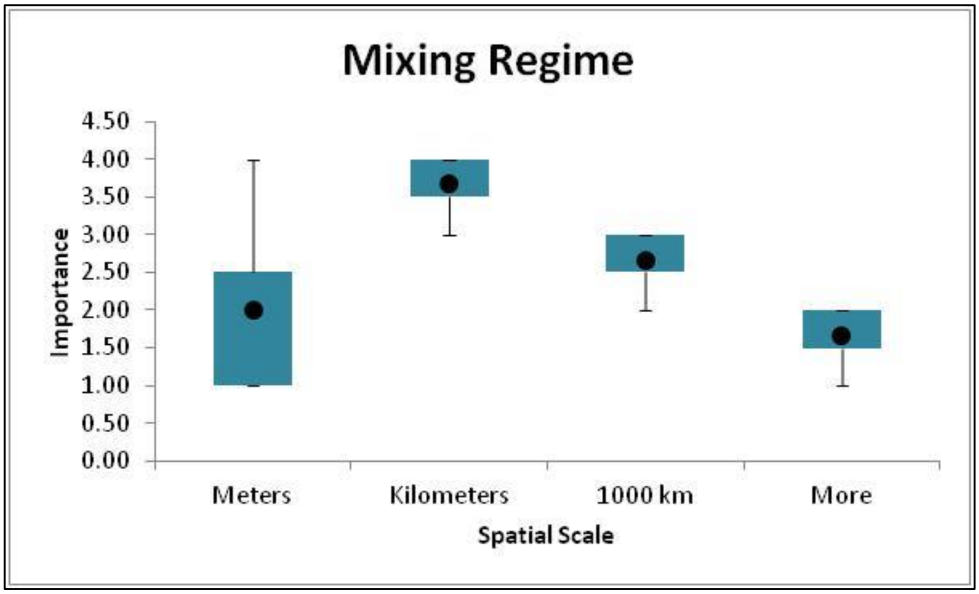


Figure C.47 EBM Spatial Scale: Mixing Regime

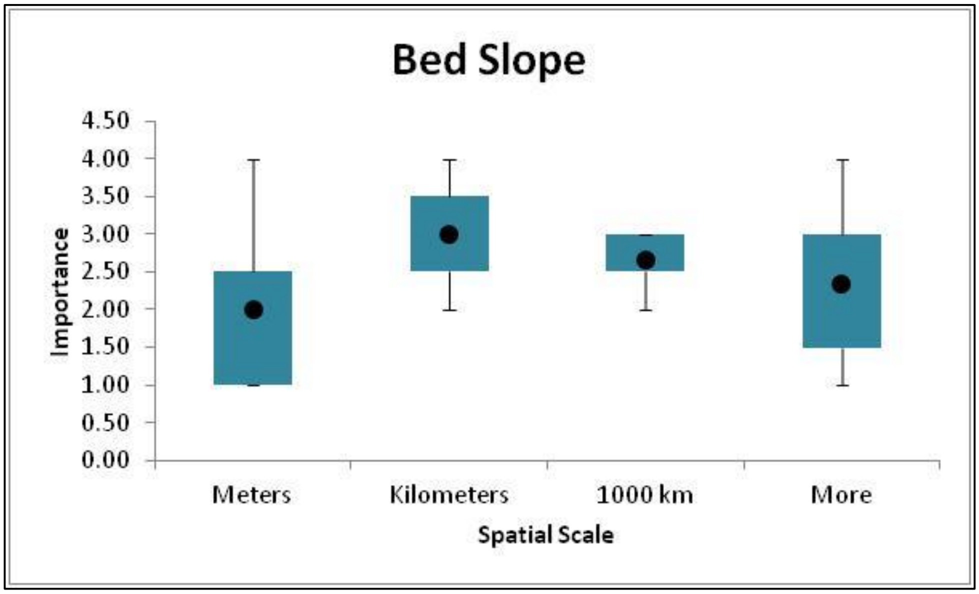


Figure C.48 EBM Spatial Scale: Bed Slope

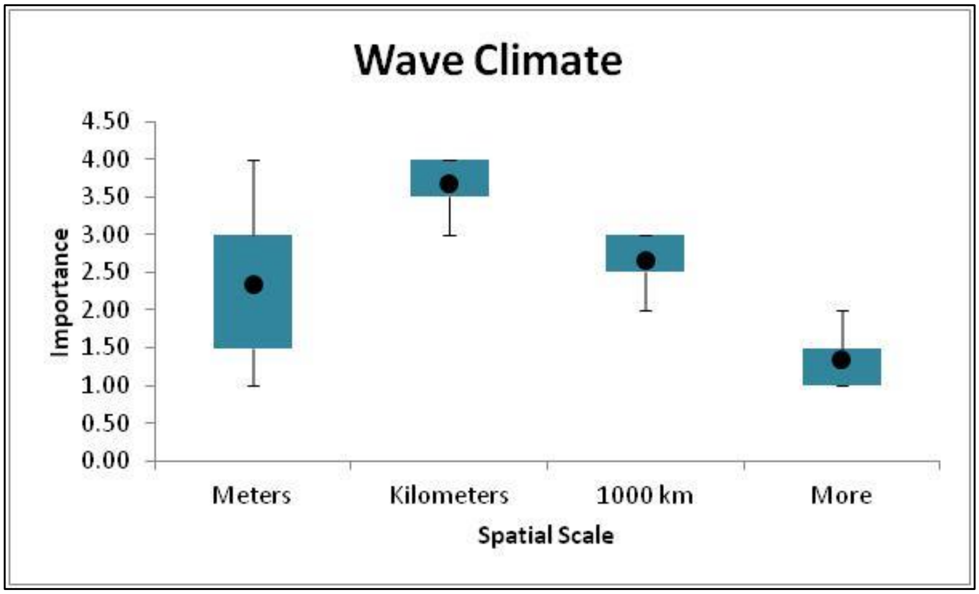


Figure C.49 EBM Spatial Scale: Wave Climate

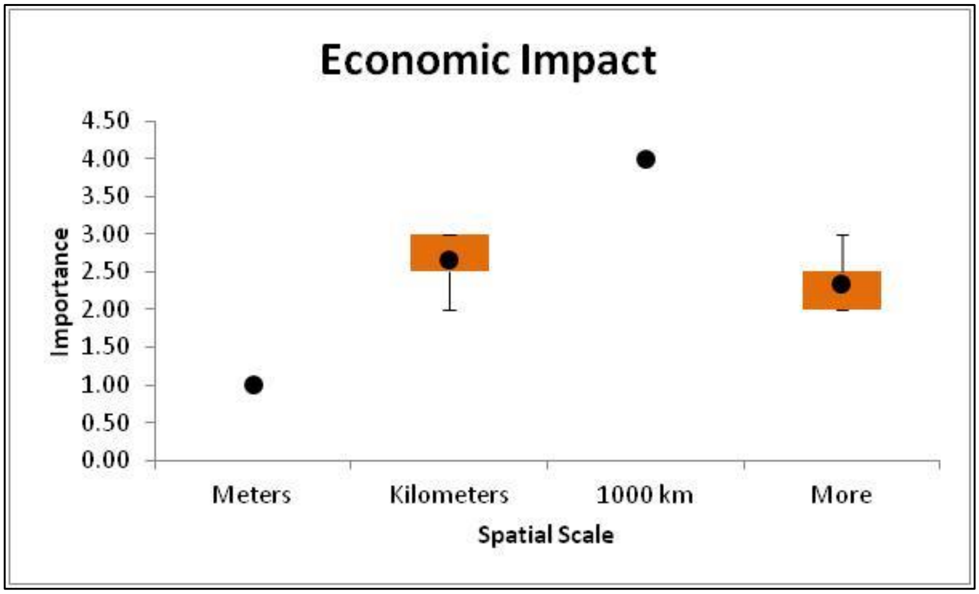


Figure C.50 EBM Spatial Scale: Economic Impact

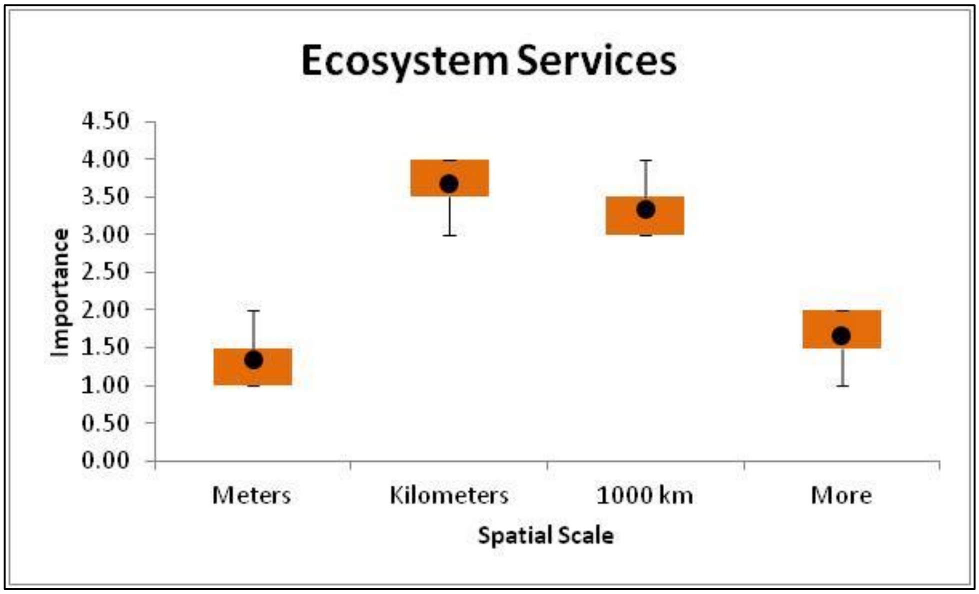


Figure C.51 EBM Spatial Scale: Ecosystem Services

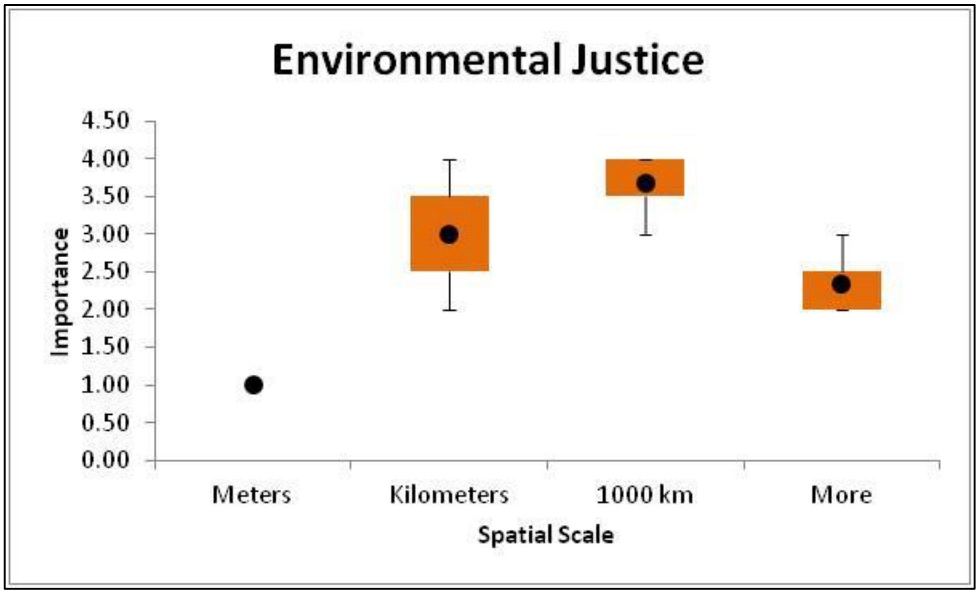


Figure C.52 EBM Spatial Scale: Environmental Justice

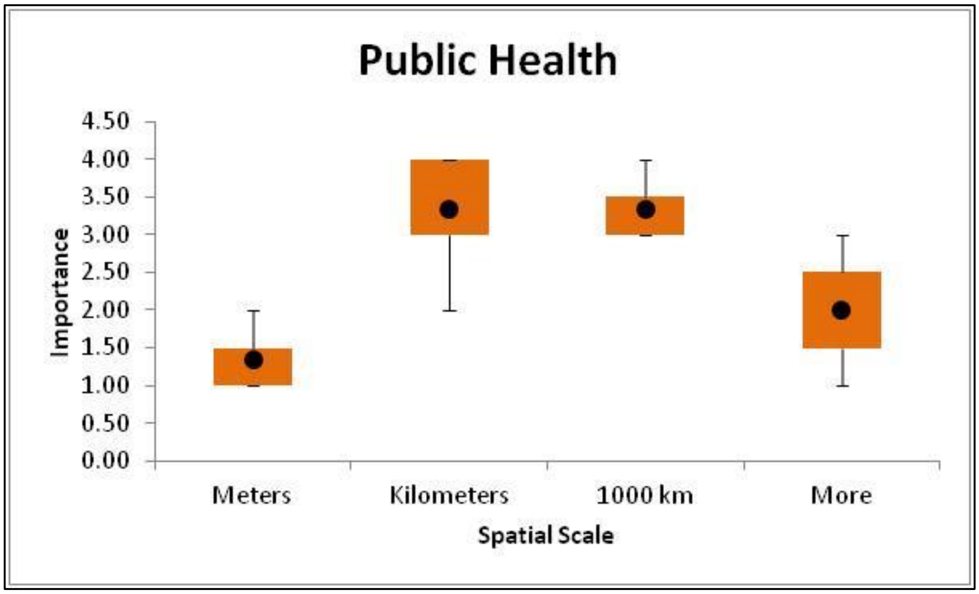


Figure C.53 EBM Spatial Scale: Public Health

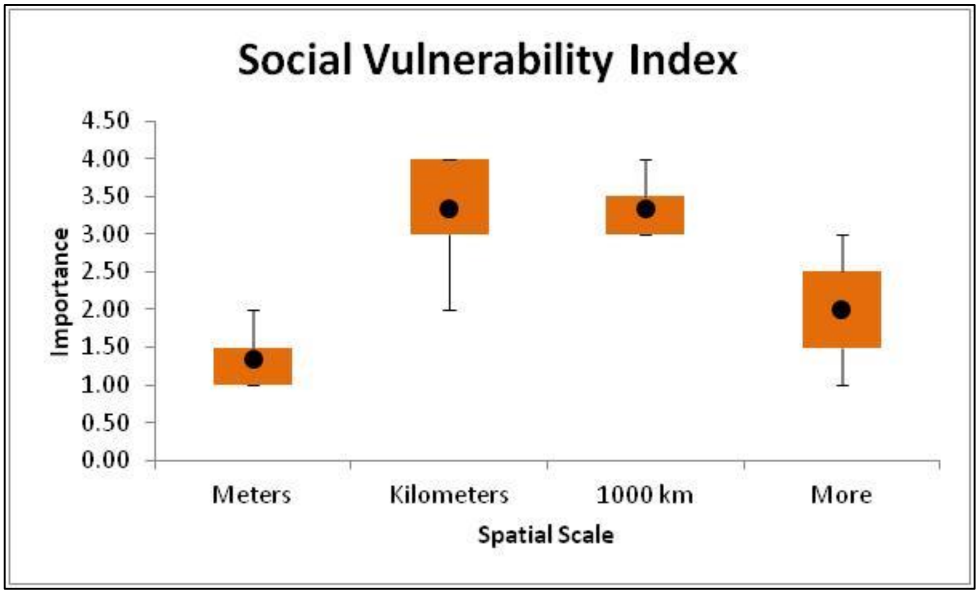


Figure C.54 EBM Spatial Scale: Social Vulnerability Index

C.4 Agglomerative Results

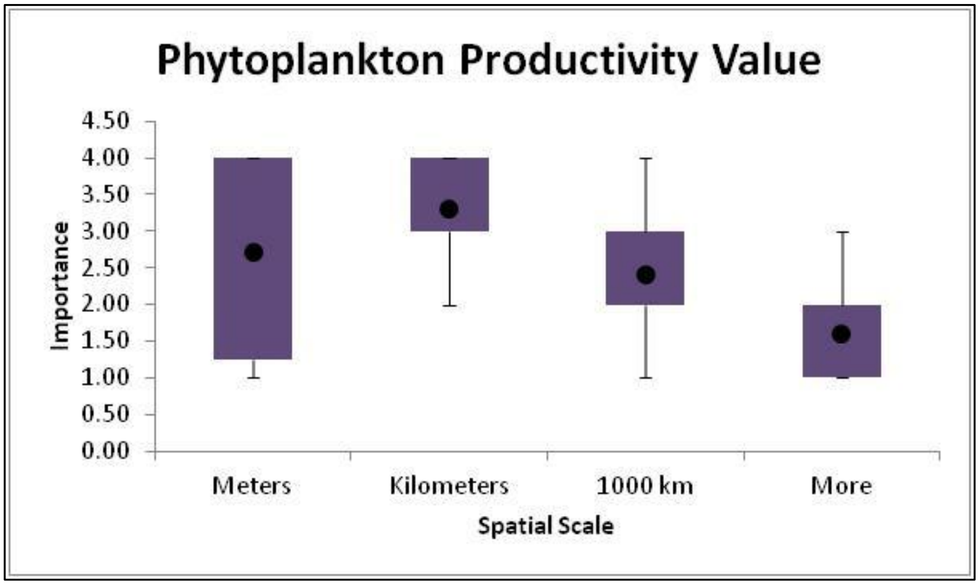


Figure C.55 Agglomerative Spatial Scale: Phytoplankton Productivity Value

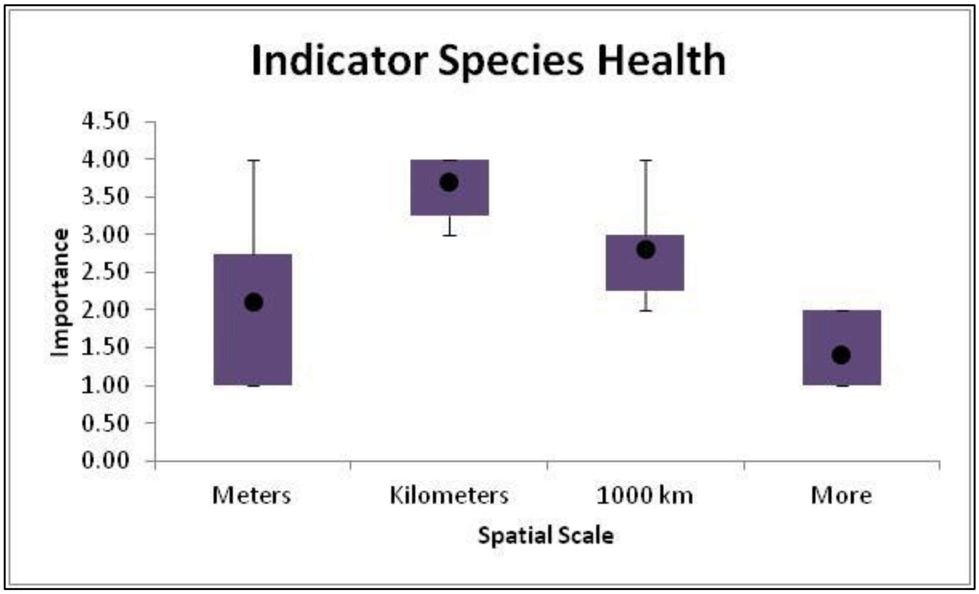


Figure C.56 Agglomerative Spatial Scale: Indicator Species Health

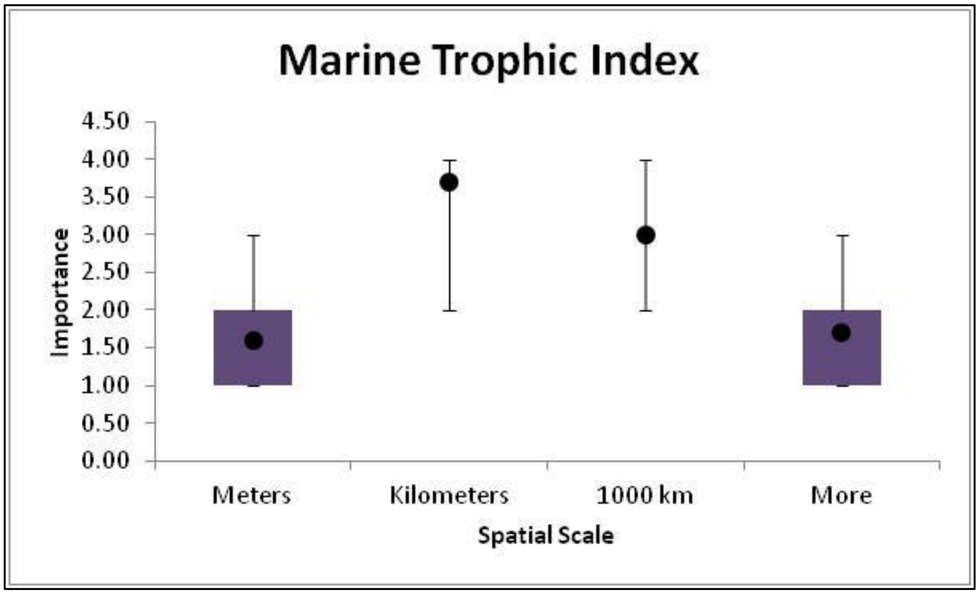


Figure C.57 Agglomerative Spatial Scale: Marine Tropic Index

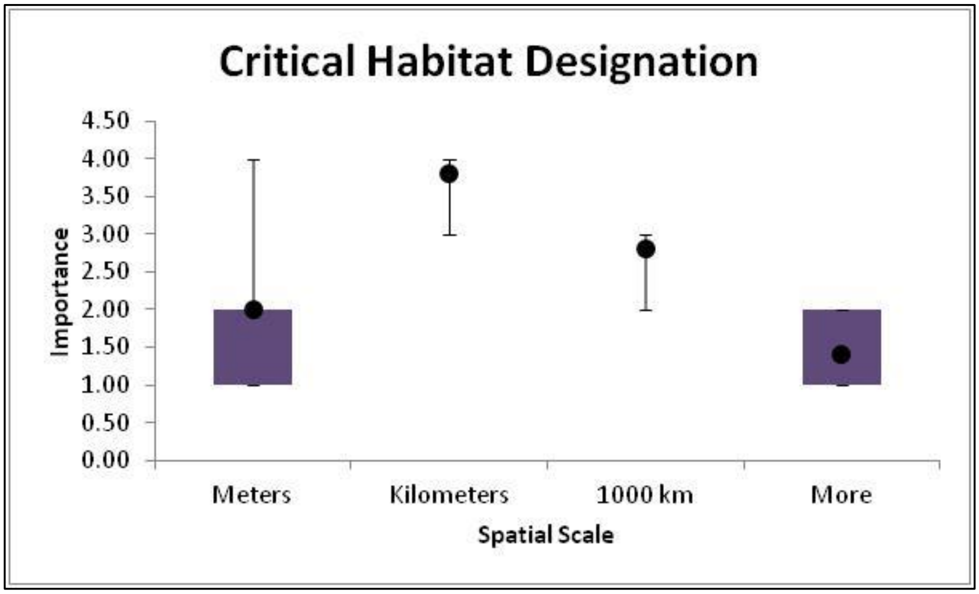


Figure C.58 Agglomerative Spatial Scale: Critical Habitat Designation

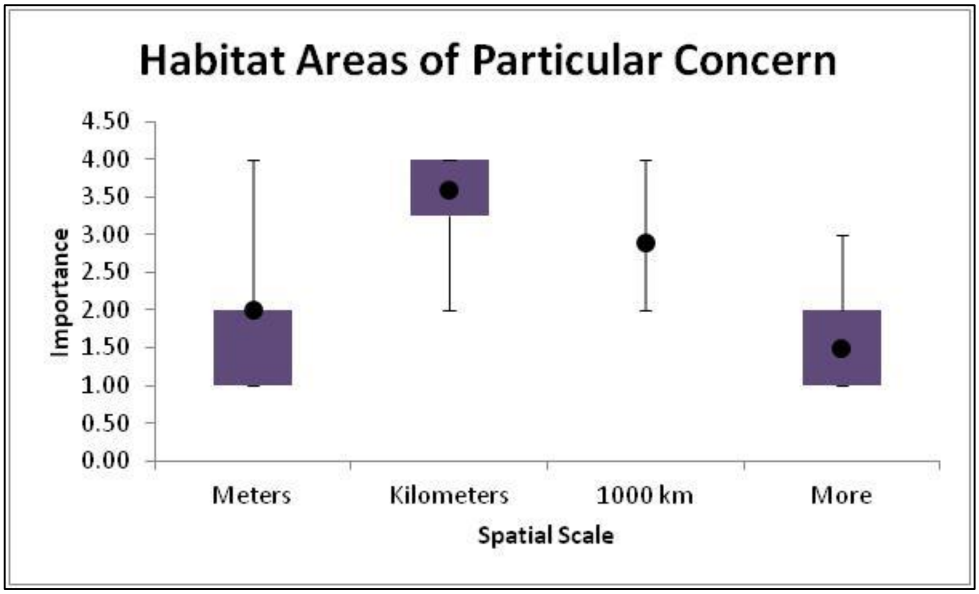


Figure C.59 Agglomerative Spatial Scale: Habitat Areas of Particular Concern

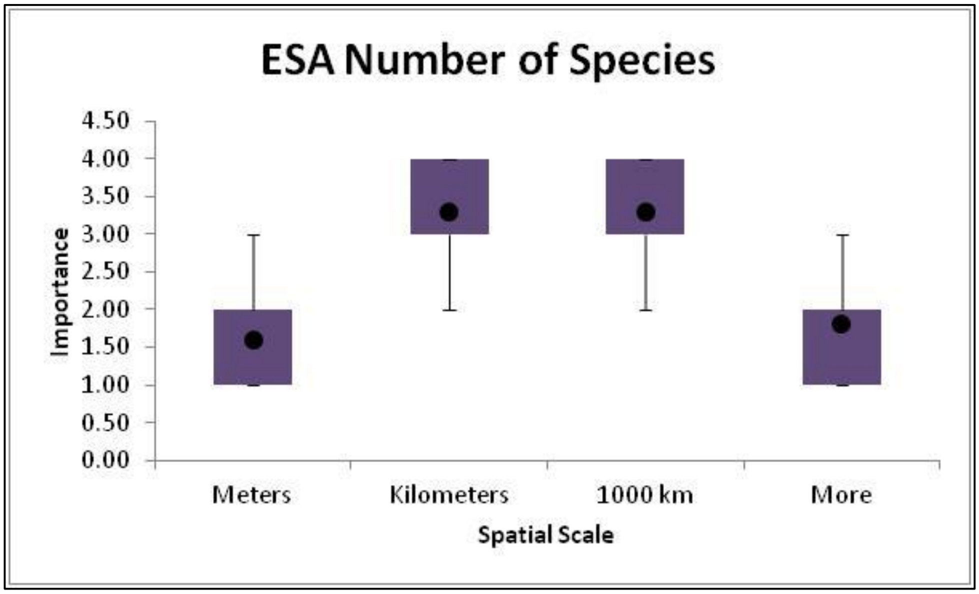


Figure C.60 Agglomerative Spatial Scale: ESA Number of Species

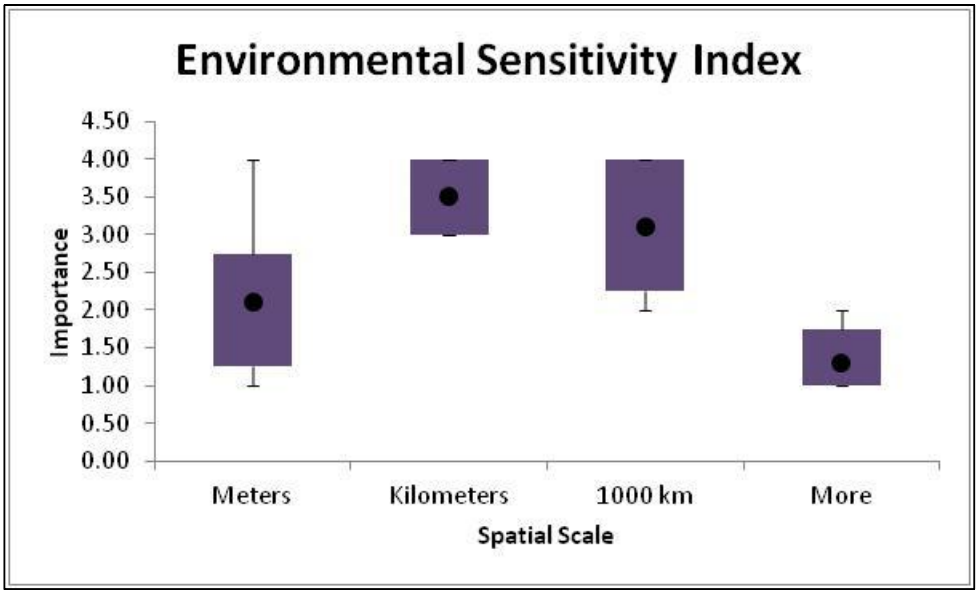


Figure C.61 Agglomerative Spatial Scale: Environmental Sensitivity Index

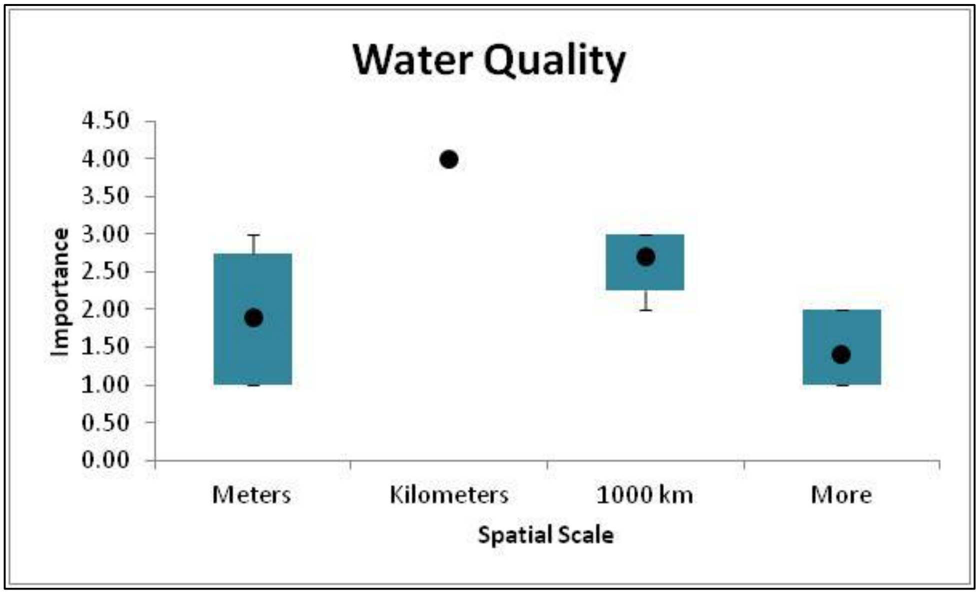


Figure C.62 Agglomerative Spatial Scale: Water Quality

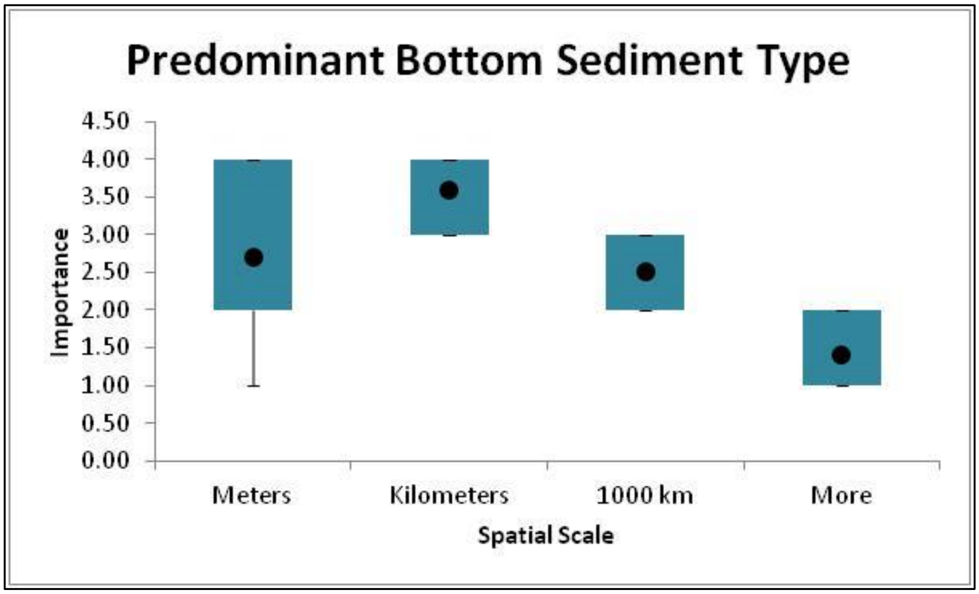


Figure C.63 Agglomerative Spatial Scale: Predominant Bottom Sediment Type

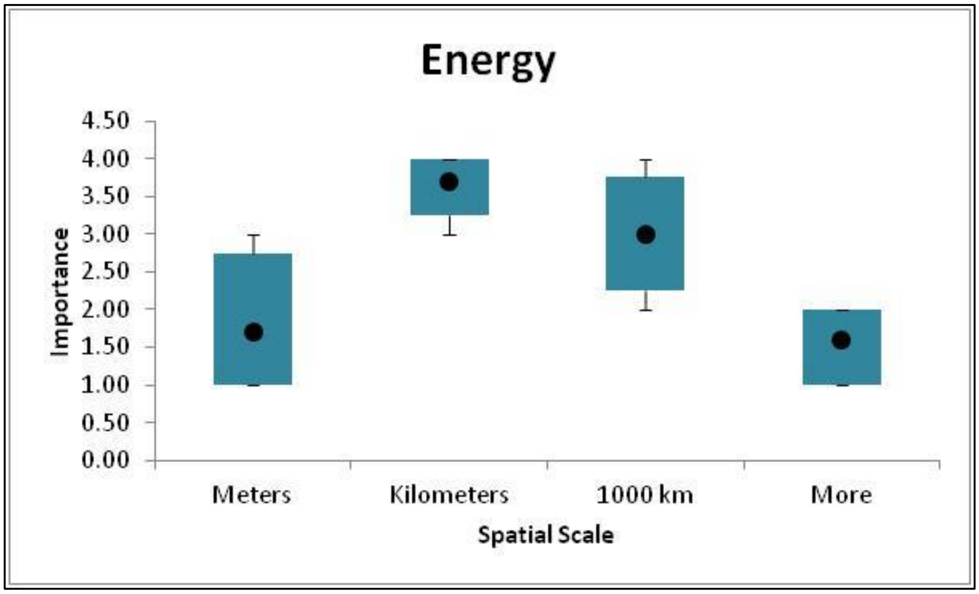


Figure C.64 Agglomerative Spatial Scale: Energy

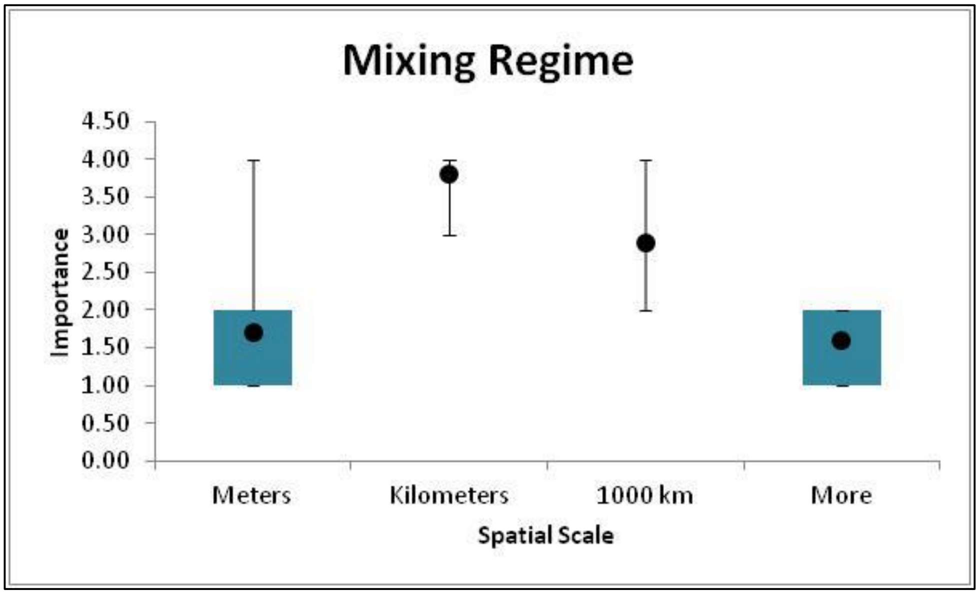


Figure C.65 Agglomerative Spatial Scale: Mixing Regime

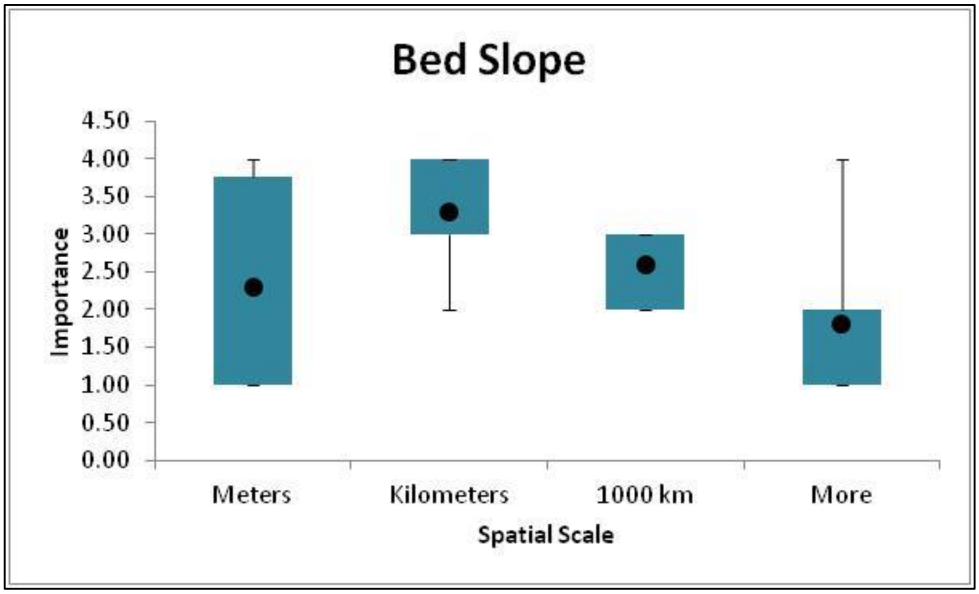


Figure C.66 Agglomerative Spatial Scale: Bed Slope

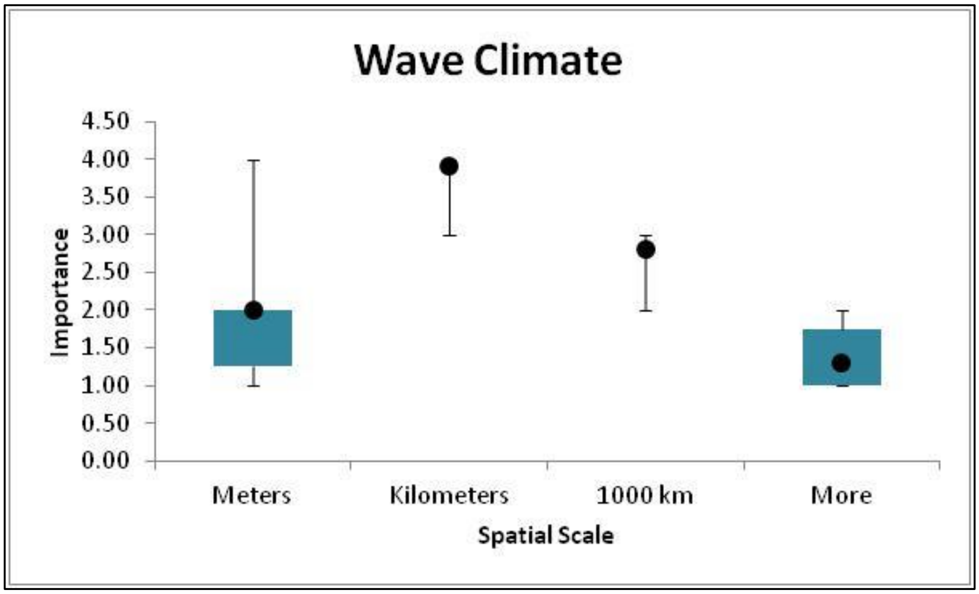


Figure C.67 Agglomerative Spatial Scale: Wave Climate

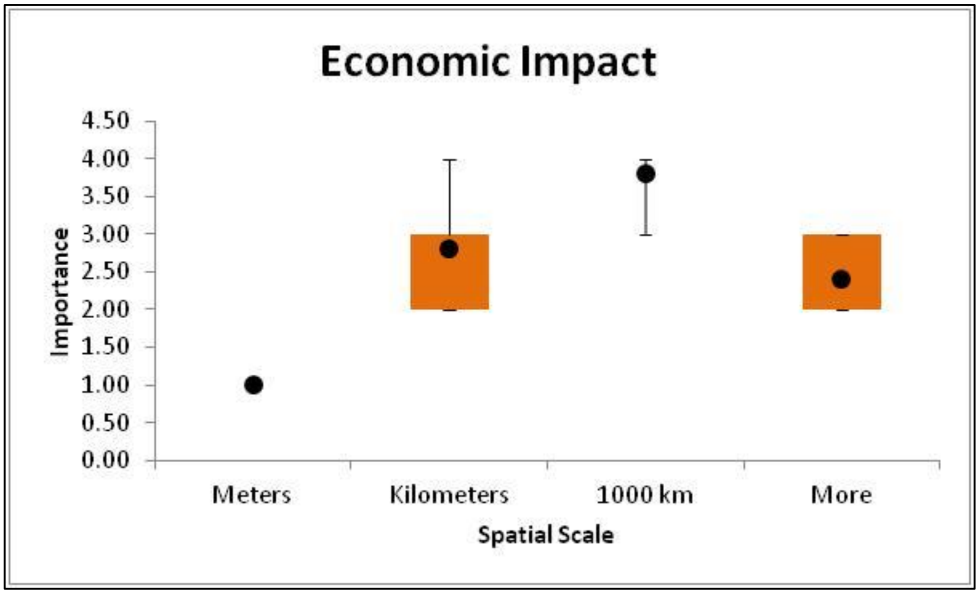


Figure C.68 Agglomerative Spatial Scale: Economic Impact

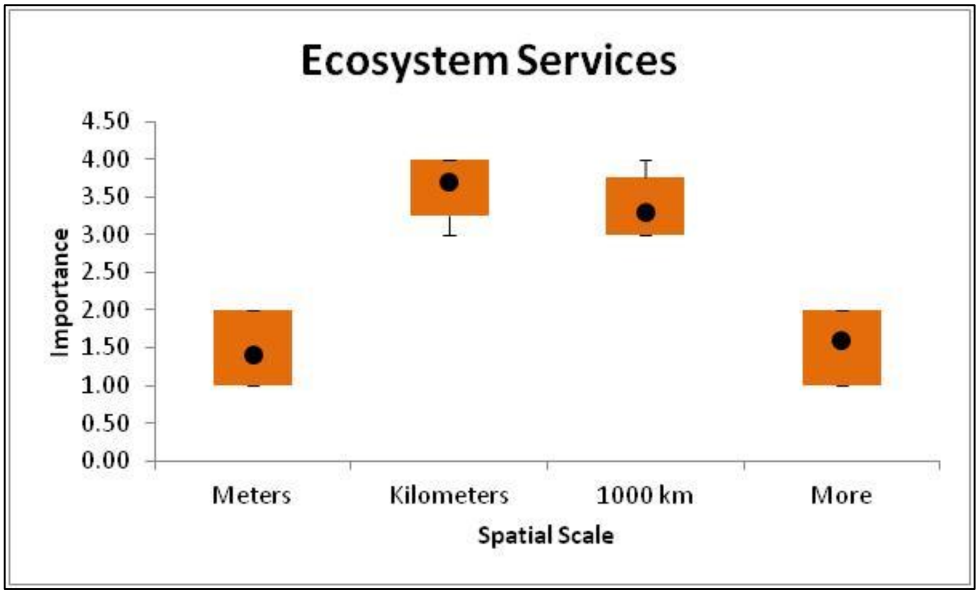


Figure C.69 Agglomerative Spatial Scale: Ecosystem Services

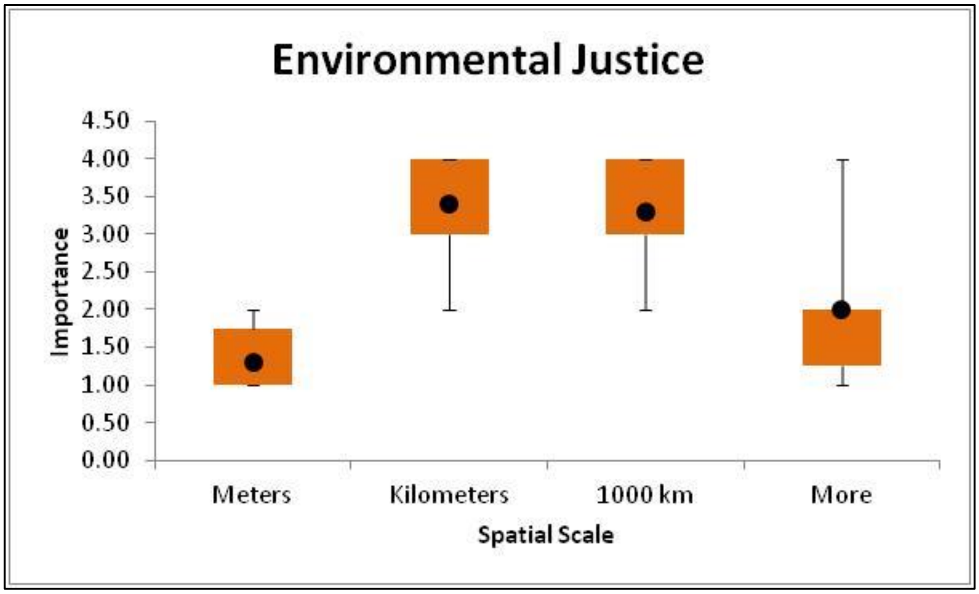


Figure C.70 Agglomerative Spatial Scale: Environmental Justice

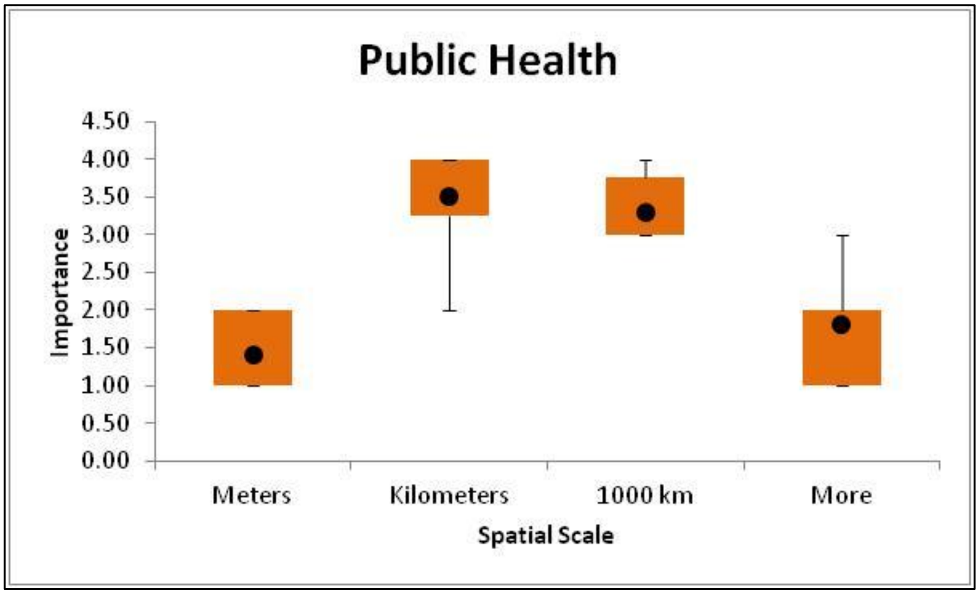


Figure C.71 Agglomerative Spatial Scale: Public Health

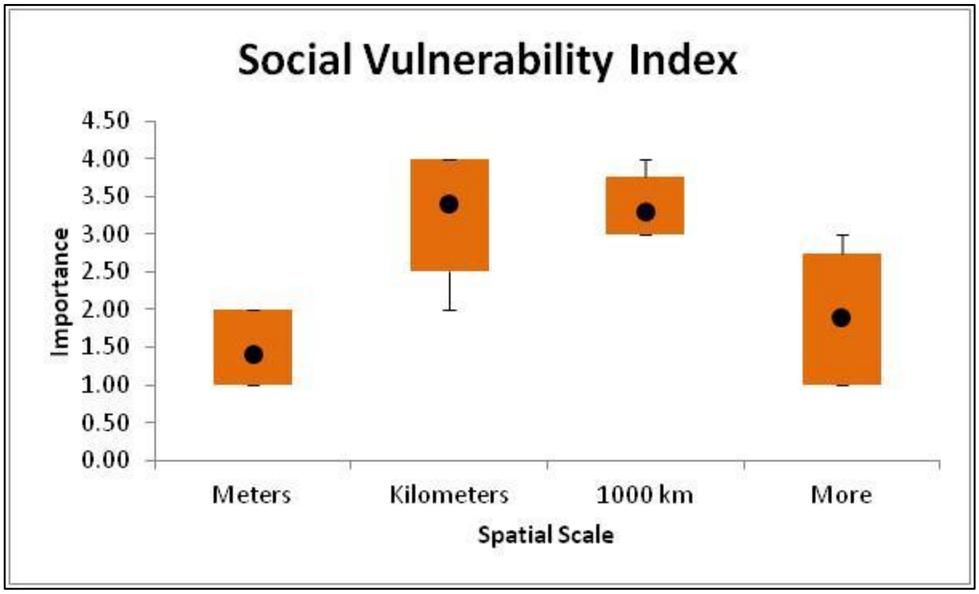


Figure C.72 Agglomerative Spatial Scale: Social Vulnerability Index

APPENDIX D

TEMPORAL SCALE BOX AND WHISKER PLOTS

D.1 Integrated Ecosystem Assessment

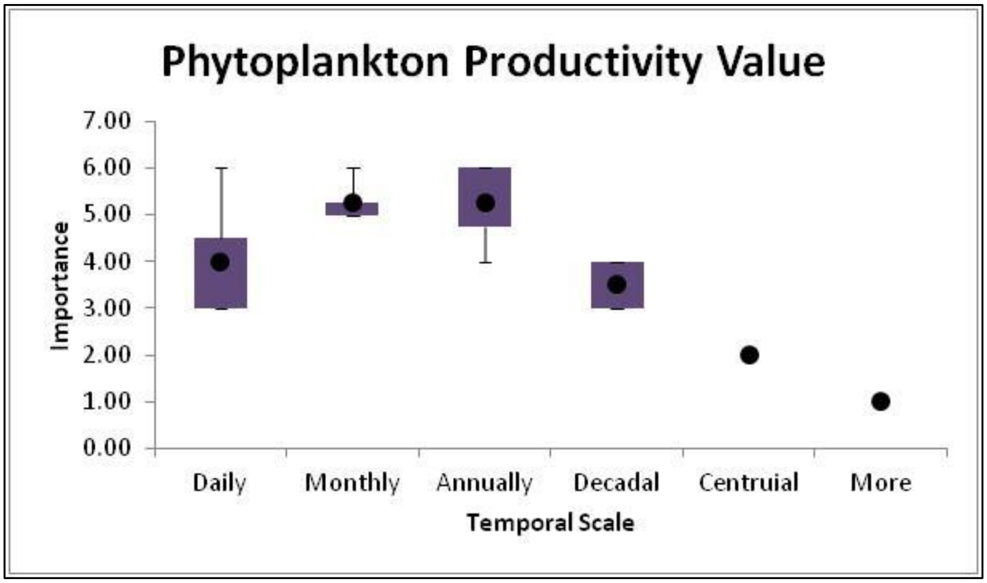


Figure D.1 IEA Temporal Scale: Phytoplankton Productivity Value

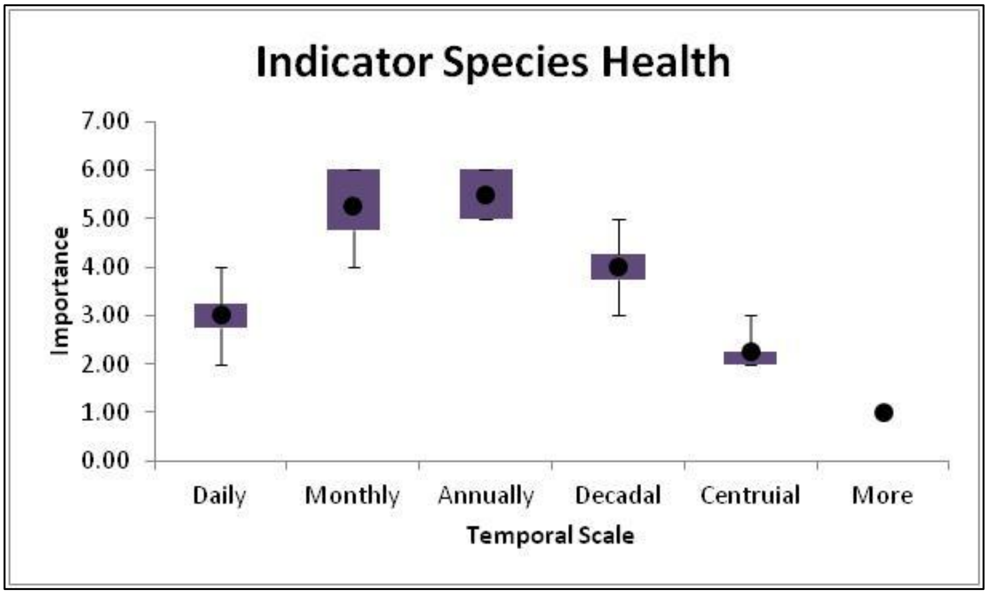


Figure D.2 IEA Temporal Scale: Indicator Species Health

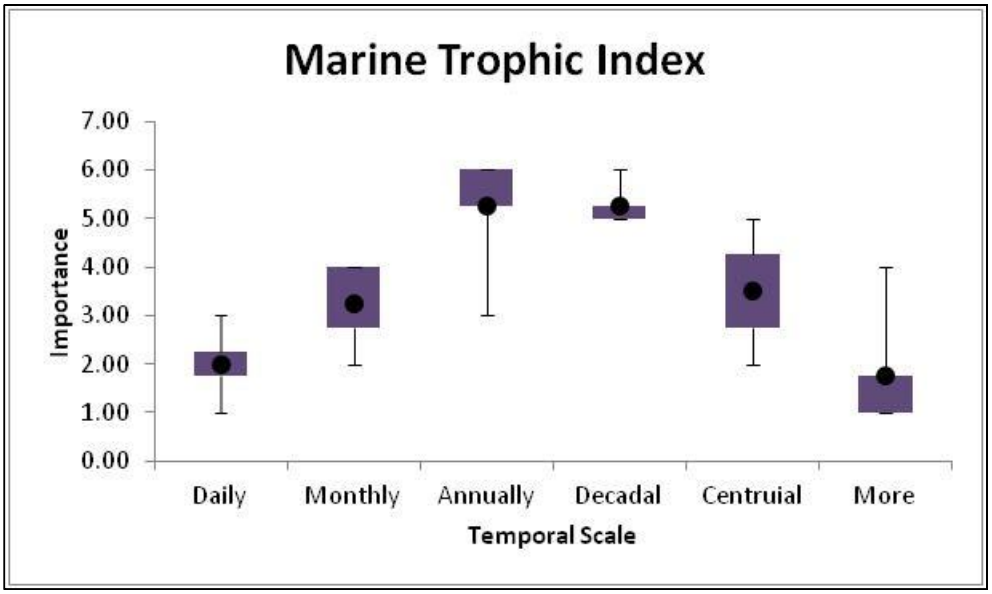


Figure D.3 IEA Temporal Scale: Marine Tropic Index

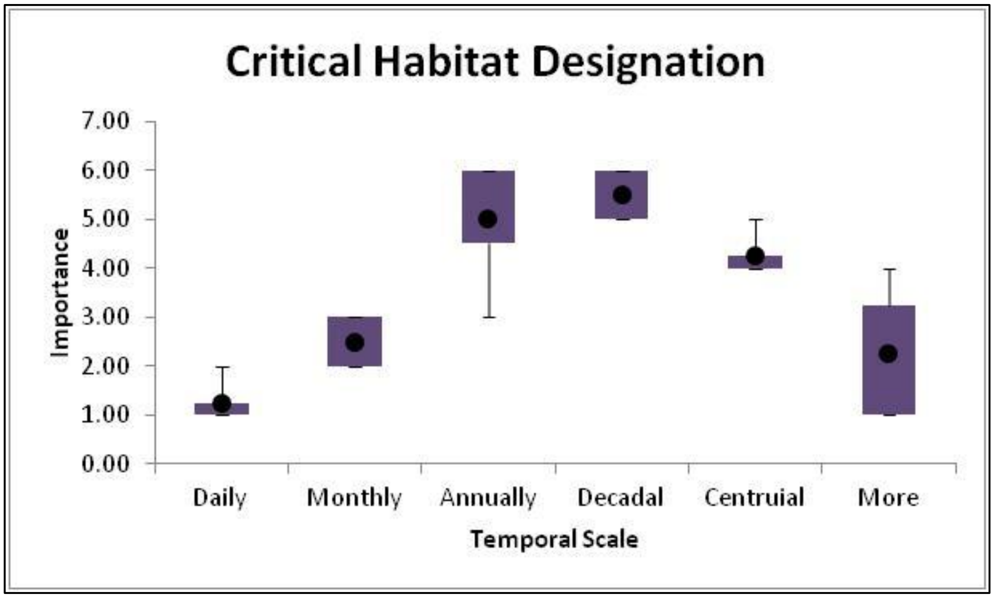


Figure D.4 IEA Temporal Scale: Critical Habitat Designation

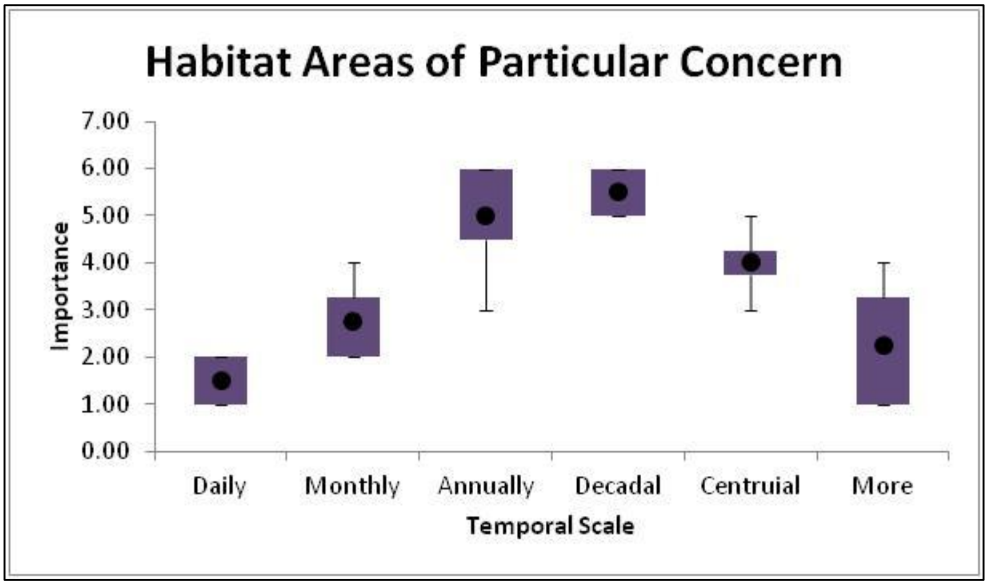


Figure D.5 IEA Temporal Scale: Habitat Areas of Particular Concern

