IDENTIFYING STRATEGIC MARINE FISHERIES HABITAT IN NORTH CAROLINA

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Masters project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment and Earth Sciences of Duke University

2005

Abstract

In 2004 North Carolina's Department of Environment and Natural Resources Regulatory Commissions adopted the Coastal Habitat Protection Plan (CHPP). One of the primary goals of the CHPP is to identify, designate, and protect Strategic Habitat Areas (SHAs)—areas of fish habitat that provide exceptional habitat functions for fishery and fishery-dependent species managed in North Carolina. This analysis uses habitat surrogates and a spatially explicit siting algorithm to identify a network of areas that meet conservation goals for SHAs within the White Oak River Basin. The analysis further identifies focal areas of wetlands, submerged aquatic vegetation, and shellfish strata that occur in an ideal reserve design and a sensible ecological placement within the Basin. NC DENR can use these focal areas as potential Strategic Habitat Areas for socioeconomic evaluation by managers, resource users, and other stakeholders.

Acknowledgements

I would like to thank the following people for their assistance with this project: Dr. Bill Kirby-Smith for his advice and support; Mike Street for his guidance related to local resources issues and the Strategic Habitat Areas concept and serving as my Division of Marine Fisheries contact; Scott Chappell, Pete Mooreside, and Anne Deaton of NC DMF for their general guidance; Rodney Guajardo, Ballingam Chepuri, Melissa Carle, Katy West, and George Joyner for their help in attaining data; and Steve Underwood and Mike Lopazanski of NC Division of Coastal Management for introducing me to the project.

Table of Contents

Introduction

Coastal habitats (freshwater, estuarine, and marine habitats within the coastal watersheds) in North Carolina are among the most important for marine fisheries of any in the United States. North Carolina has the largest estuarine system of any state on the Atlantic Coast (Street et al. 2004). The State's expansive estuarine and coastal waters and habitats provide important functions for a diversity of marine species and the economically important fishery stocks that depend on them. Lying at the convergence of the South Atlantic and the Mid-Atlantic biogeographical provinces, North Carolina's coastal areas draw from a diversity of marine flora and fauna that rarely occur together in other states. Each year the State's commercial and recreational fishery landings rank among the top for the Atlantic Coast (Street et al. 2004). Estuarine-dependent species comprise ninety percent of commercial landings and sixty percent of recreational landings (by weight) (Street et al. 2004). Without healthy coastal and estuarine habitats, North Carolina's fishing industry will suffer.

Recognizing the importance of coastal habitats to healthy and productive state fisheries, the North Carolina General Assembly passed the Fisheries Reform Act of 1997 (S.L. 1997-400, H.B. 1097) which contained a provision for the creation of Coastal Habitat Protection Plans (CHPP). This provision required the state Department of Environment and Natural Resources (DENR) to develop the CHPP for adoption and implementation by the Coastal Resources (CRC), Environmental Management (EMC), and Marine Fisheries Commissions (MFC) (G.S. 143B-279.8). The plan seeks the "long-term enhancement of coastal fisheries associated with each coastal habitat." The habitats ultimately decided upon for inclusion in the CHPP include wetlands (within coastal watersheds), submerged aquatic vegetation (SAV), shell bottom, soft bottom, hard bottom, and the water column. The law required DENR to evaluate each of these habitats for function, status, trends, and threats and then provide recommendations to protect and restore the habitats.

In the development of the CHPP, an Intercommission Review Committee (IRC) established four major goals for action based on the assessments of the six habitat types. These goals include:

1. Improve the effectiveness of existing rules and programs protecting coastal fish habitats
2. Identify, designate, and protect Strategic Habitat Areas
3. Enhance habitat and protect it from physical impacts
4. Enhance and protect water quality

This analysis will focus on Goal 2: Identifying, designating, and protecting Strategic Habitat Areas.

The intention of this project is to provide the North Carolina Division of Marine Fisheries and the Marine Fisheries Commission with a method for identifying highly functional fish habitat within the framework of the Strategic Habitat Area concept. This analysis will focus on one step in the larger process of implementing and managing a Strategic Habitat Area network. I intend for DMF to use this analysis as a method of developing a set of potential sites that managers and stakeholders can use in the larger process of developing a Strategic Habitat Areas network. Once developed, these options can be assessed for the achievement of biological and socioeconomic goals.

While DENR may potentially designate SHAs throughout the CHPP area seaward to the state jurisdictional boundary, this analysis will focus primarily on nearshore habitats in estuarine waters within the White Oak River Basin.

Strategic Habitat Areas Defined

Strategic Habitat Areas (SHAs) are habitat locations that are important to the viability of managed marine fishery stocks. The CRC, EMC, and MFC adopted the following definition of Strategic Habitat Areas: "Specific locations of individual fish habitats or systems of fish habitats that have been identified to provide exceptional habitat functions or that are particularly at risk due to imminent threats, vulnerability, or rarity. These may include areas previously delineated by other state or federal agencies (AECs, HAPCs, ORWs, for example), or others as deemed necessary in an approved CHPP. Strategic Habitat Areas allow for site-specific management measures to be recommended" (Street et al 2004). The Strategic Habitat Areas concept recognizes the importance of management measures that protect productive fisheries habitat. Conventional fishery management measures have focused on reducing fishing effort and increasing size limits. The SHA concept focuses on protecting the structure, function, and key processes of habitat that are vital for replenishing stocks and contributing to the production of fishery populations.

In the past, various fishery management entities have made efforts to identify and protect critical fish habitats. While these efforts can provide guidance for the identification of SHAs, each experience differs from the SHA concept in key ways. In 1996, amendments to the Magnusson Fishery Conservation and Management Act required fishery management plans to identify, describe, and minimize the impact to essential fish habitat (EFH). The Sustainable Fisheries Act of 1996, as the amendments became known, defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity" (Cicin-Sain 2000). The regional fishery management councils typically designate EFH on a species basis by considering that species' life history. For instance, the Councils may make an EFH designation for shrimp that differs from that of spiny lobster. The SHA concept will consider habitat identification primarily on an ecosystem basis rather than a species basis. The analysis will focus on spatial and biological relationships of different habitats and their ability to synergistically contribute to ecosystem habitat functions.

A Habitat Area of Particular Concern (HAPC) is another designation made under the Sustainable Fisheries Act. These areas are subsets of EFH that the Councils must identify on the basis of ecological function, human-induced threat, and rarity (50 CFR 600.815(a)(8)). While this concept closely resembles SHAs, fishery management Councils, again, designate HAPCs on a species basis. In addition, the Councils make these designations based on federally managed fishery species.

On the state level of government, the Marine Fisheries Commission makes designations of critical habitat areas and nursery areas. Designations of critical habitat include four classes: submerged aquatic vegetation (SAV), shellfish producing areas, anadromous fish spawning areas, and anadromous fish nursery areas (Street et al. 2004). While the

Commission has identified these four classes, they have not designated specific areas. In addition, CRC and EMC rules do not provide protection for MFC-designated critical habitat areas. The MFC has designated nursery areas extensively across the North Carolina coast. Nursery areas contain complexes of habitat that contribute to the nursery function of habitat for managed fisheries. All three management commissions identify protections for nursery areas in their rules. While designated nursery areas are similar to SHAs in concept, they may not contribute to other habitat functions.