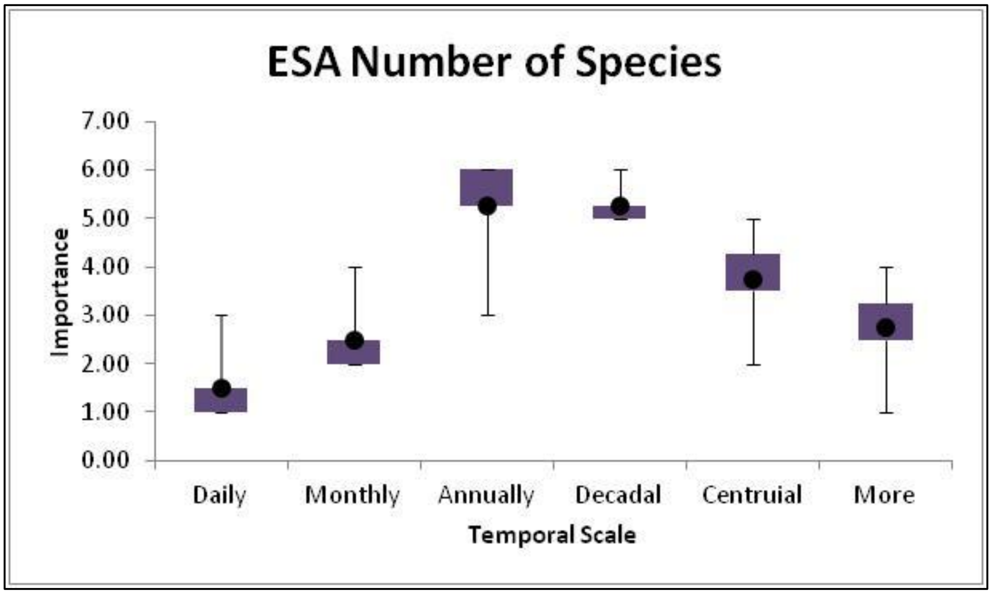


Figure D.6 IEA Temporal Scale: ESA Number of Species

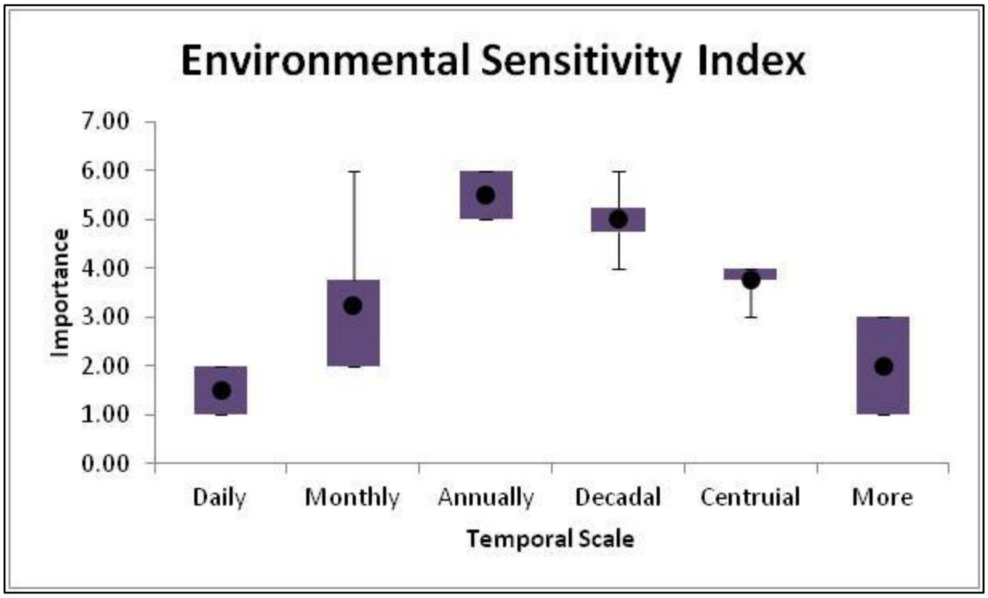


Figure D.7 IEA Temporal Scale: Environmental Sensitivity Index

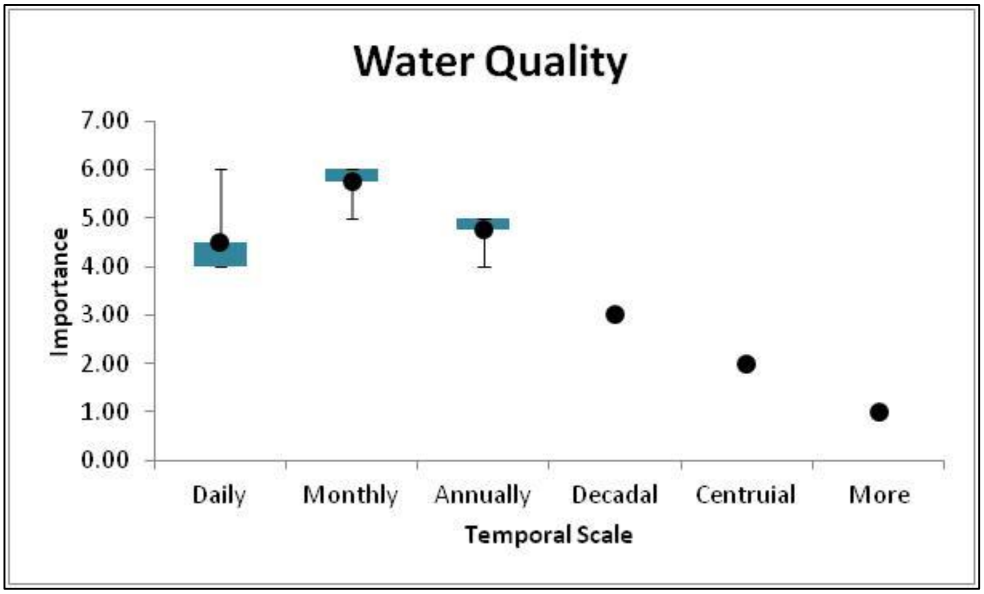


Figure D.8 IEA Temporal Scale: Water Quality

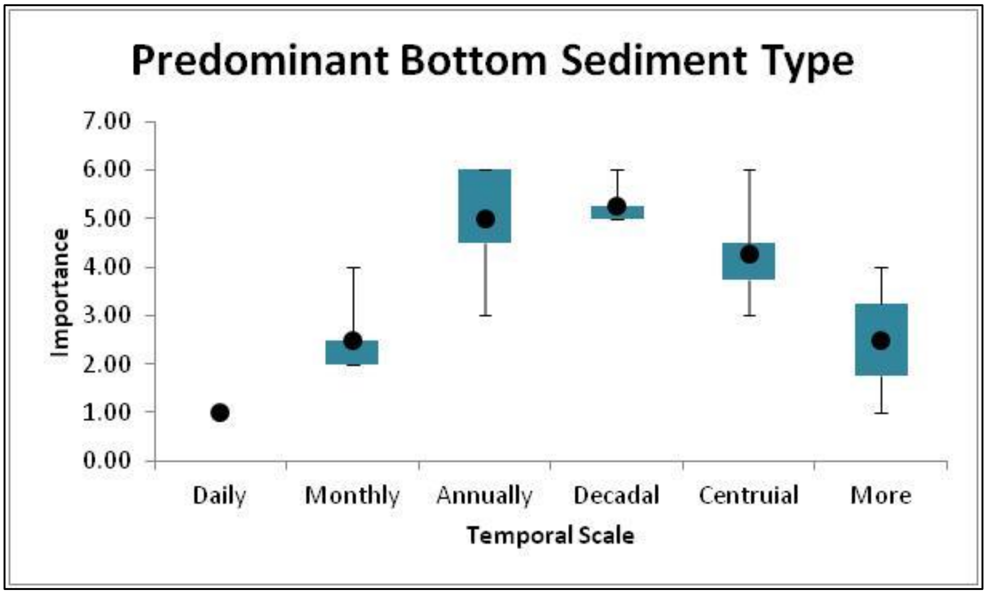


Figure D.9 IEA Temporal Scale: Predominant Bottom Sediment Type

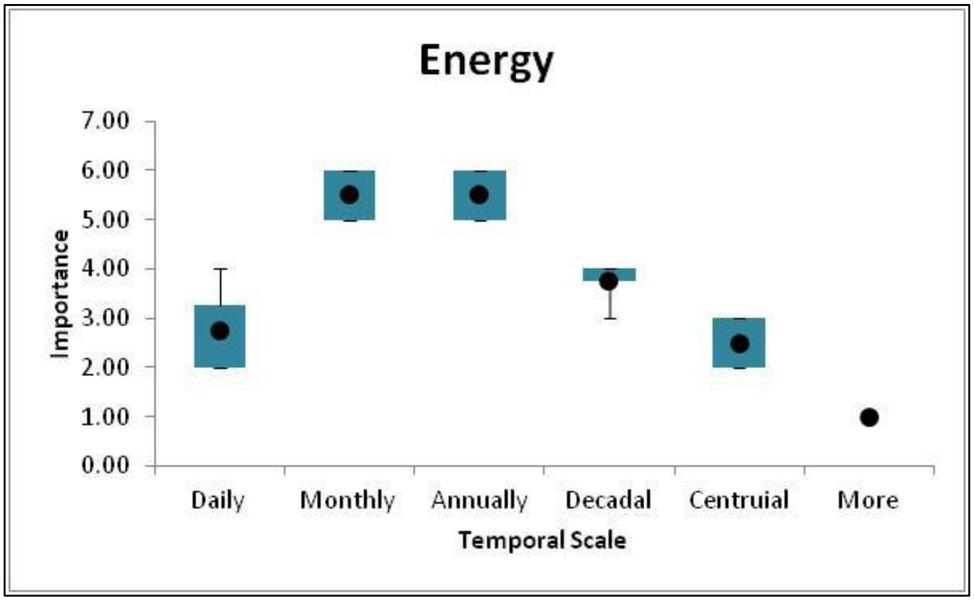


Figure D.10 IEA Temporal Scale: Energy

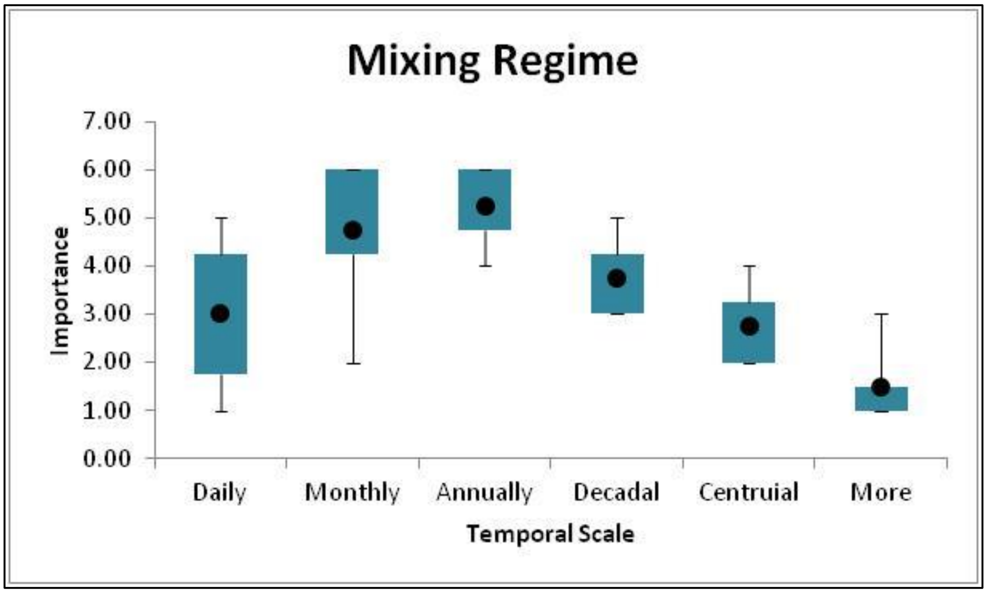


Figure D.11 IEA Temporal Scale: Mixing Regime

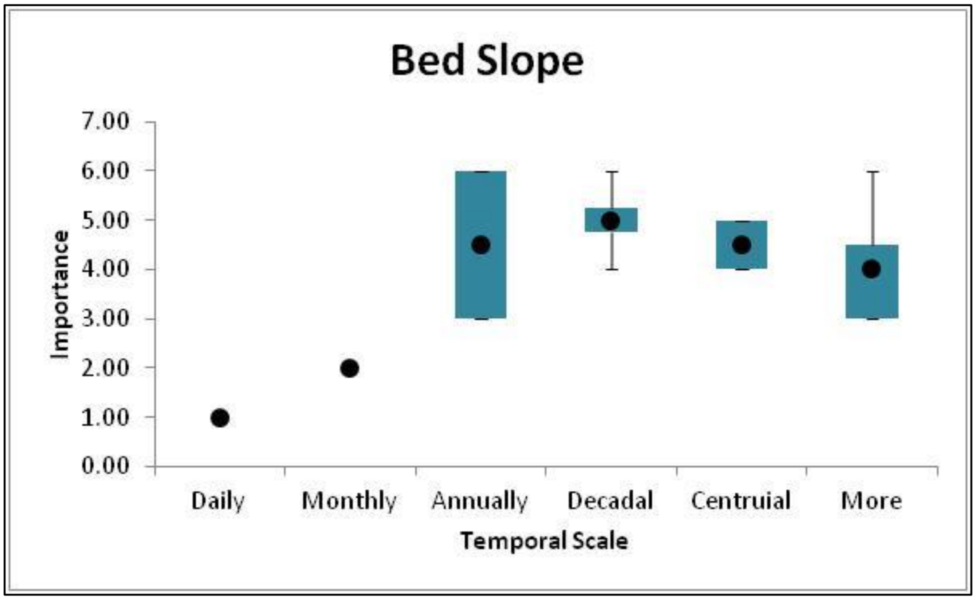


Figure D.12 IEA Temporal Scale: Bed Slope

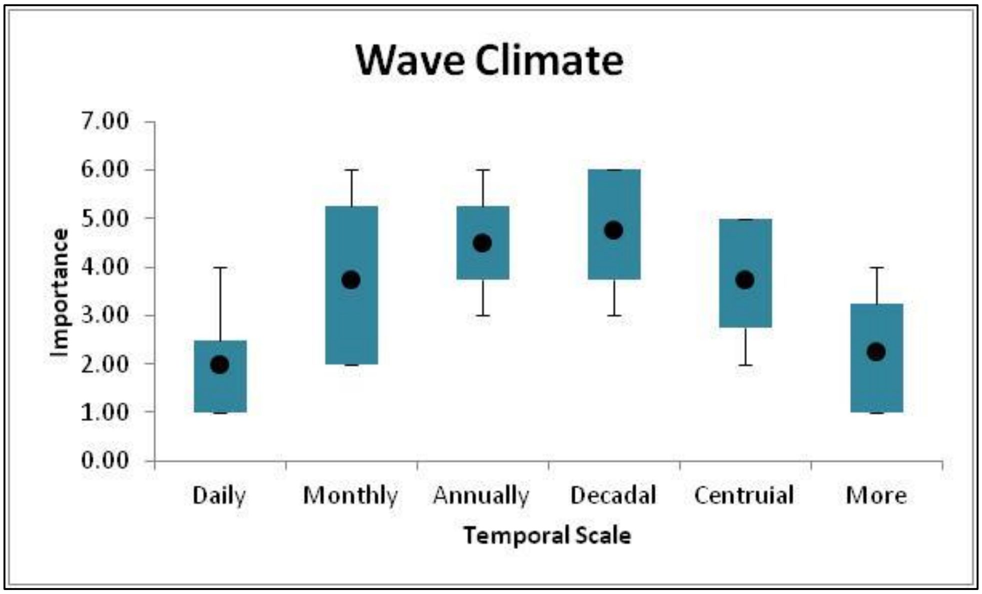


Figure D.13 IEA Temporal Scale: Wave Climate

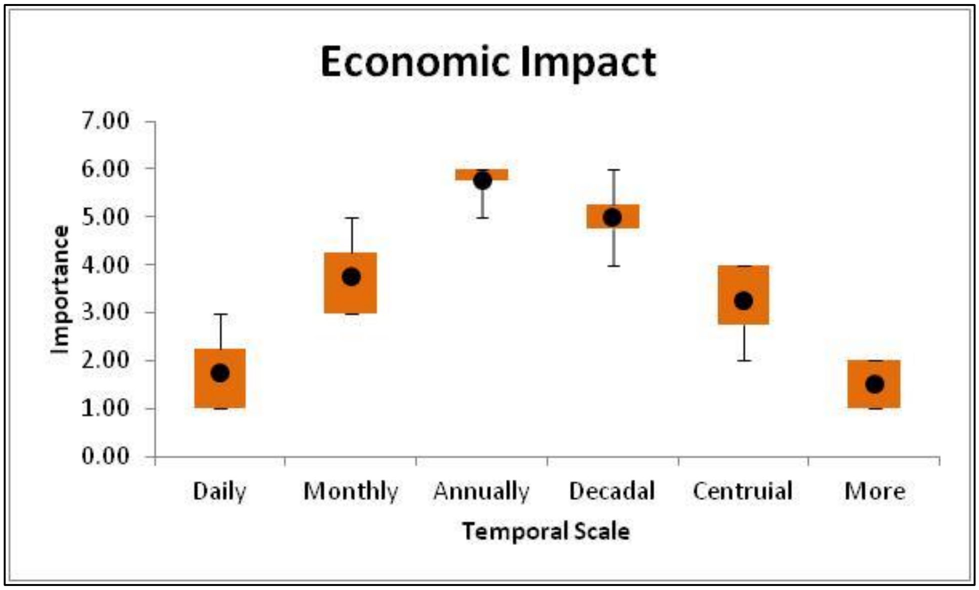


Figure D.14 IEA Temporal Scale: Economic Impact

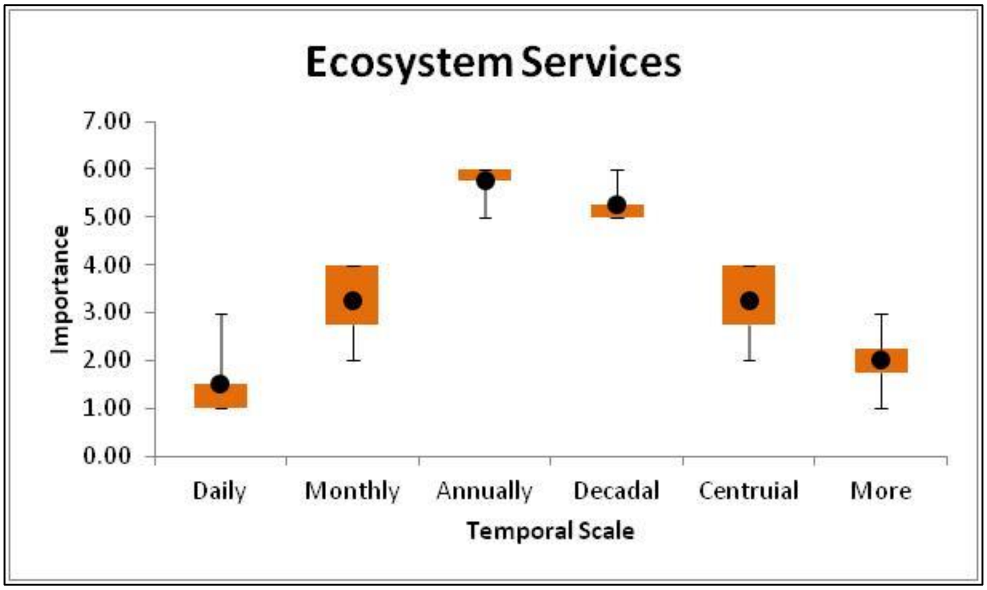


Figure D.15 IEA Temporal Scale: Ecosystem Services

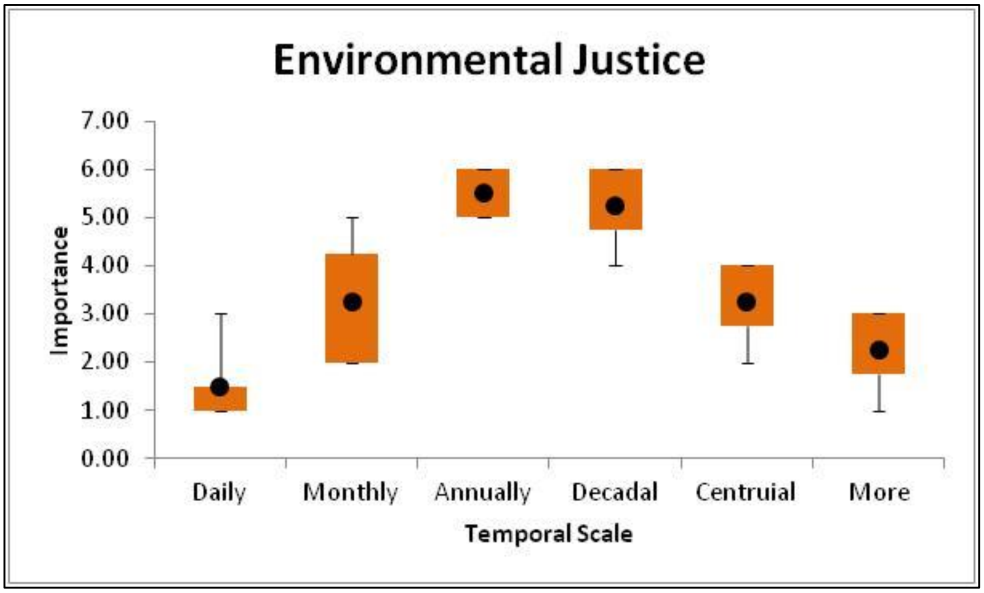


Figure D.16 IEA Temporal Scale: Environmental Justice

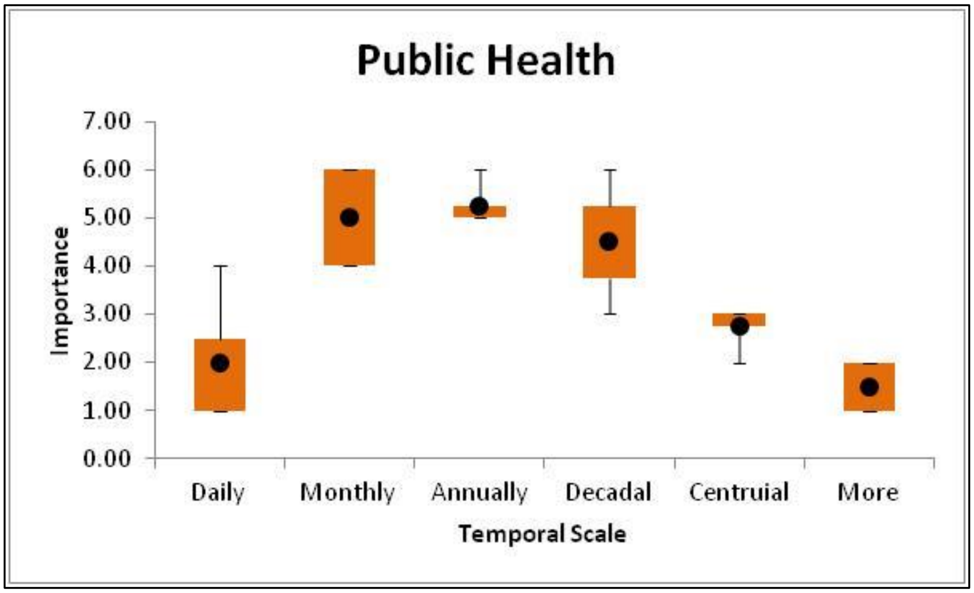


Figure D.17 IEA Temporal Scale: Public Health

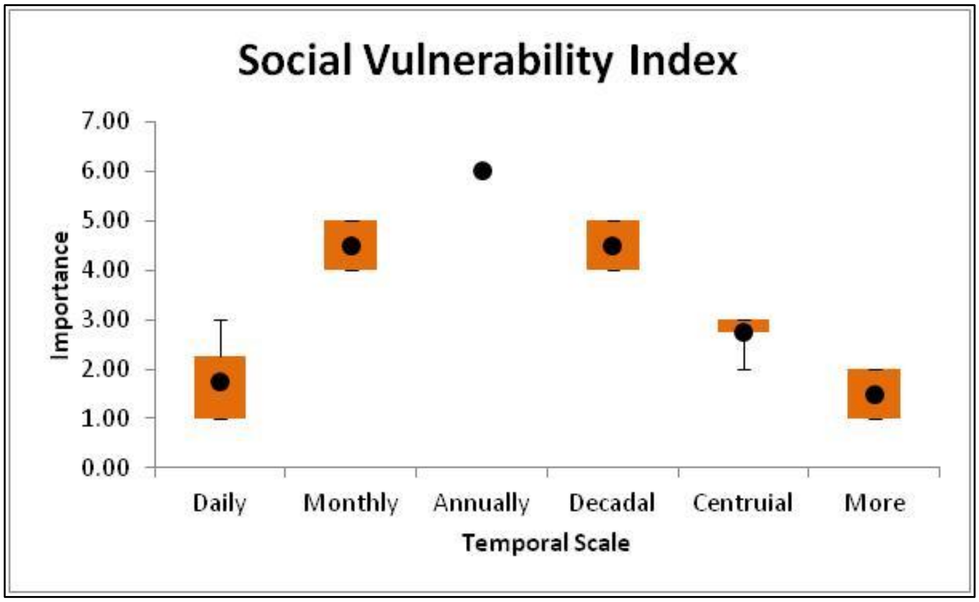


Figure D.18 IEA Temporal Scale: Social Vulnerability Index

D.2 Coastal and Marine Spatial Planning

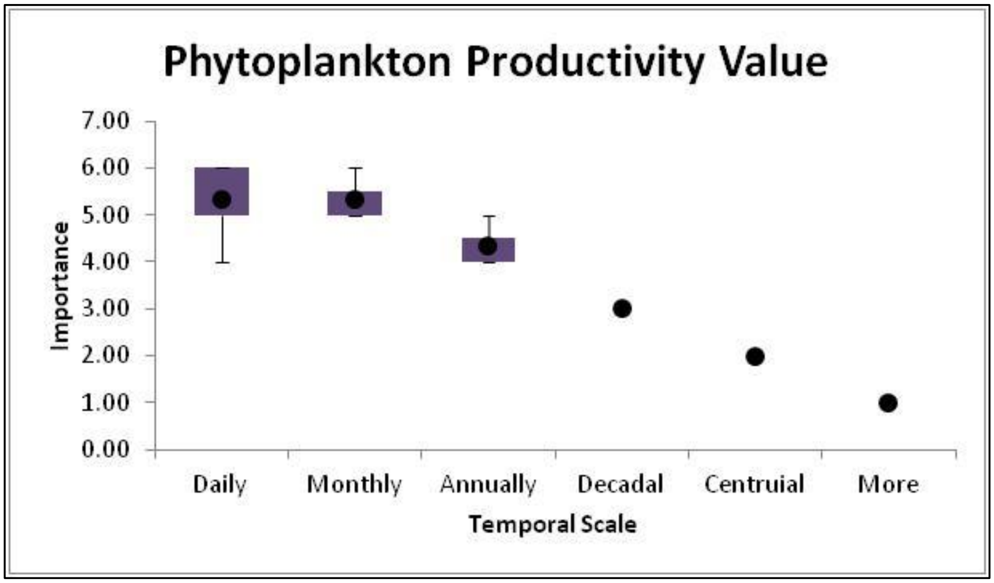


Figure D.19 CMSP Temporal Scale: Phytoplankton Productivity Value

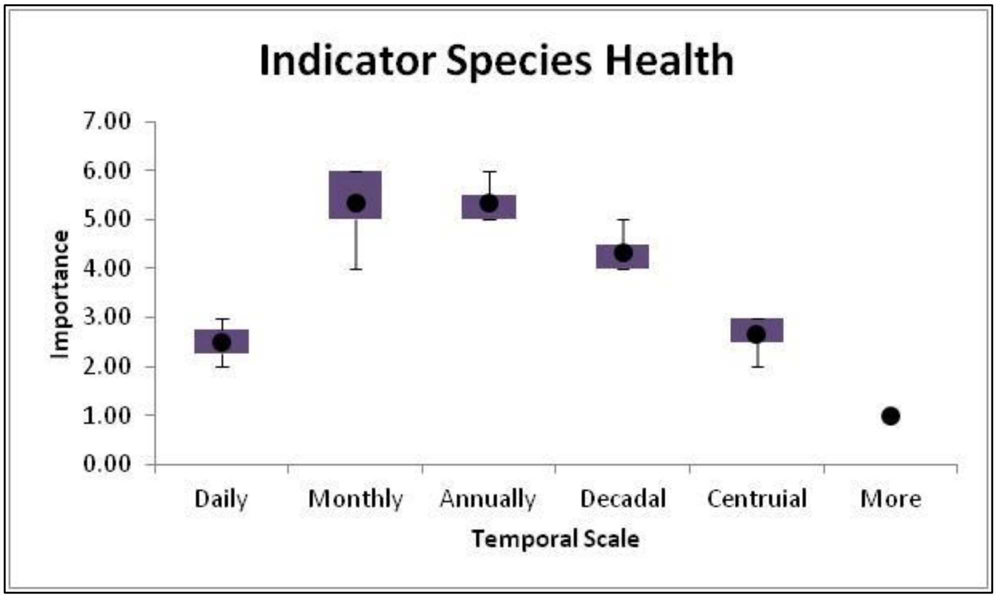


Figure D.20 CMSP Temporal Scale: Indicator Species Health

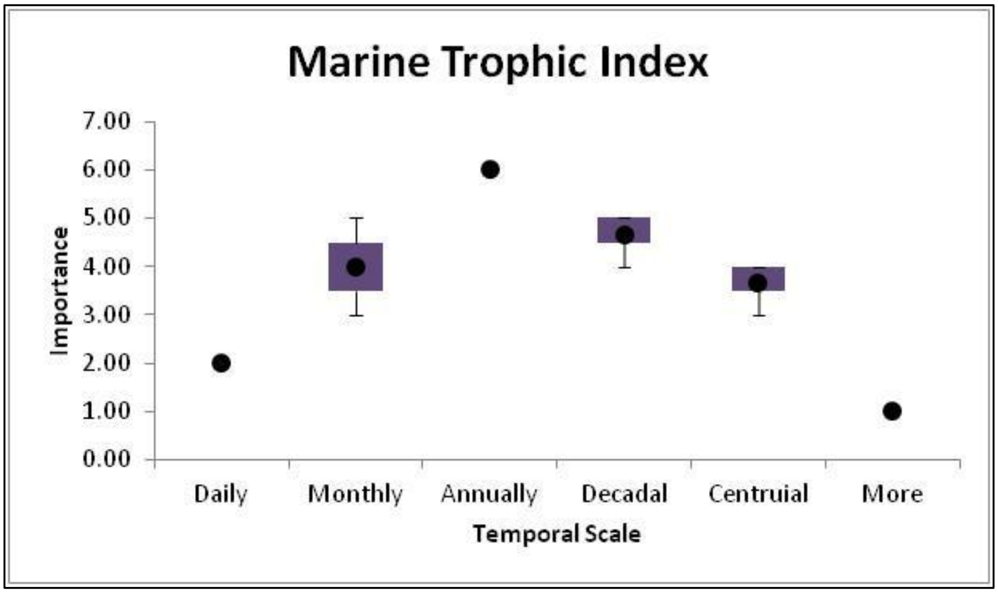


Figure D.21 CMSP Temporal Scale: Marine Trophic Index

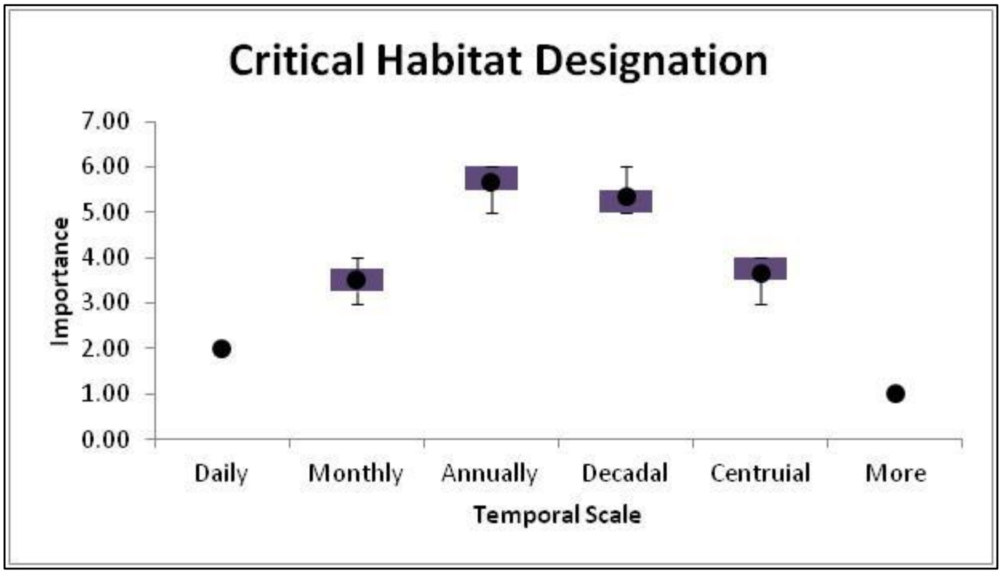


Figure D.22 CMSP Temporal Scale: Critical Habitat Designation

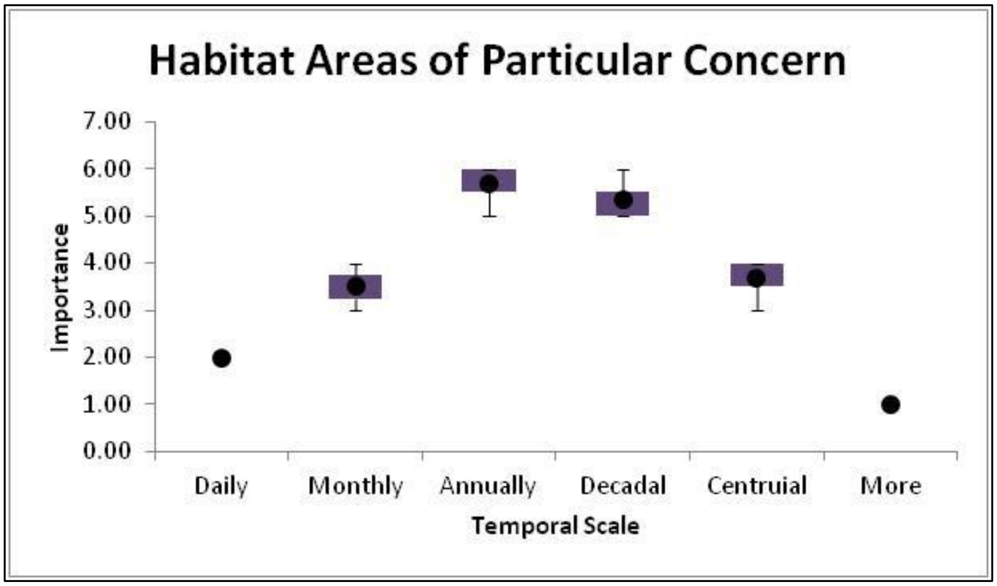


Figure D.23 CMSP Temporal Scale: Habitat Areas of Particular Concern

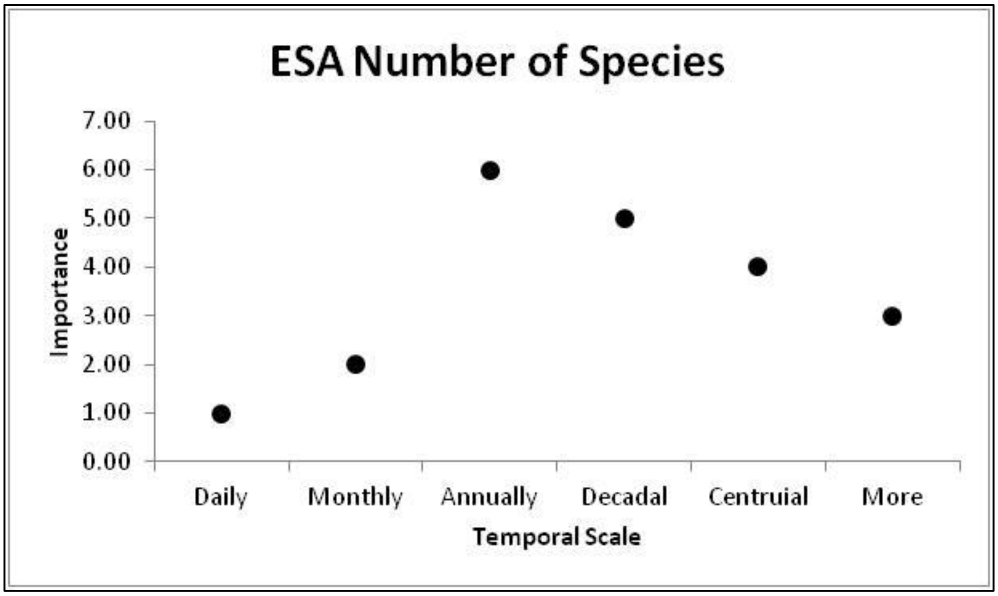


Figure D.24 CMSP Temporal Scale: ESA Number of Species

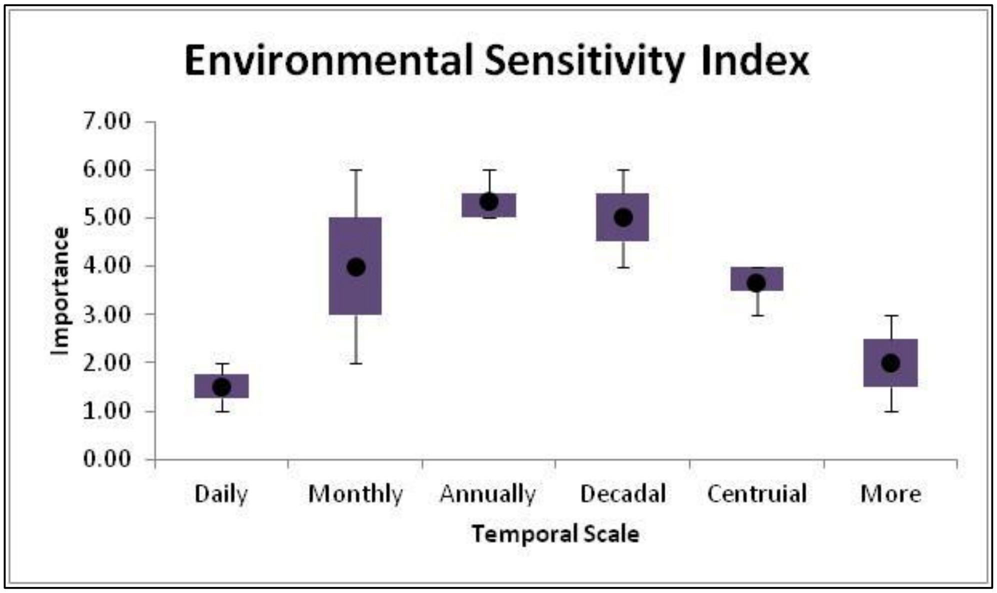


Figure D.25 CMSP Temporal Scale: Environmental Sensitivity Index

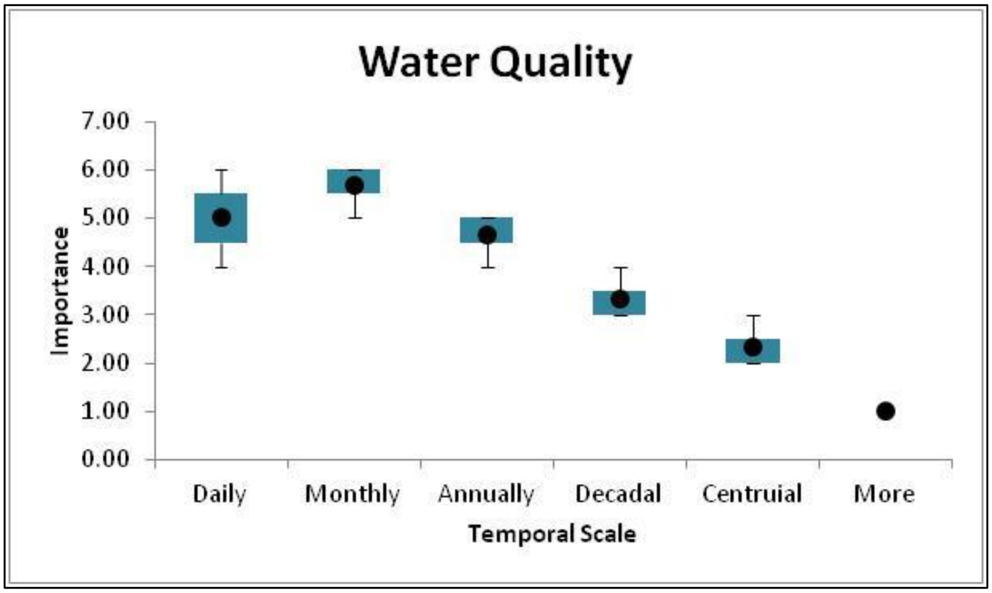


Figure D.26 CMSP Temporal Scale: Water Quality

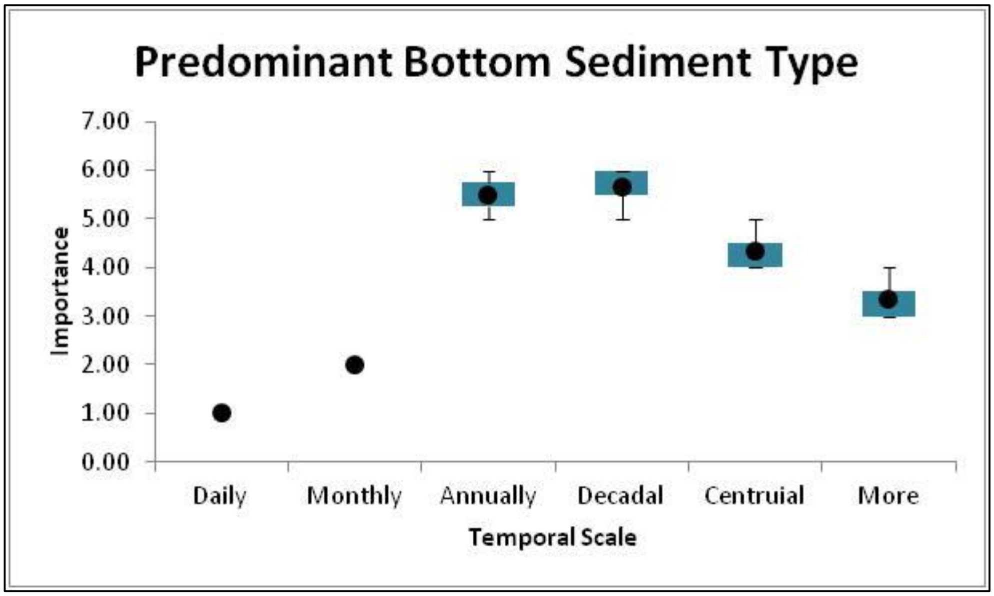


Figure D.27 CMSP Temporal Scale: Predominant Bottom Sediment Type

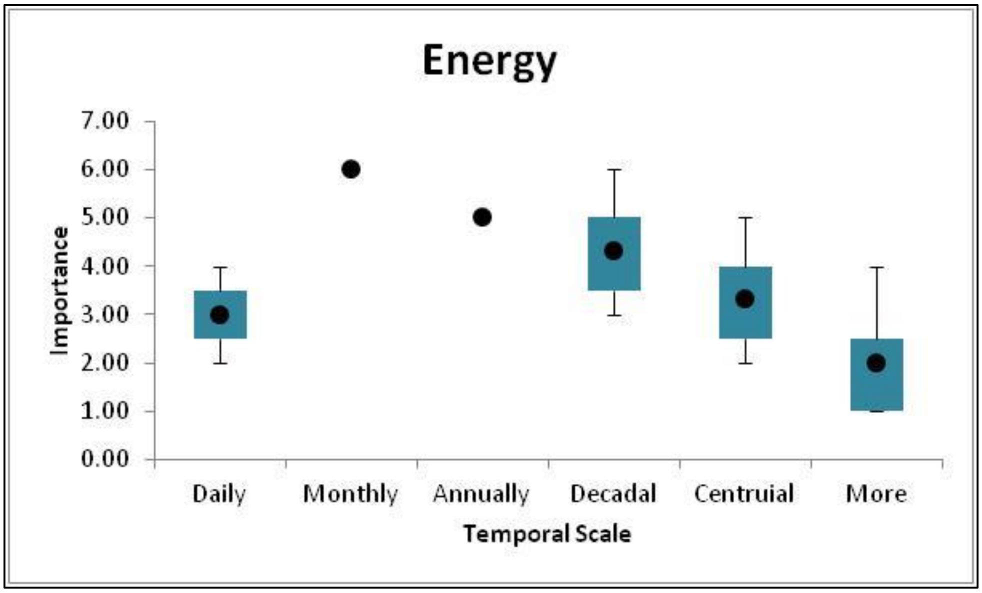


Figure D.28 CMSP Temporal Scale: Energy

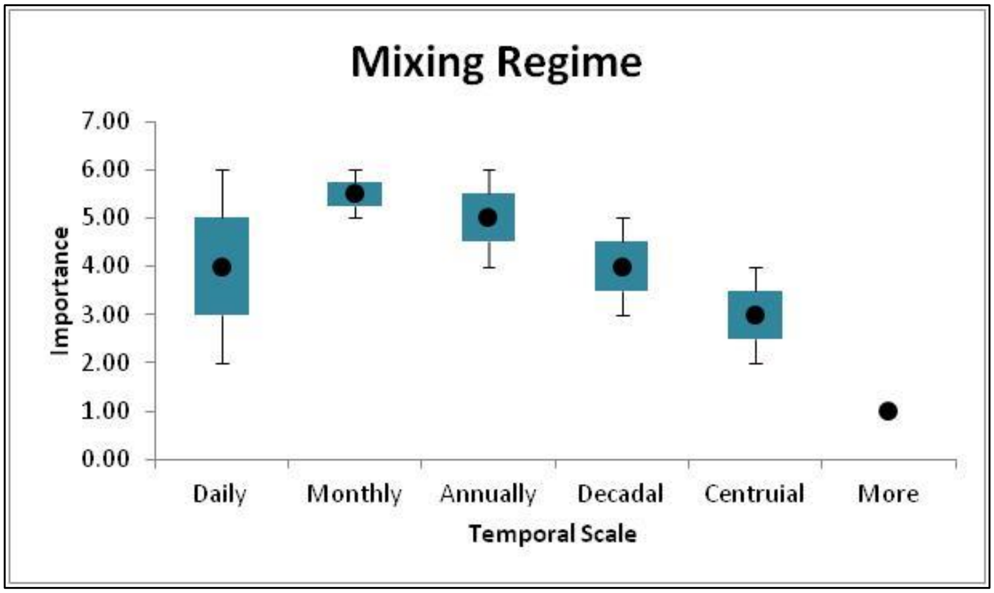


Figure D.29 CMSP Temporal Scale: Mixing Regime

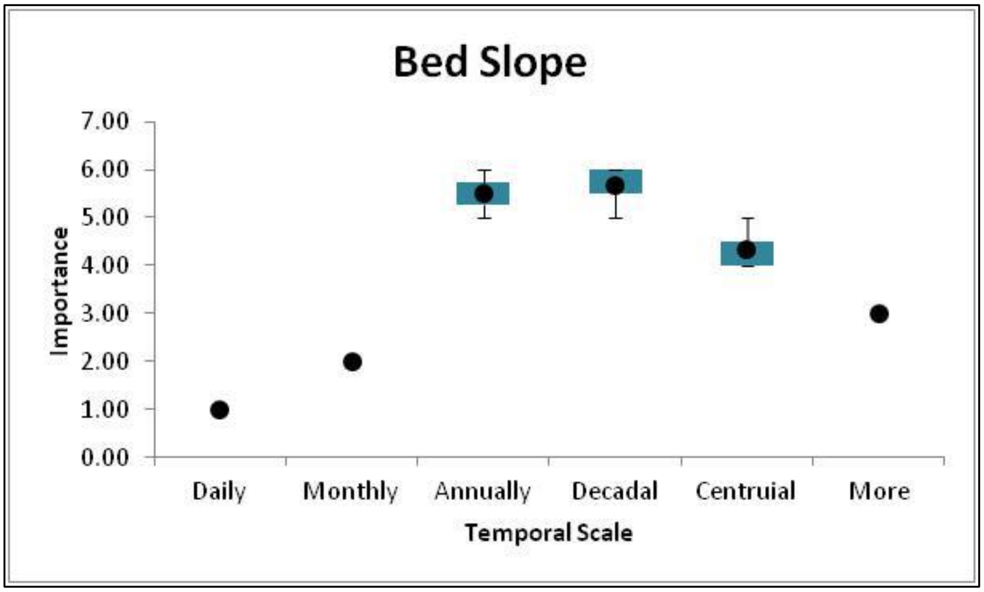


Figure D.30 CMSP Temporal Scale: Bed Slope

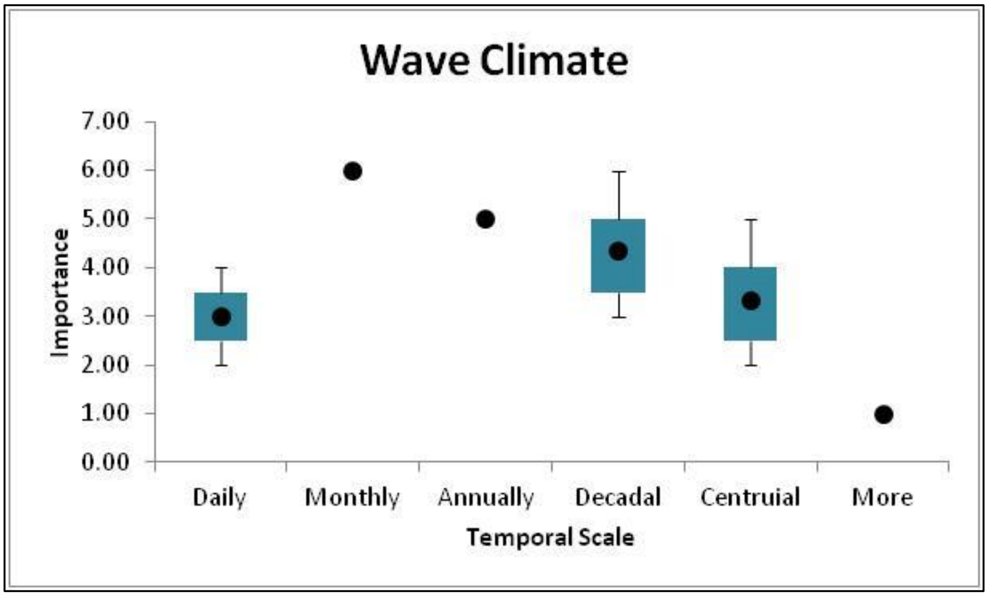


Figure D.31 CMSP Temporal Scale: Wave Climate

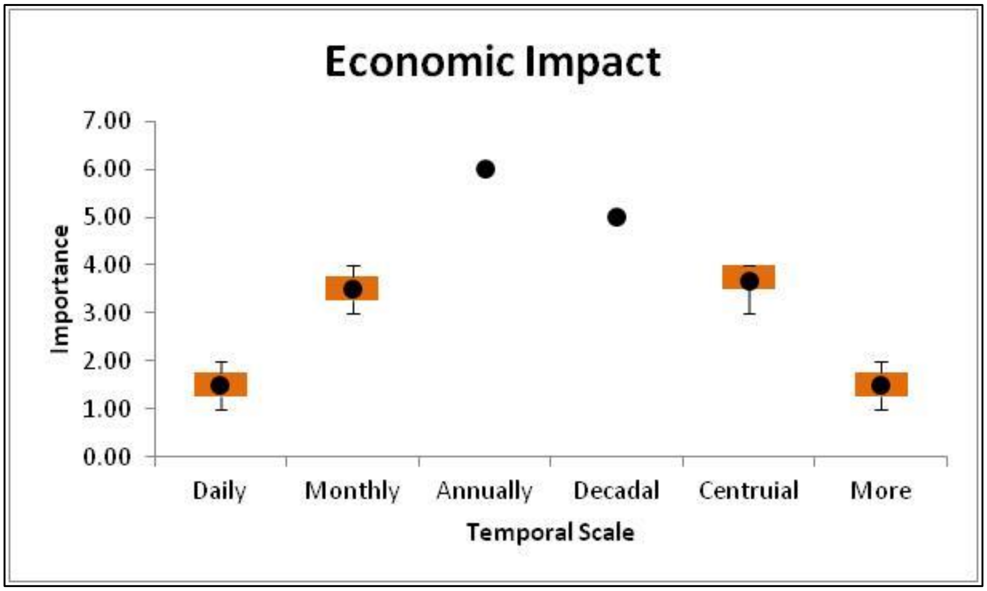


Figure D.32 CMSP Temporal Scale: Economic Impact

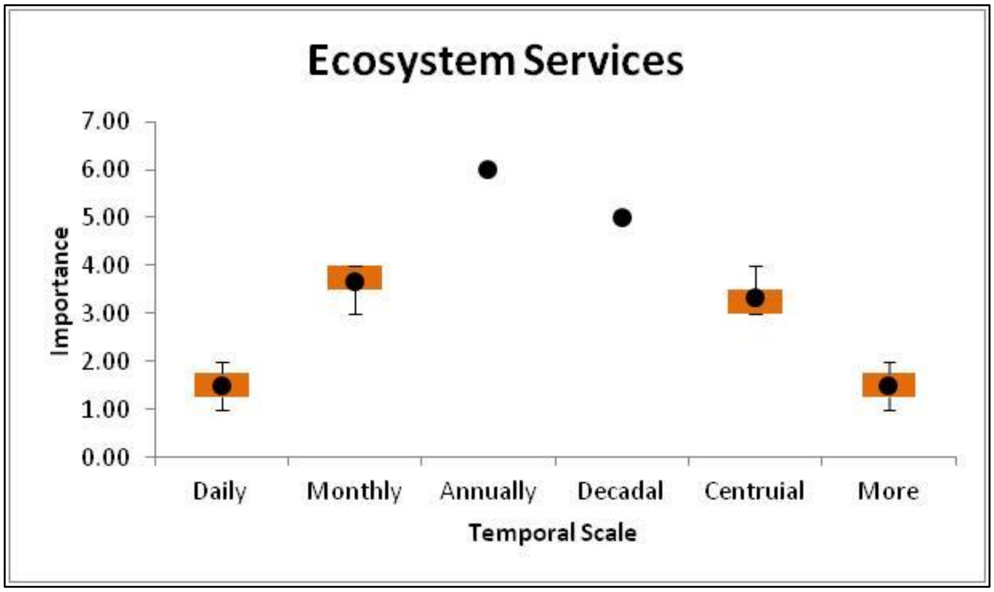


Figure D.33 CMSP Temporal Scale: Ecosystem Services

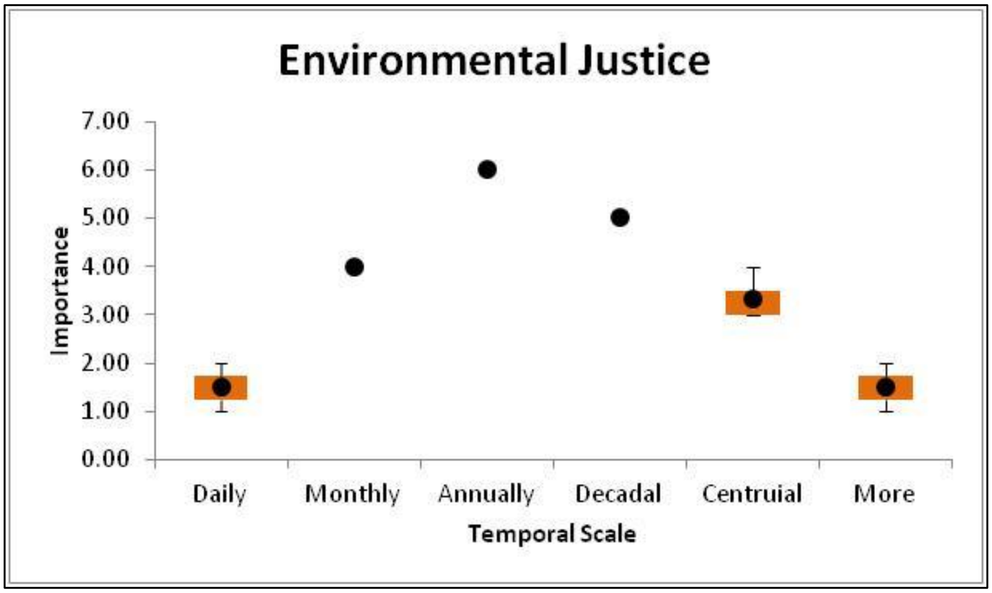


Figure D.34 CMSP Temporal Scale: Environmental Justice

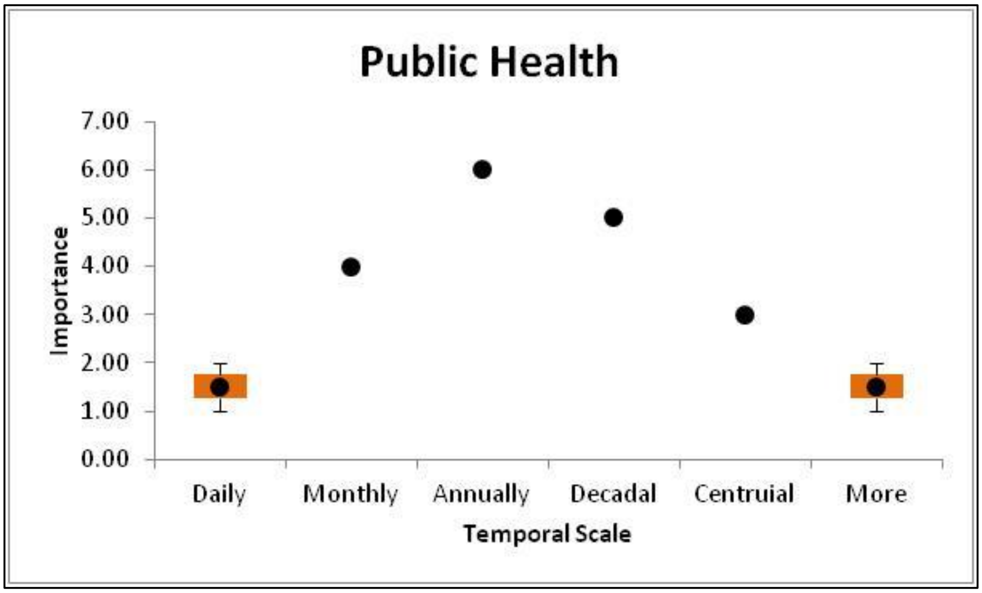


Figure D.35 CMSP Temporal Scale: Public Health

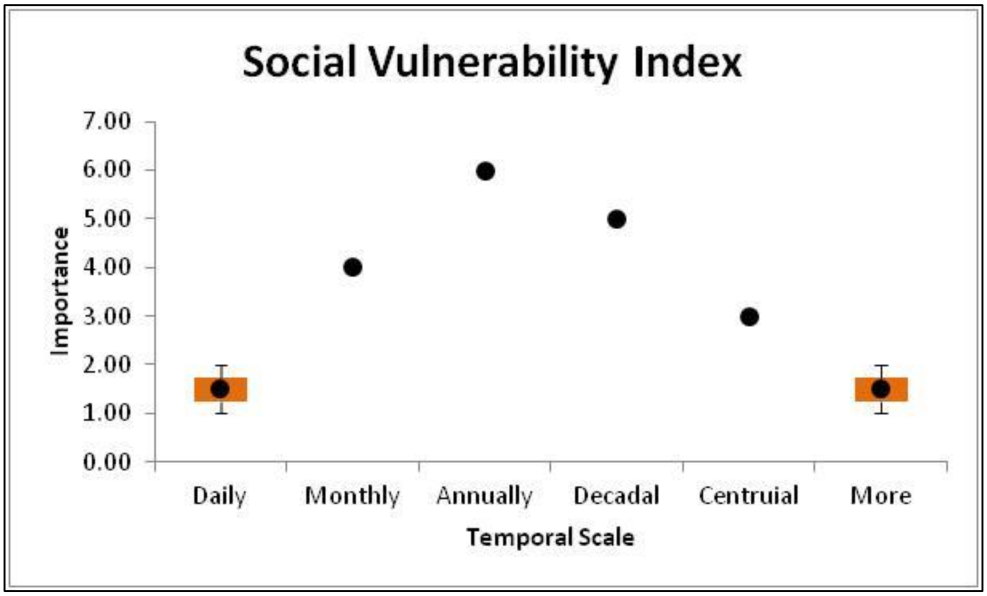


Figure D.36 CMSP Temporal Scale: Social Vulnerability Index

D.3 Ecosystem Based Management

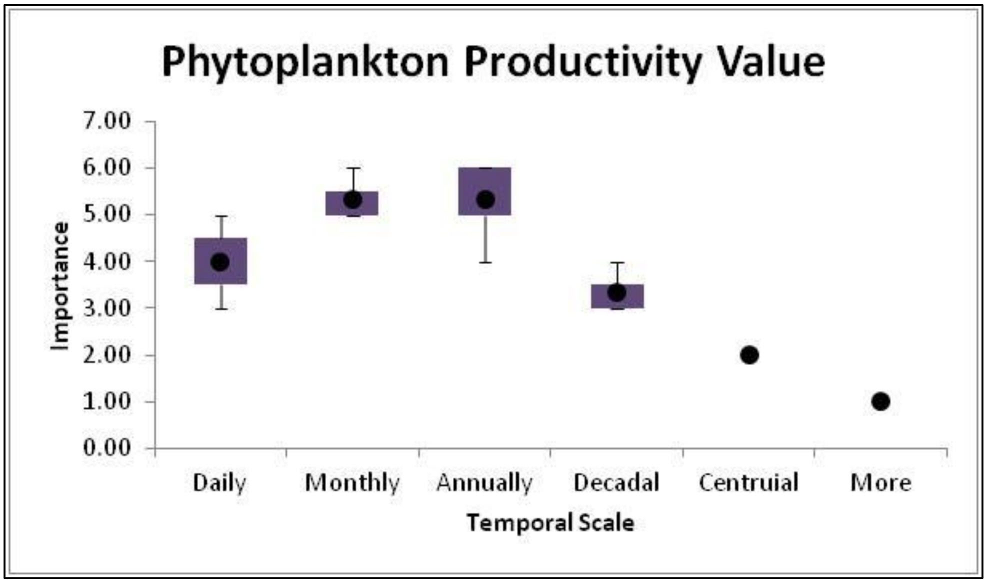


Figure D.37 EBM Temporal Scale: Phytoplankton Productivity Value

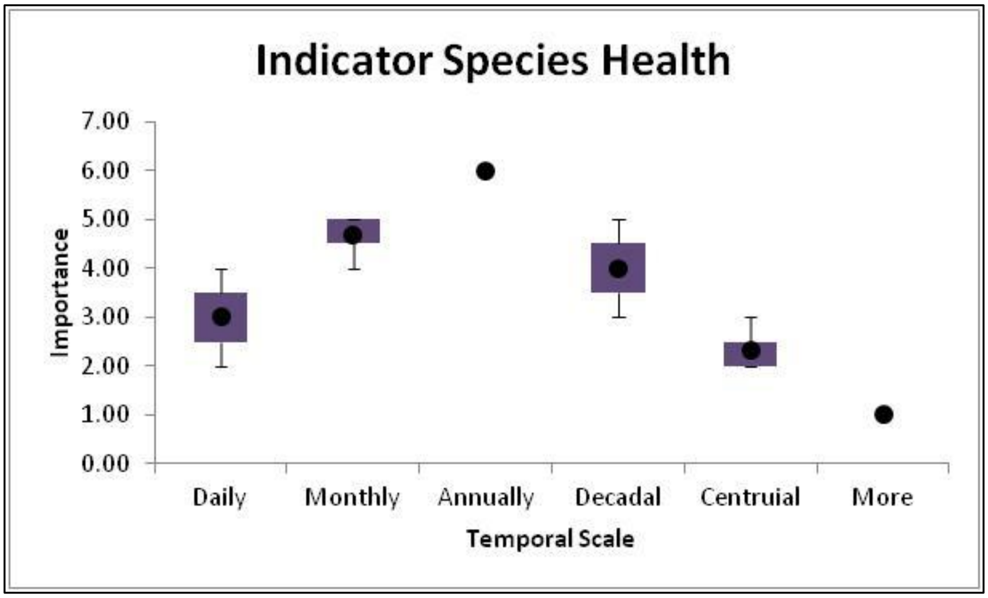


Figure D.38 EBM Temporal Scale: Indicator Species Health