Marine managed areas (MMAs) provide perhaps the most useful experience to the SHA identification and designation process. While SHAs will have site-specific management, they will likely reflect many of the qualities that MMAs possess. Their degree, permanence, constancy, and ecological scale of protection as well as restrictions on extraction will depend on site-specific goals. Marine managed areas have been designated for multiple purposes including fisheries management. Many studies have been conducted on the effectiveness of no-take marine reserves as fishery management tools (Ward 2004; Shipp 2004; Murawski et al. 2004; Bohnsack et al. 2004). While marine reserves are not a silver bullet in solving fishery management problems, if designed correctly and used in conjunction with fishing effort limitations, they can provide multiple benefits to marine ecosystems and fishery stocks. The benefits include protection of habitat (Sladek-Nowlis & Friedlander 2005), preservation of population and trophic structure (NRC 2001; Sladek-Nowlis & Friedlander 2005; Berkeley et al. 2004), increased productivity of stocks (Berkeley et al. 2004), and potential contribution of larvae and adult biomass to the fishery (NRC 2001). Reserves can only achieve these benefits if they are designed and sited appropriately. The SHA concept recognizes these siting and design criteria by emphasizing the protection of habitats of "exceptional function." In addition, these criteria should include considerations of fish movement, larval dispersal, and protection of vulnerable life-history stages (NRC 2001).

Fish and Habitat Linkages

Scientists have defined habitat in many ways. The Coastal Habitat Protection Plan defines fish habitat as "freshwater, estuarine, and marine areas that support juvenile and adult populations of economically important fish species (commercial and recreational), as well as forage species important in the food chain" (Street et. al 2004). This definition suggests an inclusion of "environment" in the habitat term. Peterson (2003) refers to environment and habitat as two distinct terms that can be viewed separately. Under this structure, environment comprises ambient conditions while habitat refers to more structured components of an area. Ryder and Kerr (1989) refer to the relationship of environment and habitat hierarchically as ". . . the pervasiveness of relatively structureless environment which provides background ambience, against the localized and highly structured habitat which acts as a center of organization and attractor for fish (and nekton) communities." The CHPP embraces this definition by including the water column, the connective medium, with the five other "structured" habitats.

Fish use habitat for various life-history functions including refuge, spawning, nursery, foraging, and corridor. Fish may use different habitats to perform these various functions. For instance, the Southern flounder may use shell bottom for foraging, submerged aquatic vegetation for nursery, wetlands for refuge, and soft bottom for corridor (Street et al. 2004). Conversely, a single species may remain in one habitat throughout its entire life cycle. These examples illustrate the importance of the diversity of habitats necessary to support fishery populations. Not only is habitat diversity important to maintaining healthy stocks, but proximity of different habitats to one another can contribute to improved functioning of existing habitat. Complexes of different habitat types can improve a habitat's functionality (Peterson 2003).

While all of the habitats outlined in the CHPP document are important to fishery species, particular areas of habitats may be more productive than others. Habitats that provide exceptional functionality are more beneficial to fisheries species than those that do not. These habitats can be termed high-quality habitats. In a fisheries context, there are several ways of determining which habitats exhibit high quality. For fisheries management purposes, habitat quality assessment can be divided into habitat assessment and site-specific productivity assessment (Hartwell 1998). Habitat assessment involves addressing how much habitat is unimpaired and what alterations are being imposed on unimpaired habitat (Hartwell 1998). A workshop on the use of biological habitat quality indicators for the designation of EFH determined that the ultimate measure of habitat quality is the response of the biological community to stresses and resources available at a given location and time frame (Hartwell 1998). The workshop advised using biological integrity indices to assess the quality of the habitat. This type of assessment goes beyond the physical and chemical evaluations of habitat to include the response of species that use the habitat.

Site-specific productivity assessments involve analyzing the ability of stocks within an area to contribute to the overall fishery population. Such an assessment may involve determining demographic levels of growth, reproduction, and survival. Additionally, larval dispersal may be considered. Crowder et al. (2000) argue that there is a source/sink paradigm among habitats for reef fish. A source is an area that, over a long period of time, is a net exporter of individuals while a sink is a net importer of individuals. In a fisheries context, habitats that export individuals would be more desirable for protection; such habitats would contribute to the overall enhancement of fishery stocks. However, this concept must be used with care in an ecosystem-level analysis. A sink habitat for one species may be a source for another (Kneib 1994). Perhaps most important when considering the linkages of fish to habitat, is the ecological community concept. Groups of species may depend on another group of species to meet their needs for survival and/or productivity. The abundance and diversity of species and the relationships among them contribute to the production of the overall community.

Identifying High-Quality Habitats

Identifying high-quality habitat sites along an entire state coastline poses a difficult challenge. Taking an abstract, idealized approach, identifying high-quality habitats would consist of evaluating nearshore habitats along the North Carolina coast for biological integrity and superior species demographics. While ideal, this method would require a massive data sampling effort. Not only would coverage and scale of the sampling area present challenges, but data would have to be collected across dozens of species, various life-histories, and many seasonal and time periods. While such an effort may be feasible in the future, current resources and data availability prevent such an analysis.

Steps can be taken to minimize the difficulties inherent in the habitat identification problem. In order to account for the uncertainty of site-specific habitat quality, many habitat identification efforts (mostly in the MPA context) have resorted to using surrogates and modeling to ensure that ecological factors are incorporated into siting efforts (Ward 2004). Ward et al. (1999) determined that habitat-level surrogates may be a cost-effective method for initially identifying areas of high priority for managing coastal marine biodiversity. In the SHA context, mapped habitats of seagrass, wetlands, and shellfish beds can be used as surrogates for high-quality habitats. Several spatial characteristics of habitats can act as indicators of underlying habitat quality—habitat size, diversity, connectivity, and proximity to threats. While this technique should not replace a biological field analysis of habitats, it serves to narrow the field of search by using spatially explicit and ecological criteria that improves the likelihood of locating an area that meets SHA objectives. Once potential sites are identified, field sampling can ensure that they are indeed healthy communities contributing to fisheries production.

Criteria for SHA Siting

Several criteria can contribute to effective SHA siting. First, a certain amount of habitat must be present for fisheries to prosper. Many studies have addressed the proportion of coastal and marine habitats that should be protected for fishery management purposes

(NRC 2001). While the general consensus has focused on preserving 20 percent of ocean area, figures range from 10 – 70 percent. Most arguments in the fisheries context focus on a given level of protection as insurance against uncertainty in conventional methods of fishery management (NRC 2001). Regardless of the proportion decided upon, the amount of protection should make ecological sense for fishery and biodiversity objectives.

Second, habitat complexes are generally more valuable to fishery and biodiversity goals than areas of a single habitat (Irlandi & Crawford 1997). Adjacency of different habitat types allows for the enhancement of movement, growth, and abundance (Irlandi & Crawford 1997). Connectivity among habitats can provide for transfer of larvae and material among biological populations and ecosystems (Roberts et al. 2003). Habitat heterogeneity within a site will contribute to the diversity of fish species present (Ward 1999). Because different species have particular associations with various habitats, inclusion of a diversity of habitats may result in higher fish species diversity and enhance ecological communities.

Third, habitats will have improved functionality with reduced exposure to sources of degradation. The CHPP outlines many threats to the habitats of concern. Many of these threats relate to human-induced water quality degradation (Street et al. 2004). Point and non-point source pollution and water flow modifications can degrade wetlands, SAV, and shellfish beds. Habitats that are located in areas without direct threats have a higher likelihood of providing function to fish species.

In addition to the qualities listed above, MMA design must consider two social criteria. While habitat protection efforts would ideally attempt to maximize total area under protection, consideration must be given to social and economic constraints. Given these constraints, one of the overall objectives in designing MMAs is the minimization of area encompassed in reserves while simultaneously attaining conservation goals (Figure 1; Pressey et al. 1993). This objective addresses issues of cost and efficiency: conservation targets should be contained within a protected area at minimal cost. This cost may be the opportunity cost of displacing existing uses or the cost of management (Ward 2004).

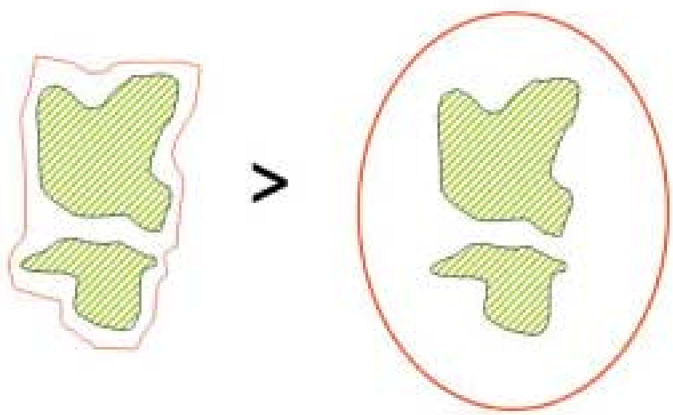


Figure 1: Conservation Efficiency: Achieve conservation goals within the least amount of area.

Spatial Modeling of Fish Habitat

Using the principles mentioned above, spatial modeling can aid in the identification of priority habitat areas. In the international effort to site marine managed areas for biodiversity objectives, reserve-siting algorithms have been developed and used to identify priority habitat areas with representative diversity in sensible spatial arrangements (Leslie et al. 2003; Ward 2004). Efforts in the past to site protected areas in terrestrial environments have used iterative heuristic algorithms. Methods traditionally used in terrestrial environments are now being applied effectively to marine environments (Leslie et al. 2003). These algorithms allow the user to achieve optimal solutions across multiple competing objectives while considering both biological and cost constraint criteria (Ward 2004). As technology and computing power has improved in recent years, new algorithms, such as simulated annealing, have replaced more simplistic algorithms.

The design process of a spatially explicit reserve system must consider several criteria. As mentioned above, the typical objective for reserve systems design seeks to provide a representative level of diversity (expressed as conservation goals) within a minimum amount of area. This problem is referred to as the minimum representation problem and can be represented through an objective function. This equation includes components for area, boundary length, and a penalty factor for failing to meet conservation goals (Possingham et al. 2000). The minimum representation problem seeks to optimize the objective function by minimizing its overall value. As mentioned previously, boundary length can provide a good indicator of relative ecological and economic costs of implementing a reserve system (McDonnell et al. 2002). Reserves with high edge to area ratios will be more costly to manage. Managers must maintain and patrol boundaries for monitoring and reserve integrity issues (Roberts et al. 2003). Depending on design criteria, the function can include a boundary length modifier (BLM) that weighs boundary length minimization against reserve area. The objective function also seeks to minimize total area of the system to reduce the opportunity costs associated with alternate uses of the sites. Finally, minimizing the conservation penalty factor ensures the reserve system design meets conservation goals. While the objective function is an effective method of measuring the value of a reserve system, it does not provide a way to decide how an optimal system will be found; heuristics and optimization methods can achieve this goal.

Past efforts to design reserves have used several methods to select sites based on their contribution of value to the reserve system. Integer linear programming (ILP) has been used to find a representation of sites that meet conservation goals in a minimum number of sites (McDonnell et al. 2002). This method seeks to build a network that minimizes area and boundary length while considering the conservation goal as a constraint. The ILP method suffers from its lack of consideration for spatial relationships—it usually leads to a fragmented network of sites (McDonnell et al. 2002). Integer linear programming also fails when the number of sites under consideration becomes too large; in this case, solutions cannot be achieved in a reasonable timeframe (Possingham et al. 2000).

Several heuristics have been used to design reserve systems as well. These methods seek to optimize the objective function by sequentially adding sites to an initial solution that contribute to the minimization of the equation (McDonnell et al. 2002). These methods use an adjacency constraint to cluster the sites of a potential reserve system. The two most common sequential heuristic algorithms are greedy and rarity. The greedy algorithm begins with an existing solution to the problem which is sequentially updated by a "neighboring solution" so as to give the largest decrease in the value of the objective function (McDonnell et al. 2002). For each neighboring solution, a change in the cost of the reserve system is calculated iteratively. The algorithm repeats this process until it reaches the conservation goal. The rarity algorithm operates in a similar manner except its initial solution targets the rarest species and builds a complementary set of sites from that point (McDonnell et al. 2002). The drawback of these two methods is that they can quickly converge on a local minimum instead of a global one. By sequentially adding sites that neighbor the initial solution, there is no guarantee the algorithm will consider all sites and build an optimal solution.

Recently, reserve design efforts have employed simulated annealing, a heuristic optimization algorithm adapted from the process of annealing metals and glass (Possingham et al. 2000). Simulated annealing operates by generating a completely random initial reserve system. The algorithm then makes random changes to the system by iteratively exploring trial solutions. It may add a new site to the system or delete an existing site. At each step, the algorithm compares the new solution with the previous one to find the best solution. The advantage of simulated annealing over other heuristic algorithms is that it allows the reserve system to move through sub-optimal solutions, increasing the number of paths to the global minimum (Possingham et al. 2000). The algorithm initially accepts any change to the system no matter if it increases or decreases the system value. As the algorithm proceeds through more iterations, it begins to accept only those solutions that decrease the overall value. Simulated annealing performs better than more simple heuristics, but at the cost of a slower running time.

Marxan

Marxan is a computer software program that employs simulated annealing to aid in the design of marine reserve systems. The program was designed to identify marine reserve systems based on the terrestrial reserve design software, Spexan. Marxan was designed under contract for the Great Barrier Reef Marine Park Authority. The package uses an objective function whose factors include cost, boundary length, a conservation penalty, and an optional cost threshold penalty (Figure 2). Marxan can use three methods for optimization of the objective function: iterative improvement, simulated annealing, and

$$\Sigma_{\text{sites}} \text{Cost} + \text{BLM} \Sigma_{\text{sites}} \text{Boundary} + \Sigma_{\text{ConValue}} \text{CFPF} * \text{Penalty} + \text{Cost Threshold Penalty (t)}$$

Figure 2: Marxan Objective Function ("Σ_{sites} Cost" measures relative cost, "BLM Σ_{sites} Boundary" measures boundary length, "Σ_{ConValue} CFPF * Penalty" measures the conservation penalty, and "Cost Threshold Penalty (t)" measures an optional cost threshold penalty)

the greedy heuristic. Inputs required for Marxan include a list of potential reserve sites with an associated cost, area, and boundary length; conservation goals (usually represented as an amount of area) for each species of concern; and the amount of each species or habitat within each potential site. The program then uses one of the above optimization methods to minimize the objective function and produce a list of sites that comprise an optimal solution.

The advantages of Marxan are that it allows the designer to use quantitative data to develop potential reserve systems and compare different scenarios and spatial configurations. While the automation of this process improves the comparison of different scenarios across the landscape, the software was not intended to produce a final reserve system, but rather a set of potential areas based on the input criteria that should be considered further with subjective criteria. Once the software incorporates quantitative data to develop target sites, designers may use qualitative data to evaluate these areas and "finalize" the reserve system.

Using Marxan to Identify SHAs

Marxan can be used to aid in the identification of Strategic Habitat Areas. As mentioned above, SHAs will be habitats that perform exceptional habitat functions. While Marxan is not specifically designed to locate habitats based on biological function, it can incorporate several criteria that will aid in the identification of areas that will likely function exceptionally well. Essentially, Marxan can help narrow the search area across the seascape.