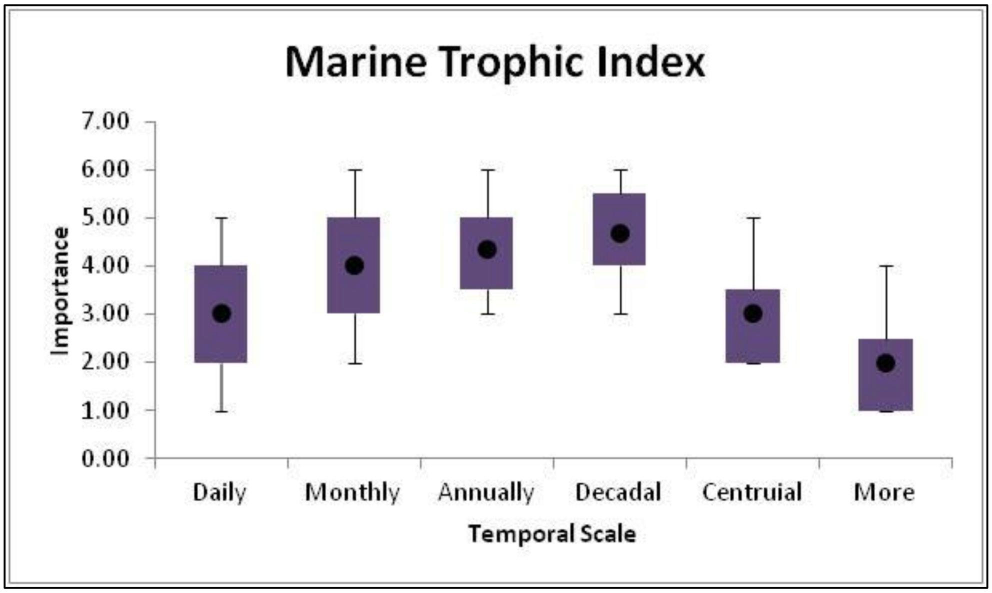


Figure D.39 EBM Temporal Scale: Marine Tropic Index

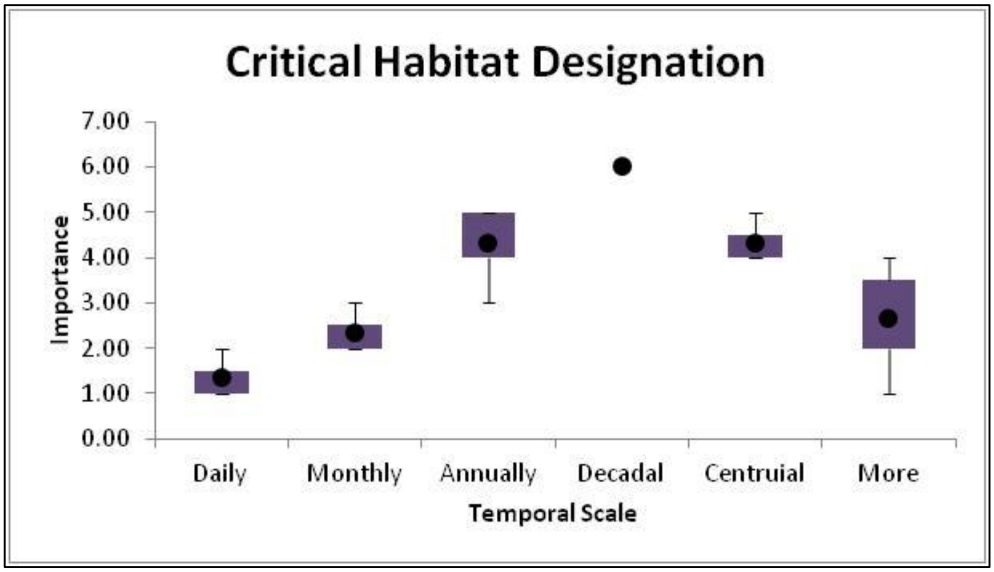


Figure D.40 EBM Temporal Scale: Critical Habitat Designation

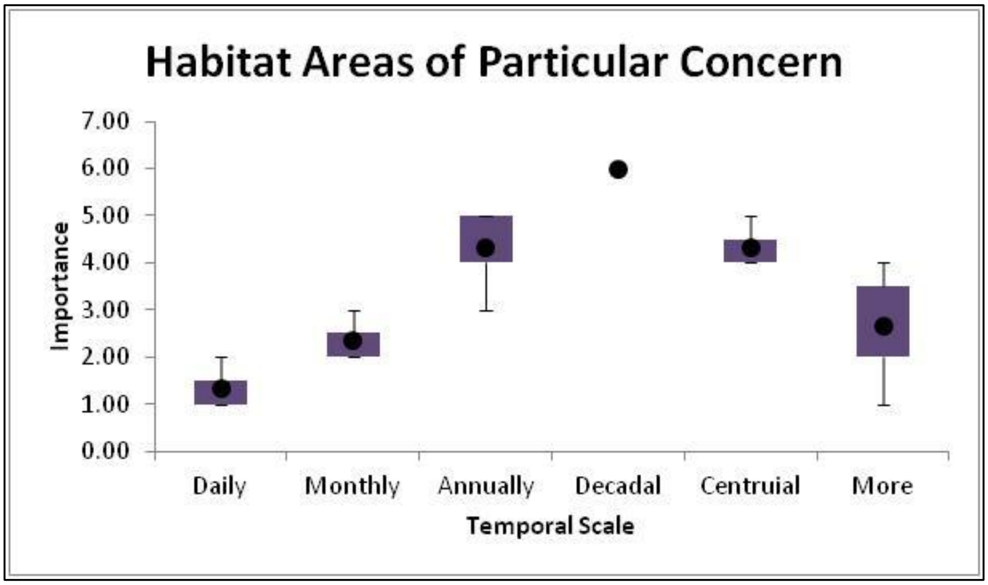


Figure D.41 EBM Temporal Scale: Habitat Areas of Particular Concern

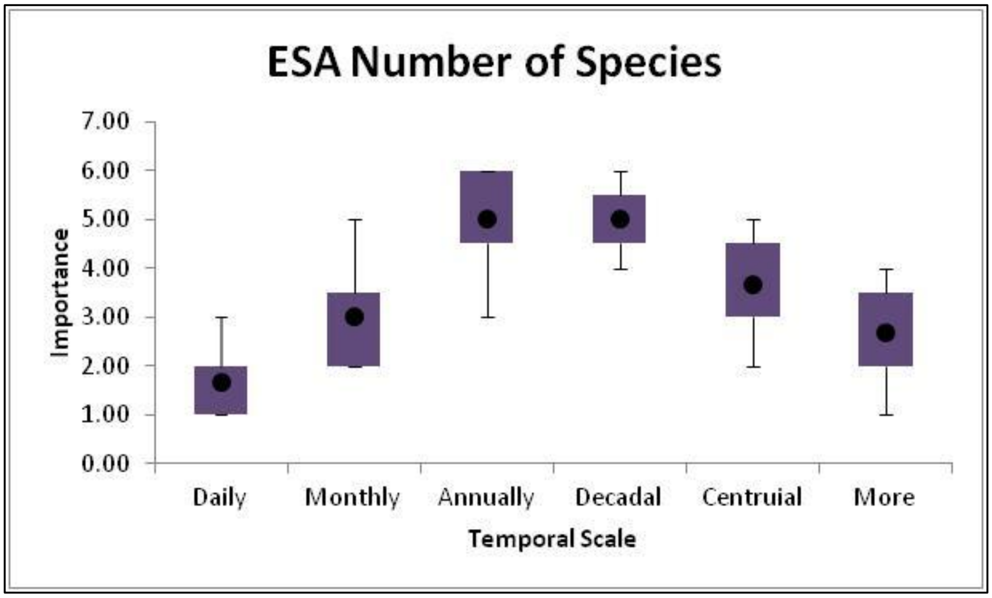


Figure D.42 EBM Temporal Scale: ESA Number of Species

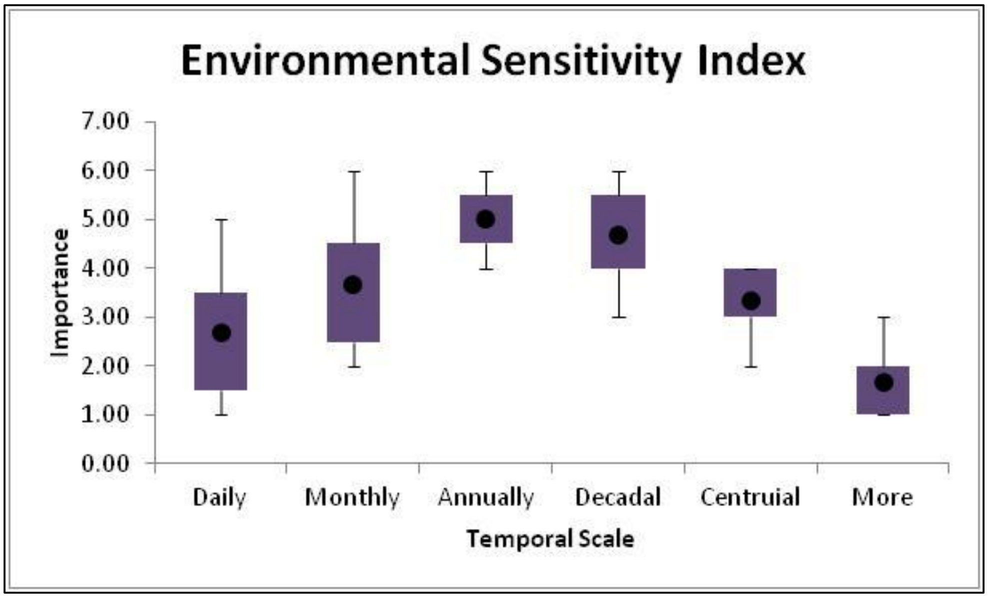


Figure D.43 EBM Temporal Scale: Environmental Sensitivity Index

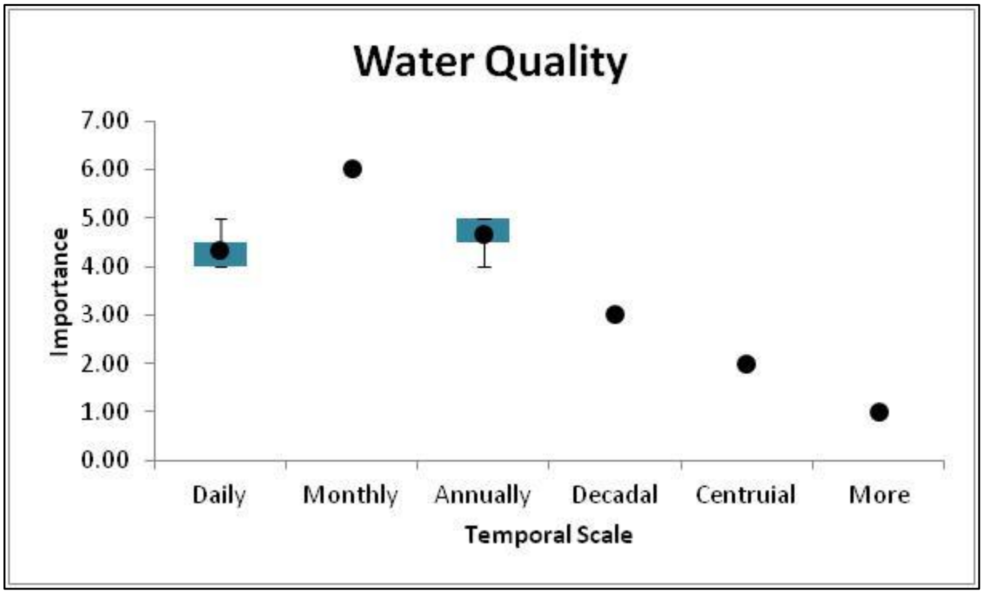


Figure D.44 EBM Temporal Scale: Water Quality

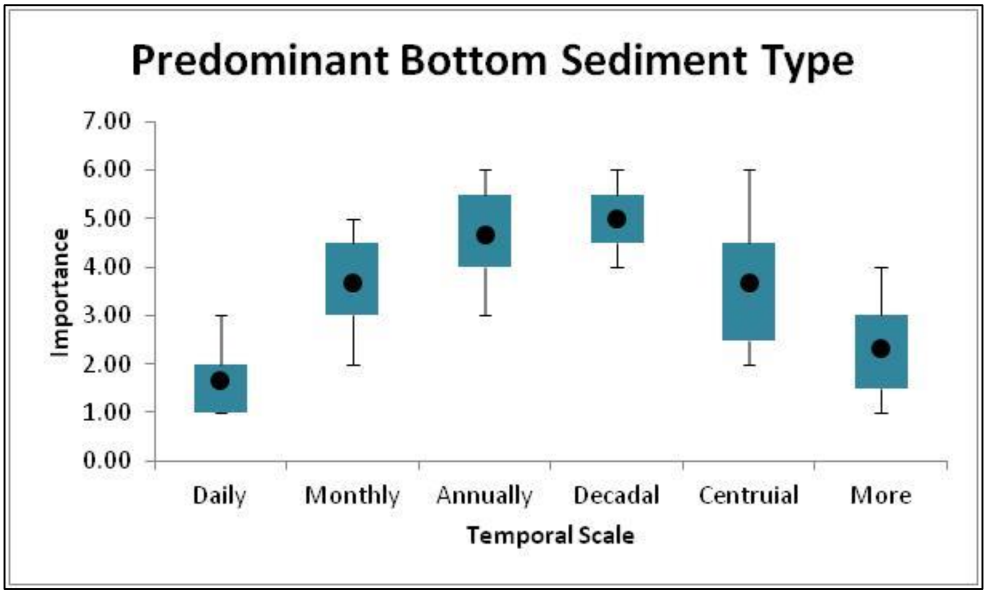


Figure D.45 EBM Temporal Scale: Predominant Bottom Sediment Type

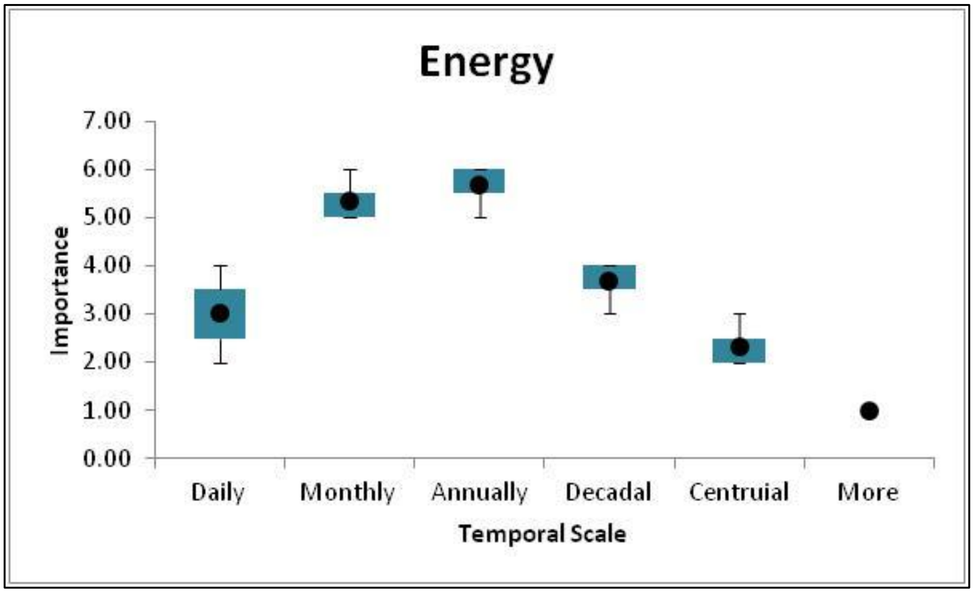


Figure D.46 EBM Temporal Scale: Energy

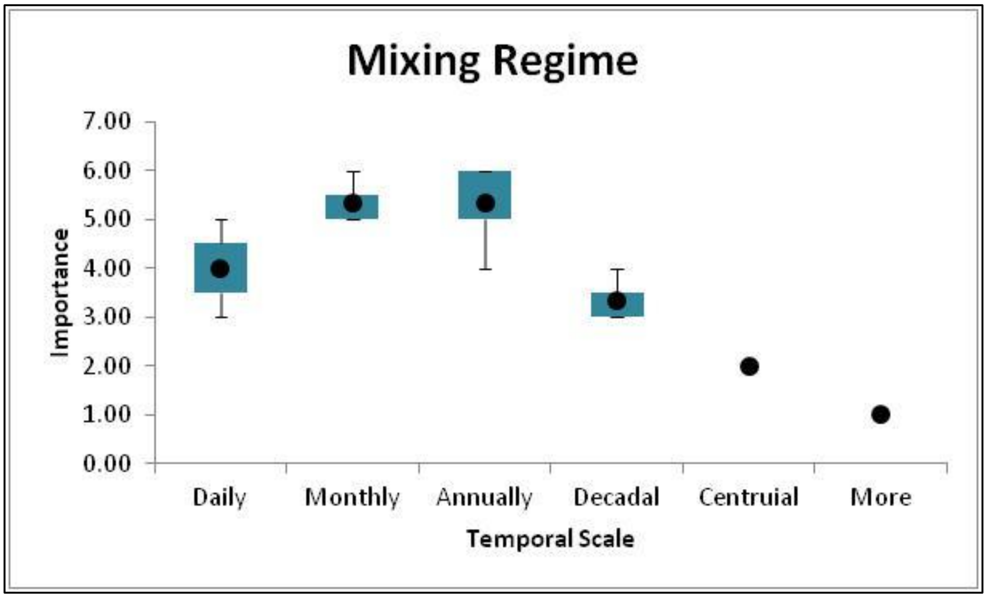


Figure D.47 EBM Temporal Scale: Mixing Regime

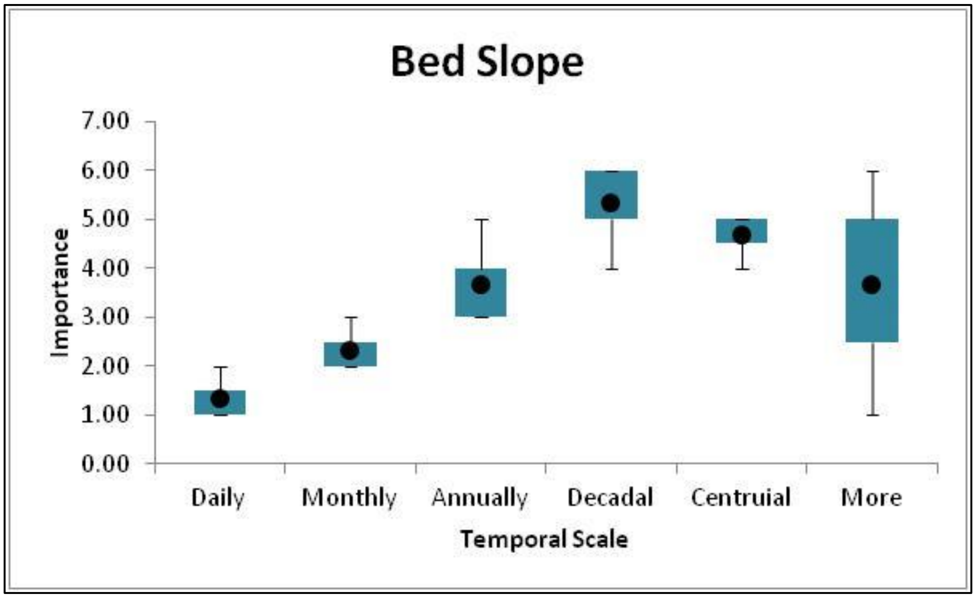


Figure D.48 EBM Temporal Scale: Bed Slope

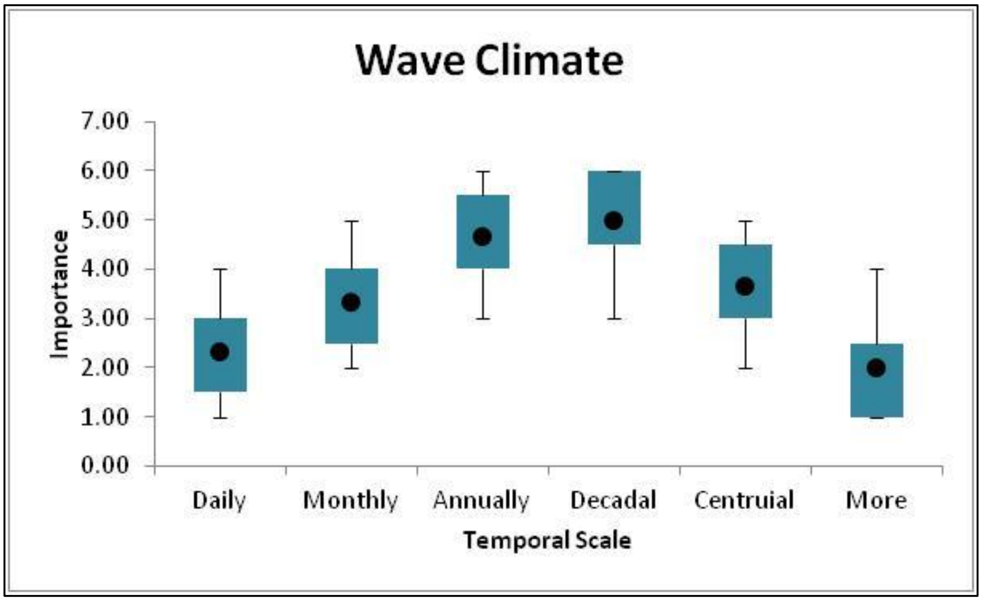


Figure D.49 EBM Temporal Scale: Wave Climate

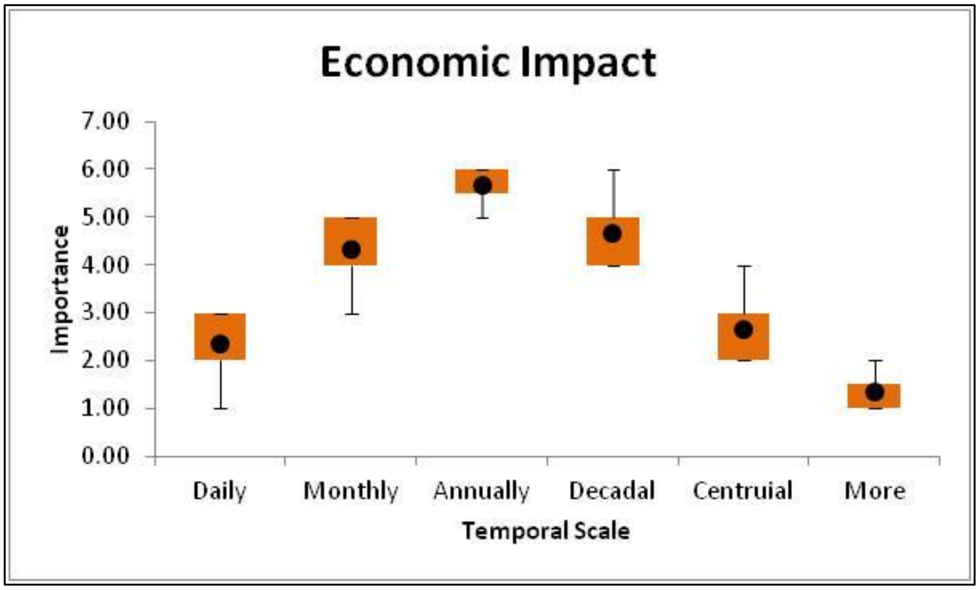


Figure D.50 EBM Temporal Scale: Economic Impact

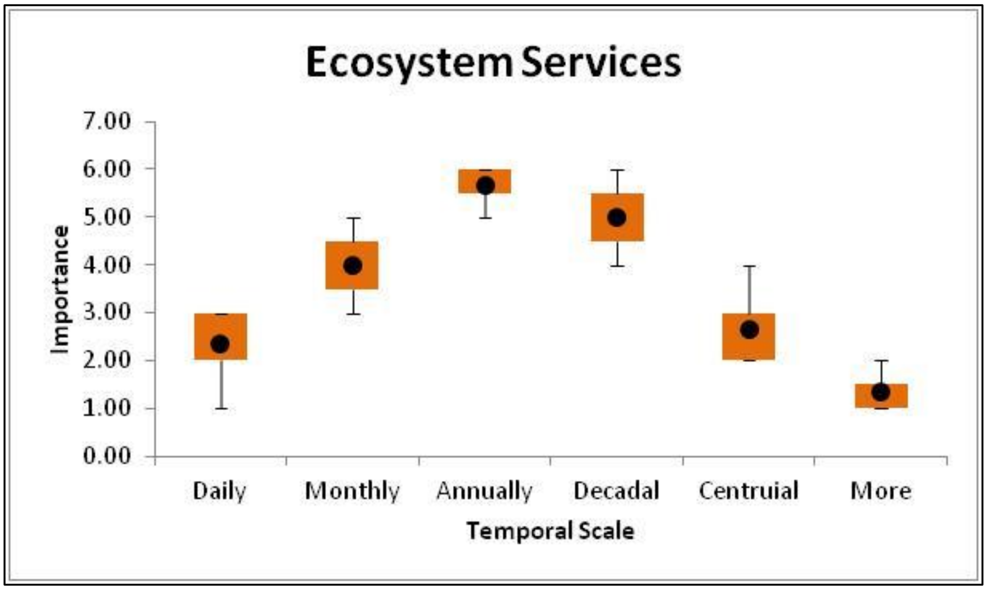


Figure D.51 EBM Temporal Scale: Ecosystem Services

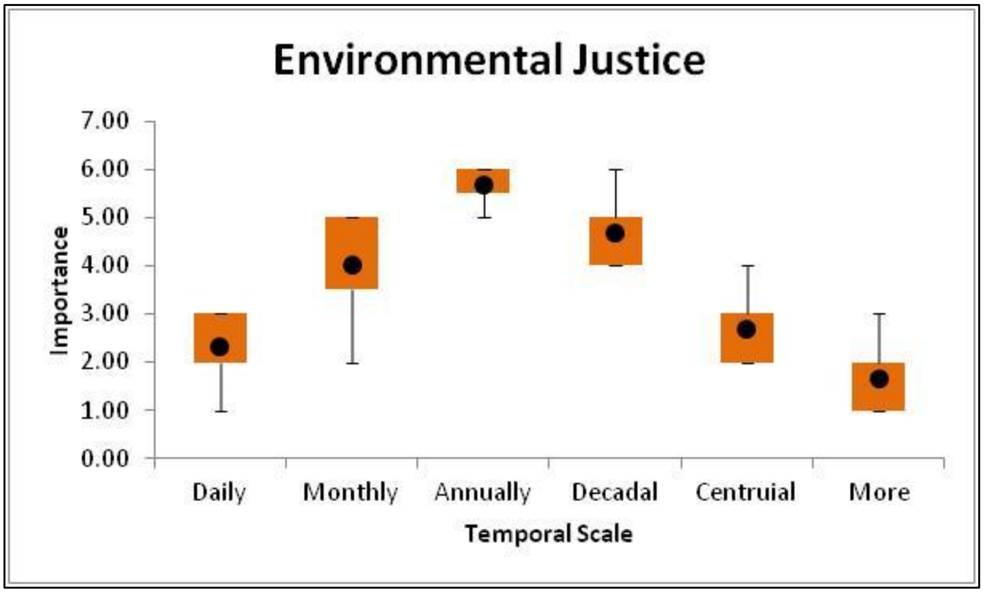


Figure D.52 EBM Temporal Scale: Environmental Justice

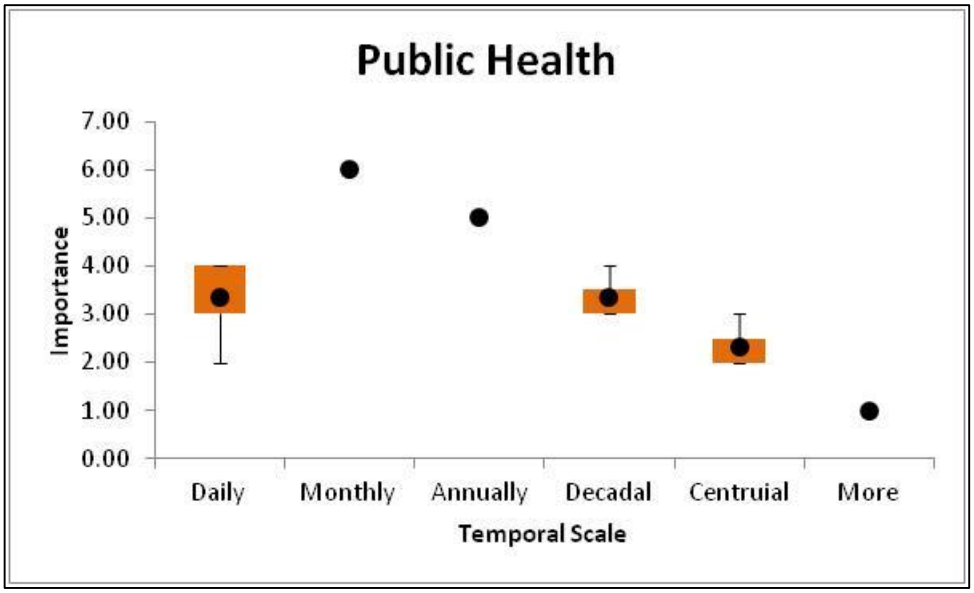


Figure D.53 EBM Temporal Scale: Public Health

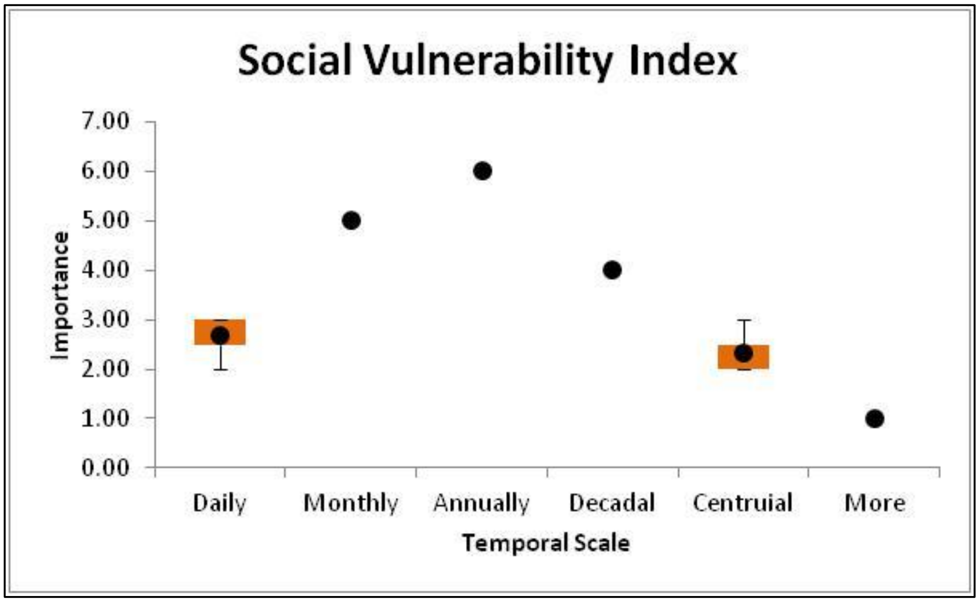


Figure D.54 EBM Temporal Scale: Social Vulnerability Index

D.4 Agglomerative Results

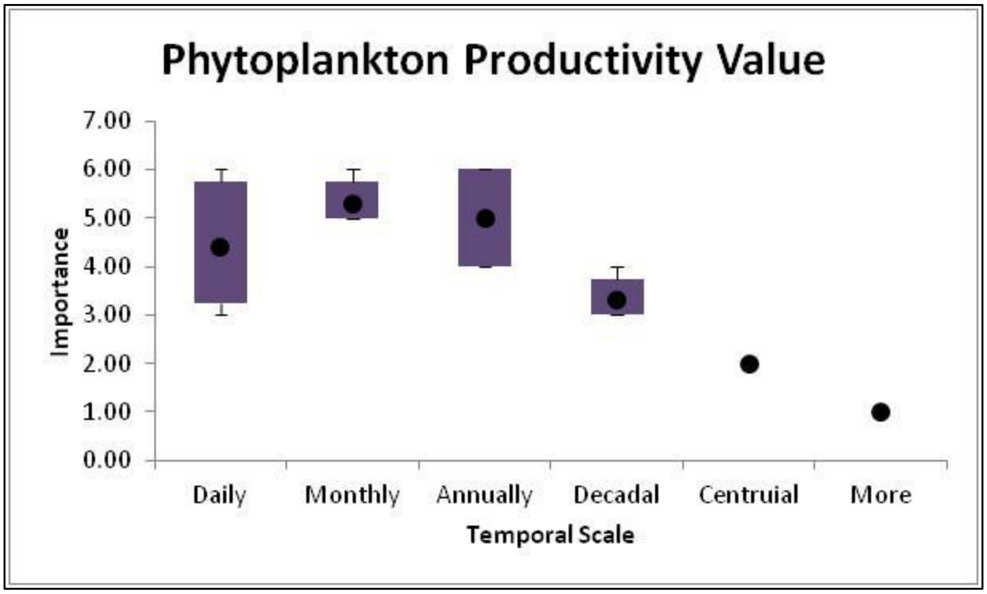


Figure D.55 Agglomerative Temporal Scale: Phytoplankton Productivity Value

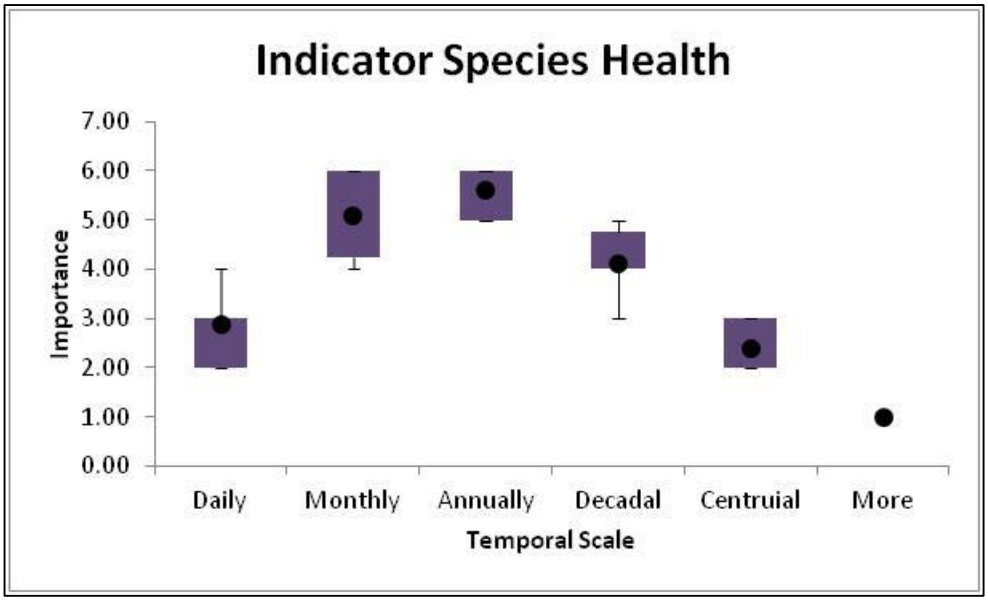


Figure D.56 Agglomerative Temporal Scale: Indicator Species Health

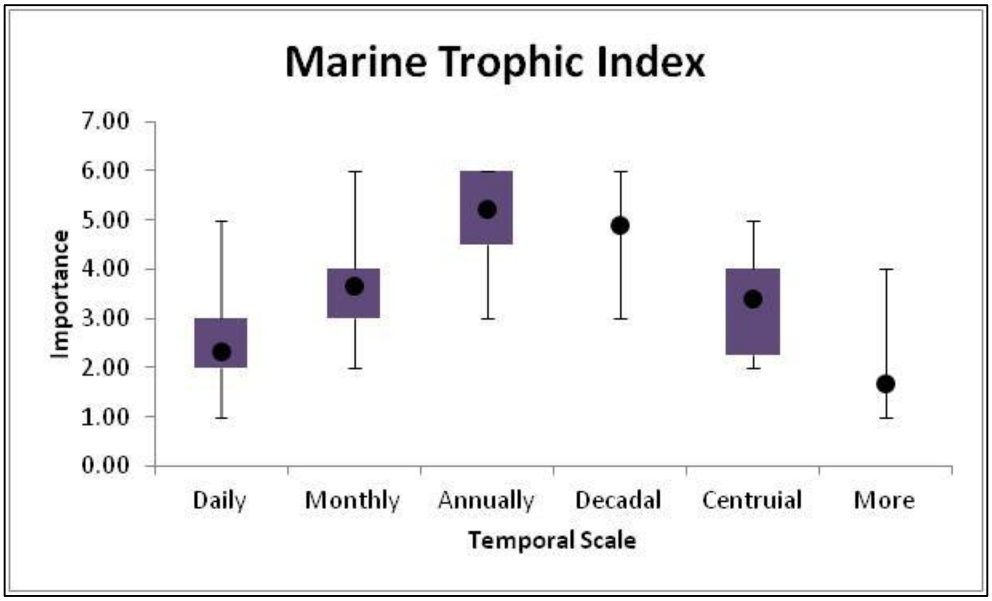


Figure D.57 Agglomerative Temporal Scale: Marine Trophic Index

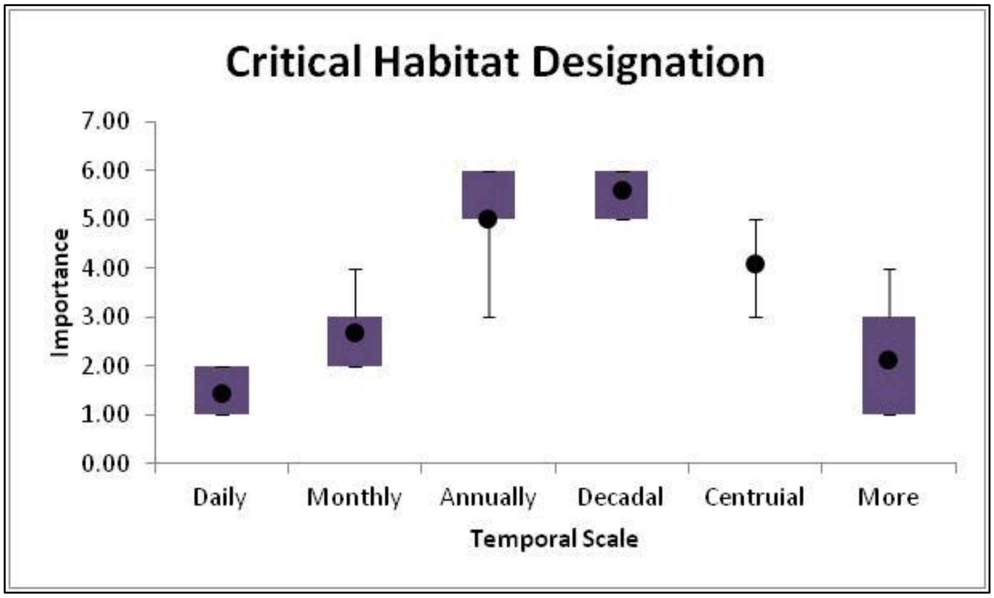


Figure D.58 Agglomerative Temporal Scale: Critical Habitat Designation

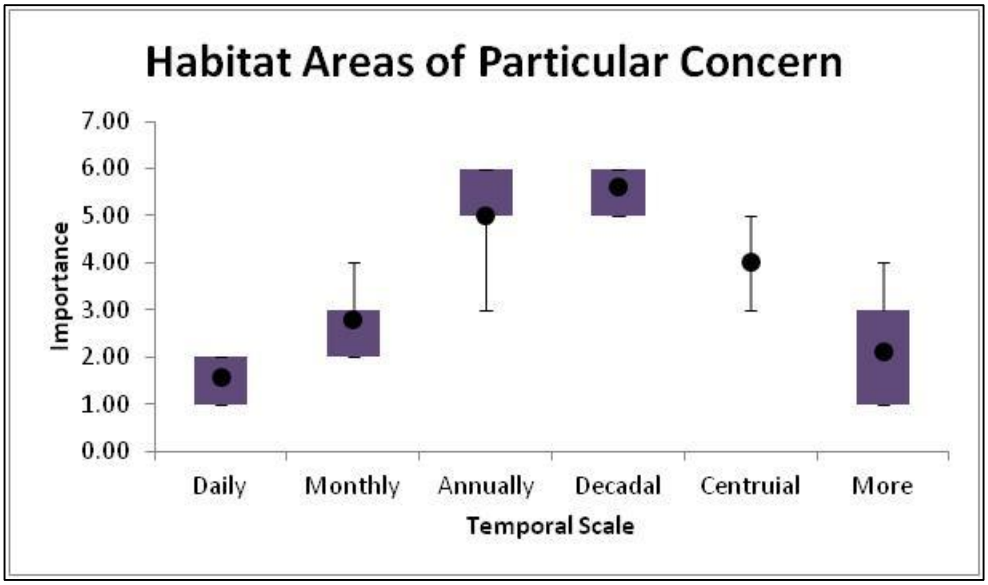


Figure D.59 Agglomerative Temporal Scale: Habitat Areas of Particular Concern

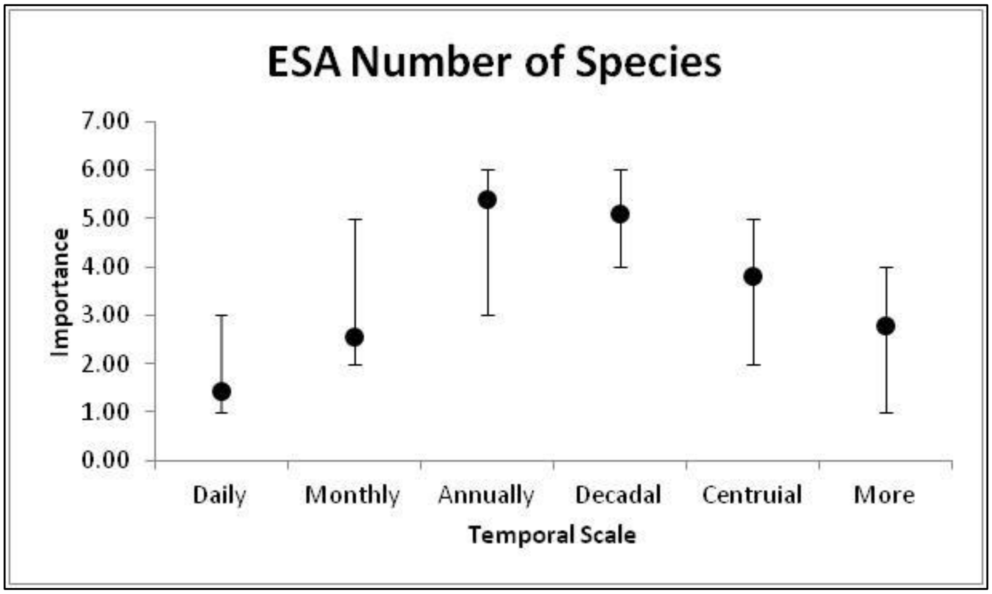


Figure D.60 Agglomerative Temporal Scale: ESA Number of Species

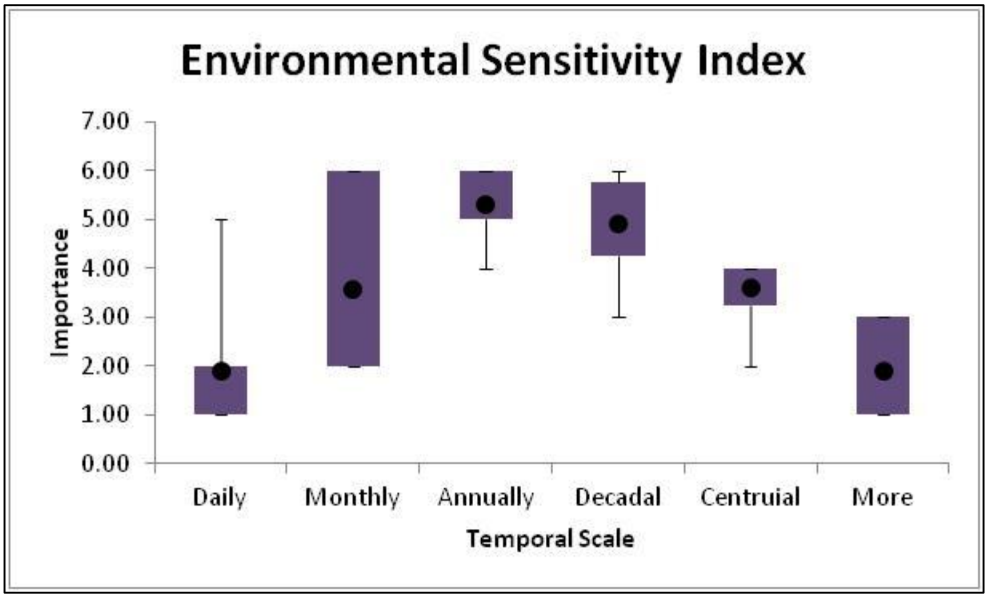


Figure D.61 Agglomerative Temporal Scale: Environmental Sensitivity Index

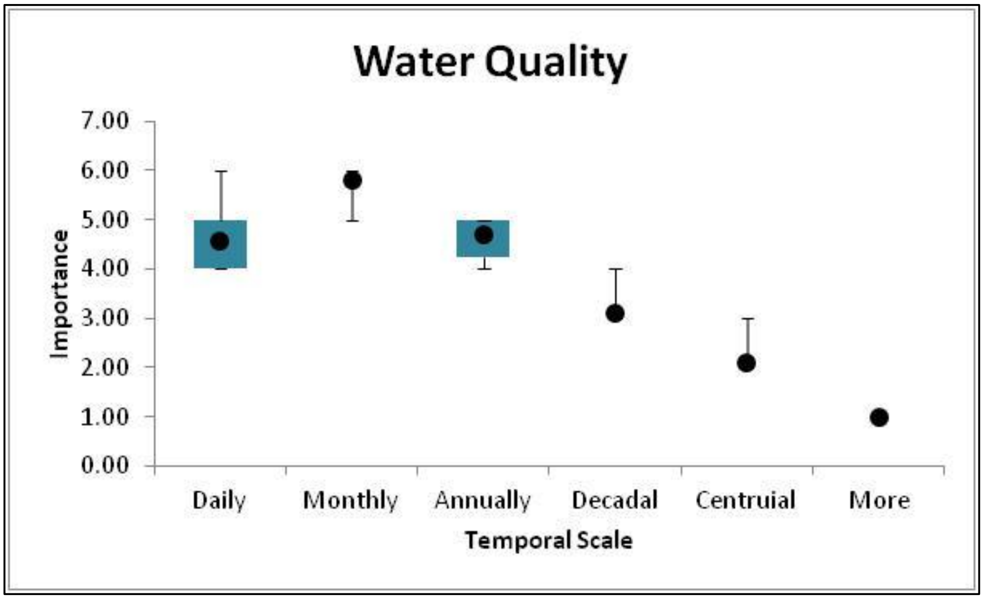


Figure D.62 Agglomerative Temporal Scale: Water Quality

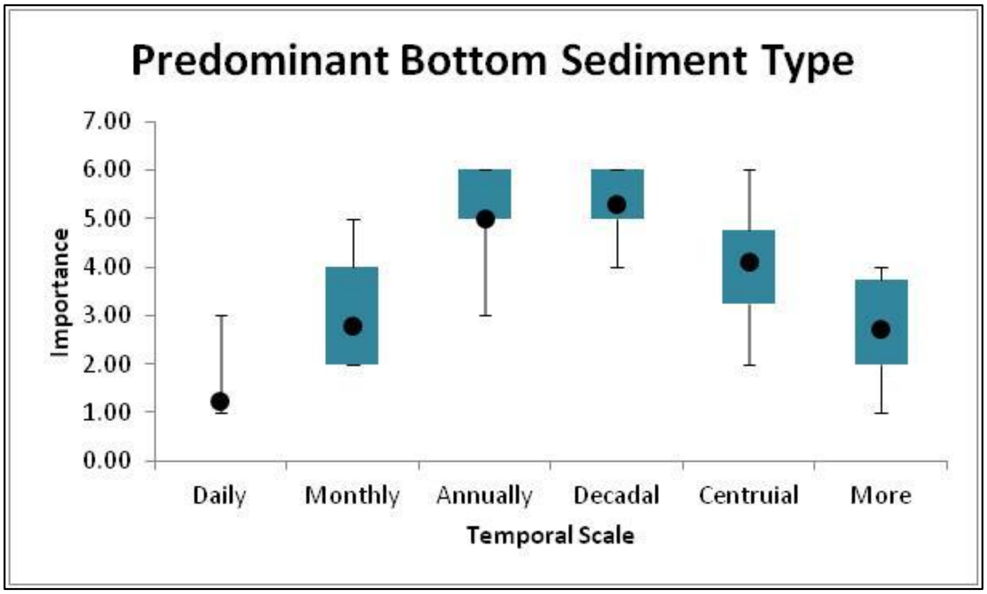


Figure D.63 Agglomerative Temporal Scale: Predominant Bottom Sediment Type

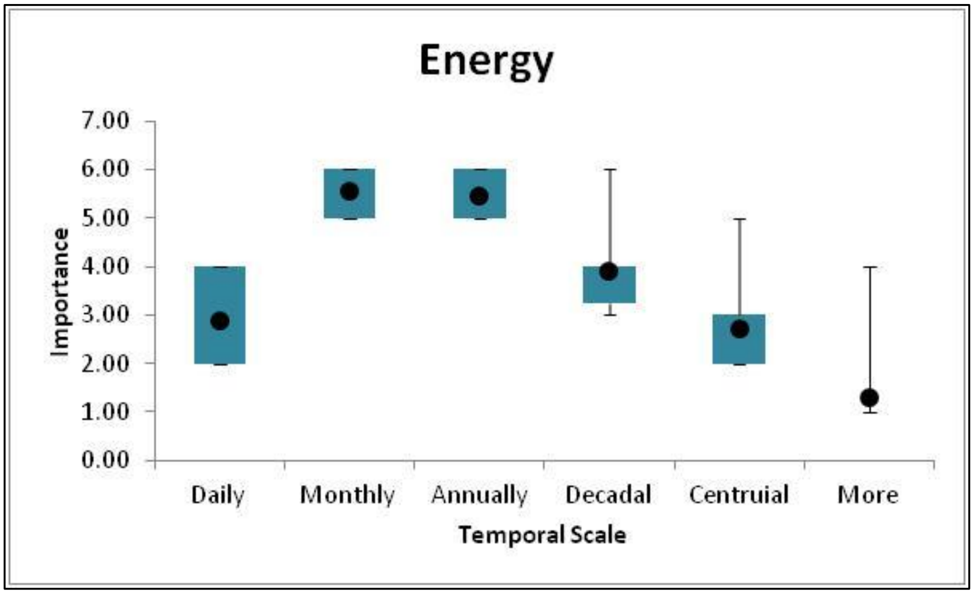


Figure D.64 Agglomerative Temporal Scale: Energy

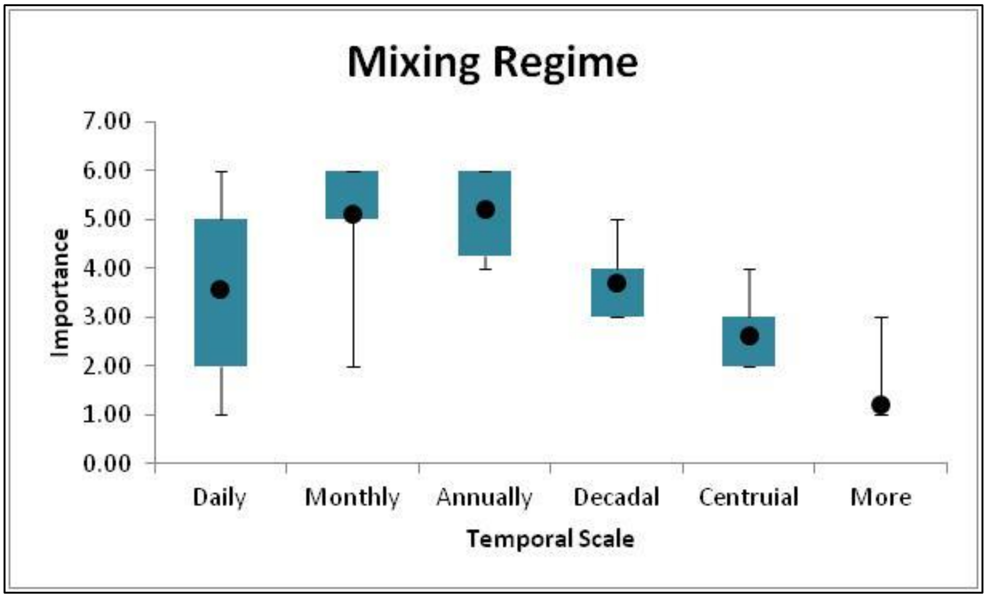


Figure D.65 Agglomerative Temporal Scale: Mixing Regime

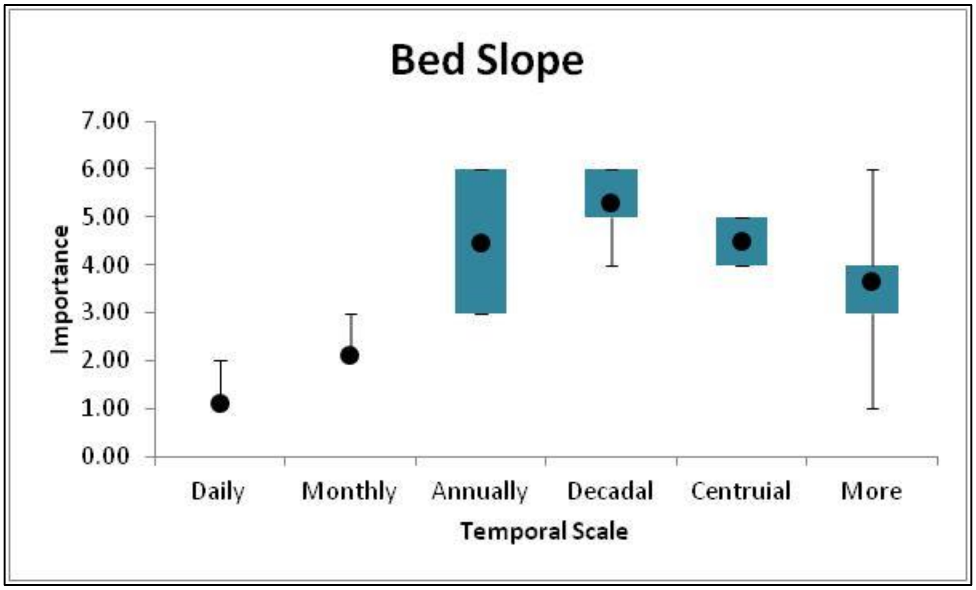


Figure D.66 Agglomerative Temporal Scale: Bed Slope

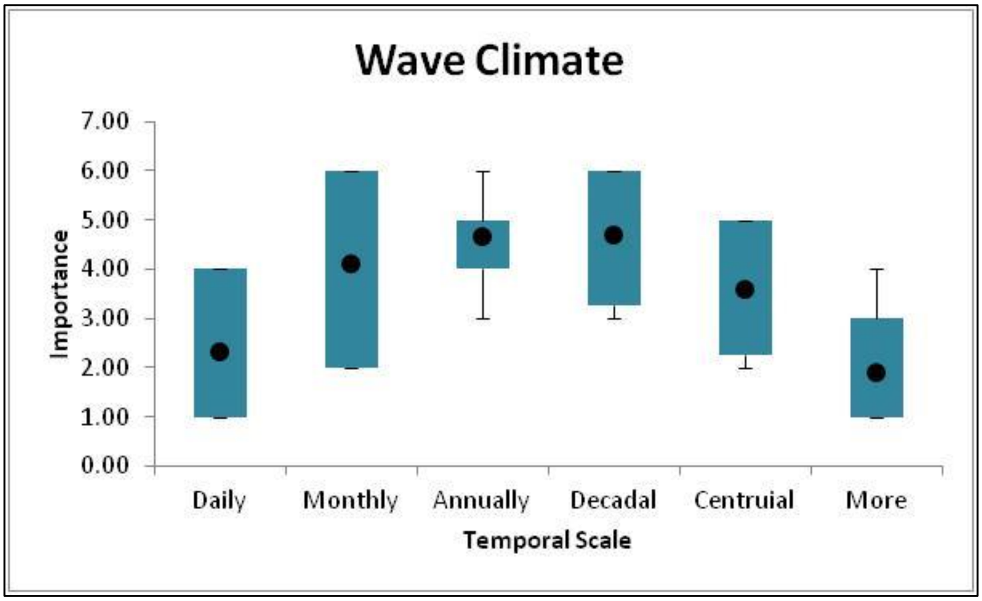


Figure D.67 Agglomerative Temporal Scale: Wave Climate

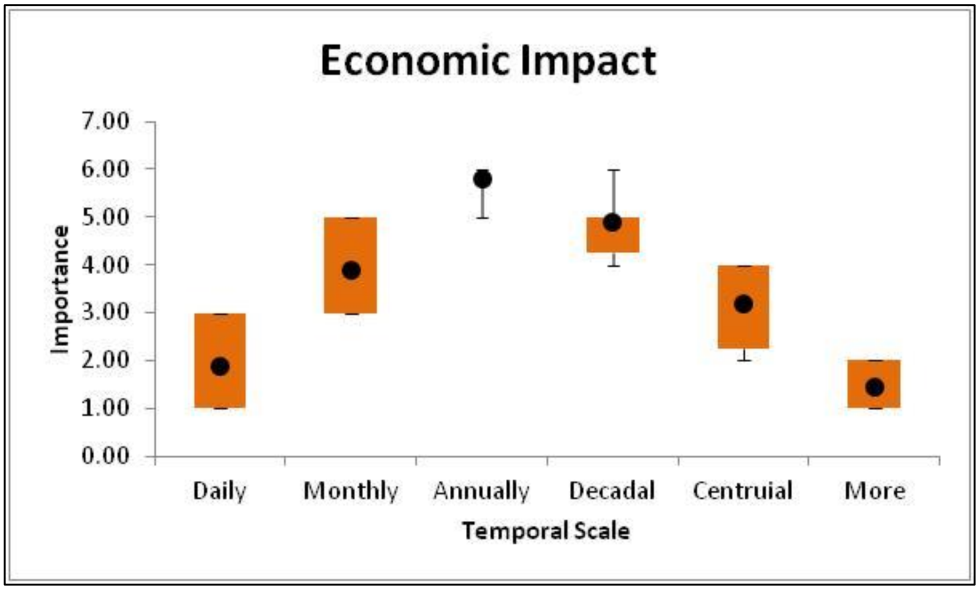


Figure D.68 Agglomerative Temporal Scale: Economic Impact

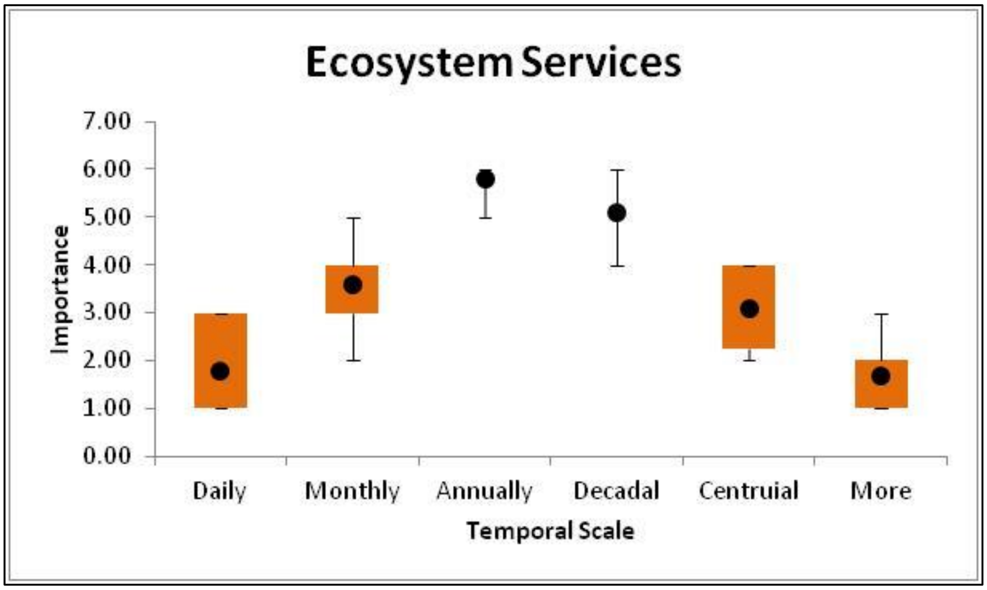


Figure D.69 Agglomerative Temporal Scale: Ecosystem Services

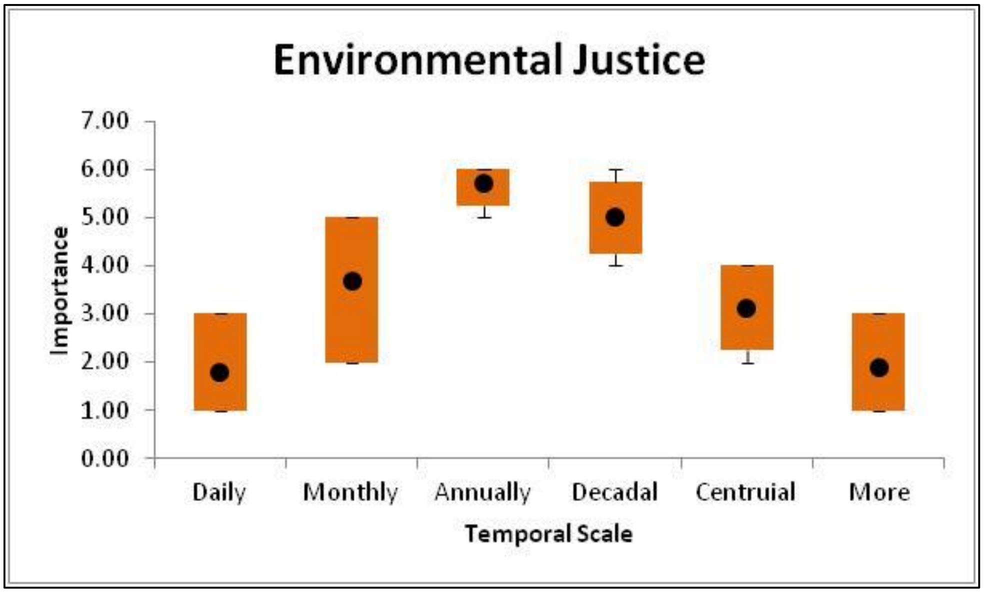


Figure D.70 Agglomerative Temporal Scale: Environmental Justice