<u>White Oak River Basin</u>

This study focuses its analysis on the White Oak River Basin (Figure 3). The Basin includes the New River, the White Oak River, the Newport River, the North River, Bogue Sound, Back Sound, and Core Sound. Several areas within the basin are managed for conservation and open space including Cape Lookout National Seashore, Cedar Island National Wildlife Refuge, the Rachel Carson National Estuarine Research Reserve, Croatan National Forest, the Hoffman State Forest, Fort Macon State Park, and Hammocks Beach State Park. The basin includes 54,487 acres of mapped estuarine wetlands, 9,434 acres of mapped wetland that perform functions for anadromous fish, 23,910 acres of mapped submerged aquatic vegetation, and 7,134 acres of mapped shellbottom. There are 267 miles of freshwater streams and rivers and 192 square miles of saltwater in the basin.

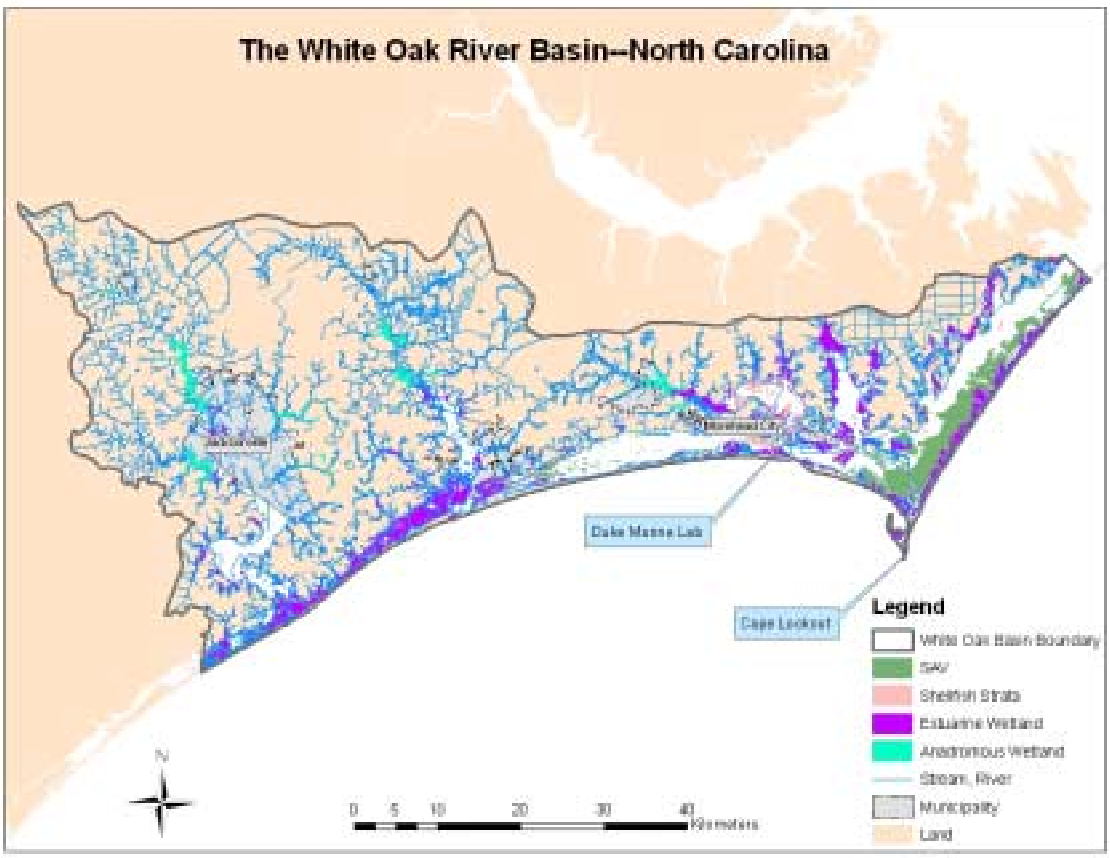


Figure 3: White Oak River Basin, North Carolina

<u>Data Inputs</u>

Three primary datasets were used in this analysis and came from various sources with various mapping protocols. The datasets were mapped in a geographical information system (GIS) format. The datasets used in the analysis include SAV, the DMF Shellfish

Habitat and Abundance Mapping Program, and the DCM North Carolina Coastal Regional Evaluation of Wetland Significance (NC-CREWS). The SAV dataset was developed by Carraway and Priddy in 1983. The DMF Shellfish Mapping Program was developed using a stratified random sampling design that delineates all bottom habitats and samples the density of oysters, clams, and bay scallops in these areas (Street et al. 2004). The program defines shell habitat as coverage of greater than 30% of bottom of living or dead shells (Street et al. 2004). The NC-CREWS dataset is "a watershed-based wetland functional assessment model that uses GIS software and data to assess the level of water quality, wildlife habitat, and hydrologic functions of individual wetlands" (DCM Website). The NC-CREWS model rates wetlands on the basis of overall function, primary functions, subfunctions, and parameter and subparameters. Estuarine wetlands are grouped into an overriding category and given an exceptional overall rating; none of their subfunctions are rated. The ratings also consider various habitat functions including those for aquatic life. A subhabitat function of primary importance in this analysis is for anadromous fish. Wetlands rated high for the anadromous fish subhabitat function were used in this analysis as forested wetlands.

Four separate conservation goals were developed from these three datasets: SAV, shellbottom, estuarine wetlands, and wetlands rated high for performing habitat functions for anadromous fish (forested wetlands). These habitat are limited to estuarine and nearshore areas and include all of the "structured" habitats evaluated in the CHPP. Ocean hardbottom was not included here because this analysis is limited to estuarine areas. Softbottom was not incorporated because it is typically not as threatened as the “structured” habitats and can be relatively easily recolonized following a disturbance. The water column habitat type was incorporated into a different part of the analysis and explained later.

<u>Data Preparation</u>

Data must be prepared in a specific format in order for Marxan to use it. Data preparation is described in detail in the Marxan operation manual (Ball & Possingham 2000). The first step in the data preparation process was to create a uniform hexagonal grid that covers the study area. Each section of the grid was numbered and comprises a potential site for selection by the algorithm. Hexagon shapes were chosen for their compactness. These shapes are the most compact form that can tessellate into a grid. Compactness is important when considering the minimization of boundary length and reserve area. The sites have an area of 50 hectares and have a perimeter of 2.63 km. Next, each habitat type was intersected with the site grid to determine how much area of each habitat was located within each site. A site cannot contain more than 50 hectares of habitat.

Conservation goals were designated for each habitat type. For this analysis conservation goals were based upon area of existing mapped habitat within the basin (Table 1). Conservation goals were set at 10, 20, and 30 percent of existing habitat under various analysis scenarios. As mentioned before, several studies have been conducted that explore the amount of marine and nearshore areas that should be protected for various reasons

Habitat type	Area (m2)	% of Basin	30% Area	20% Area	10% Area
SAV	96,760,483.00	2.96%	29,028,145	19,352,096.60	9,676,048.30
Shellbottom	28,870,006.00	0.88%	8,661,002	5,774,001.20	2,887,000.60
Estuarine Wetlands	220,502,435.00	6.74%	66,150,731	44,100,487.00	22,050,243.50
Wetland Performing Functions for Anadromous Fish	38,179,754.00	1.17%	11,453,926	7,635,950.80	3,817,975.40
Totals	384,312,678.00	11.74%	115,293,803.40	76,862,535.60	38,431,267.80
Total Basin	3,272,777,073.91				

Table 1: Conservation Goals for the White Oak River Basin

(NRC 2001). The selection of the conservation goal can vary depending on the habitat and the scenario. For instance, one may wish to preserve one hundred percent of a habitat type if it is extremely rare and it performs essential habitat functions for fish populations.

Finally, a relative cost was assigned to each site within the study area. The goal of cost assignment was to steer site selection into areas that will most likely perform exceptional habitat functions and allow for sustained protection. Costs were assigned based on proximity to six conservation designations and ecological areas. Distance was measured from inlets, DMF Nursery Areas, EMC Outstanding Resource Waters/Shellfish Areas, National Wildlife Refuges, National Estuarine Research Reserves, and National Seashores. Proximity to these areas has significance for ecological and managerial reasons. Habitats in close proximity to inlets will be able to benefit from salinity variation, water column mixing, and larval transport as exchange occurs between estuarine and marine environments (Street et al. 2004). Habitats within DMF Nursery Areas are already known to provide essential nursery functions to several important fishery species. Habitats in close proximity to these areas can augment those existing nursery functions. Outstanding Resource Waters/Shellfish Areas are those areas designated by EMC that are commercial shellfish waters "of exceptional state or national recreational or ecological significance . . . having excellent water quality" in conjunction with shellfish resources (Street et al. 2004). This criterion incorporates water quality as a habitat and decreases the probability that habitats in these waters will suffer from water quality degradation. Habitats in close proximity to the other three federal designations will likely be protected from incompatible land uses that could potentially degrade habitats.

Costs increased incrementally as distance from each feature increased. Sites in close proximity to each feature received a lower score than those further away. Each site was given a base cost of 100 and could receive a maximum cost score of 170 (Figure 4). All other factors being equal, the algorithm will choose sites with the lowest cost score.

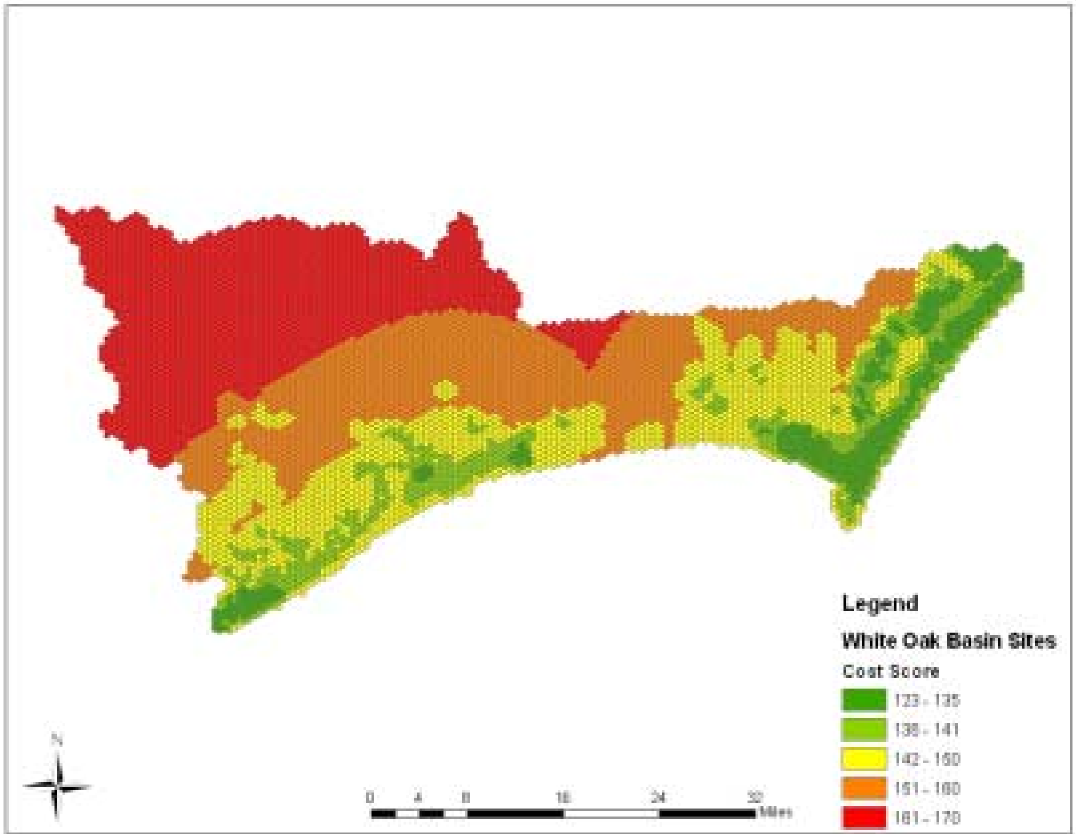


Figure 4: Cost Score for Potential Sites in the White Oak Basin

<u>Experimental Design</u>

I ran several scenarios with the Marxan software to determine which sites comprise the core areas for potential Strategic Habitat Areas in the White Oak Basin and which settings produced the best results. For each scenario, the BLM and the levels of the conservation goals were altered. This experimental design tests the importance of boundary length and reserve area amount in the design of the SHA network. Nine scenarios were run through the software. Each scenario had a different BLM or conservation goal. All conservation goals were altered in equal proportions; no conservation target (habitat) had a conservation goal proportion that differed from other conservation targets.

Each scenario ran 100 times repeatedly. Simulated Annealing was used in each run followed by the summed irreplaceability heuristic and normal iterative improvement. The irreplaceability heuristic examines how necessary each planning unit is to achieve the target for a given conservation feature (Ball & Possingham 2000); summed irreplaceability is a specific type of the irreplaceability heuristic. The iterative improvement heuristic is a simple optimization method that is effective in aiding the simulated annealing algorithm. When used following simulated annealing, this heuristic ensures that no simple improvements are possible (Ball & Possingham 2000). In normal iterative improvement, the only changes considered to the reserve system are adding or removing each planning unit. The annealing process included 100,000,000 iterations per run and used adaptive annealing. The number of iterations determines how long the annealing algorithm will run; the greater the number of iterations, the more likely the algorithm will find a better solution (Ball & Possingham 2000). The adaptive annealing process considers the length of computation time that bad changes will be accepted into the reserve system. The simulated annealing process includes a temperature factor that determines how long bad changes are accepted. When the temperature is high, bad changes are accepted into the system. As the temperature decreases, the chance of accepting bad changes decreases until they are no longer accepted. Adaptive annealing derives the temperature parameters from the data of the specific problem.

Results

The outcomes of each scenario demonstrated the effects of altering the boundary length modifier and conservation goals. While each solution had varying spatial configurations, the algorithm chose certain sites repeatedly across all scenarios. This information will be valuable in determining core areas for potential SHAs. Each scenario was comprised of 100 runs. Each run has an associated solution. While an individual solution may have,