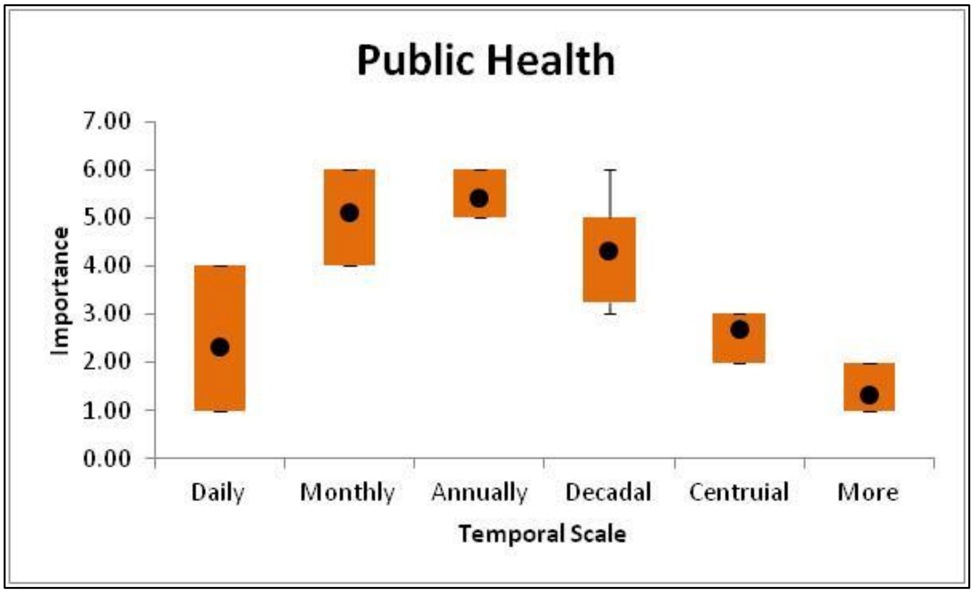


Figure D.71 Agglomerative Temporal Scale: Public Health

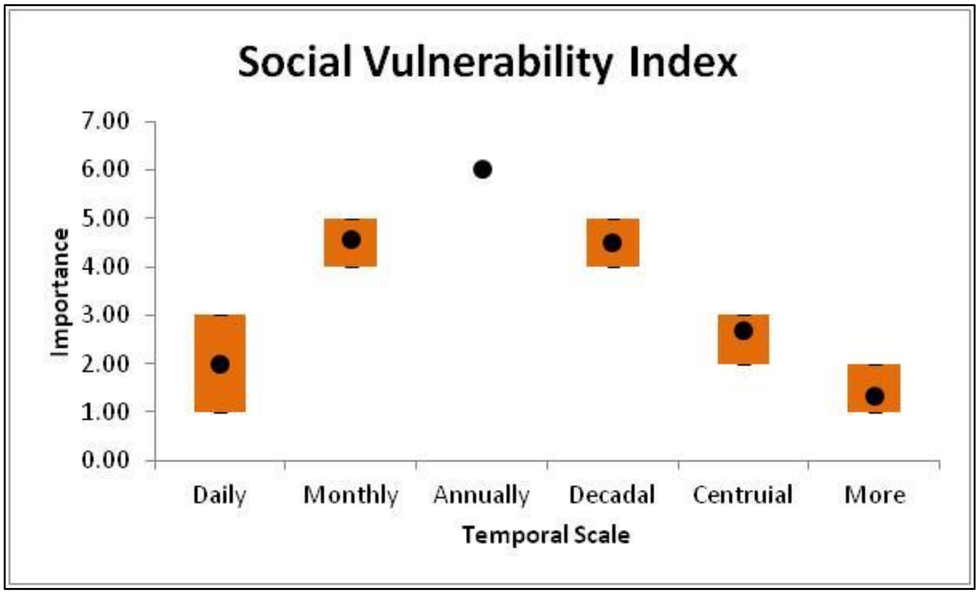


Figure D.72 Agglomerative Temporal Scale: Social Vulnerability Index

APPENDIX E

MATLAB R2011A CODE FOR MULTI-VARIANT AGGLOMERATIVE HIERARCHY CLUSTERING

```
     clc; clear all;

     outFilename = 'complete_output.xml'; % Name for
file to contain all output
     criteria = [ 2 3 4 5 6 7 8 9 10 ];
     link_type = 'single'; % could be:
                           %   'average' Unweighted
average distance (UPGMA)
                           %   'centroid' Centroid
distance (UPGMC), appropriate for Euclidean distances
only
                           %   'complete' Furthest
distance
                           %   'median' Weighted
center of mass distance (WPGMC), appropriate for
Euclidean distances only
                           %   'single' Shortest
distance
                           %   'ward' Inner squared
distance (minimum variance algorithm), appropriate for
Euclidean distances only
                           %   'weighted' Weighted
average distance (WPGMA)


     files = dir( '*.csv' ); % Get list of all CSV
files in local directory
     output = fopen( outFilename , 'wt' ); % Open file
for writing text (Windows)

     % Results will be written to a text file in an
XML format, which will
     % facilate post-processing
     xmlFormat = '   <element filename="%s"
criterion="%d" cluster="%d" fid="%d" /> \n';
     % XML opening tag
     fprintf( output , '<?xml version="1.0"
?>\n<%s>\n' , 'clustering' );
     for i = 1:numel(files)
         filename = files(i).name;
         if( strcmp( filename , 'complete_output.csv'
) )
             continue;
         end
         figname = sprintf( '%s.fig' , filename );
         data = csvread( filename );
```

```
         % First column is the ID numbers
         fids = data( : , 1 );

         % Pickout specific columns to cluster with
(all but first column)
         toCluster = data( : , 2:end );

         % Cluster performs an Agglomerative
Hiearchical Cluster Analysis
         % Cluster will return a vector that
identifies the cluster assignment
         % of each row in the matrix toCluster. Second
argument is a limitation
         % on cluster size or max number of clusters.

         Y = pdist( toCluster );
         Z = linkage( Y, link_type );
         dendrogram( Z ); % Create dendrogram
         saveas( gcf , figname , 'fig' ); % Save
current figure
         close( gcf ); % Close dendrogram

         for j = 1:numel( criteria )
            criterion = criteria(j);

            if( criterion <= 2 )
                crit_name = 'cutoff';
            else
                crit_name = 'maxclust';
            end
            myClusters = cluster( Z , crit_name ,
criterion );

            % Perform clustering analysis with
different specified maxclust
            % values
            for k=1:max( myClusters )
                clusterMembers = fids(  myClusters ==
k  );
                for m=1:numel( clusterMembers )
                 fprintf( output , xmlFormat ,
filename , criterion , k , clusterMembers(m) );
                end
            end
         end
```

```
end

% Closing XML tag
fprintf( output , '</%s>' , 'clustering' );
fclose(output);
```