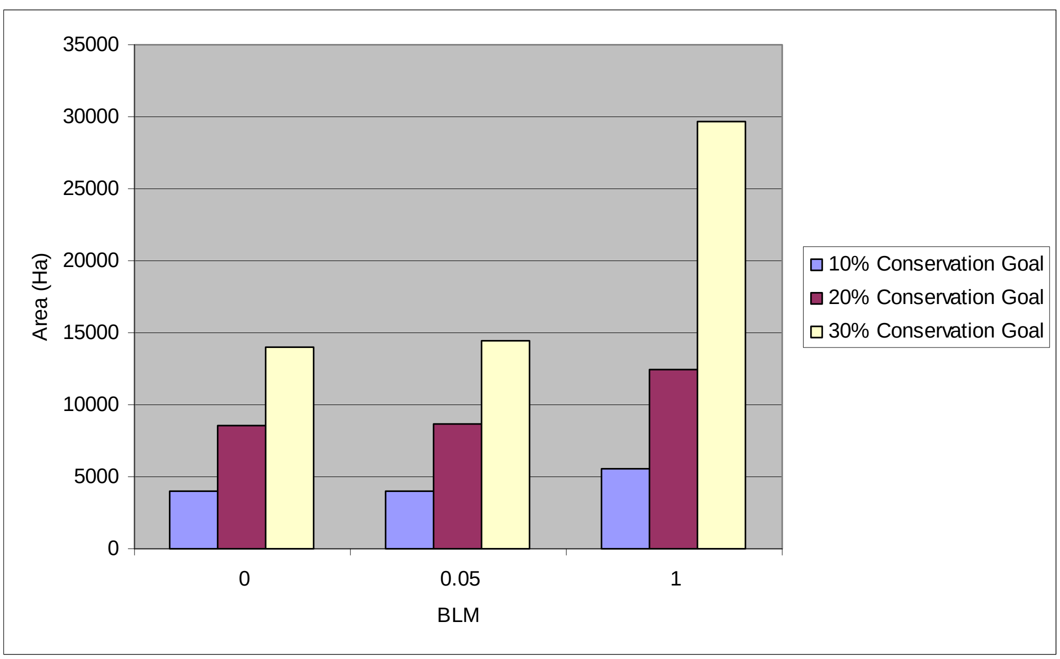
Conservation Goal %	BLM	Minimum Area (ha)	Maximum Area (ha)	Best Area (ha)	Minimum Perimeter (km)	Maximum Perimeter (km)	Best Perimeter (km)	Clustering Ratio
10	0	3950	4150	3950	162.315	187.759	167.58	7.5236541
10	0.05	3900	4200	3950	107.04	132.484	108.795	4.8844489
10	1	5000	6000	5550	70.19	75.454	70.19	2.6584833
20	0	8600	9000	8600	306.206	357.094	307.961	9.3702607
20	0.05	8650	9100	8700	209.694	236.893	219.345	6.6354945
20	1	11150	13200	12400	138.626	149.154	140.381	3.557154
30	0	14050	14450	14050	438.691	485.192	456.238	10.860716
30	0.05	14350	14750	14400	327.263	350.075	335.159	7.8808819
30	1	19100	29700	29700	189.514	231.628	189.514	3.1029034

Table 2: Scenario Solutions

for example, the best perimeter of any other run, it is not considered the best run. Each run is scored according to the objective function. The run with the lowest score (combining scores for area, perimeter, conservation penalty, etc.) is considered the "best" solution. I evaluated each scenario based on the "best" score as determined by the objective function. All scenarios produced results that met conservation targets for each habitat type. Each scenario offers guidance for both reserve design—the spatial configuration of the reserve system—and reserve placement—specific locations within the basin and the habitats they include.

Design Analysis

As expected, increasing the BLM in each scenario generally increased the total area, decreased the total perimeter of the reserve system, and decreased the compactness ratio (Table 2). An exception to this trend occurred when increasing the BLM from 0 to 0.05 at each of the conservation goal levels. As BLM increased from 0 to 0.05, area within the reserve system did not increase significantly (Figure 5(a)); however, with this increase in BLM the perimeter of the total reserve system decreased significantly (Figure 5(b)). In addition, the cluster ratio of perimeter to area[1] decreased at each conservation goal level (Figure 5c). This occurrence indicates that increasing the BLM and accounting for minimization of perimeter can increase the compactness of the reserve system while maintaining the total



[1] McDonnell et al. 2002 describe a measurement of reserve compactness as the boundary length of the reserve divided by its area. A non-dimensional measure of this ratio divides the boundary length of the reserve system by the circumference of a circle with the same area as the reserve. The circle is the most compact shape possible. Thus, this ratio is a measure of boundary length to a theoretical minimum of area.

Figure 5(a): Boundary Length Modifier Effect on Best Area (Ha)

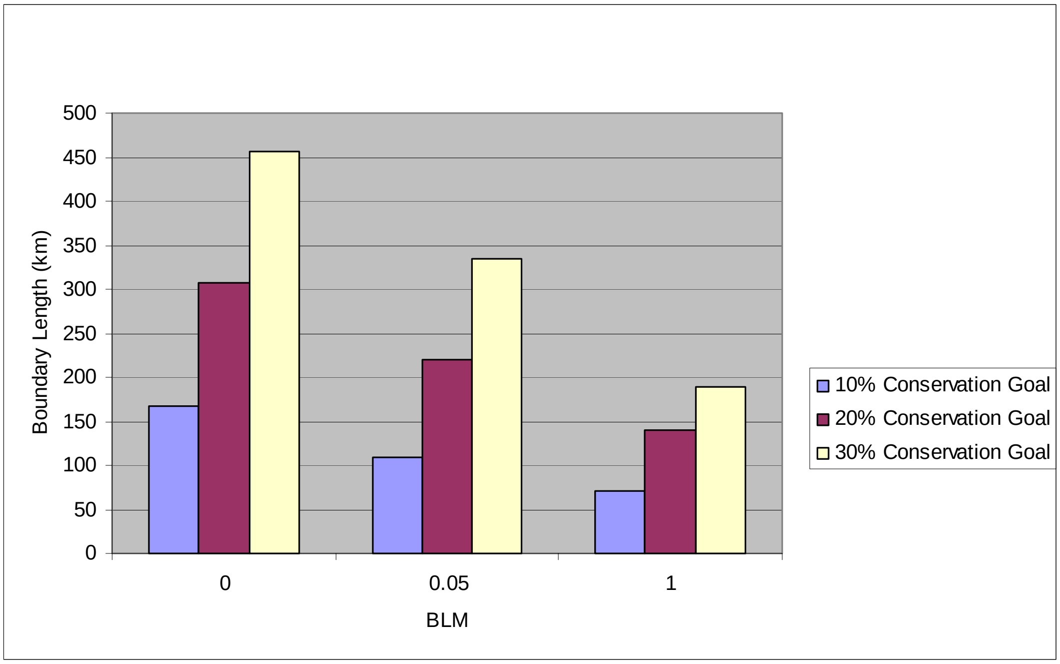


Figure 5(b): Boundary Length Modifier Effect on Best Perimeter

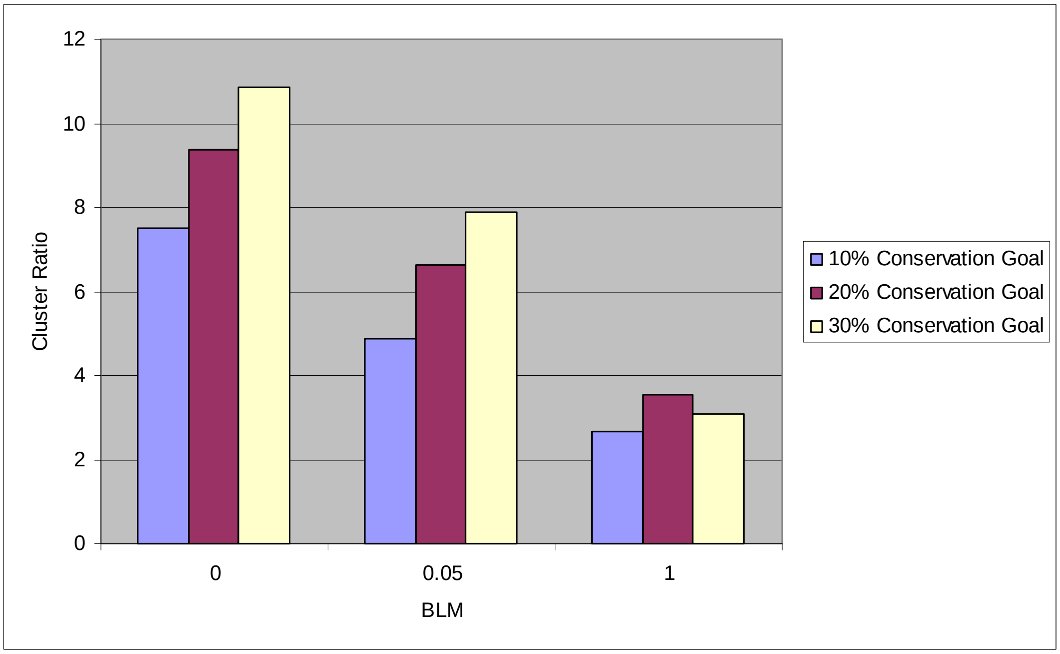


Figure 5(c): Boundary Length Modifier Effect on Cluster Ratio

area under management. Increasing the BLM from 0.05 to 1 increased the area and decreased the boundary length at all three conservation goal levels (Figure 5(a)-(b)).