APPENDIX F

SUPPLEMENTAL PIVOT TABLES FOR CHAPTER VI

F.1 Perdido Bay

Table F.1 Perdido: 1 km^2 Grid; CMSP

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	276										276
3	1	145	130								276
4	11	134	1	130							276
5	6	128	11	1	130						276
6	20	108	6	11	1	130					276
7	20	88	20	6	11	1	130				276
8	5	125	20	88	20	6	11	1			276
9	39	49	5	125	20	20	6	11	1		276
10	51	74	39	49	5	20	20	6	11	1	276

Table F.2 Perdido 1 km^2 Grid; CMSP Sensitivity Analysis

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	276										276
3	1	145	130								276
4	11	134	1	130							276
5	6	128	11	1	130						276
6	20	108	6	11	1	130					276
7	49	59	20	6	11	1	130				276
8	74	56	49	59	20	6	11	1			276
9	4	7	74	56	49	59	20	6	1		276
10	20	39	4	7	74	56	49	20	6	1	276

Table F.3 Perdido: 1 km^2 Grid; EBM

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	276										276
3	225	12	39								276
4	1	11	225	39							276
5	19	20	1	11	225						276
6	77	148	19	20	1	11					276
7	34	114	77	19	20	1	11				276
8	1	19	34	114	77	19	1	11			276
9	12	7	1	19	34	114	77	1	11		276
10	1	18	12	7	1	34	114	77	1	11	276

Table F.4 Perdido: 1 km^2 Grid; EBM Sensitivity Analysis

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	276										276
3	225	12	39								276
4	1	11	225	39							276
5	19	20	1	11	225						276
6	77	148	19	20	1	11					276
7	34	114	77	19	20	1	11				276
8	1	19	34	114	77	19	1	11			276
9	7	12	1	19	34	114	77	1	11		276
10	1	18	7	12	1	34	114	77	1	11	276

Table F.5 Perdido: 1 km^2 Grid; IEA

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	276										276
3	1	236	39								276
4	11	225	1	39							276
5	1	38	11	225	1						276
6	3	222	1	38	11	1					276
7	19	19	3	222	1	11	1				276
8	6	216	19	19	3	1	11	1			276
9	105	111	6	19	19	3	1	11	1		276
10	1	18	105	111	6	19	3	1	11	1	276

Table F.6 Perdido: 1 km^2 Grid; IEA Sensitivity Analysis

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	276										276
3	225	12	39								276
4	1	11	225	39							276
5	1	38	1	11	225						276
6	3	222	1	38	1	11					276
7	182	40	3	1	38	1	11				276
8	6	34	182	3	1	38	1	11			276
9	19	19	6	34	182	3	1	1	11		276
10	105	77	19	19	6	34	3	1	1	11	276

Table F.7 Perdido: 2 km^2 Grid

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	94										94
3	1	9	84								94
4	1	83	1	9							94
5	79	4	1	1	9						94
6	1	3	79	1	1	9					94
7	1	78	1	3	1	1	9				94
8	2	76	1	1	3	1	1	9			94
9	2	74	2	1	1	3	1	1	9		94
10	1	73	2	2	1	1	3	1	1	9	94

Table F.8 Perdido: 2 km^2 Grid; Sensitivity Analysis

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	94										94
3	1	9	84								94
4	1	83	1	9							94
5	79	4	1	1	9						94
6	1	3	79	1	1	9					94
7	1	78	1	3	1	1	9				94
8	2	76	1	1	3	1	1	9			94
9	2	74	2	1	1	3	1	1	9		94
10	1	73	2	2	1	1	3	1	1	9	94

Table F.9 Perdido: 2 km^2 Grid; CMSP

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	94										94
3	49	5	40								94
4	2	3	49	40							94
5	20	20	2	3	49						94
6	9	11	20	2	3	49					94
7	10	39	9	11	20	2	3				94
8	14	25	10	9	11	20	2	3			94
9	5	5	14	25	9	11	20	2	3		94
10	7	4	5	5	14	25	9	20	2	3	94

Table F.10 Perdido: 2 km^2 Grid; CMSP Sensitivity Analysis

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	94										94
3	49	5	40								94
4	2	3	49	40							94
5	20	20	2	3	49						94
6	25	24	20	20	2	3					94
7	5	19	25	20	20	2	3				94
8	9	11	5	19	25	20	2	3			94
9	14	5	9	11	5	25	20	2	3		94
10	7	4	14	5	9	5	25	20	2	3	94

Table F.11 Perdido: 2 km^2 Grid; EBM

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	94										94
3	5	79	10								94
4	2	77	5	10							94
5	39	38	2	5	10						94
6	35	3	39	2	5	10					94
7	1	2	35	39	2	5	10				94
8	1	34	1	2	39	2	5	10			94
9	1	38	1	34	1	2	2	5	10		94
10	15	19	1	38	1	1	2	2	5	10	94

Table F.12 Perdido: 2 km^2 Grid; EBM Sensitivity Analysis

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	94										94
3	5	79	10								94
4	2	77	5	10							94
5	39	38	2	5	10						94
6	35	3	39	2	5	10					94
7	1	2	35	39	2	5	10				94
8	1	34	1	2	39	2	5	10			94
9	1	38	1	34	1	2	2	5	10		94
10	15	19	1	38	1	1	2	2	5	10	94

Table F.13 Perdido: 2 km^2 Grid; IEA

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	94										94
3	5	79	10								94
4	1	78	5	10							94
5	38	40	1	5	10						94
6	2	38	38	1	5	10					94
7	1	37	2	38	1	5	10				94
8	4	6	1	37	2	38	1	5			94
9	13	24	4	6	1	2	38	1	5		94
10	1	37	13	24	4	6	1	2	1	5	94

Table F.14 Perdido: 2 km^2 Grid; IEA Sensitivity Analysis

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	94										94
3	5	79	10								94
4	1	78	5	10							94
5	38	40	1	5	10						94
6	2	38	38	1	5	10					94
7	1	37	2	38	1	5	10				94
8	4	6	1	37	2	38	1	5			94
9	13	24	4	6	1	2	38	1	5		94
10	1	37	13	24	4	6	1	2	1	5	94

Table F.15 Perdido: 4 km^2 Grid

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	32										32
3	1	25	6								32
4	1	24	1	6							32
5	17	7	1	1	6						32
6	2	5	17	1	1	6					32
7	1	4	2	17	1	1	6				32
8	1	16	1	4	2	1	1	6			32
9	1	1	1	16	1	4	1	1	6		32
10	2	2	1	1	1	16	1	1	1	6	32

Table F.16 Perdido: 4 km^2 Grid; Sensitivity Analysis

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	32										32
3	1	25	6								32
4	1	24	1	6							32
5	17	7	1	1	6						32
6	2	5	17	1	1	6					32
7	1	4	2	17	1	1	6				32
8	1	16	1	4	2	1	1	6			32
9	1	1	1	16	1	4	1	1	6		32
10	2	2	1	1	1	16	1	1	1	6	32

Table F.17 Perdido: 4 km^2 Grid; CMSP

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	32										32
3	12	14	6								32
4	3	11	12	6							32
5	1	11	3	11	6						32
6	3	8	1	11	3	6					32
7	3	8	3	8	1	3	6				32
8	4	4	3	8	3	1	3	6			32
9	1	3	4	3	8	3	1	3	6		32
10	1	2	1	4	3	8	3	1	3	6	32

Table F.18 Perdido: 4 km^2 Grid; CMSP Sensitivity Analysis

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	32										32
3	12	14	6								32
4	3	11	12	6							32
5	1	11	3	11	6						32
6	3	8	1	11	3	6					32
7	3	8	3	8	1	3	6				32
8	4	4	3	8	3	1	3	6			32
9	1	3	4	3	8	3	1	3	6		32
10	1	2	1	3	4	3	8	3	1	6	32

Table F.19 Perdido: 4 km^2 Grid; EBM

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	32										32
3	1	25	6								32
4	3	22	1	6							32
5	2	20	3	1	6						32
6	9	11	2	3	1	6					32
7	1	1	9	11	3	1	6				32
8	3	8	1	1	9	3	1	6			32
9	5	4	3	8	1	1	3	1	6		32
10	2	2	5	3	8	1	1	3	1	6	32

Table F.20 Perdido: 4 km^2 Grid; EBM Sensitivity Analysis

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	32										32
3	1	25	6								32
4	3	22	1	6							32
5	2	20	3	1	6						32
6	9	11	2	3	1	6					32
7	1	1	9	11	3	1	6				32
8	3	8	1	1	9	3	1	6			32
9	5	4	3	8	1	1	3	1	6		32
10	2	2	5	3	8	1	1	3	1	6	32

Table F.21 Perdido: 4 km^2 Grid; IEA

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	32										32
3	1	25	6								32
4	3	22	1	6							32
5	3	19	3	1	6						32
6	8	11	3	3	1	6					32
7	2	9	8	3	3	1	6				32
8	4	5	2	8	3	3	1	6			32
9	2	3	4	2	8	3	3	1	6		32
10	3	5	2	3	4	2	3	3	1	6	32

Table F.22 Perdido: 4 km^2 Grid; IEA Sensitivity Analysis

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	32										32
3	1	25	6								32
4	3	22	1	6							32
5	3	19	3	1	6						32
6	8	11	3	3	1	6					32
7	2	9	8	3	3	1	6				32
8	4	5	2	8	3	3	1	6			32
9	3	2	4	2	8	3	3	1	6		32
10	3	5	3	2	4	2	3	3	1	6	32

F.2 Galveston Bay

Table F.23 Galveston: 1 km^2 Grid; CMSP

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	2295										2295
3	12	2243	40								2295
4	8	2235	12	40							2295
5	1833	402	8	12	40						2295
6	281	121	1833	8	12	40					2295
7	2	1831	281	121	8	12	40				2295
8	2	1829	2	281	121	8	12	40			2295
9	2	1827	2	2	281	121	8	12	40		2295
10	1	1826	2	2	2	281	121	8	12	40	2295

Table F.24 Galveston: 1 km^2 Grid; EBM

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	2295										2295
3	359	531	1405								2295
4	39	492	359	1405							2295
5	8	484	39	359	1405						2295
6	1	358	8	484	39	1405					2295
7	469	15	1	358	8	39	1405				2295
8	13	2	469	1	358	8	39	1405			2295
9	232	237	13	2	1	358	8	39	1405		2295
10	8	350	232	237	13	2	1	8	39	1405	2295

Table F.25 Galveston: 1 km^2 Grid; IEA

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	2295										2295
3	4	2288	3								2295
4	4	2284	4	3							2295
5	4	2280	4	4	3						2295
6	5	2275	4	4	4	3					2295
7	5	2270	5	4	4	4	3				2295
8	1147	1123	5	5	4	4	4	3			2295
9	5	1118	1147	5	5	4	4	4	3		2295
10	5	1113	5	1147	5	5	4	4	4	3	2295

Table F.26 Galveston: 2 km^2 Grid

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	643										643
3	1	2	640								643
4	71	569	1	2							643
5	1	1	71	569	1						643
6	3	566	1	1	71	1					643
7	1	565	3	1	1	71	1				643
8	1	70	1	565	3	1	1	1			643
9	9	61	1	1	565	3	1	1	1		643
10	1	564	9	61	1	1	3	1	1	1	643

Table F.27 Galveston: 2 km^2 Grid; CMSP

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	643										643
3	1	7	635								643
4	63	572	1	7							643
5	3	569	63	1	7						643
6	1	62	3	569	1	7					643
7	75	494	1	62	3	1	7				643
8	18	476	75	1	62	3	1	7			643
9	1	475	18	75	1	62	3	1	7		643
10	6	56	1	475	18	75	1	3	1	7	643

Table F.28 Galveston: 2 km^2 Grid; EBM

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	643										643
3	1	641	1								643
4	9	632	1	1							643
5	8	624	9	1	1						643
6	54	570	8	9	1	1					643
7	1	569	54	8	9	1	1				643
8	3	566	1	54	8	9	1	1			643
9	11	555	3	1	54	8	9	1	1		643
10	1	554	11	3	1	54	8	9	1	1	643

Table F.29 Galveston: 2 km^2 Grid; IEA

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	643										643
3	8	632	3								643
4	63	569	8	3							643
5	1	568	63	8	3						643
6	1	567	1	63	8	3					643
7	53	514	1	1	63	8	3				643
8	1	513	53	1	1	63	8	3			643
9	9	54	1	513	53	1	1	8	3		643
10	1	512	9	54	1	53	1	1	8	3	643

Table F.30 Galveston: 4 km^2 Grid

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	197										197
3	31	165	1								197
4	1	164	31	1							197
5	2	162	1	31	1						197
6	4	27	2	162	1	1					197
7	1	161	4	27	2	1	1				197
8	1	26	1	161	4	2	1	1			197
9	1	160	1	26	1	4	2	1	1		197
10	6	20	1	160	1	1	4	2	1	1	197

Table F.31 Galveston: 4 km^2 Grid; CMSP

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	197										197
3	28	3	166								197
4	1	2	28	166							197
5	23	143	1	2	28						197
6	1	142	23	1	2	28					197
7	2	26	1	142	23	1	2				197
8	2	140	2	26	1	23	1	2			197
9	18	5	2	140	2	26	1	1	2		197
10	110	30	18	5	2	2	26	1	1	2	197

Table F.32 Galveston: 4 km^2 Grid; EBM

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	197										197
3	6	167	24								197
4	3	21	6	167							197
5	1	166	3	21	6						197
6	3	163	1	3	21	6					197
7	23	140	3	1	3	21	6				197
8	8	13	23	140	3	1	3	6			197
9	1	2	8	13	23	140	3	1	6		197
10	4	2	1	2	8	13	23	140	3	1	197

Table F.33 Galveston: 4 km^2 Grid; IEA

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	197										197
3	1	165	31								197
4	4	27	1	165							197
5	3	24	4	1	165						197
6	1	164	3	24	4	1					197
7	3	161	1	3	24	4	1				197
8	20	141	3	1	3	24	4	1			197
9	3	21	20	141	3	1	3	4	1		197
10	13	8	3	20	141	3	1	3	4	1	197

APPENDIX G

SUPPLEMENTAL DENDROGRAMS FOR CHAPTER VI

G.1 Perdido Bay

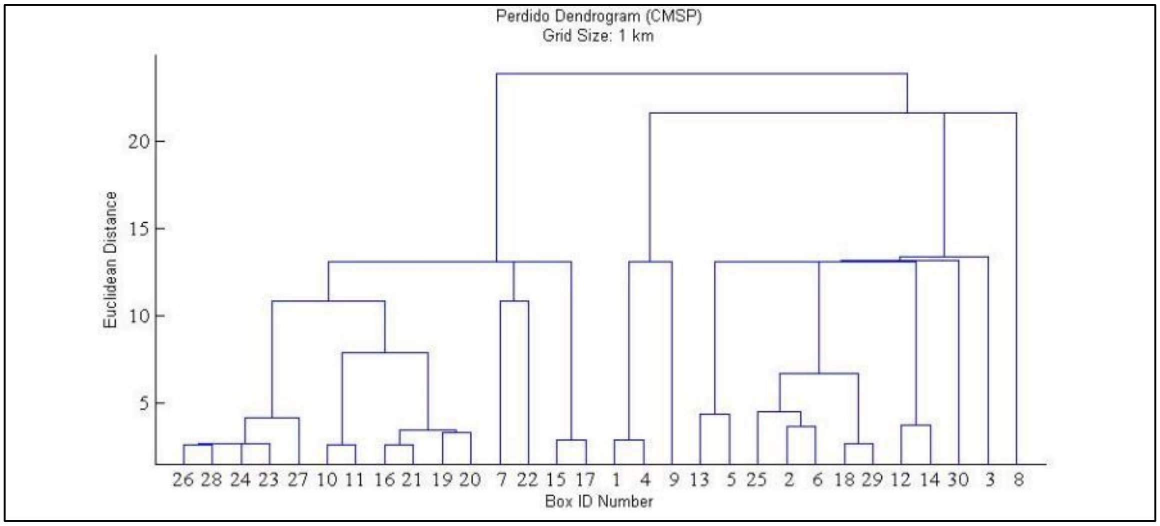


Figure G.1 Perdido Cluster Dendrogram; Grid Size 1 km^2; CMSP

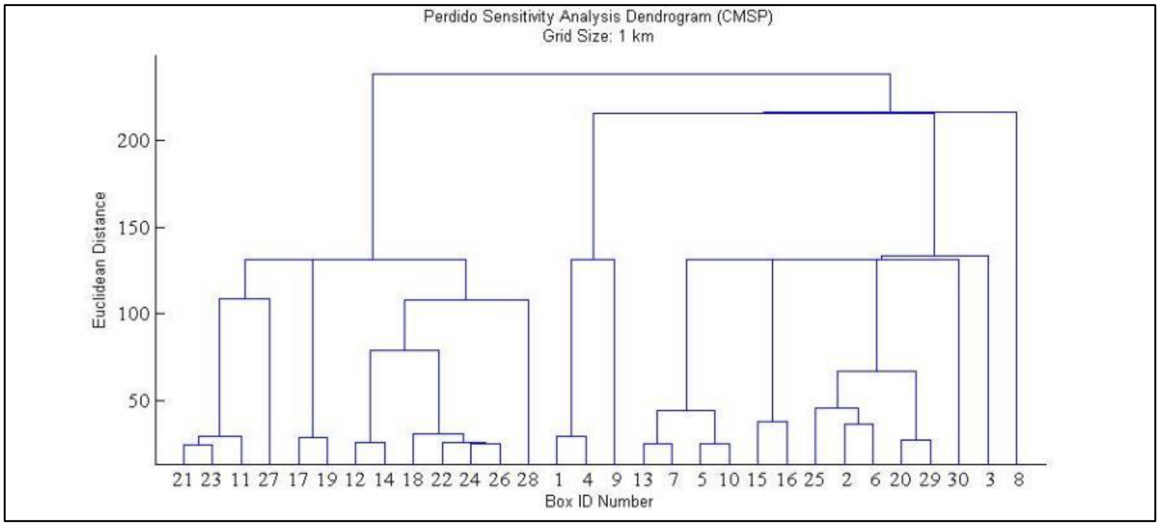


Figure G.2 Perdido Cluster Dendrogram for Sensitivity Analysis; Grid Size 1 km^2

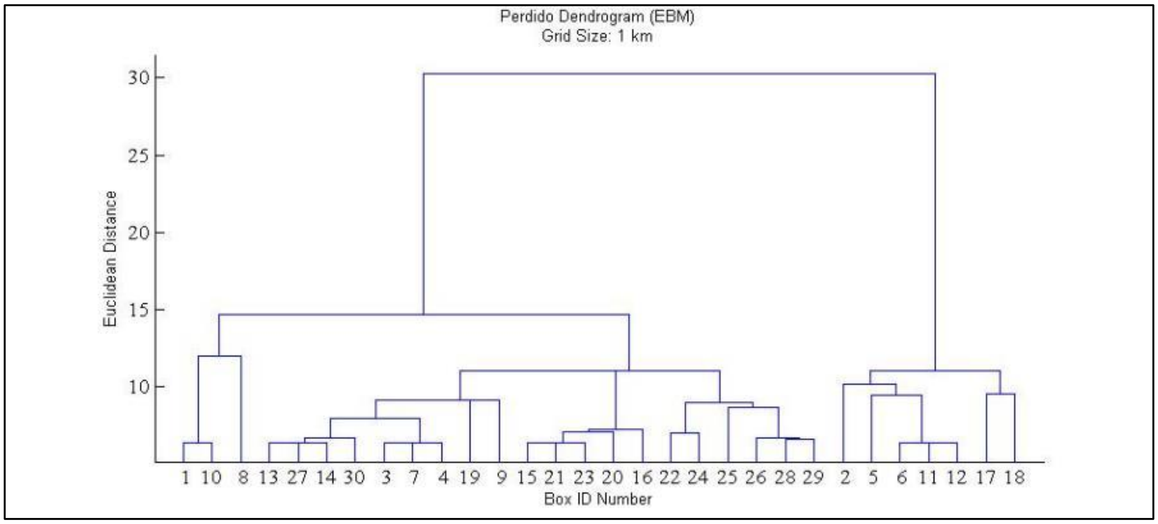


Figure G.3 Perdido Cluster Dendrogram; Grid Size 1 km^2; EBM

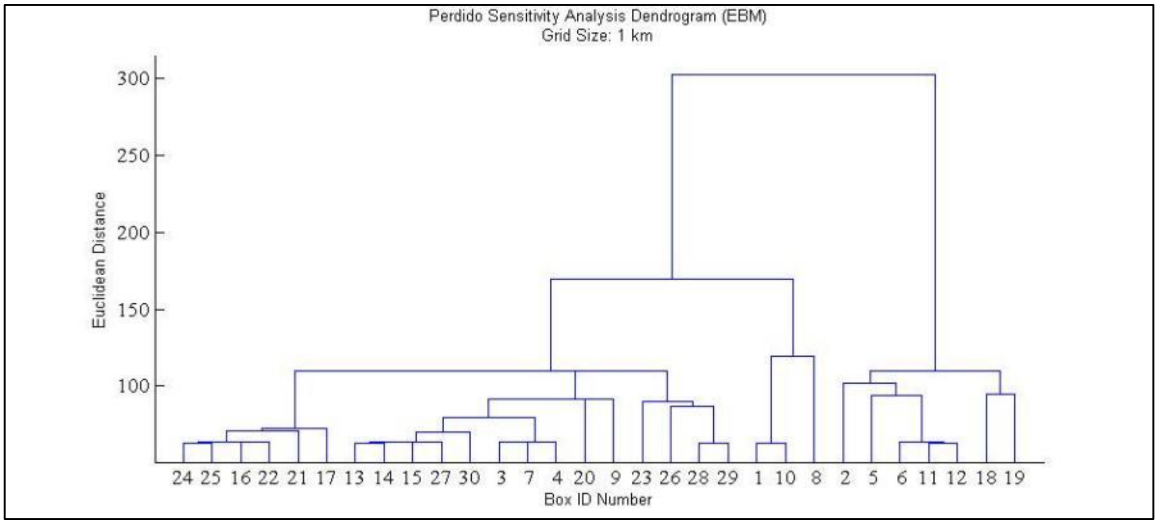


Figure G.4 Perdido Cluster Dendrogram for Sensitivity Analysis; Grid Size 1 km^2; EBM

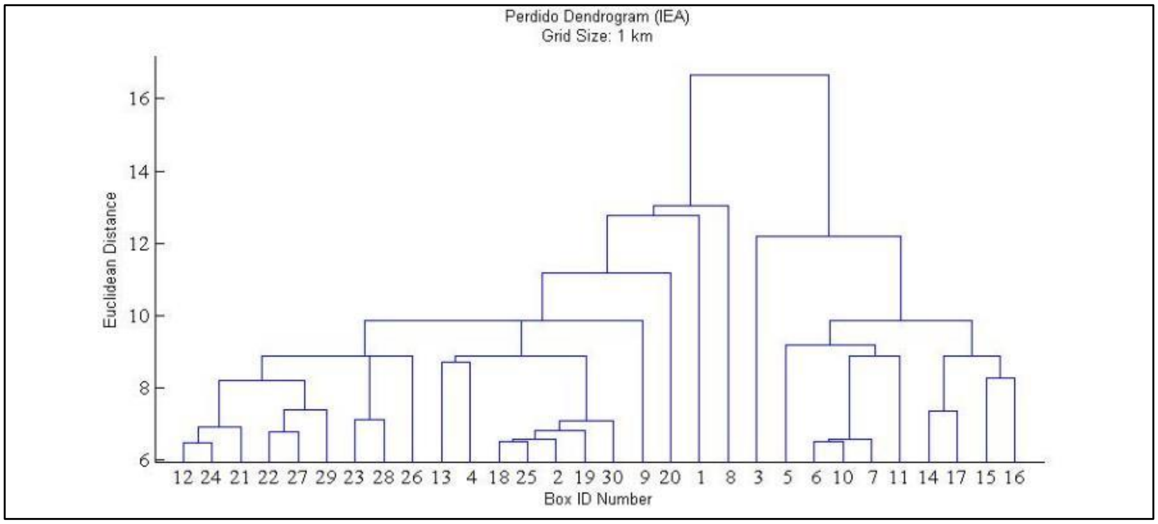


Figure G.5 Perdido Cluster Dendrogram; Grid Size 1 km^2; IEA

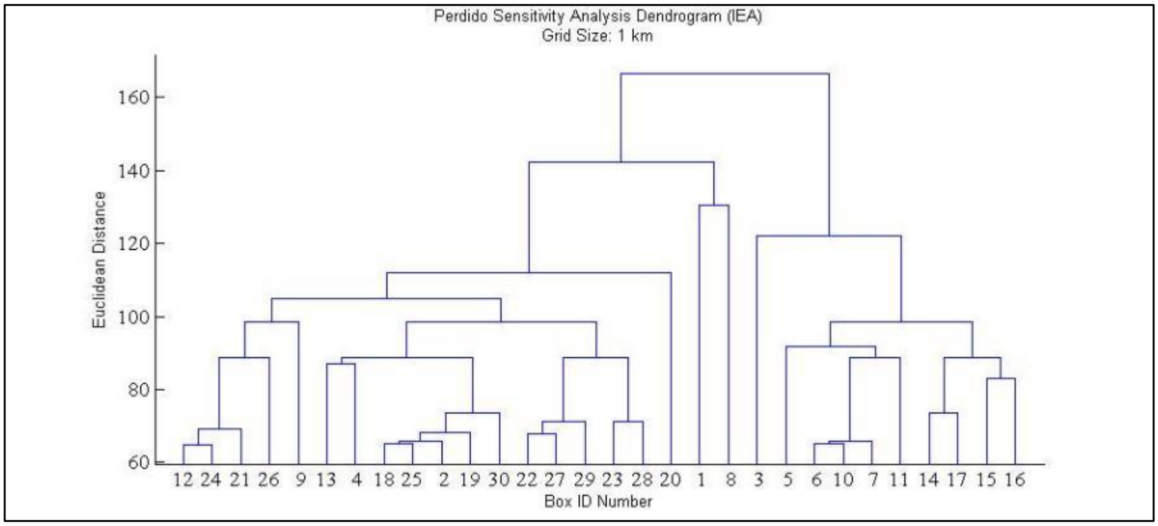


Figure G.6 Perdido Cluster Dendrogram for Sensitivity Analysis; Grid Size 1 km^2; IEA

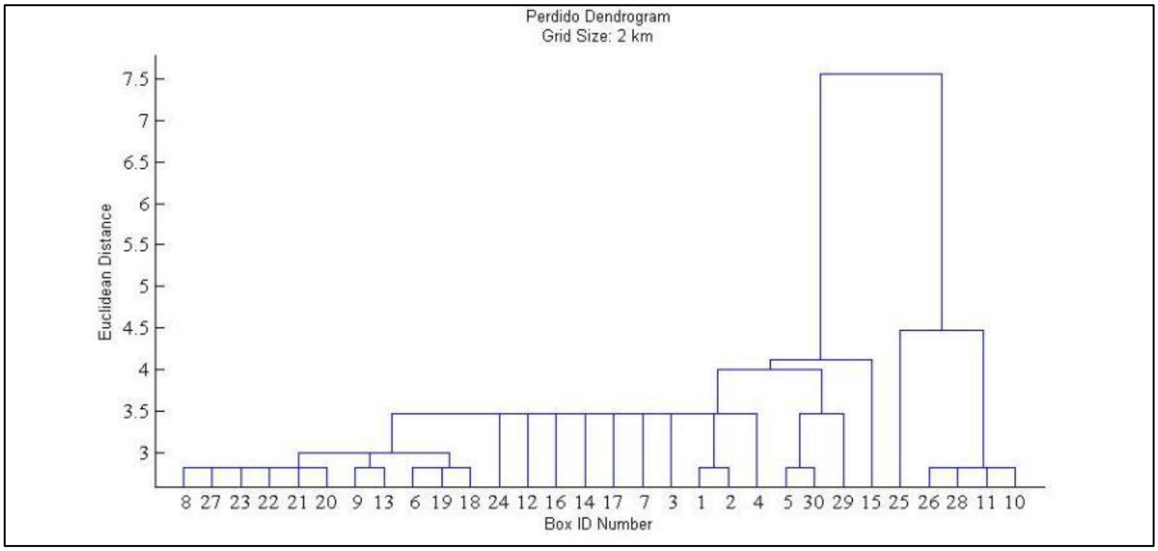


Figure G.7 Perdido Cluster Dendrogram; Grid Size 2 km^2

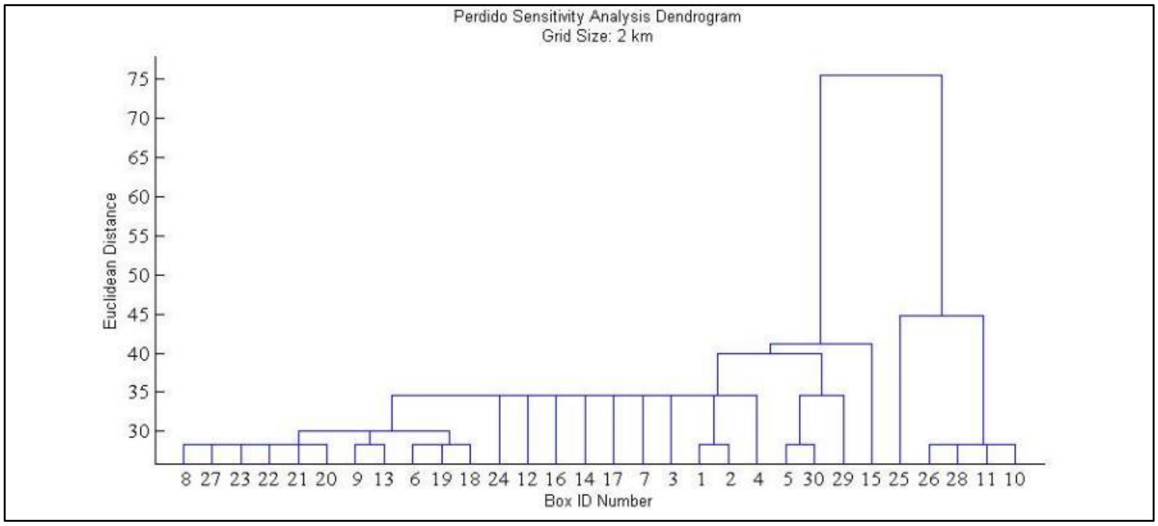


Figure G.8 Perdido Cluster Dendrogram for Sensitivity Analysis; Grid Size 2 km^2

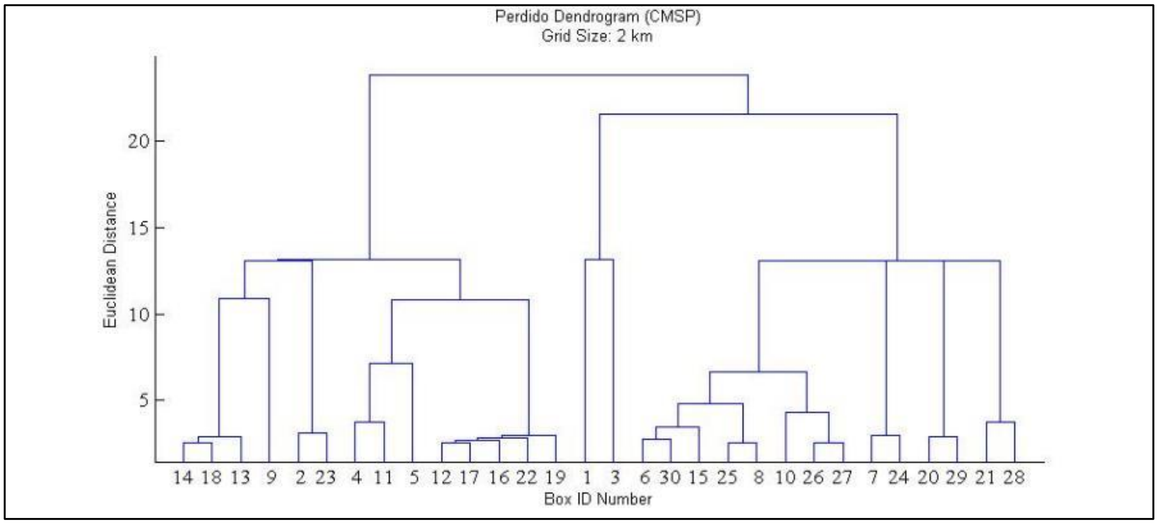


Figure G.9 Perdido Cluster Dendrogram; Grid Size 2 km^2; CMSP

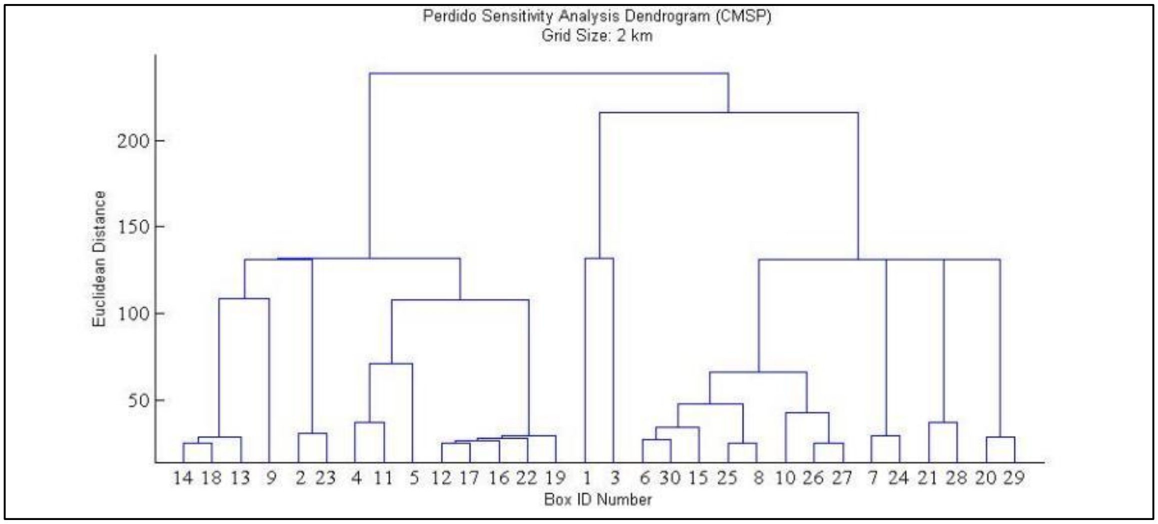


Figure G.10 Perdido Cluster Dendrogram for Sensitivity Analysis; Grid Size 2 km^2; CMSP

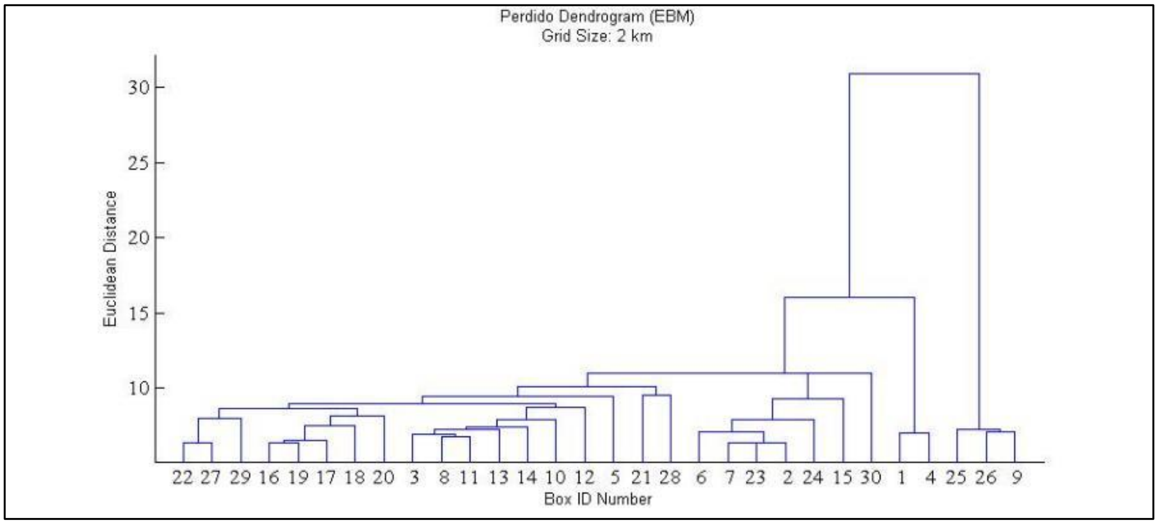


Figure G.11 Perdido Cluster Dendrogram; Grid Size 2 km^2; EBM

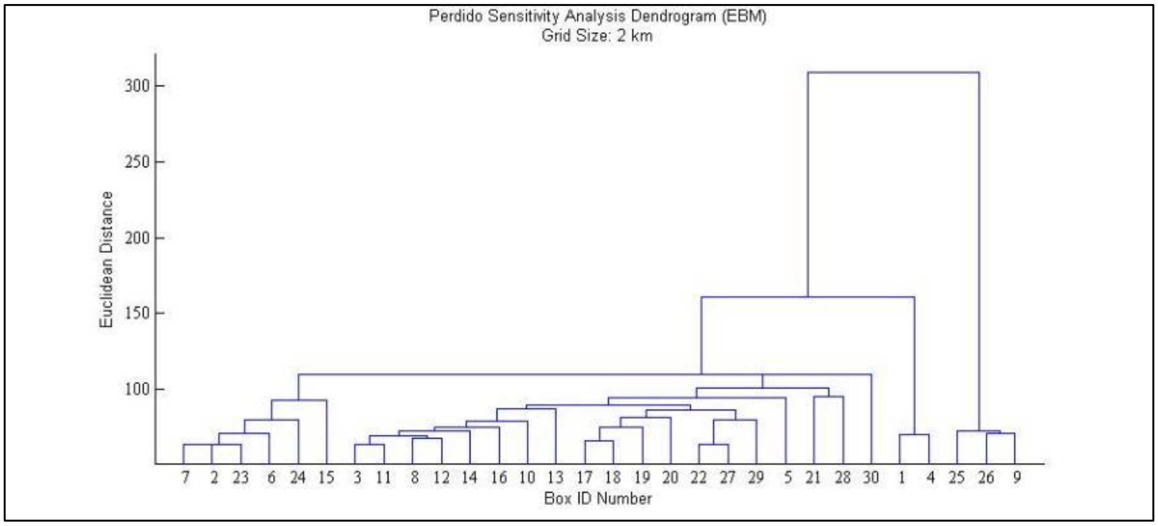


Figure G.12 Perdido Cluster Dendrogram for Sensitivity Analysis; Grid Size 2 km^2; EBM

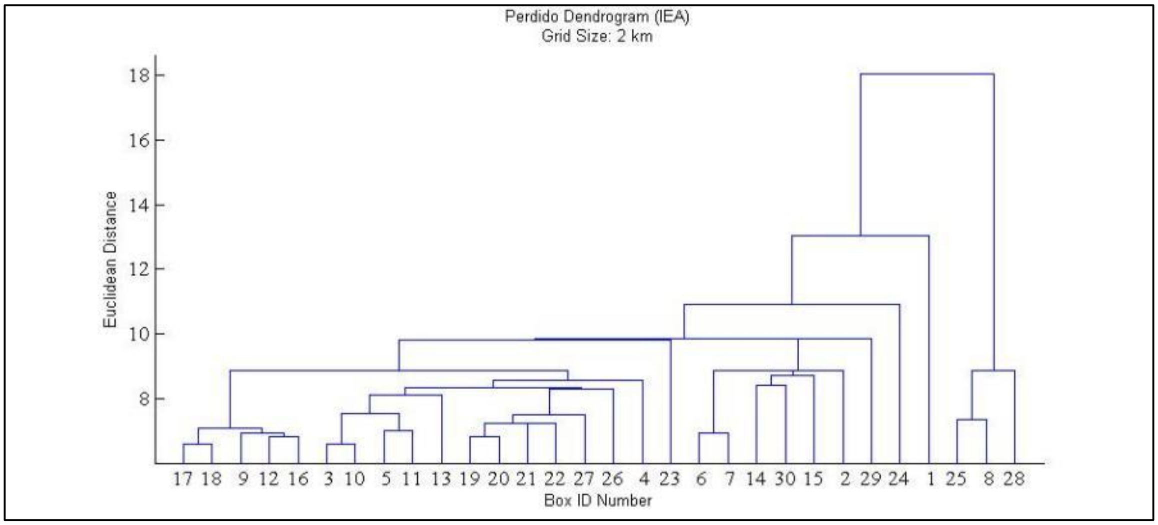


Figure G.13 Perdido Cluster Dendrogram; Grid Size 2 km^2; IEA

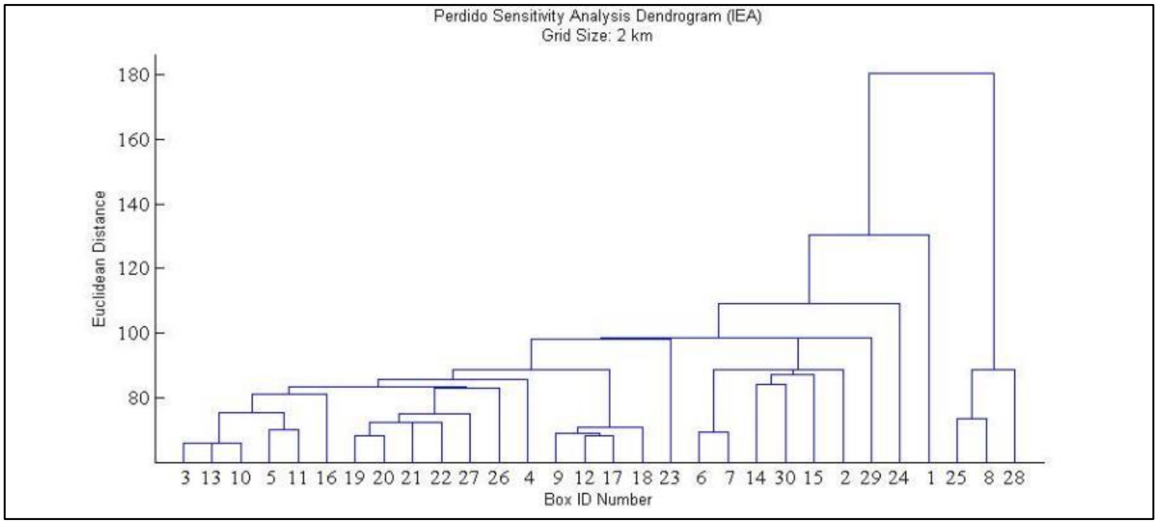


Figure G.14 Perdido Cluster Dendrogram for Sensitivity Analysis; Grid Size 2 km^2; IEA