Increasing the conservation goal level had a similar effect on boundary length, area, and the compactness ratio across each BLM level (Figure 5). For each of these parameters (boundary length, area, and compactness ratio), levels increased as the conservation goal increased. As the algorithm attempted to meet an increasing area-based conservation goal, it tended to increase boundary length, area, and compactness ratio. An exception to this trend occurred when increasing the conservation goal from 20 percent to 30 percent with a BLM of 1 (Figure 5(c)). Under this particular scenario, the BLM level puts more weight on minimizing boundary length and, as a result, tends to increase total area in the reserve system. In addition, increasing the area-based conservation goal from 20 percent to 30 percent increases the total area required within the reserve system. These two parameters combine to significantly increase the total area of the reserve system under scenario 9 (Figure 5(a)). As a result of this increase in area, the compactness ratio for this scenario decreases instead of maintaining an increasing trend (Figure 5(c)).

While improving the compactness ratio can be a design advantage, it has produced some undesirable effects in this situation. Although, the reserve system is statistically more compact in scenario 9 (CG = 30%, BLM = 1), it has come close to over representing conservation goals for shellbottom and SAV (See Appendix 2). While neither of these habitats was statistically overrepresented (> 130% of goal), they were not efficiently represented in this scenario. Efficiency of representation is central to the overall reserve design goal of meeting conservation goals and minimizing the total cost of the network.

In addition, increasing the BLM and conservation goal level in tandem can potentially include sites in the network that contribute no ecological value.

Irreplaceability Analysis

Irreplaceability relates to the idea that certain sites in a network are so valuable to meeting network goals that they cannot be replaced. Pressey et al. (1993) define irreplaceability in two ways: (1) the potential contribution of a site to a reserve system goal; and (2) the extent to which the options for reserve are lost if the site is lost. In this analysis, irreplaceability refers to the frequency with which a site is included in a scenario's best solution or its frequency of inclusion in a certain percentage of a scenario's runs. Different levels of irreplaceability exist. Those sites chosen most often would receive high irreplaceability scores while those chosen less often would receive lower scores.

The White Oak River analysis produced various levels of irreplaceability depending upon the level of conservation goal set for each scenario (Figures 6(a) – (c)). At the 10% conservation goal, fewer sites were selected with high frequency (Figure 6(a)). This is due partly to the increased flexibility in the number of sites from which the algorithm could choose to meet the 10% area goal. As the conservation goal level increased, the algorithm had to choose more habitat area for the reserve system given a fixed amount of habitat in the basin. This requirement restricted the flexibility in the number of sites that the algorithm could choose; therefore, the frequency of any single important site chosen for the reserve system increased. As the conservation goal level increased, the number of irreplaceable sites increased.

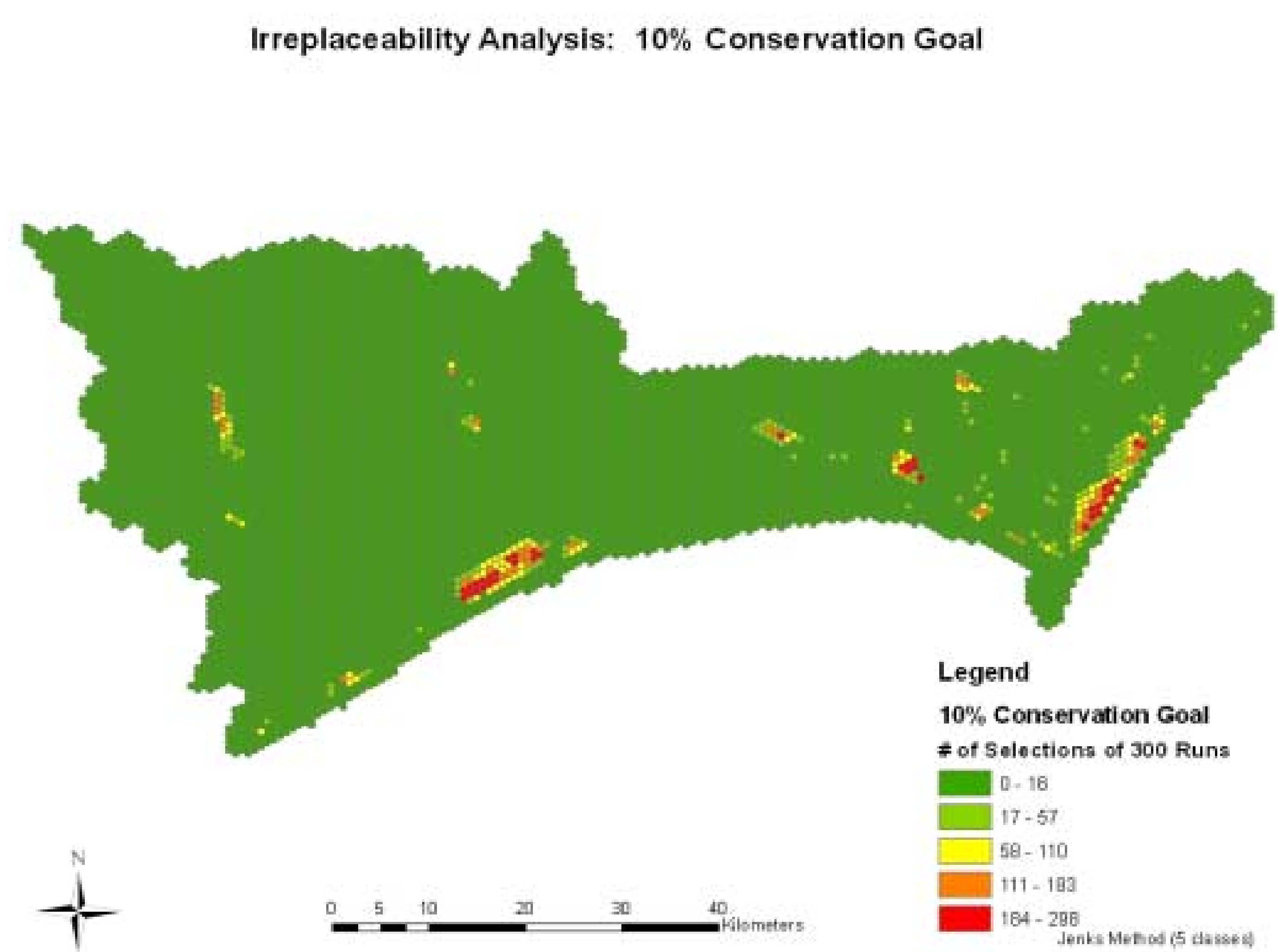


Figure 6(a): Irreplaceable Sites for 10% Conservation Goals (Scenarios 1 – 3)