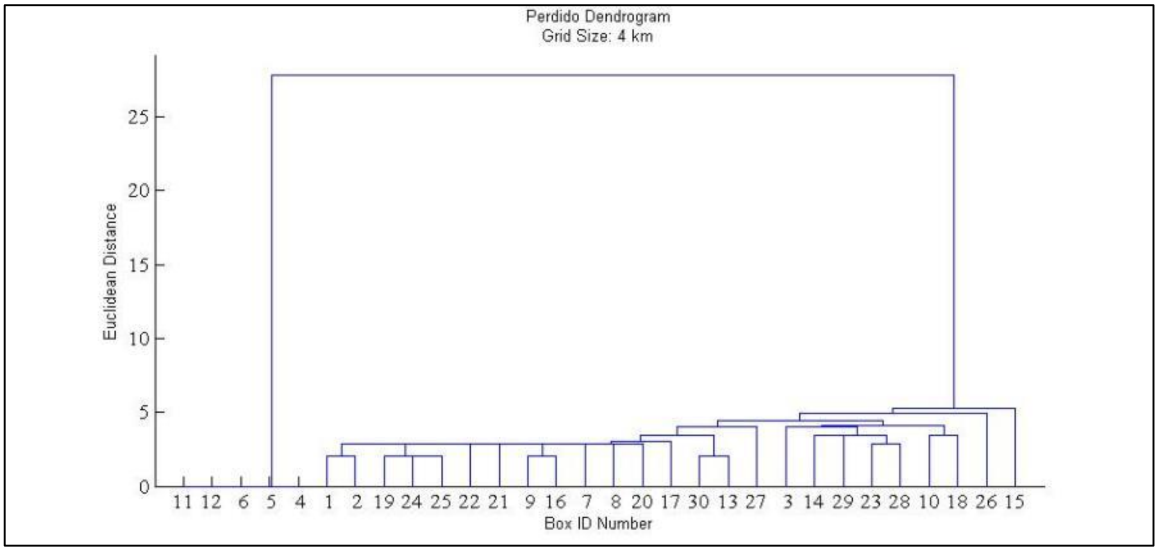


Figure G.15 Perdido Cluster Dendrogram; Grid Size 4 km^2

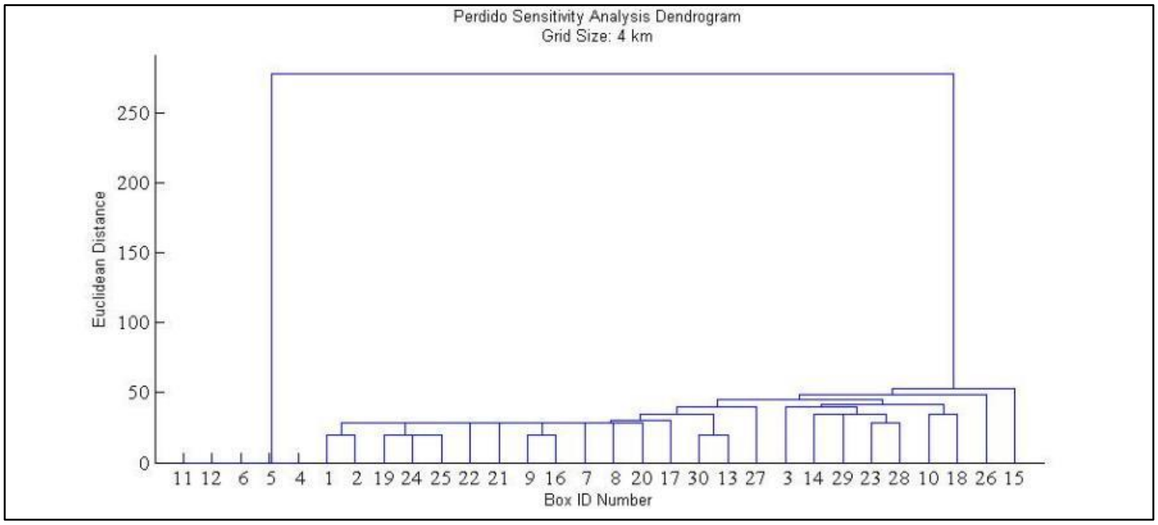


Figure G.16 Perdido Cluster Dendrogram for Sensitivity Analysis; Grid Size 4 km^2

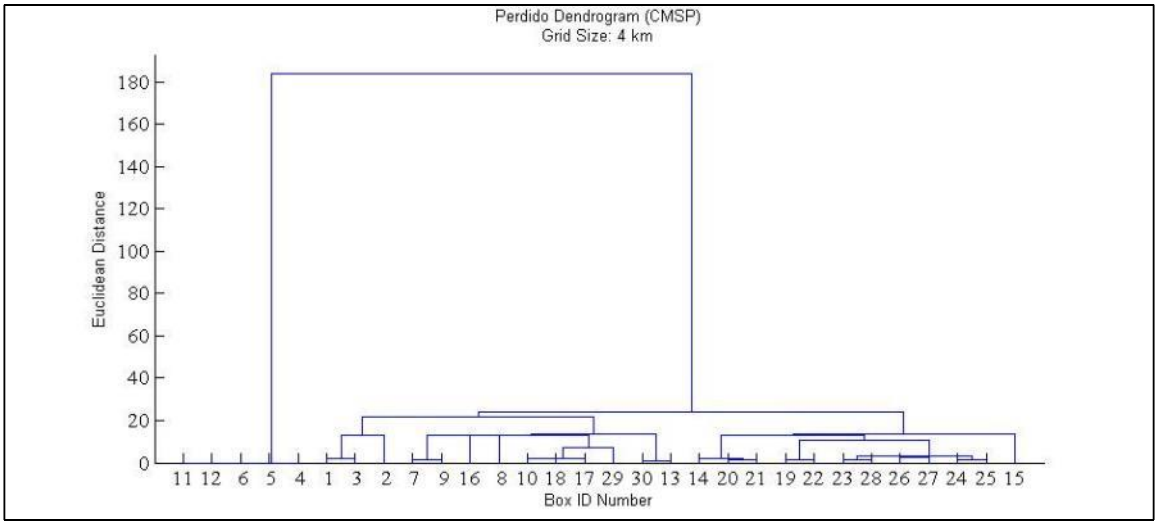


Figure G.17 Perdido Cluster Dendrogram; Grid Size 4 km^2; CMSP

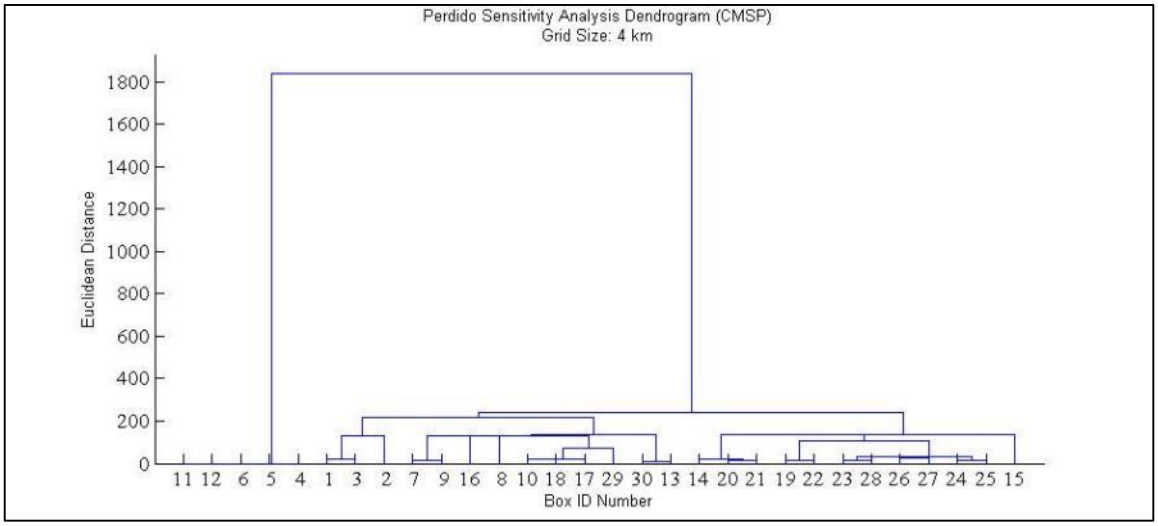


Figure G.18 Perdido Cluster Dendrogram for Sensitivity Analysis; Grid Size 4 km^2; CMSP

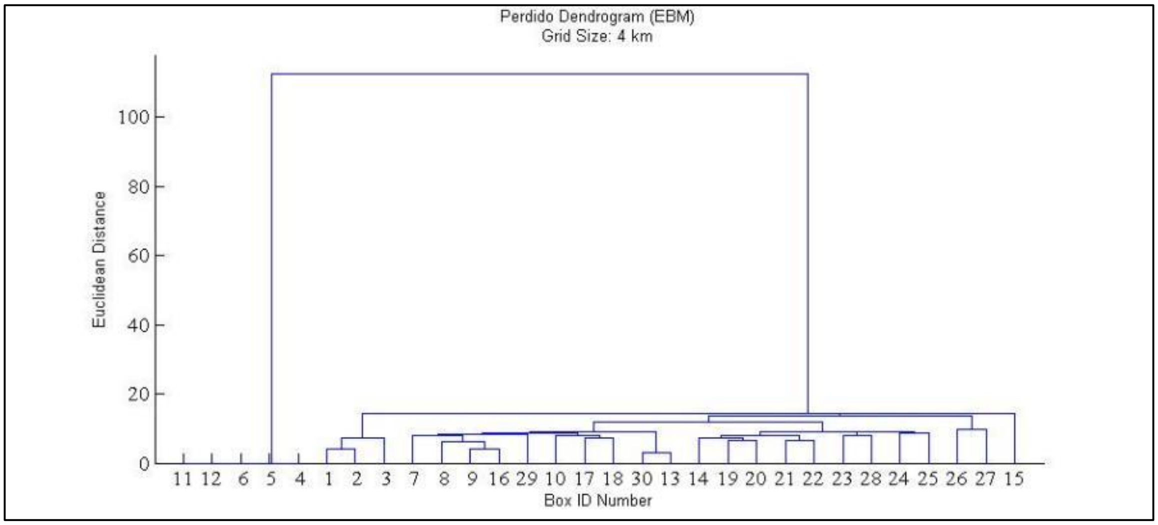


Figure G.19 Perdido Cluster Dendrogram; Grid Size 4 km^2; EBM

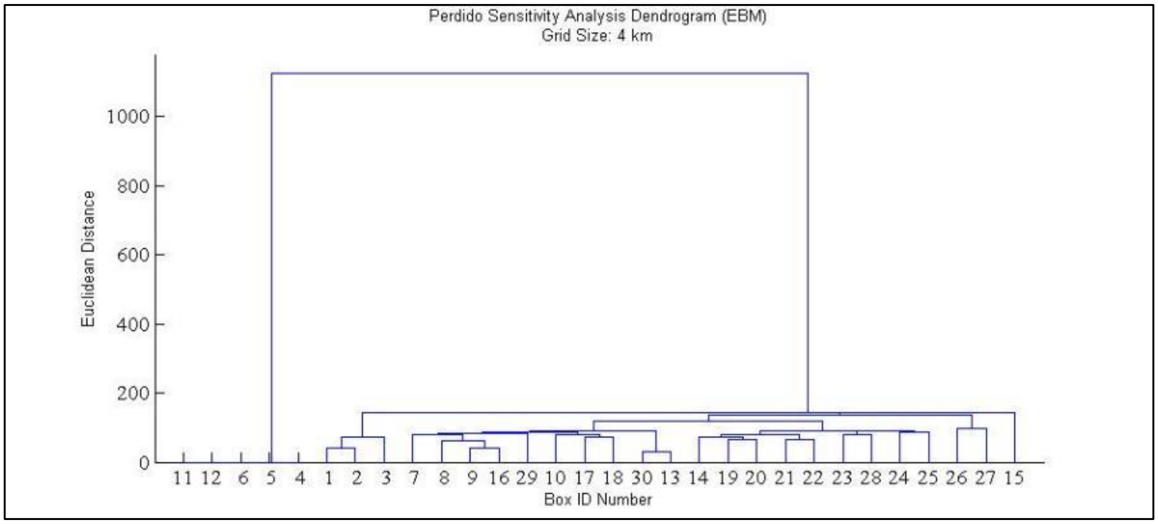


Figure G.20 Perdido Cluster Dendrogram for Sensitivity Analysis; Grid Size 4 km^2; EBM

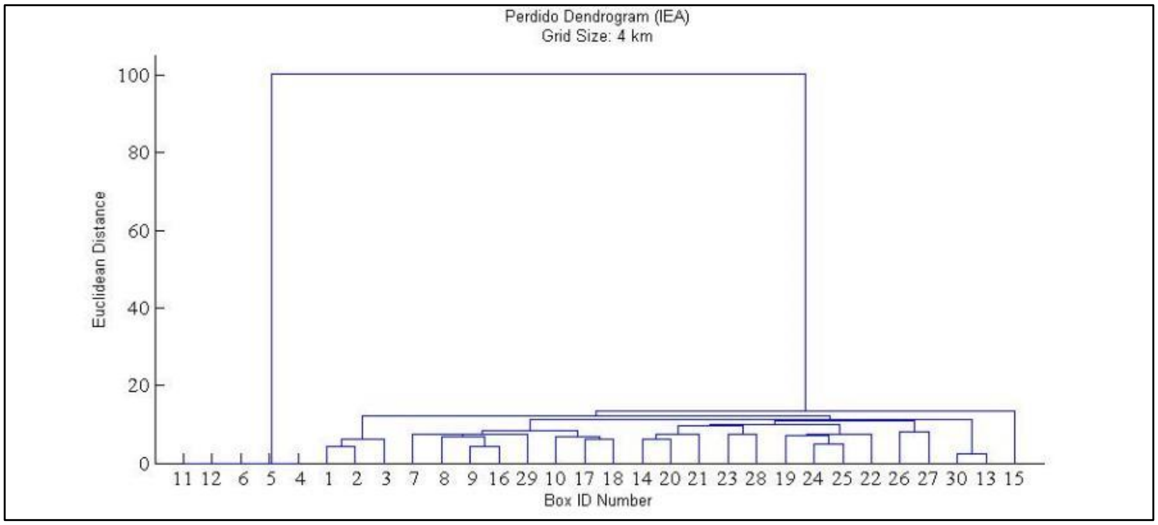


Figure G.21 Perdido Cluster Dendrogram; Grid Size 4 km^2; IEA

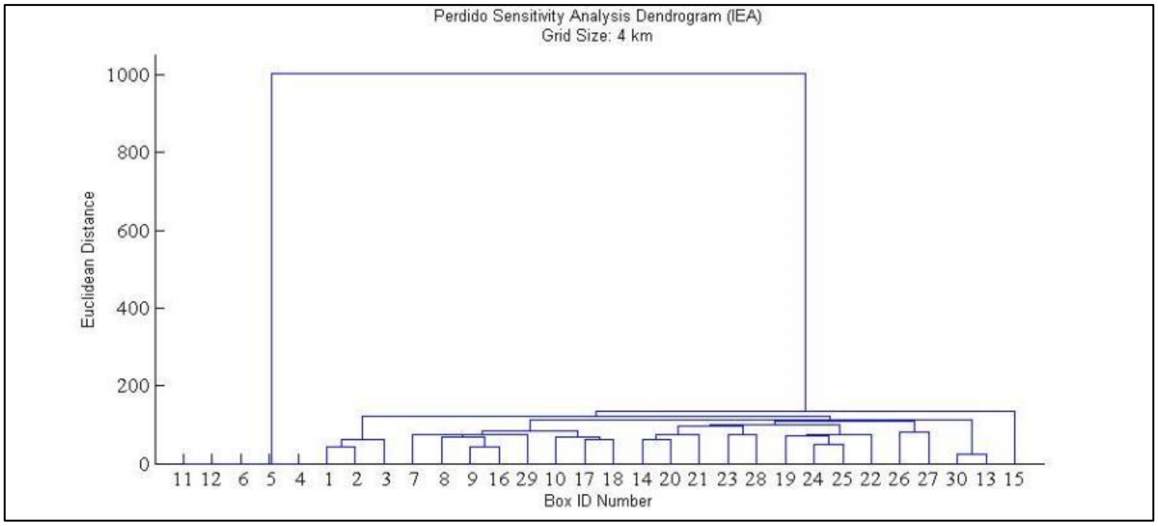


Figure G.22 Perdido Cluster Dendrogram for Sensitivity Analysis; Grid Size 4 km^2; IEA

G.2 Galveston Bay

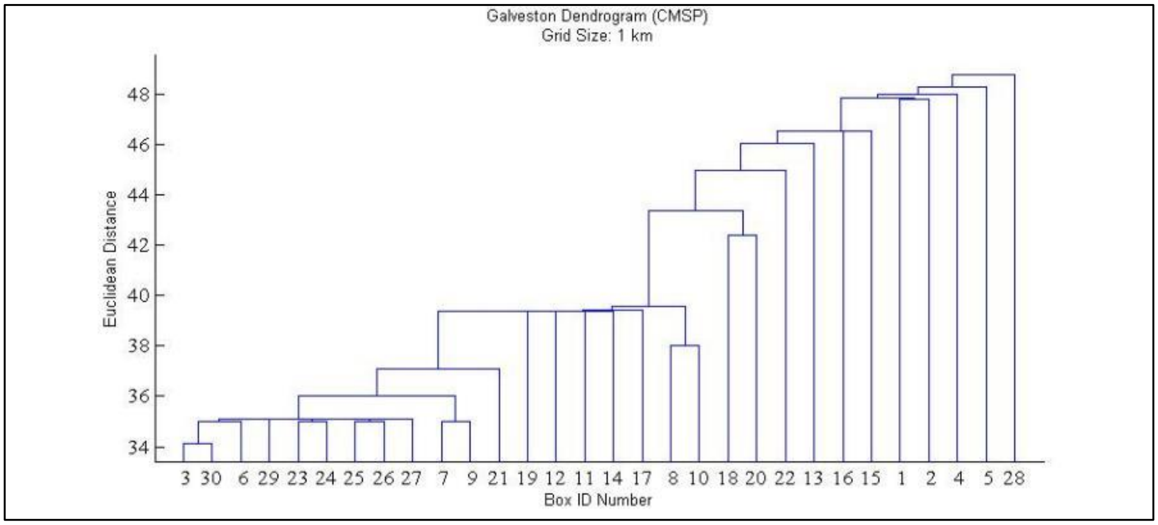


Figure G.23 Galveston Cluster Dendrogram; Grid Size 1 km^2; CMSP

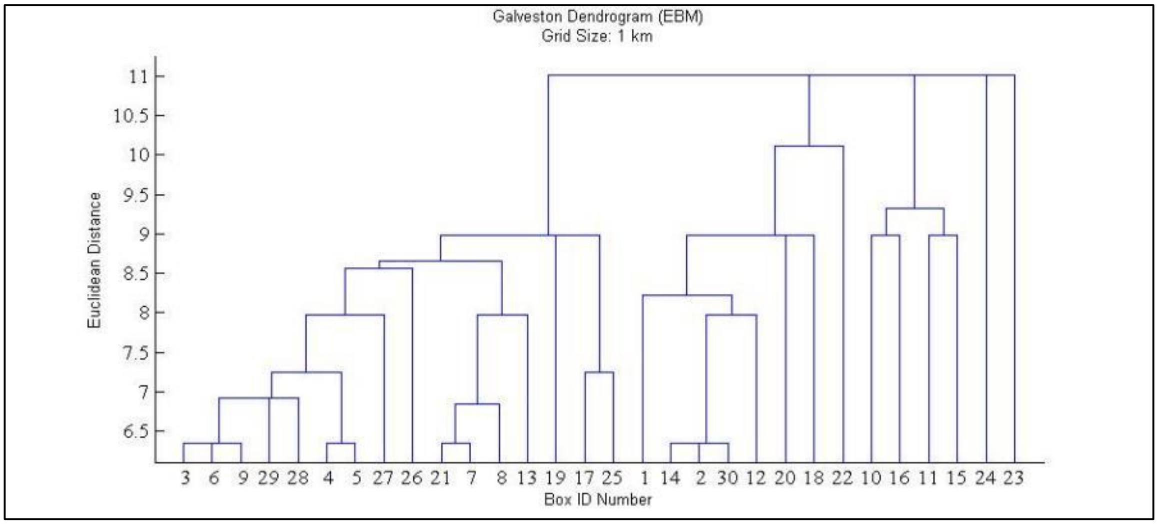


Figure G.24 Galveston Cluster Dendrogram; Grid Size 1 km^2; EBM

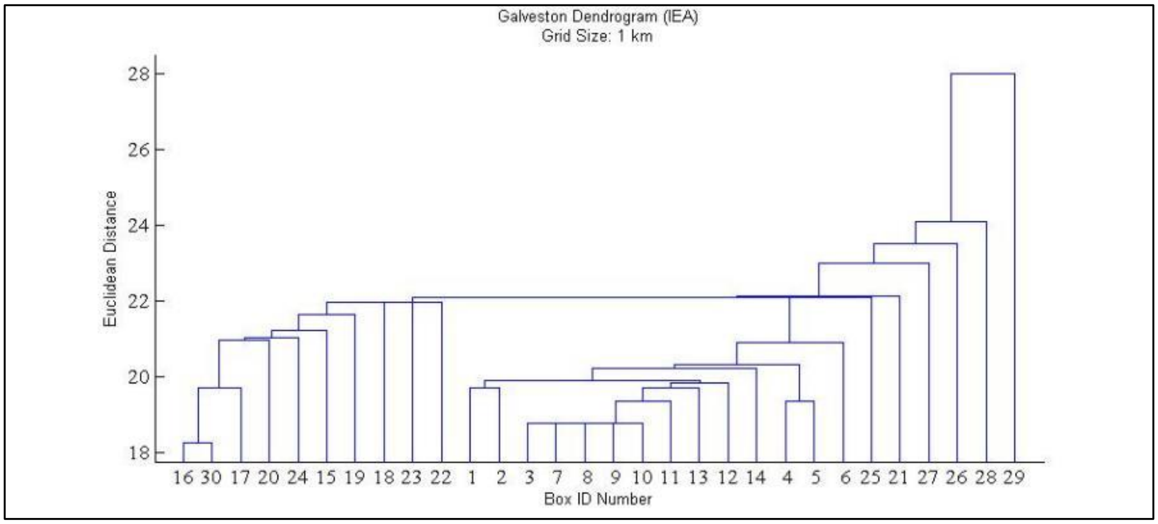


Figure G.25 Perdido Cluster Dendrogram; Grid Size 1 km^2; IEA

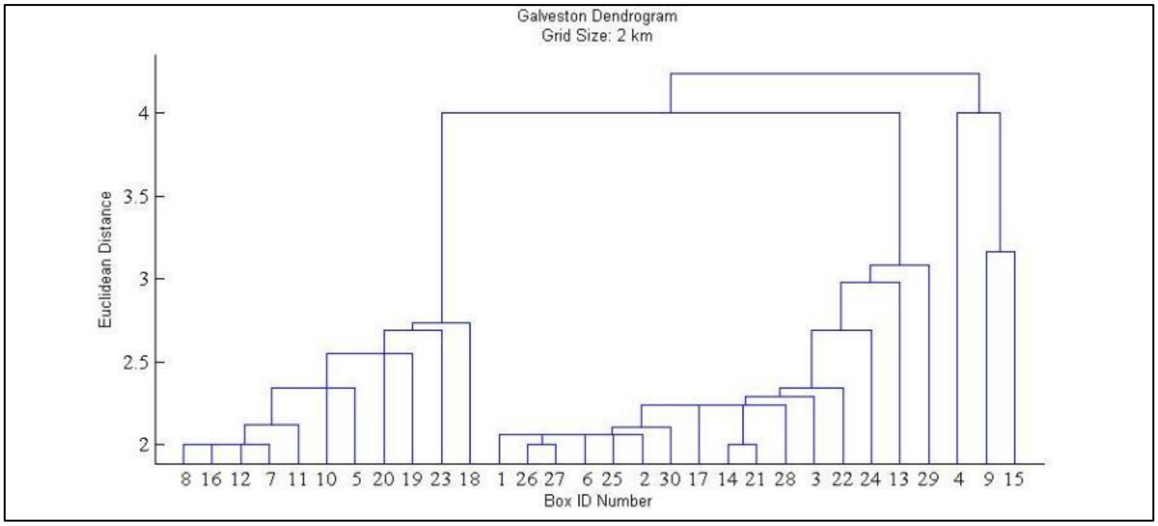


Figure G.26 Galveston Cluster Dendrogram; Grid Size 2 km^2

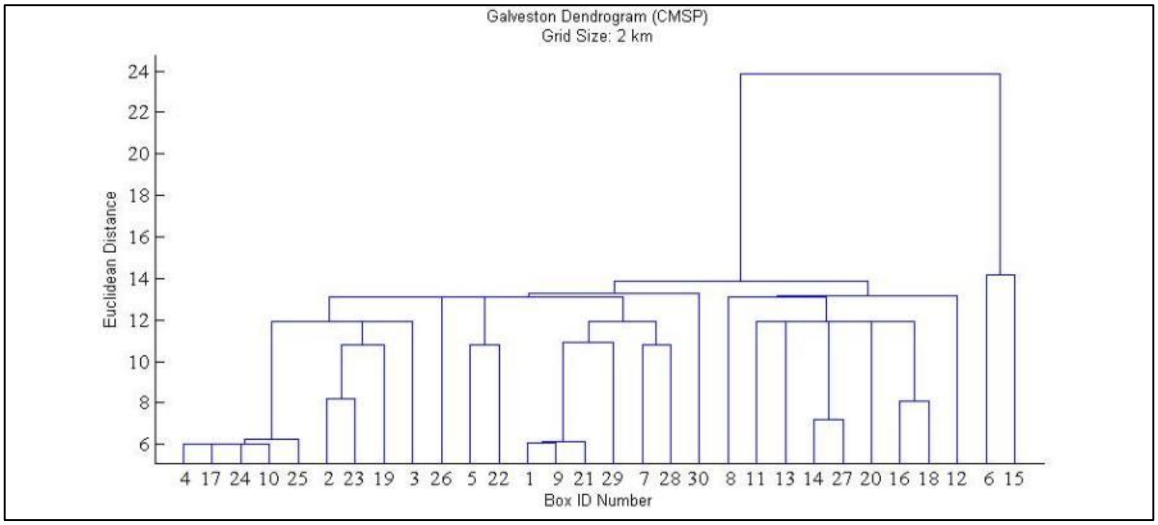


Figure G.27 Galveston Cluster Dendrogram; Grid Size 2 km^2; CMSP

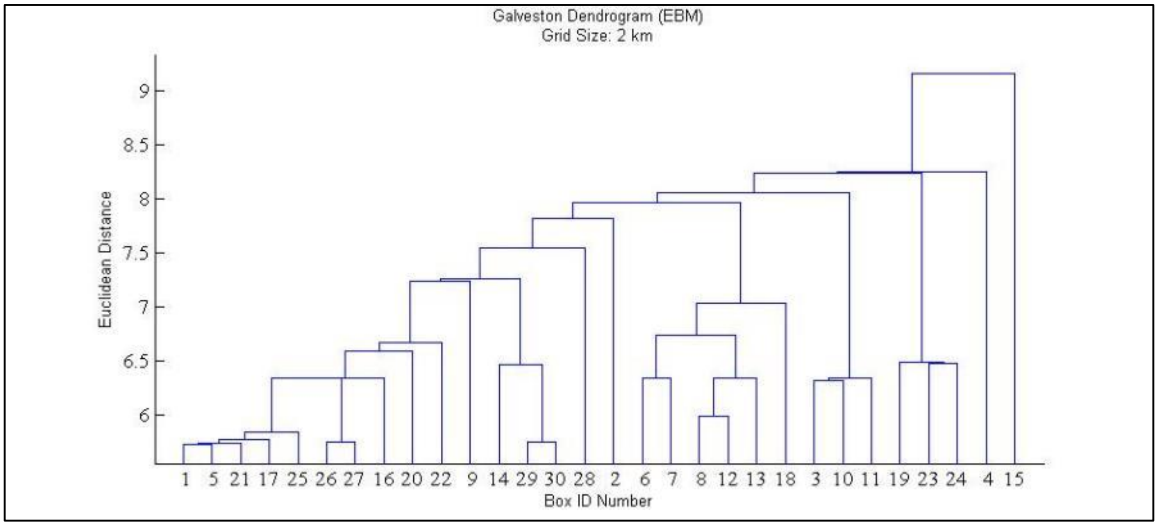


Figure G.28 Galveston Cluster Dendrogram; Grid Size 2 km^2; EBM

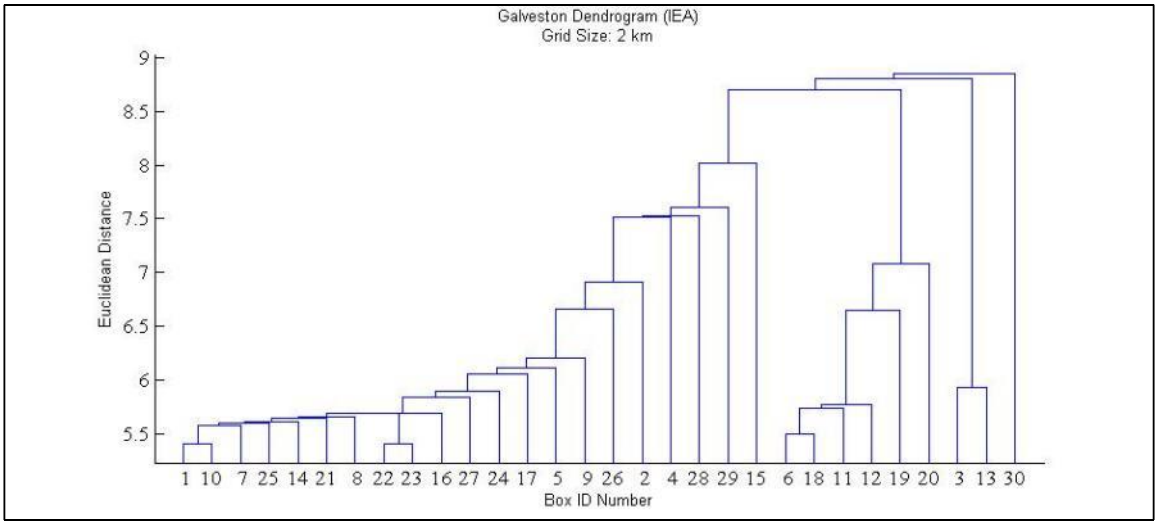


Figure G.29 Galveston Cluster Dendrogram; Grid Size 2 km^2; IEA

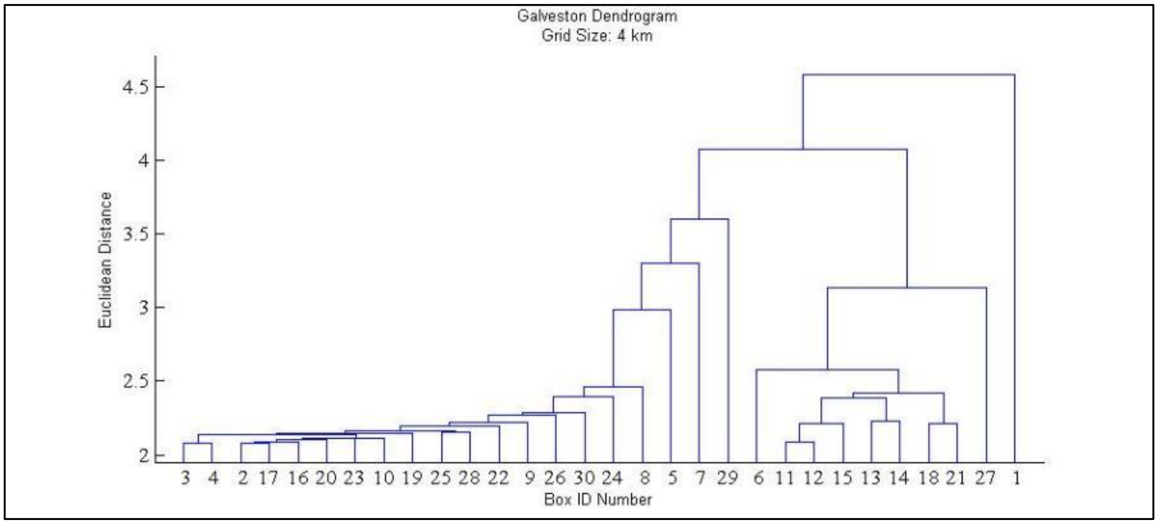


Figure G.30 Galveston Cluster Dendrogram; Grid Size 4 km^2

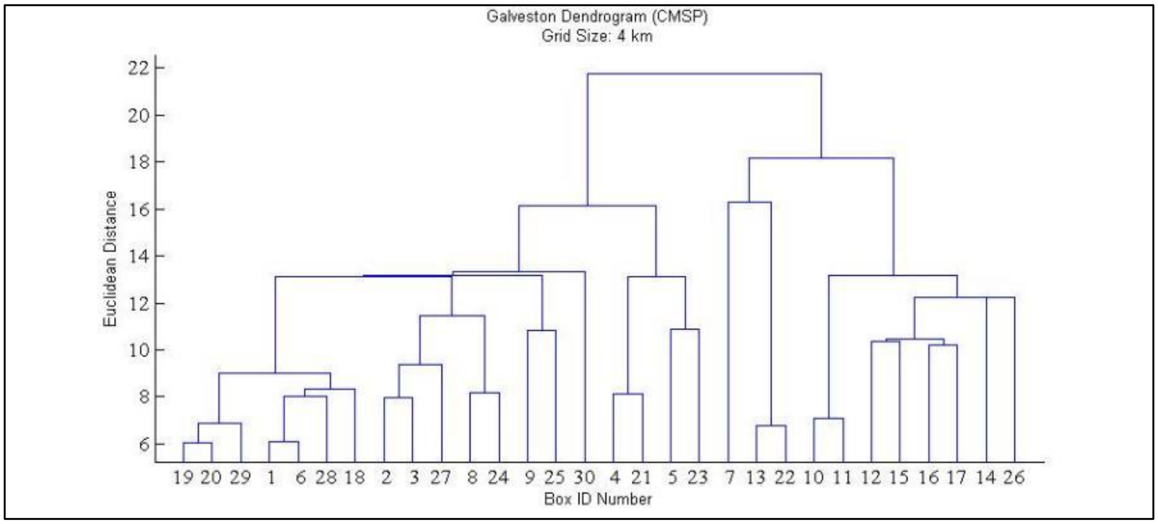


Figure G.31 Galveston Cluster Dendrogram; Grid Size 4 km^2; CMSP

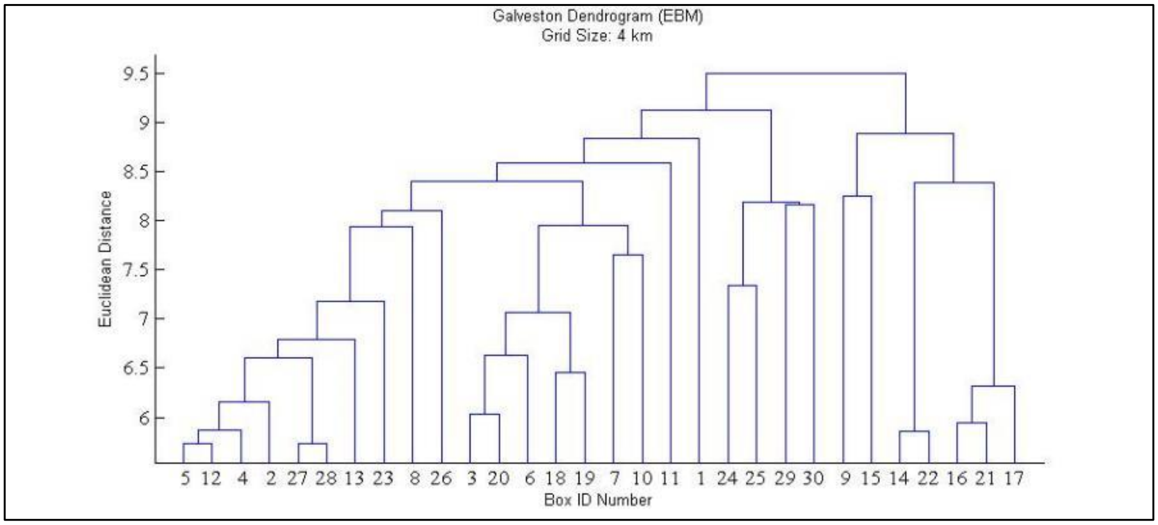


Figure G.32 Galveston Cluster Dendrogram; Grid Size 4 km^2; EBM

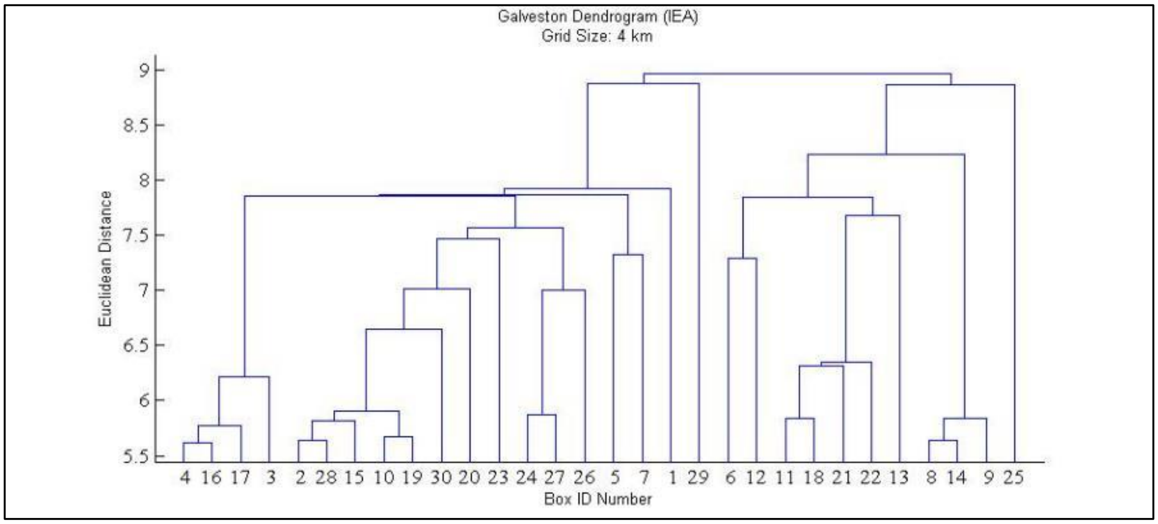


Figure G.33 Galveston Cluster Dendrogram; Grid Size 4 km^2; IEA

APPENDIX H

PIVOT TABLES AND DENDROGRAMS FOR GALVESTON BAY USING AN 8 KM^2 GRID

H.1 Pivot Tables

Table H.1 Galveston: 8 km^2 Grid

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	65										65
3	1	48	16								65
4	1	47	1	16							65
5	4	12	1	47	1						65
6	1	46	4	12	1	1					65
7	5	41	1	4	12	1	1				65
8	3	38	5	1	4	12	1	1			65
9	1	37	3	5	1	4	12	1	1		65
10	1	4	1	37	3	1	4	12	1	1	65

Table H.2 Galveston: 8 km^2 Grid; CMSP

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	65										65
3	2	14	49								65
4	2	47	2	14							65
5	1	46	2	2	14						65
6	12	34	1	2	2	14					65
7	4	30	12	1	2	2	14				65
8	12	2	4	30	12	1	2	2			65
9	6	6	12	2	4	30	1	2	2		65
10	3	3	6	12	2	4	30	1	2	2	65

Table H.3 Galveston: 8 km^2 Grid; EBM

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	65										65
3	1	48	16								65
4	4	44	1	16							65
5	1	43	4	1	16						65
6	4	12	1	43	4	1					65
7	3	9	4	1	43	4	1				65
8	1	42	3	9	4	1	4	1			65
9	3	39	1	3	9	4	1	4	1		65
10	1	8	3	39	1	3	4	1	4	1	65

Table H.4 Galveston: 8 km^2 Grid; IEA

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	65										65
3	5	44	16								65
4	1	43	5	16							65
5	1	42	1	5	16						65
6	1	41	1	1	5	16					65
7	4	37	1	1	1	5	16				65
8	3	13	4	37	1	1	1	5			65
9	1	36	3	13	4	1	1	1	5		65
10	1	12	1	36	3	4	1	1	1	5	65

H.2 Dendrograms

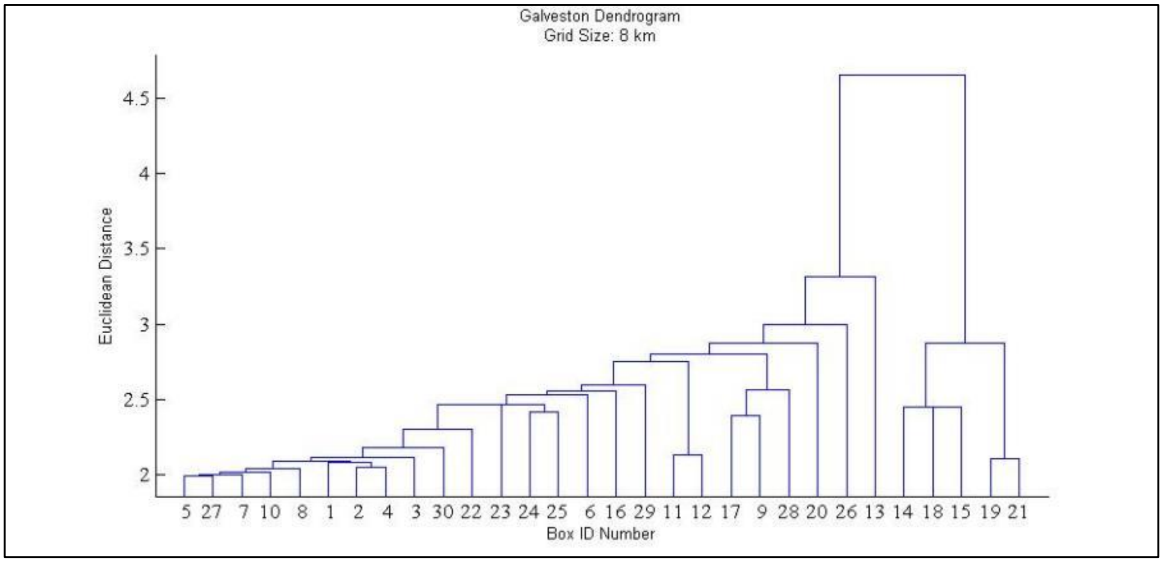


Figure H.1 Galveston Cluster Dendrogram; Grid Size: 8 km^2

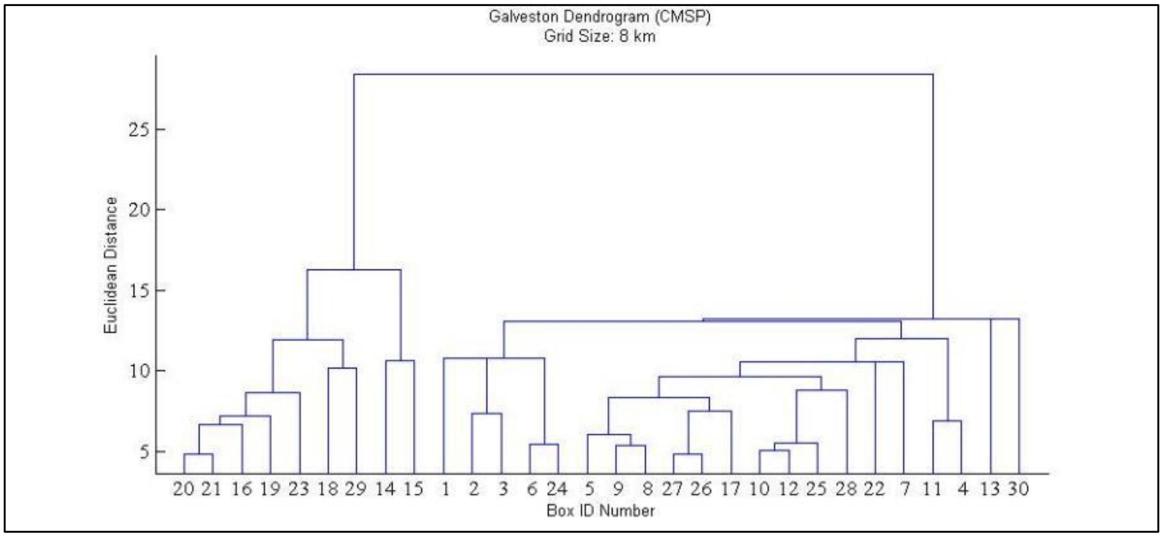


Figure H.2 Galveston Cluster Dendrogram; Grid Size: 8 km^2; CMSP

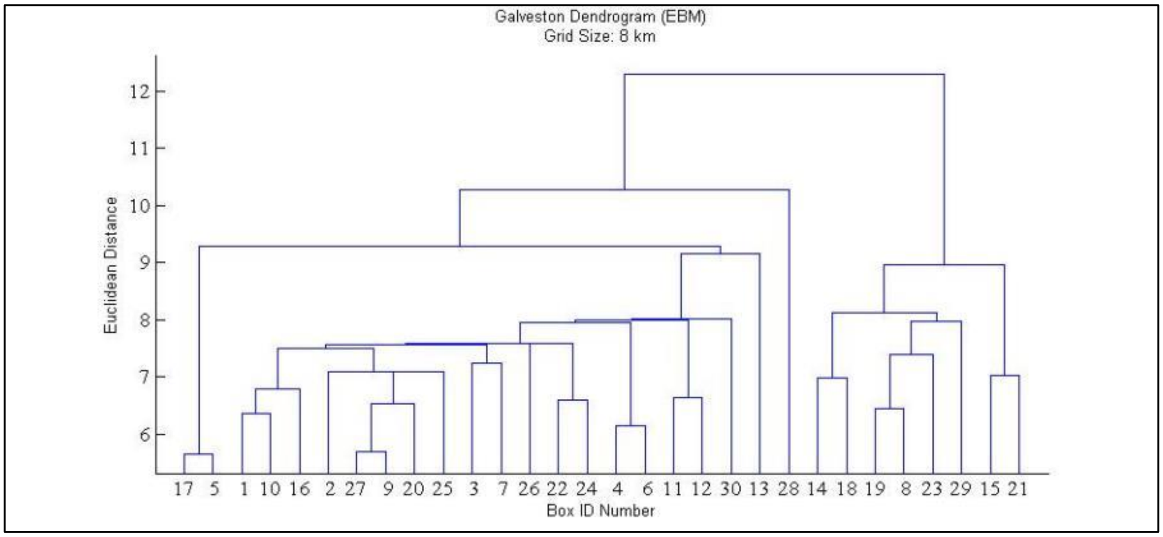


Figure H.3 Galveston Cluster Dendrogram: Grid Size: 8 km^2; EBM

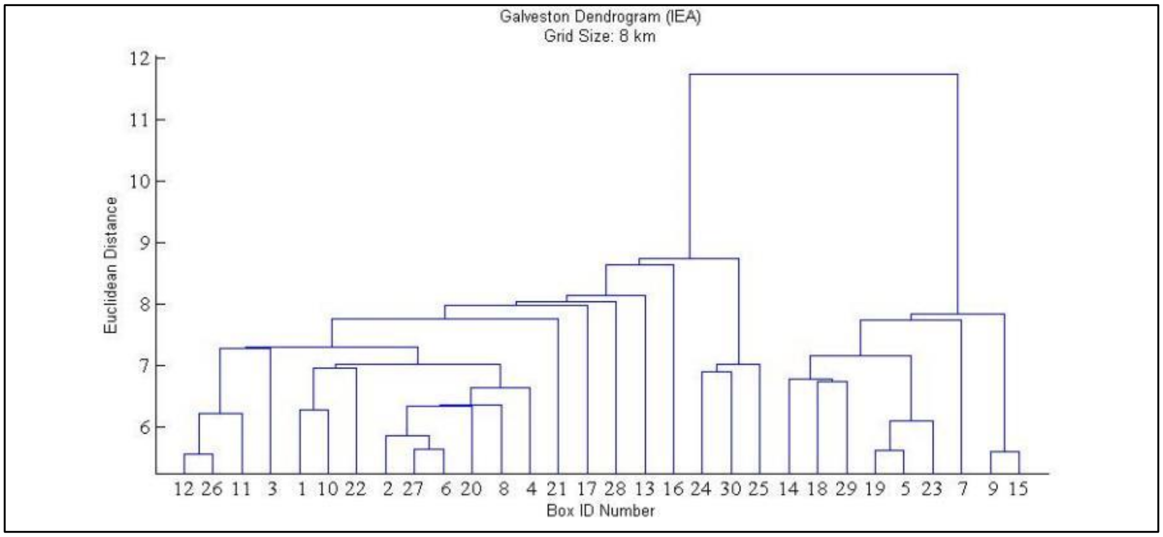


Figure H.4 Galveston Cluster Dendrogram; Grid Size: 8 km^2; IEA

APPENDIX I

SUPPLEMENTAL PIVOT TABLES FOR CHAPTER VII

I.1 Barataria Bay

Table I.1 Barataria Bay, 2 km^2 Grid

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	485										485
3	481	3	1								485
4	1	2	481	1							485
5	1	480	1	2	1						485
6	4	476	1	1	2	1					485
7	1	475	4	1	1	2	1				485
8	1	474	1	4	1	1	2	1			485
9	1	1	1	474	1	4	1	1	1		485
10	1	3	1	1	1	474	1	1	1	1	485

Table I.2 Barataria Bay, 2 km^2 Grid; CMSP

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	485										485
3	481	3	1								485
4	1	2	481	1							485
5	1	480	1	2	1						485
6	476	4	1	1	2	1					485
7	1	1	476	4	1	1	1				485
8	1	3	1	1	476	1	1	1			485
9	1	475	1	3	1	1	1	1	1		485
10	1	474	1	1	3	1	1	1	1	1	485

Table I.3 Barataria Bay, 2 km^2 Grid; EBM

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	485										485
3	481	3	1								485
4	1	2	481	1							485
5	4	477	1	2	1						485
6	1	476	4	1	2	1					485
7	1	475	1	4	1	2	1				485
8	1	474	1	1	4	1	2	1			485
9	1	3	1	474	1	1	1	2	1		485
10	1	1	1	3	1	474	1	1	1	1	485

Table I.4 Barataria Bay, 2 km^2 Grid; IEA

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	485										485
3	481	3	1								485
4	1	2	481	1							485
5	1	480	1	2	1						485
6	476	4	1	1	2	1					485
7	1	1	476	4	1	1	1				485
8	1	3	1	1	476	1	1	1			485
9	1	475	1	3	1	1	1	1	1		485
10	1	474	1	1	3	1	1	1	1	1	485

Table I.5 Barataria Bay, 4 km^2 Grid

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	145										145
3	1	143	1								145
4	2	141	1	1							145
5	1	140	2	1	1						145
6	1	139	1	2	1	1					145
7	16	123	1	1	2	1	1				145
8	2	121	16	1	1	2	1	1			145
9	48	73	2	16	1	1	2	1	1		145
10	1	72	48	2	16	1	1	2	1	1	145

Table I.6 Barataria Bay, 4 km^2 Grid; CMSP

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	145										145
3	1	143	1								145
4	141	2	1	1							145
5	1	1	141	1	1						145
6	124	17	1	1	1	1					145
7	5	12	124	1	1	1	1				145
8	5	119	5	12	1	1	1	1			145
9	3	116	5	5	12	1	1	1	1		145
10	68	48	3	5	5	12	1	1	1	1	145

Table I.7 Barataria Bay, 4 km^2 Grid; EBM

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	145										145
3	1	143	1								145
4	141	2	1	1							145
5	1	1	141	1	1						145
6	93	48	1	1	1	1					145
7	1	47	93	1	1	1	1				145
8	1	92	1	47	1	1	1	1			145
9	1	91	1	1	47	1	1	1	1		145
10	2	89	1	1	1	47	1	1	1	1	145

Table I.8 Barataria Bay, 4 km^2 Grid; IEA

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	145										145
3	1	143	1								145
4	141	2	1	1							145
5	1	1	141	1	1						145
6	93	48	1	1	1	1					145
7	1	47	93	1	1	1	1				145
8	3	90	1	47	1	1	1	1			145
9	1	89	3	1	47	1	1	1	1		145
10	1	88	1	3	1	47	1	1	1	1	145

Table I.9 Barataria Bay, 8 km^2 Grid

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	50										50
3	12	37	1								50
4	17	20	12	1							50
5	1	11	17	20	1						50
6	1	10	1	17	20	1					50
7	1	19	1	10	1	17	1				50
8	1	18	1	1	10	1	17	1			50
9	16	2	1	1	1	10	1	17	1		50
10	1	9	16	2	1	1	1	1	17	1	50

Table I.10 Barataria Bay, 8 km^2 Grid; CMSP

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	50										50
3	37	12	1								50
4	2	10	37	1							50
5	7	3	2	37	1						50
6	1	36	7	3	2	1					50
7	19	17	1	7	3	2	1				50
8	1	16	19	1	7	3	2	1			50
9	6	10	1	19	1	7	3	2	1		50
10	2	8	6	1	19	1	7	3	2	1	50

Table I.11 Barataria Bay, 8 km^2 Grid; EBM

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	50										50
3	17	32	1								50
4	1	31	17	1							50
5	10	7	1	31	1						50
6	1	30	10	7	1	1					50
7	9	21	1	10	7	1	1				50
8	1	6	9	21	1	10	1	1			50
9	1	20	1	6	9	1	10	1	1		50
10	2	8	1	20	1	6	9	1	1	1	50

Table I.12 Barataria Bay, 8 km^2 Grid; IEA

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	50										50
3	17	32	1								50
4	10	22	17	1							50
5	6	11	10	22	1						50
6	2	9	6	10	22	1					50
7	1	21	2	9	6	10	1				50
8	1	20	1	2	9	6	10	1			50
9	2	4	1	20	1	2	9	10	1		50
10	1	8	2	4	1	20	1	2	10	1	50

I.2 Mississippi Sound

Table I.13 Mississippi Sound, 2 km^2 Grid

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	1222										1222
3	1	66	1155								1222
4	3	1152	1	66							1222
5	1	1151	3	1	66						1222
6	3	1148	1	3	1	66					1222
7	1	1147	3	1	3	1	66				1222
8	2	1145	1	3	1	3	1	66			1222
9	956	189	2	1	3	1	3	1	66		1222
10	1	65	956	189	2	1	3	1	3	1	1222

Table I.14 Mississippi Sound, 2 km^2 Grid; CMSP

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	1222										1222
3	990	165	67								1222
4	24	43	990	165							1222
5	1	42	24	990	165						1222
6	3	162	1	42	24	990					1222
7	1	161	3	1	42	24	990				1222
8	48	113	1	3	1	42	24	990			1222
9	3	987	48	113	1	3	1	42	24		1222
10	845	142	3	48	113	1	3	1	42	24	1222

Table I.15 Mississippi Sound, 2 km^2 Grid; EBM

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	1222										1222
3	1	66	1155								1222
4	3	1152	1	66							1222
5	3	1149	3	1	66						1222
6	1	1148	3	3	1	66					1222
7	1	1147	1	3	3	1	66				1222
8	2	1145	1	1	3	3	1	66			1222
9	956	189	2	1	1	3	3	1	66		1222
10	1	65	956	189	2	1	1	3	3	1	1222

Table I.16 Mississippi Sound, 2 km^2 Grid; IEA

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	1222										1222
3	1	66	1155								1222
4	3	1152	1	66							1222
5	990	162	3	1	66						1222
6	42	24	990	162	3	1					1222
7	1	23	42	990	162	3	1				1222
8	1	22	1	42	990	162	3	1			1222
9	2	160	1	22	1	42	990	3	1		1222
10	48	112	2	1	22	1	42	990	3	1	1222

Table I.17 Mississippi Sound, 4 km^2 Grid

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	347										347
3	2	343	2								347
4	8	335	2	2							347
5	1	334	8	2	2						347
6	1	333	1	8	2	2					347
7	1	7	1	333	1	2	2				347
8	8	325	1	7	1	1	2	2			347
9	2	323	8	1	7	1	1	2	2		347
10	1	322	2	8	1	7	1	1	2	2	347

Table I.18 Mississippi Sound, 4 km^2 Grid; CMSP

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	347										347
3	4	340	3								347
4	1	339	4	3							347
5	271	68	1	4	3						347
6	2	66	271	1	4	3					347
7	18	48	2	271	1	4	3				347
8	10	38	18	2	271	1	4	3			347
9	1	3	10	38	18	2	271	1	3		347
10	6	12	1	3	10	38	2	271	1	3	347

Table I.19 Mississippi Sound, 4 km^2 Grid; EBM

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	347										347
3	2	343	2								347
4	1	342	2	2							347
5	1	341	1	2	2						347
6	8	333	1	1	2	2					347
7	1	332	8	1	1	2	2				347
8	1	331	1	8	1	1	2	2			347
9	1	330	1	1	8	1	1	2	2		347
10	1	329	1	1	1	8	1	1	2	2	347

Table I.20 Mississippi Sound, 4 km^2 Grid; IEA

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	347										347
3	2	343	2								347
4	1	342	2	2							347
5	1	341	1	2	2						347
6	7	334	1	1	2	2					347
7	1	333	7	1	1	2	2				347
8	1	332	1	7	1	1	2	2			347
9	1	331	1	1	7	1	1	2	2		347
10	3	328	1	1	1	7	1	1	2	2	347

Table I.21 Mississippi Sound, 8 km^2 Grid

Number of Clusters	Cluster Group										Total
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	109										109
3	1	102	6								109
4	2	4	1	102							109
5	1	101	2	4	1						109
6	1	100	1	2	4	1					109
7	1	99	1	1	2	4	1				109
8	1	98	1	1	1	2	4	1			109
9	3	95	1	1	1	1	2	4	1		109
10	2	93	3	1	1	1	1	2	4	1	109

Table I.22 Mississippi Sound, 8 km^2 Grid; CMSP

Number of Clusters	Cluster Group										Total
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	109										109
3	5	102	2								109
4	1	101	5	2							109
5	65	36	1	5	2						109
6	1	4	65	36	1	2					109
7	10	26	1	4	65	1	2				109
8	7	19	10	1	4	65	1	2			109
9	1	1	7	19	10	1	4	65	1		109
10	5	14	1	1	7	10	1	4	65	1	109

Table I.23 Mississippi Sound, 8 km^2 Grid; EBM

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	109										109
3	1	107	1								109
4	2	105	1	1							109
5	3	102	2	1	1						109
6	2	100	3	2	1	1					109
7	1	99	2	3	2	1	1				109
8	1	1	1	99	2	3	1	1			109
9	1	2	1	1	1	99	2	1	1		109
10	1	98	1	2	1	1	1	2	1	1	109

Table I.24 Mississippi Sound, 8 km^2 Grid; IEA

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	109										109
3	1	107	1								109
4	105	2	1	1							109
5	1	1	105	1	1						109
6	1	104	1	1	1	1					109
7	1	103	1	1	1	1	1				109
8	1	102	1	1	1	1	1	1			109
9	2	100	1	1	1	1	1	1	1		109
10	1	99	2	1	1	1	1	1	1	1	109

I.3 Mobile Bay

Table I.25 Mobile Bay, 2 km^2 Grid

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	501										501
3	2	498	1								501
4	1	497	2	1							501
5	2	495	1	2	1						501
6	1	494	2	1	2	1					501
7	1	493	1	2	1	2	1				501
8	111	382	1	1	2	1	2	1			501
9	1	1	111	382	1	1	2	1	1		501
10	34	348	1	1	111	1	1	2	1	1	501

Table I.26 Mobile Bay, 2 km^2 Grid; CMSP

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	501										501
3	1	499	1								501
4	1	498	1	1							501
5	1	497	1	1	1						501
6	2	495	1	1	1	1					501
7	1	494	2	1	1	1	1				501
8	66	428	1	2	1	1	1	1			501
9	57	371	66	1	2	1	1	1	1		501
10	1	370	57	66	1	2	1	1	1	1	501

Table I.27 Mobile Bay, 2 km^2 Grid; EBM

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	501										501
3	497	3	1								501
4	1	2	497	1							501
5	2	495	1	2	1						501
6	1	494	2	1	2	1					501
7	1	493	1	2	1	2	1				501
8	382	111	1	1	2	1	2	1			501
9	1	1	382	111	1	1	2	1	1		501
10	5	106	1	1	382	1	1	2	1	1	501

Table I.28 Mobile Bay, 2 km^2 Grid; IEA

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	501										501
3	2	498	1								501
4	1	497	2	1							501
5	1	1	1	497	1						501
6	2	495	1	1	1	1					501
7	1	494	2	1	1	1	1				501
8	1	493	1	2	1	1	1	1			501
9	382	111	1	1	2	1	1	1	1		501
10	105	6	382	1	1	2	1	1	1	1	501

Table I.29 Mobile Bay, 4 km^2 Grid

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	147										147
3	8	90	49								147
4	6	84	8	49							147
5	1	48	6	84	8						147
6	1	83	1	48	6	8					147
7	1	5	1	83	1	48	8				147
8	80	3	1	5	1	1	48	8			147
9	1	2	80	1	5	1	1	48	8		147
10	9	39	1	2	80	1	5	1	1	8	147

Table I.30 Mobile Bay, 4 km^2 Grid; CMSP

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	147										147
3	2	47	98								147
4	9	89	2	47							147
5	3	86	9	2	47						147
6	3	83	3	9	2	47					147
7	4	5	3	83	3	2	47				147
8	1	46	4	5	3	83	3	2			147
9	1	45	1	4	5	3	83	3	2		147
10	44	39	1	45	1	4	5	3	3	2	147

Table I.31 Mobile Bay, 4 km^2 Grid; EBM

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	147										147
3	1	145	1								147
4	1	144	1	1							147
5	2	142	1	1	1						147
6	1	141	2	1	1	1					147
7	1	140	1	2	1	1	1				147
8	83	57	1	1	2	1	1	1			147
9	39	18	83	1	1	2	1	1	1		147
10	1	82	39	18	1	1	2	1	1	1	147

Table I.32 Mobile Bay, 4 km^2 Grid; IEA

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	147										147
3	2	144	1								147
4	87	57	2	1							147
5	8	49	87	2	1						147
6	1	86	8	49	2	1					147
7	1	48	1	86	8	2	1				147
8	1	85	1	48	1	8	2	1			147
9	1	84	1	1	48	1	8	2	1		147
10	1	83	1	1	1	48	1	8	2	1	147

Table I.33 Mobile Bay, 8 km^2 Grid

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	45										45
3	1	25	19								45
4	2	23	1	19							45
5	1	22	2	1	19						45
6	3	16	1	22	2	1					45
7	4	18	3	16	1	2	1				45
8	1	17	4	3	16	1	2	1			45
9	2	15	1	4	3	16	1	2	1		45
10	7	9	2	15	1	4	3	1	2	1	45

Table I.34 Mobile Bay, 8 km^2 Grid; CMSP

Number of Clusters	Cluster Group										Total
	1	2	3	4	5	6	7	8	9	10	
2	45										45
3	3	23	19								45
4	1	18	3	23							45
5	16	2	1	3	23						45
6	2	21	16	2	1	3					45
7	1	1	2	21	16	1	3				45
8	3	18	1	1	2	16	1	3			45
9	3	15	3	1	1	2	16	1	3		45
10	1	14	3	3	1	1	2	16	1	3	45

Table I.35 Mobile Bay, 8 km^2 Grid; EBM

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	45										45
3	16	28	1								45
4	2	26	16	1							45
5	2	24	2	16	1						45
6	6	18	2	2	16	1					45
7	1	17	6	2	2	16	1				45
8	3	3	1	17	2	2	16	1			45
9	1	2	3	1	17	2	2	16	1		45
10	1	1	1	3	1	17	2	2	16	1	45

Table I.36 Mobile Bay, 8 km^2 Grid; IEA

Number of Clusters	**Cluster Group**										**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
2	45										45
3	1	40	4								45
4	19	21	1	4							45
5	1	20	19	1	4						45
6	2	2	1	20	19	1					45
7	16	3	2	2	1	20	1				45
8	2	18	16	3	2	2	1	1			45
9	3	15	2	16	3	2	2	1	1		45
10	1	2	3	15	2	16	2	2	1	1	45

APPENDIX J

SUPPLEMENTAL DENDROGRAMS FOR CHAPTER VII

J.1 Barataria Bay

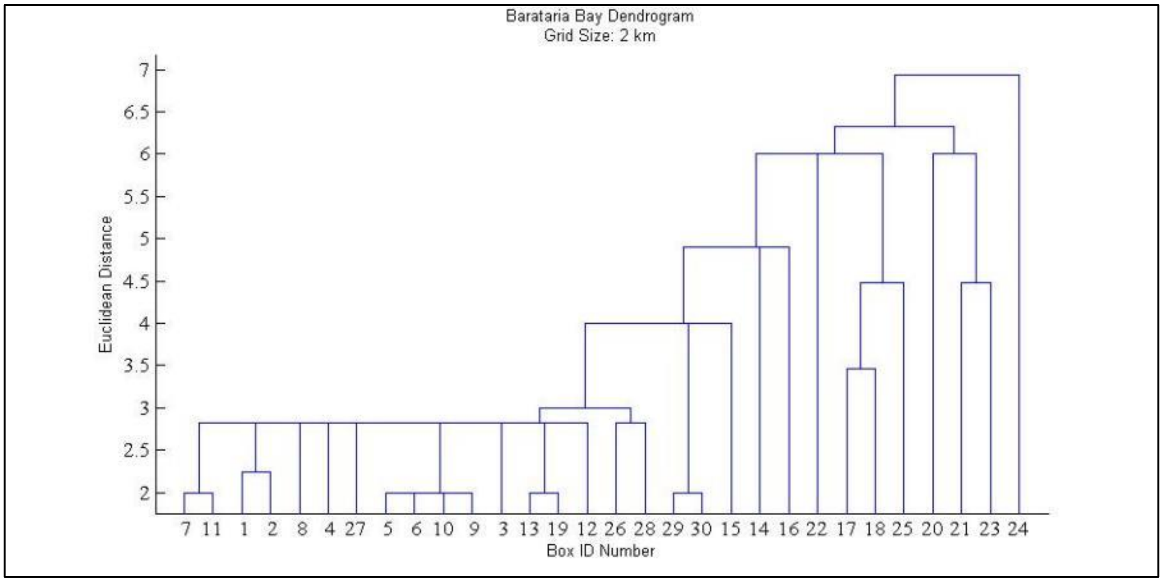


Figure J.1 Barataria Cluster Dendrogram; Grid Size: 2 km^2

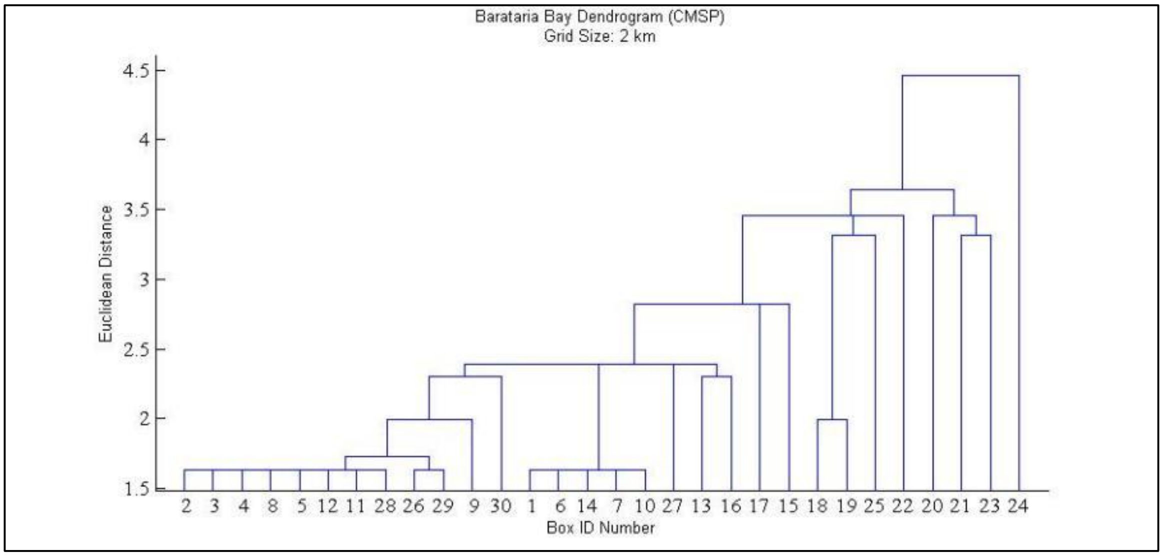


Figure J.2 Barataria Cluster Dendrogram; Grid Size: 2 km^2; CMSP

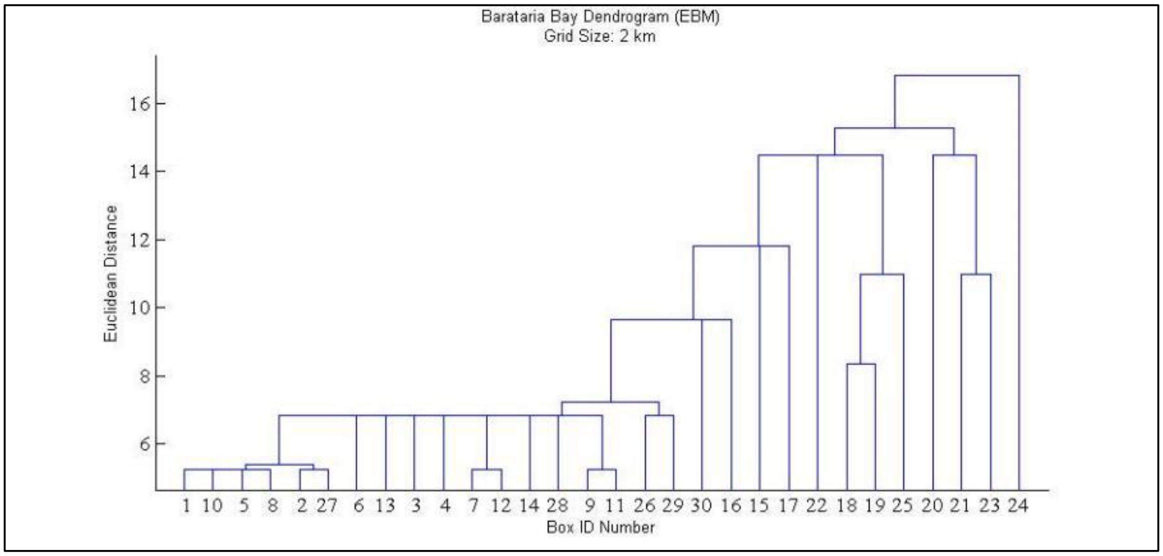


Figure J.3 Barataria Cluster Dendrogram; Grid Size: 2 km^2; EBM

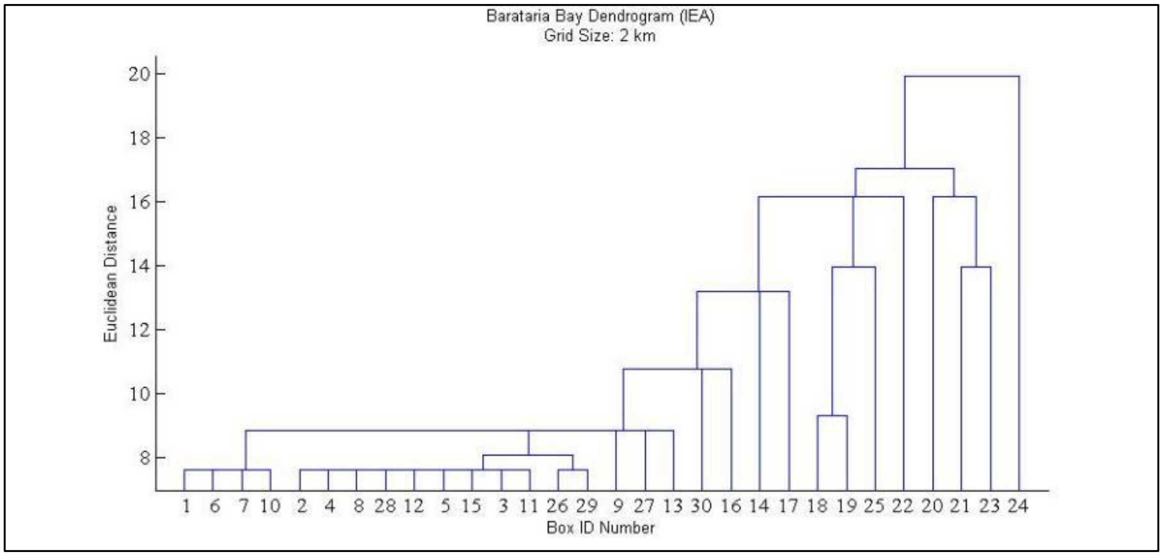


Figure J.4 Barataria Cluster Dendrogram; Grid Size: 2 km^2; IEA

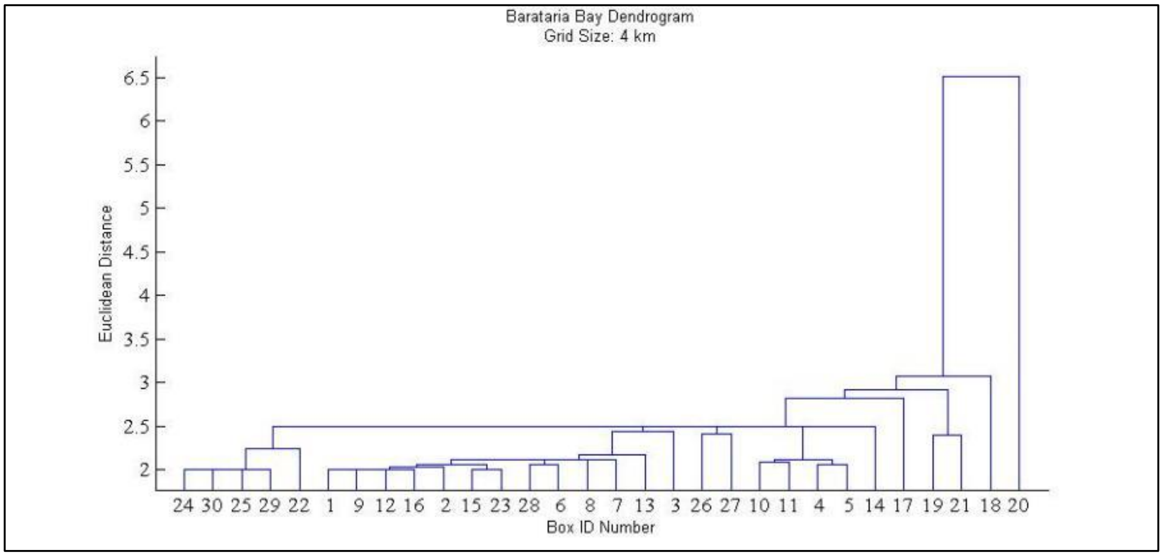


Figure J.5 Barataria Cluster Dendrogram; Grid Size: 4 km^2

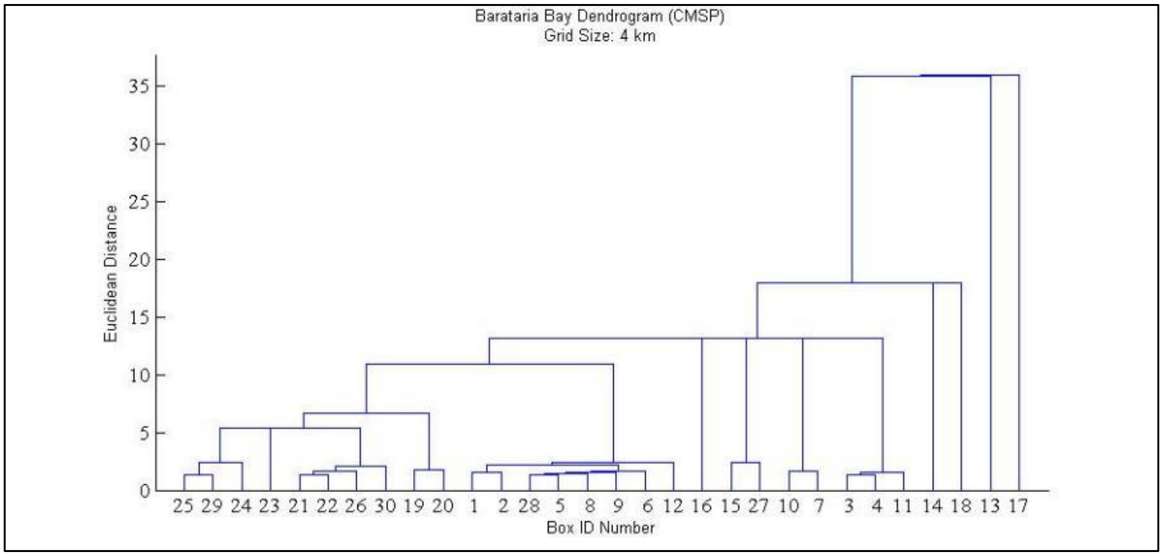


Figure J.6 Barataria Cluster Dendrogram; Grid Size: 4 km^2; CMSP

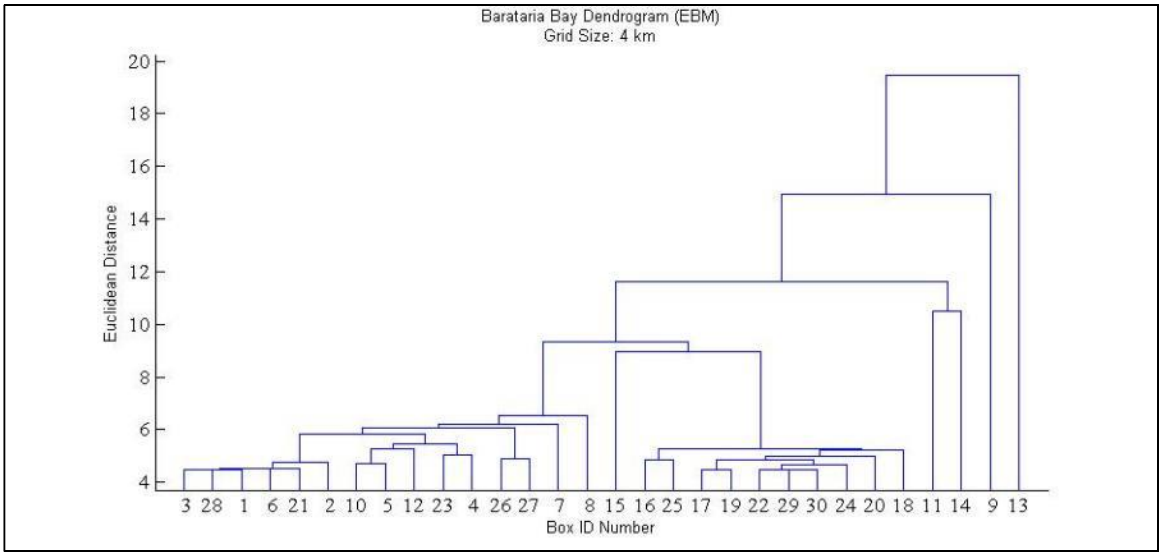


Figure J.7 Barataria Cluster Dendrogram; Grid Size: 4 km^2; EBM

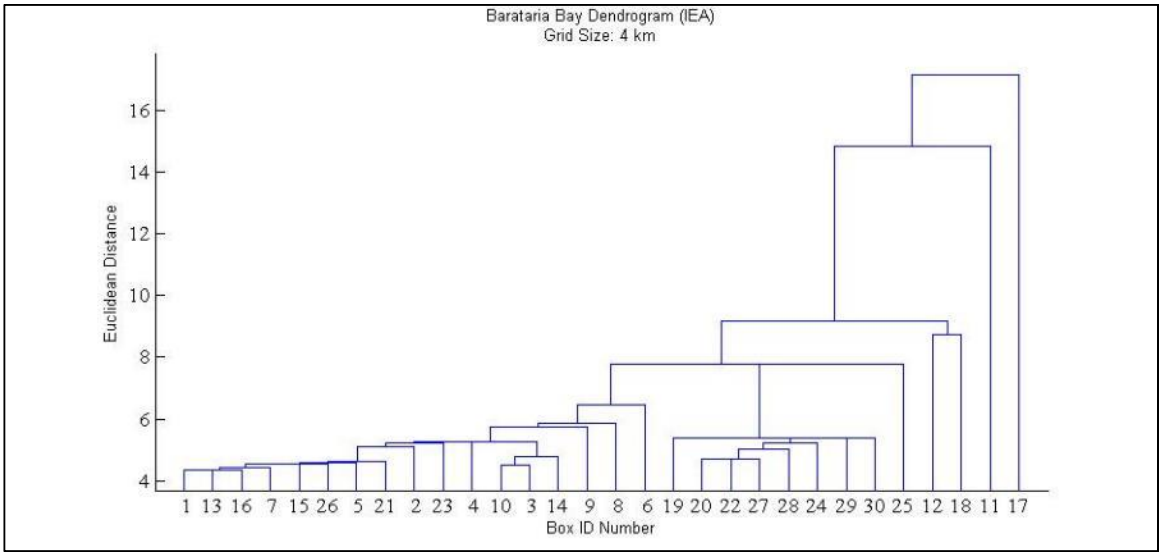


Figure J.8 Barataria Cluster Dendrogram; Grid Size: 4 km^2; IEA

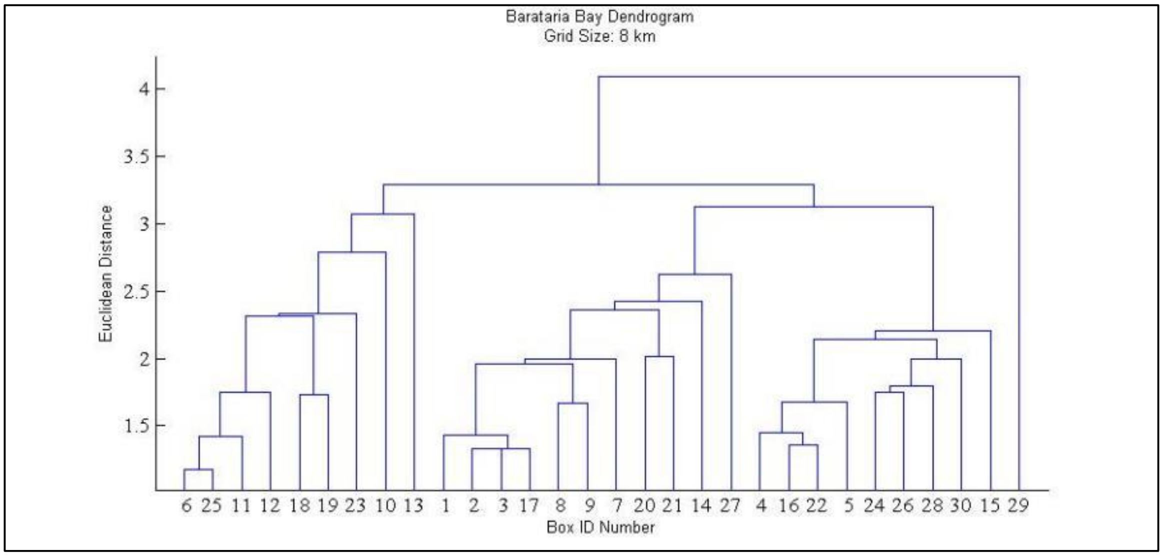


Figure J.9 Barataria Cluster Dendrogram; Grid Size: 8 km^2

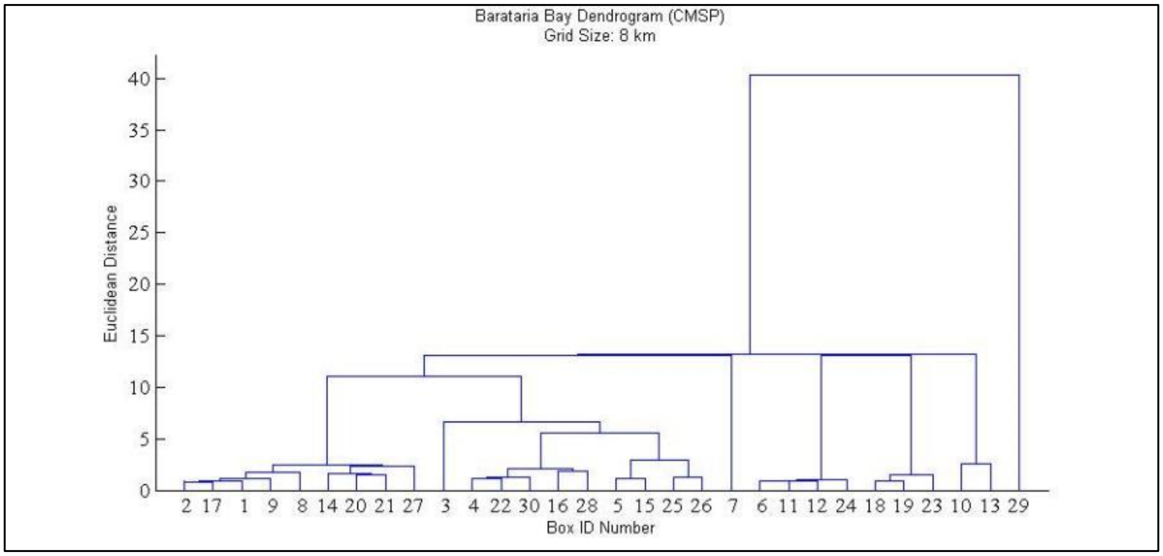


Figure J.10 Barataria Cluster Dendrogram; Grid Size: 8 km^2; CMSP

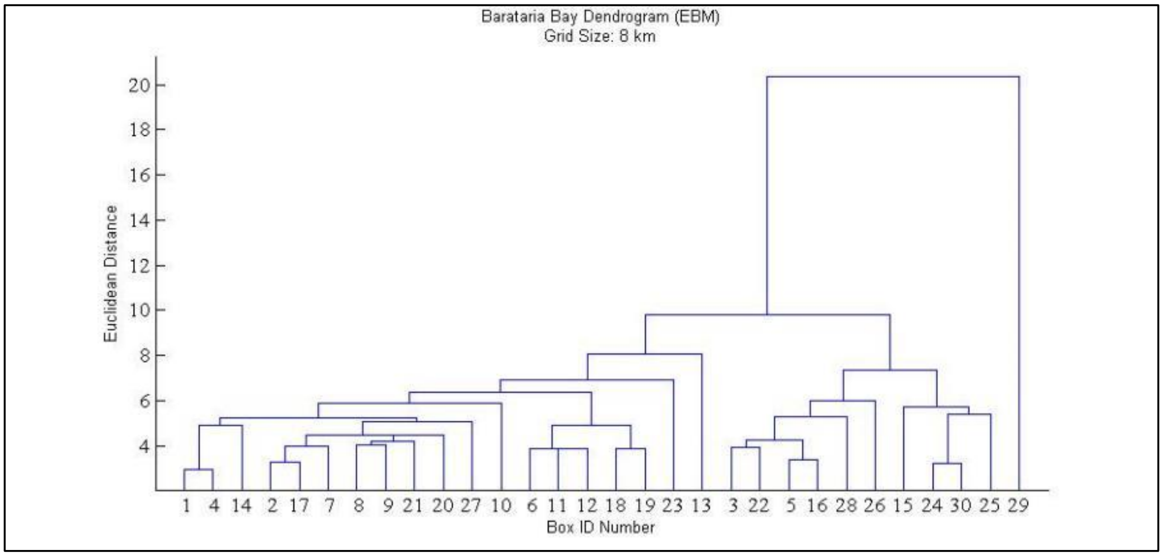


Figure J.11 Barataria Cluster Dendrogram; Grid Size: 8 km^2; EBM

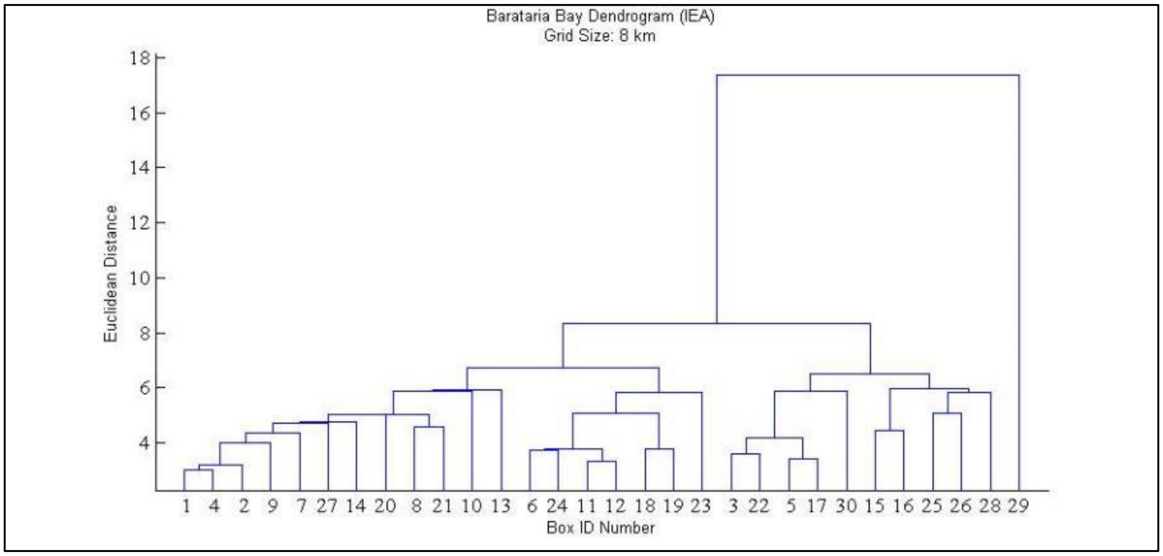


Figure J.12 Barataria Cluster Dendrogram; Grid Size: 8 km^2; IEA

J.2 Mississippi Sound

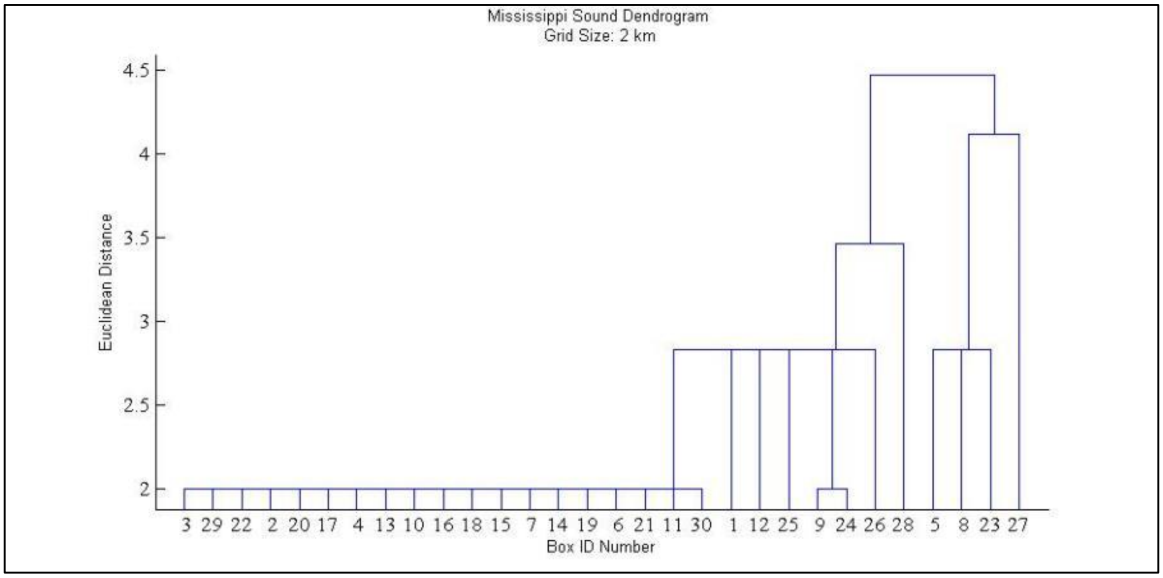


Figure J.13 Mississippi Sound Cluster Dendrogram; Grid Size: 2 km^2

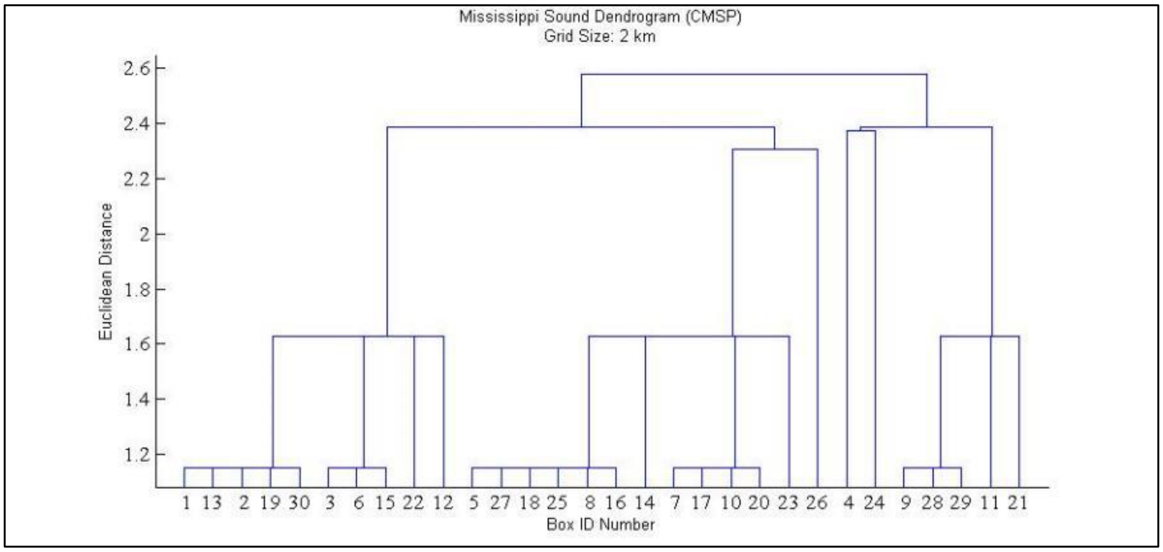


Figure J.14 Mississippi Sound Cluster Dendrogram; Grid Size: 2 km^2; CMSP

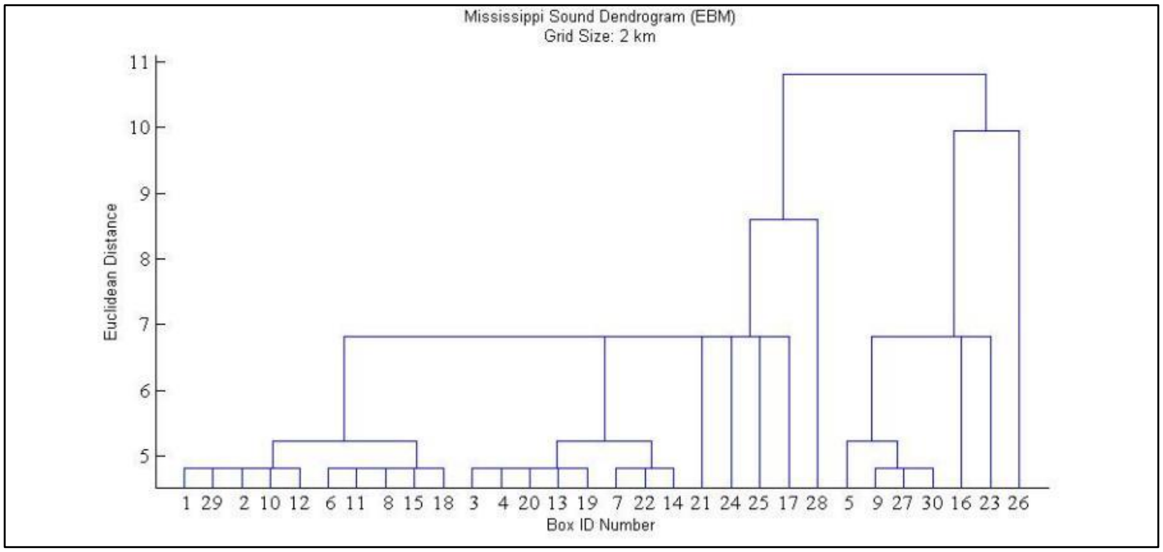


Figure J.15 Mississippi Sound Cluster Dendrogram; Grid Size: 2 km^2; EBM

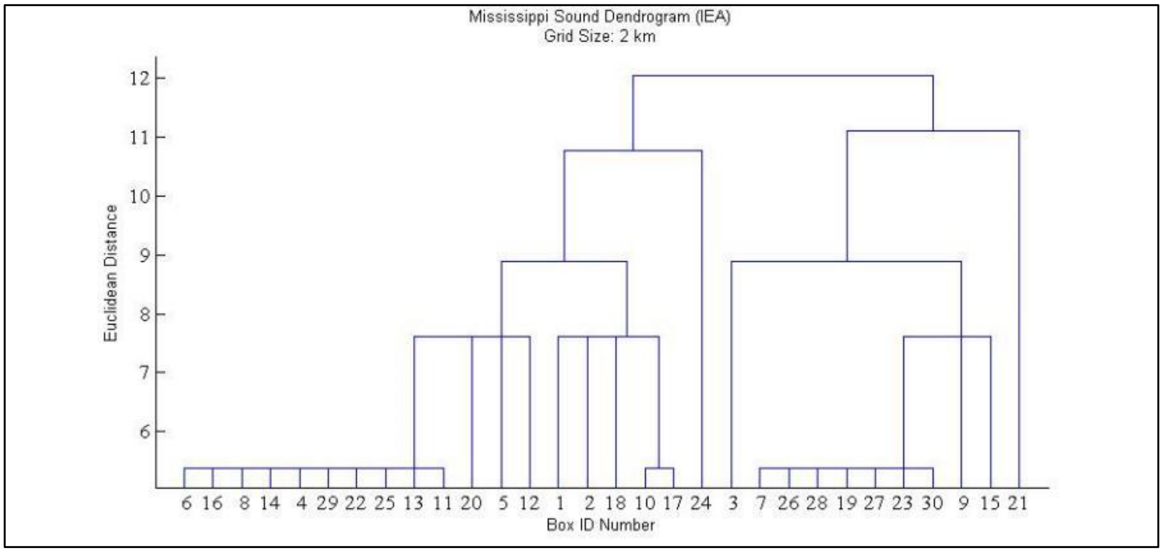


Figure J.16 Mississippi Sound Cluster Dendrogram; Grid Size: 2 km^2; IEA

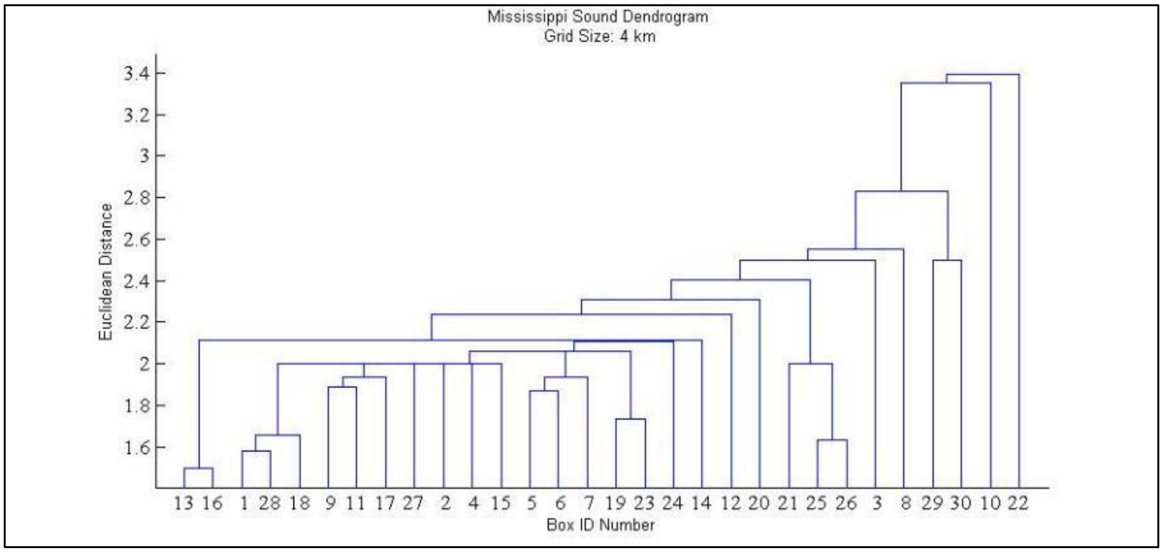


Figure J.17 Mississippi Sound Cluster Dendrogram; Grid Size: 4 km^2

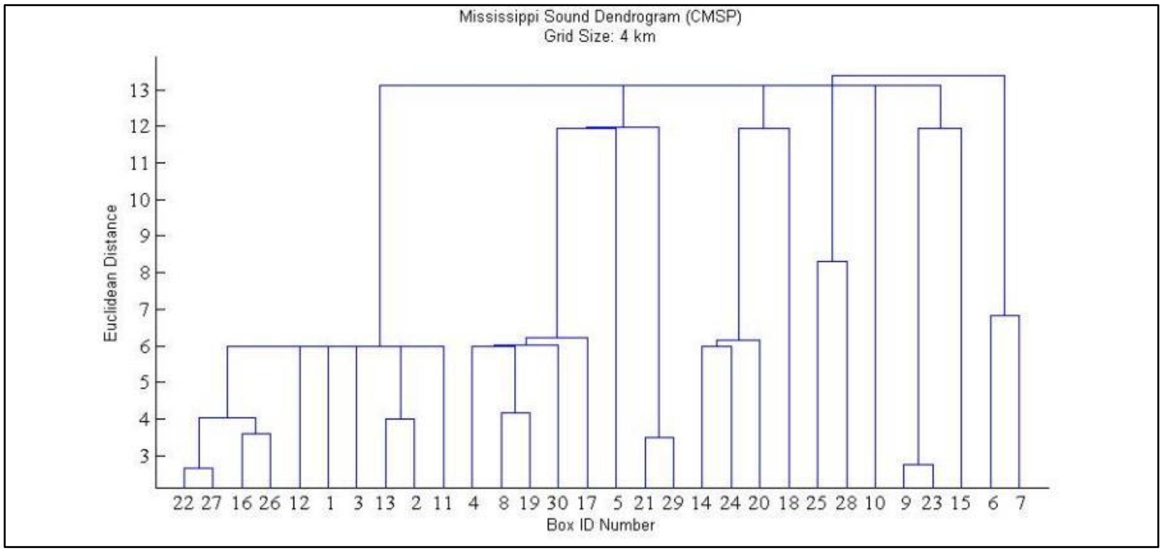


Figure J.18 Mississippi Sound Cluster Dendrogram; Grid Size: 4 km^2; CMSP

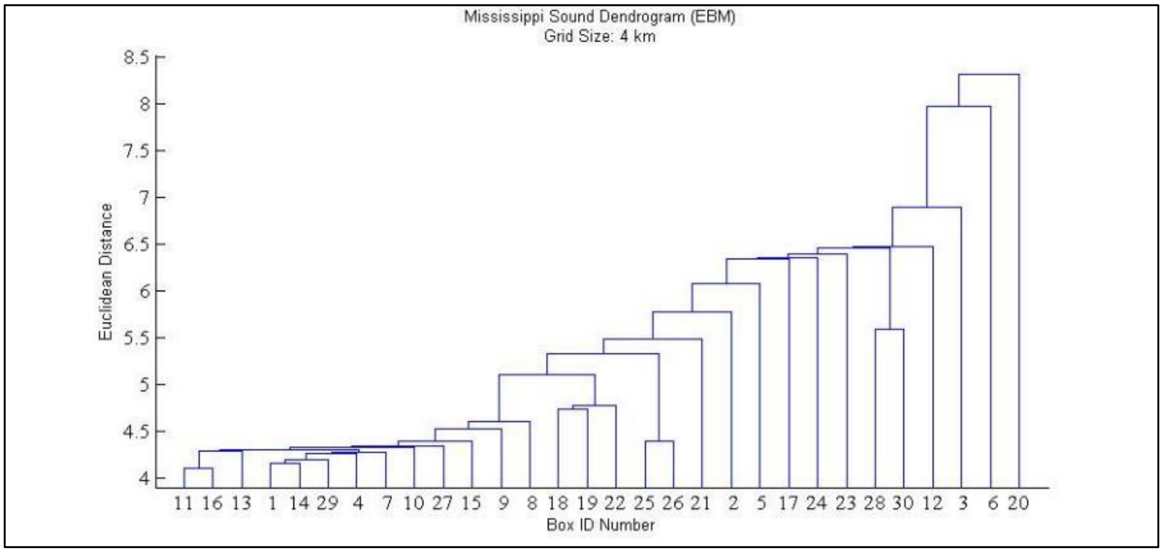


Figure J.19 Mississippi Sound Cluster Dendrogram; Grid Size: 4 km^2; EBM

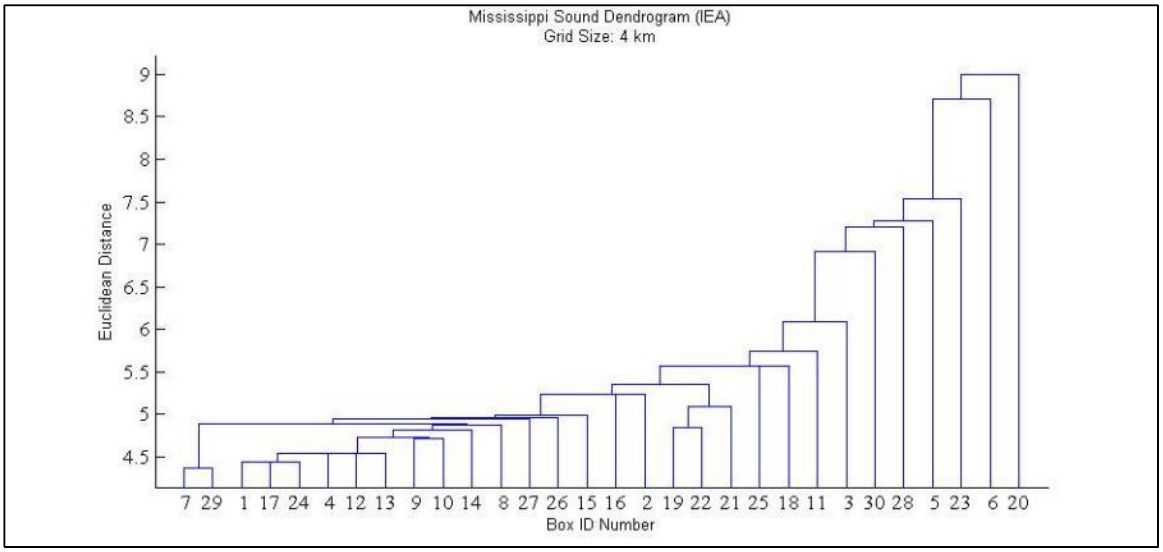


Figure J.20 Mississippi Sound Cluster Dendrogram; Grid Size: 4 km^2; IEA

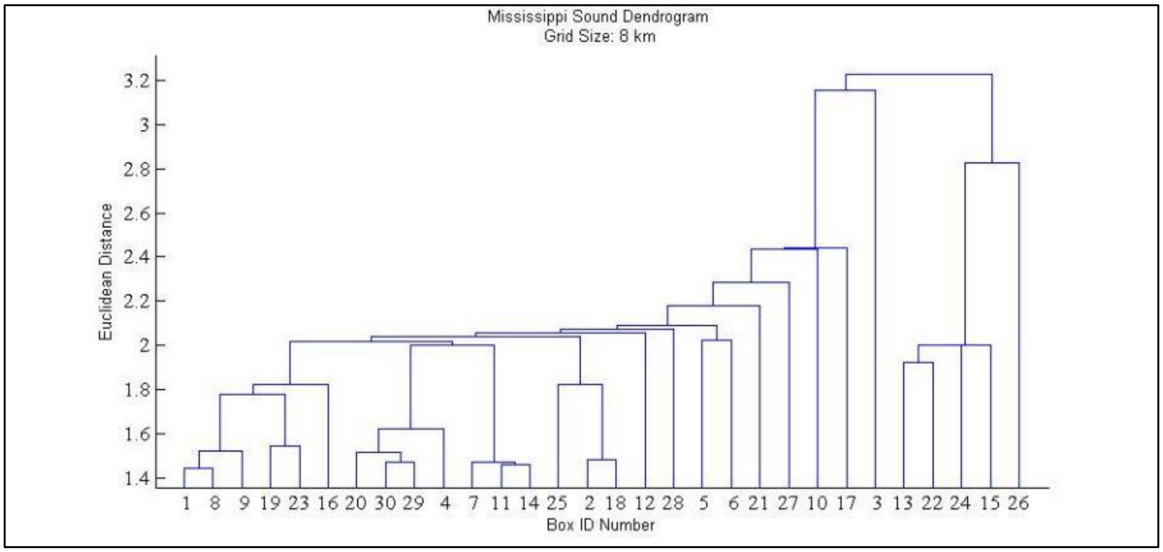


Figure J.21 Mississippi Sound Cluster Dendrogram; Grid Size: 8 km^2

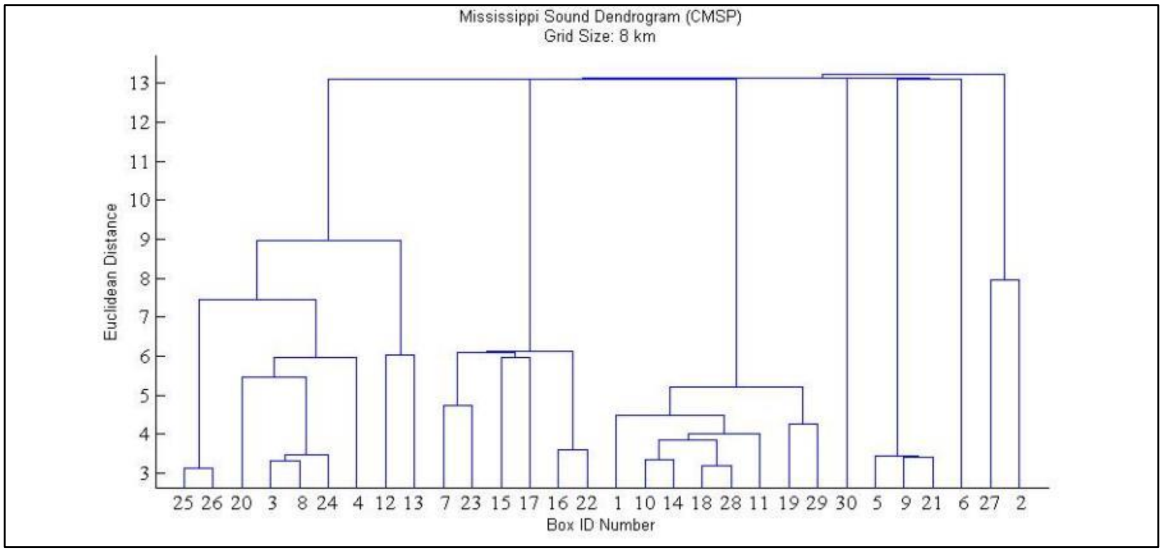


Figure J.22 Mississippi Sound Cluster Dendrogram; Grid Size: 8 km^2; CMSP

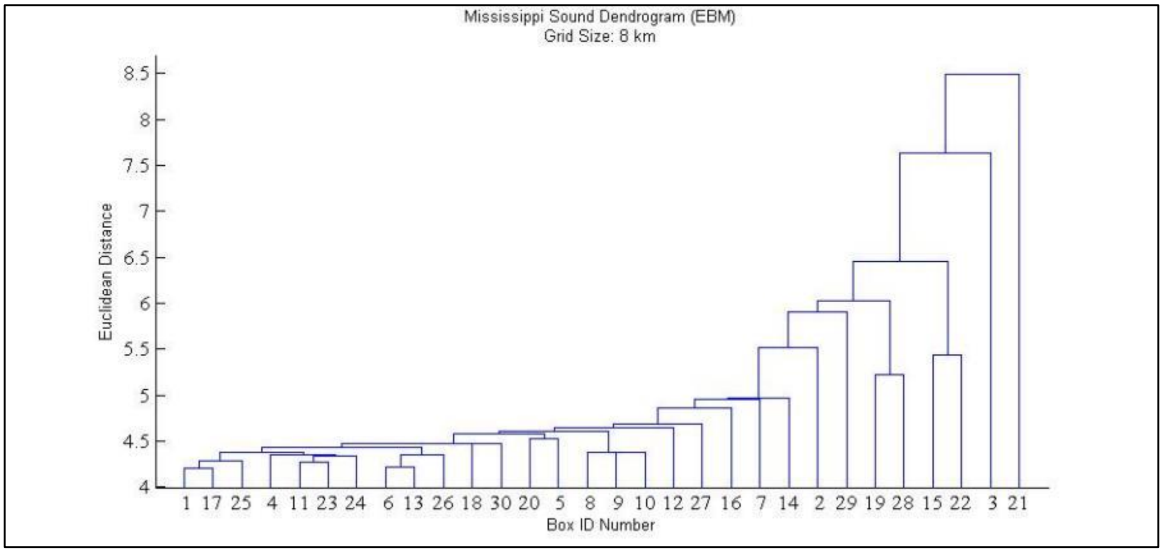


Figure J.23 Mississippi Sound Cluster Dendrogram; Grid Size: 8 km^2; EBM

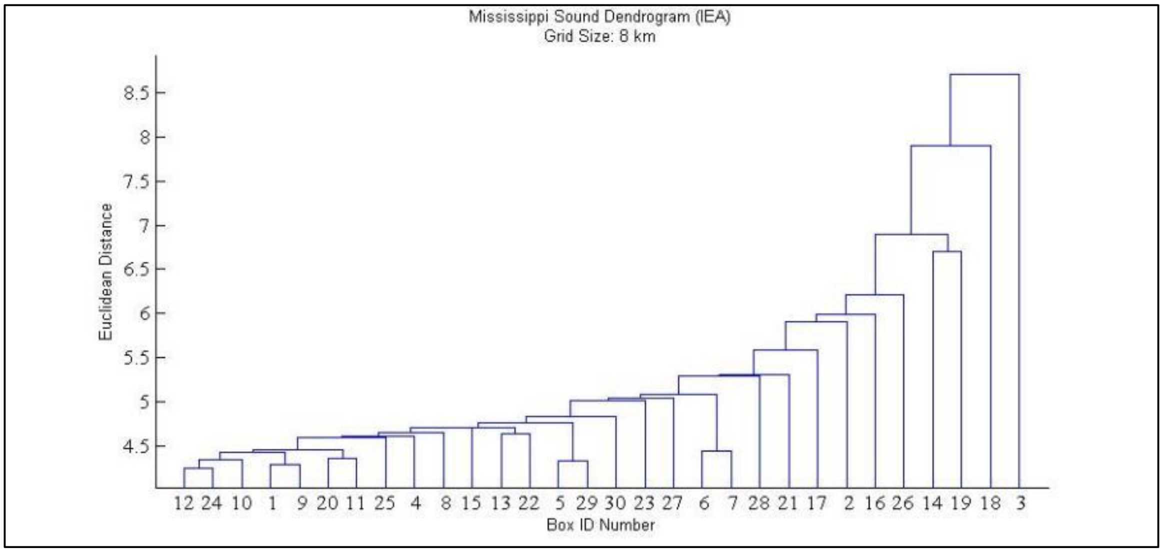


Figure J.24 Mississippi Sound Cluster Dendrogram; Grid Size: 8 km^2; IEA

J.3 Mobile Bay

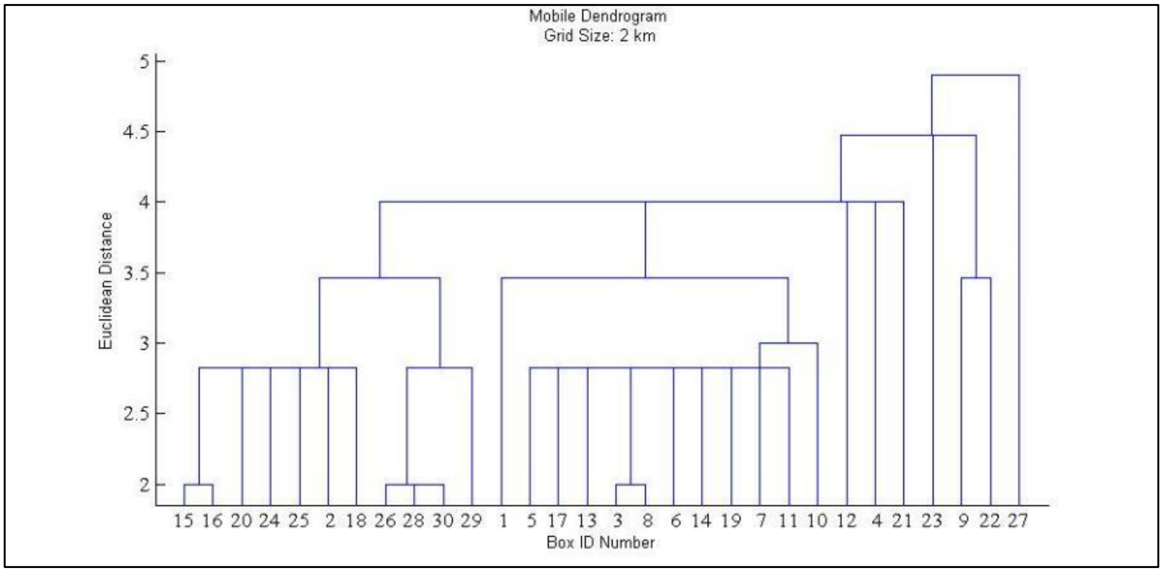


Figure J.25 Mobile Bay Cluster Dendrogram; Grid Size: 2 km^2

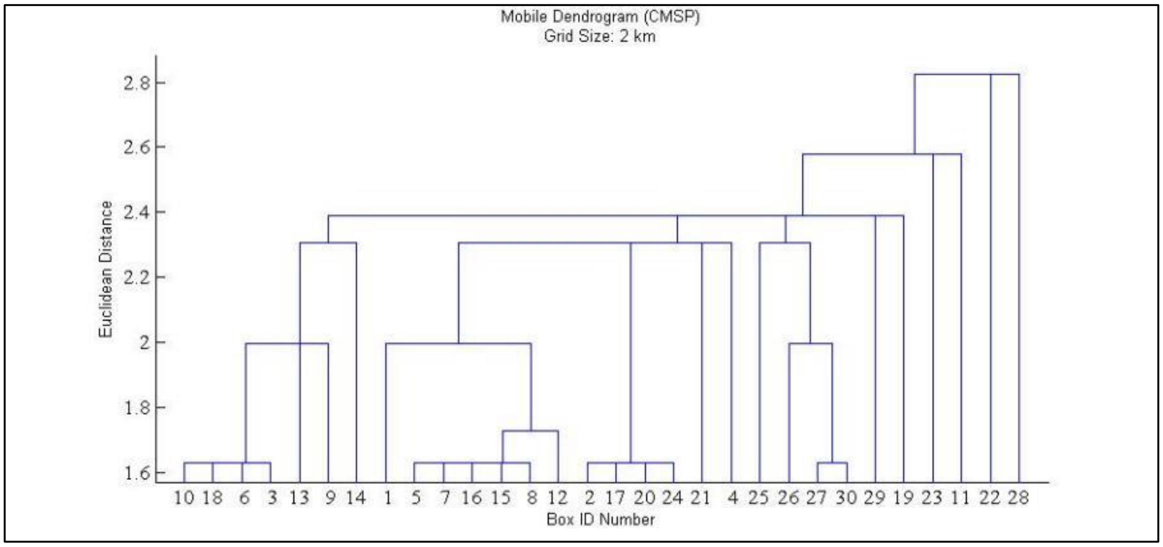


Figure J.26 Mobile Bay Cluster Dendrogram; Grid Size: 2 km^2; CMSP

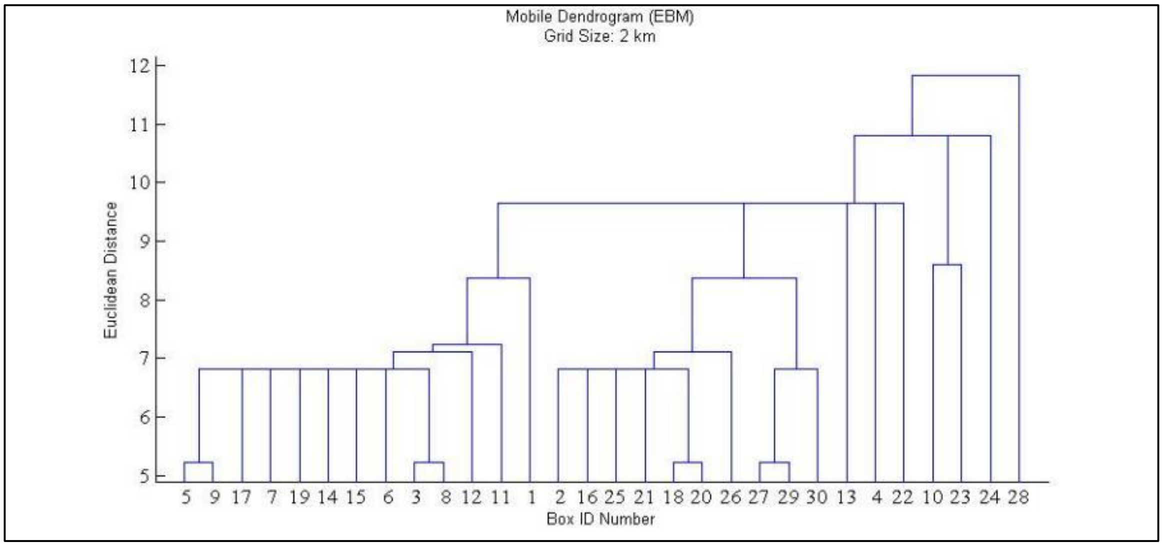


Figure J.27 Mobile Bay Cluster Dendrogram; Grid Size: 2 km^2; EBM

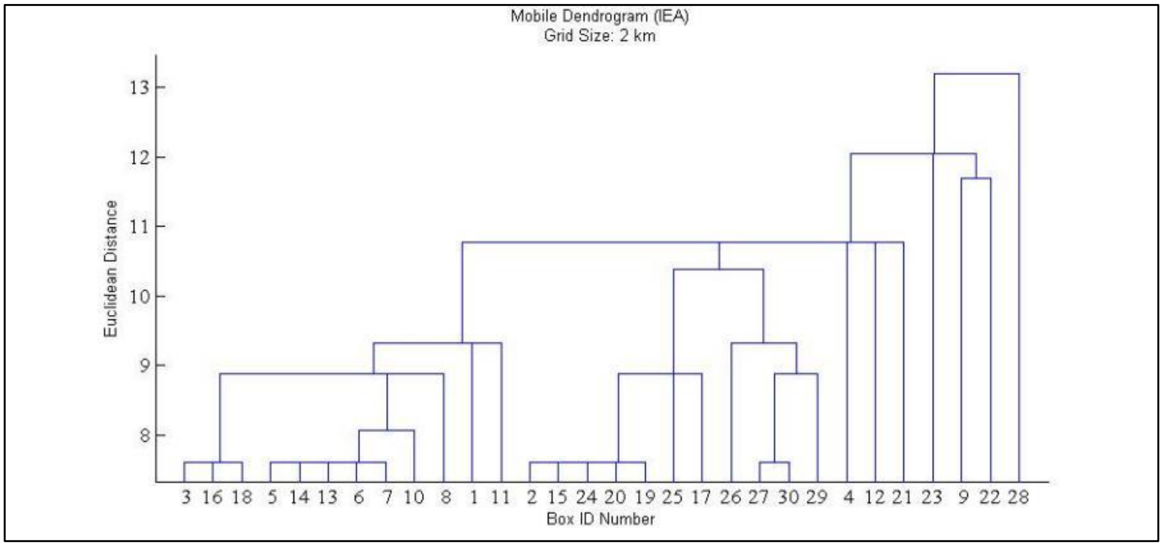


Figure J.28 Mobile Bay Cluster Dendrogram; Grid Size: 2 km^2; IEA

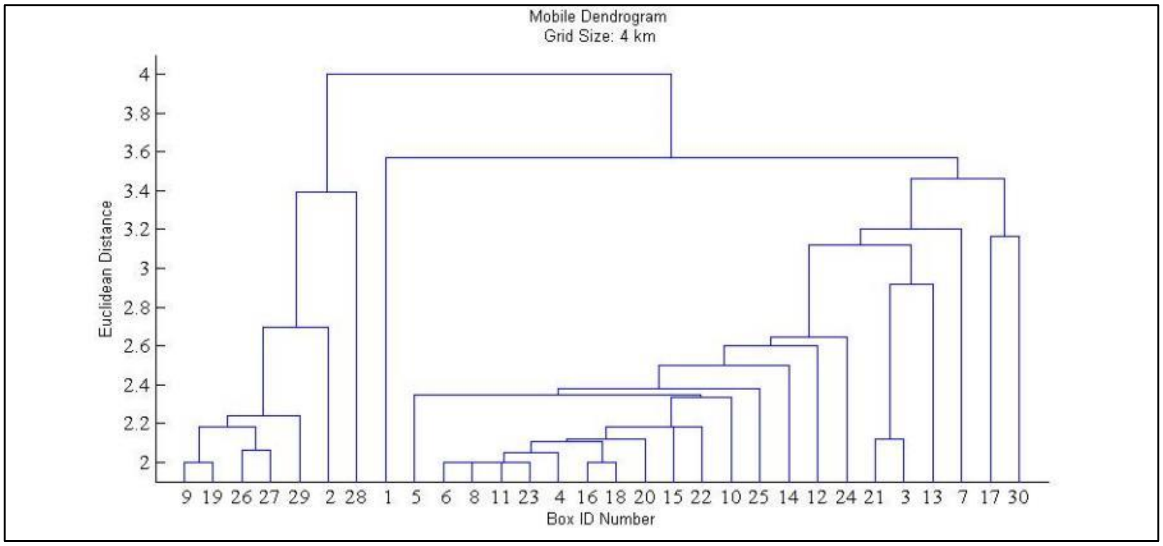


Figure J.29 Mobile Bay Cluster Dendrogram; Grid Size: 4 km^2

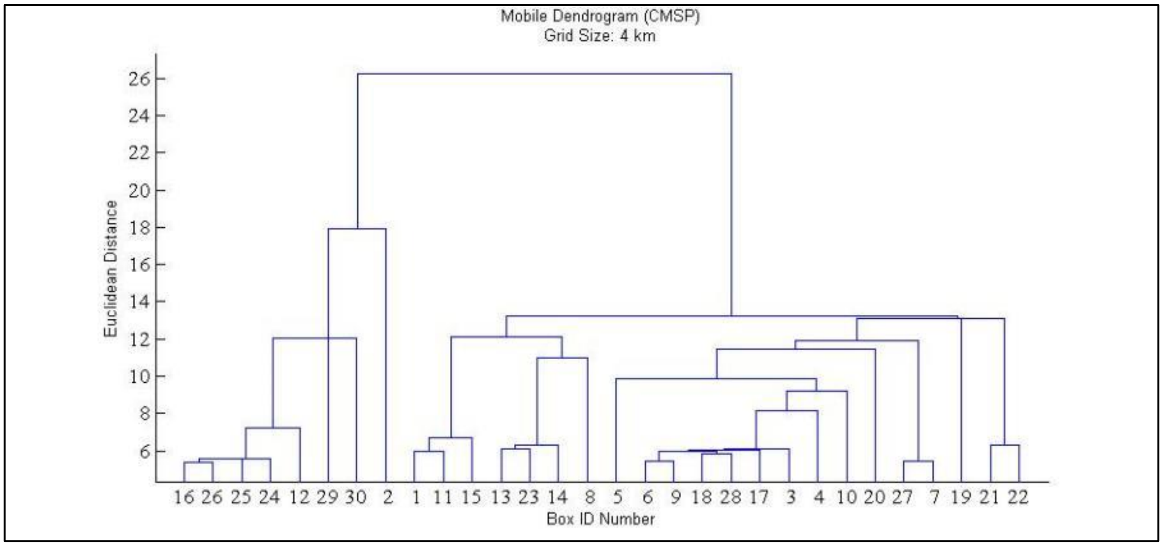


Figure J.30 Mobile Bay Cluster Dendrogram; Grid Size: 4 km^2; CMSP

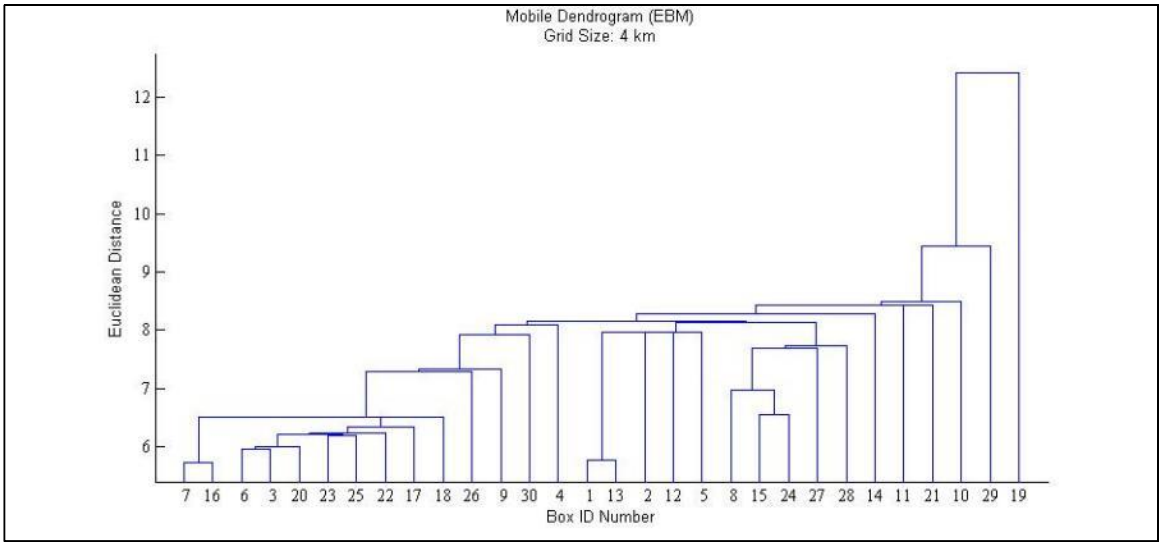


Figure J.31 Mobile Bay Cluster Dendrogram; Grid Size: 4 km^2; EBM

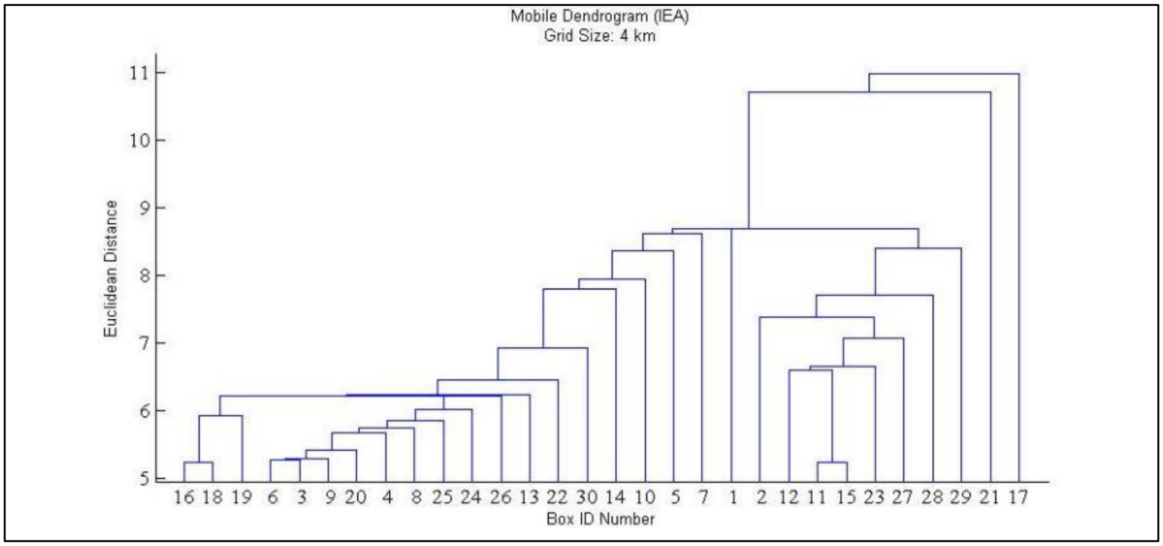


Figure J.32 Mobile Bay Cluster Dendrogram; Grid Size: 4 km^2; IEA

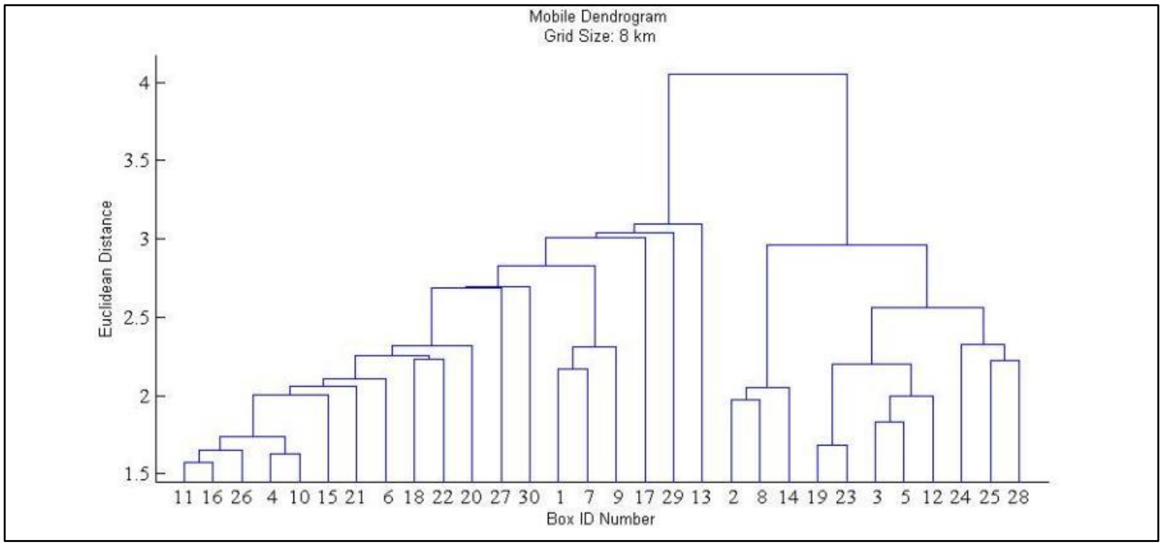


Figure J.33 Mobile Bay Cluster Dendrogram; Grid Size: 8 km^2

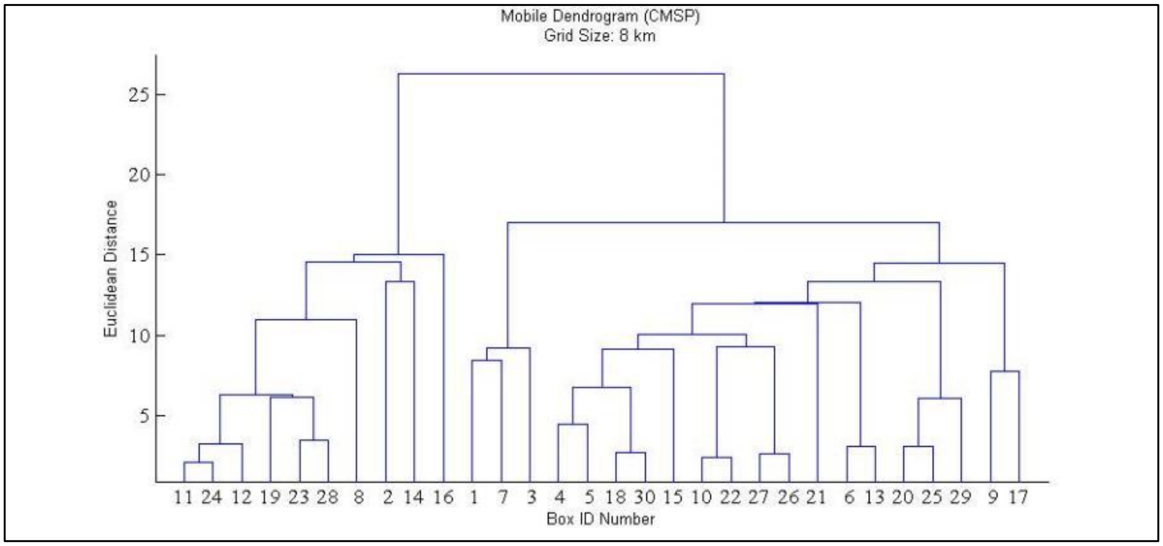


Figure J.34 Mobile Bay Cluster Dendrogram; Grid Size: 8 km^2; CMSP

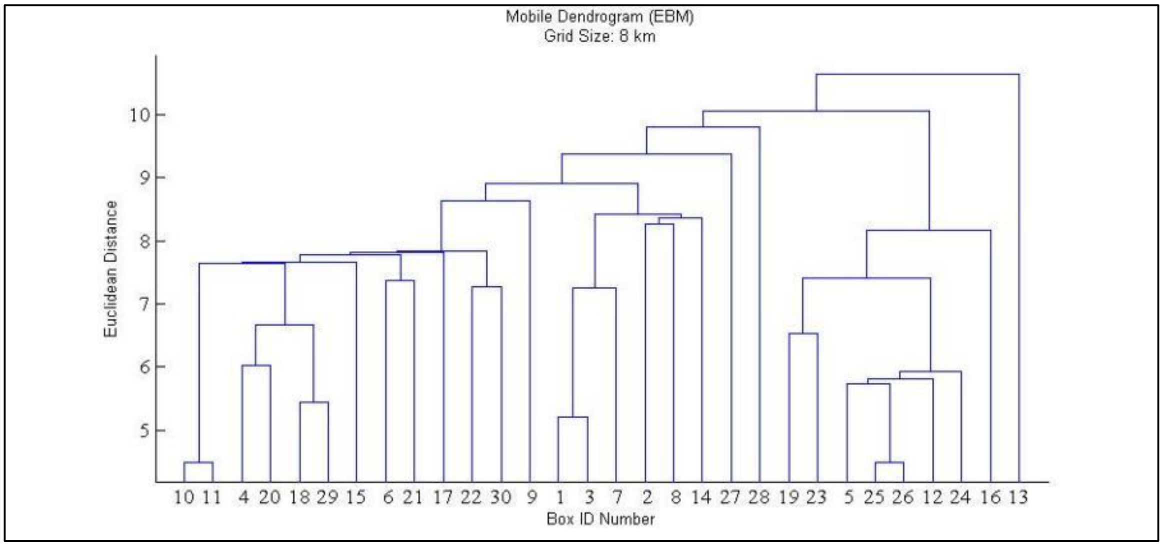


Figure J.35 Mobile Bay Cluster Dendrogram; Grid Size: 8 km^2; EBM

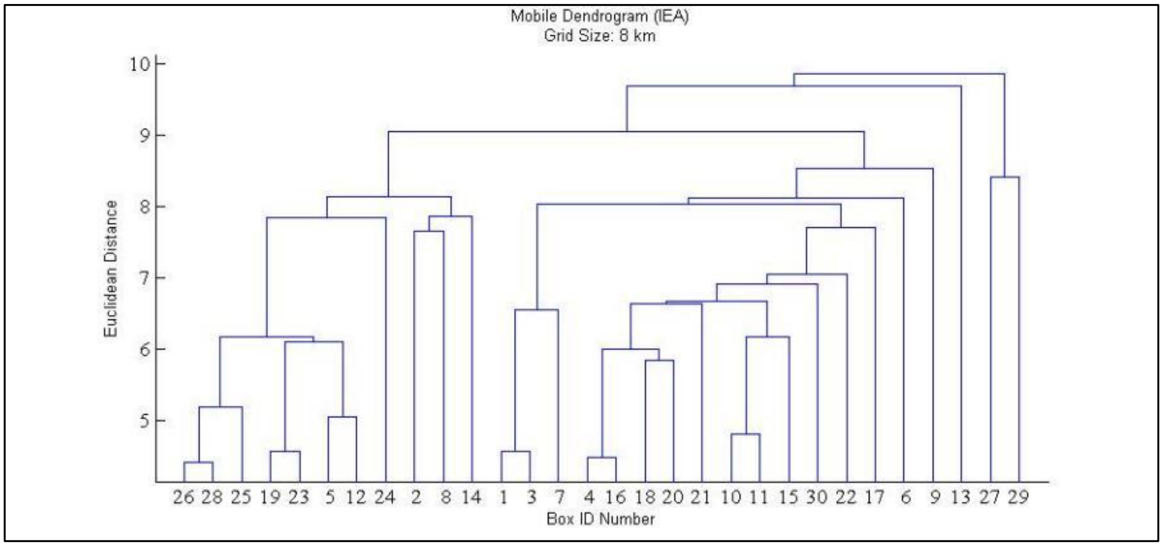


Figure J.36 Mobile Bay Cluster Dendrogram; Grid Size: 8 km^2; IEA