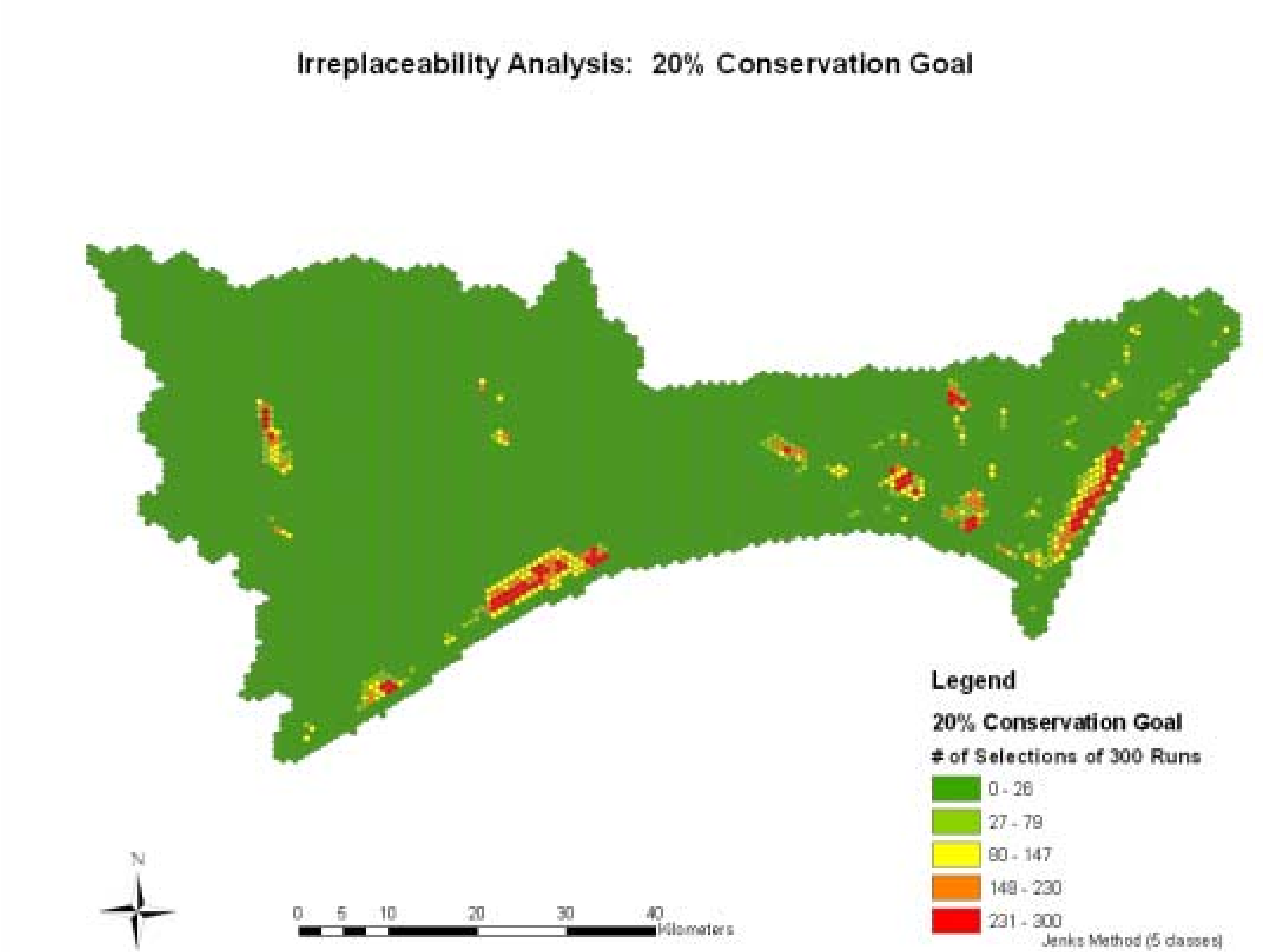


Figure 6(b): Irreplaceable Sites for 20% Conservation Goals (Scenarios 4 – 6)

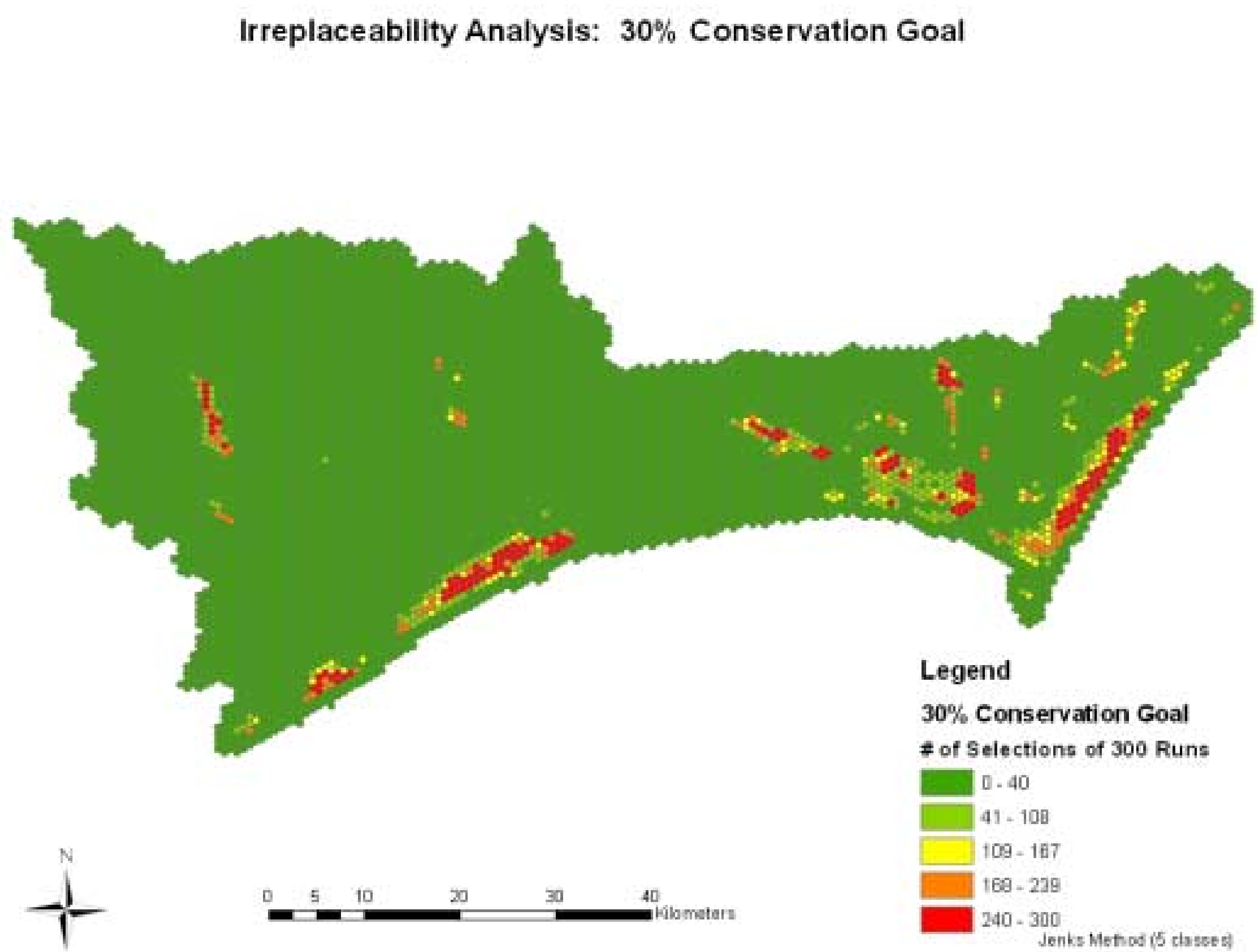


Figure 6(c): Irreplaceable Sites for 30% Conservation Goals (Scenarios 7 – 9)

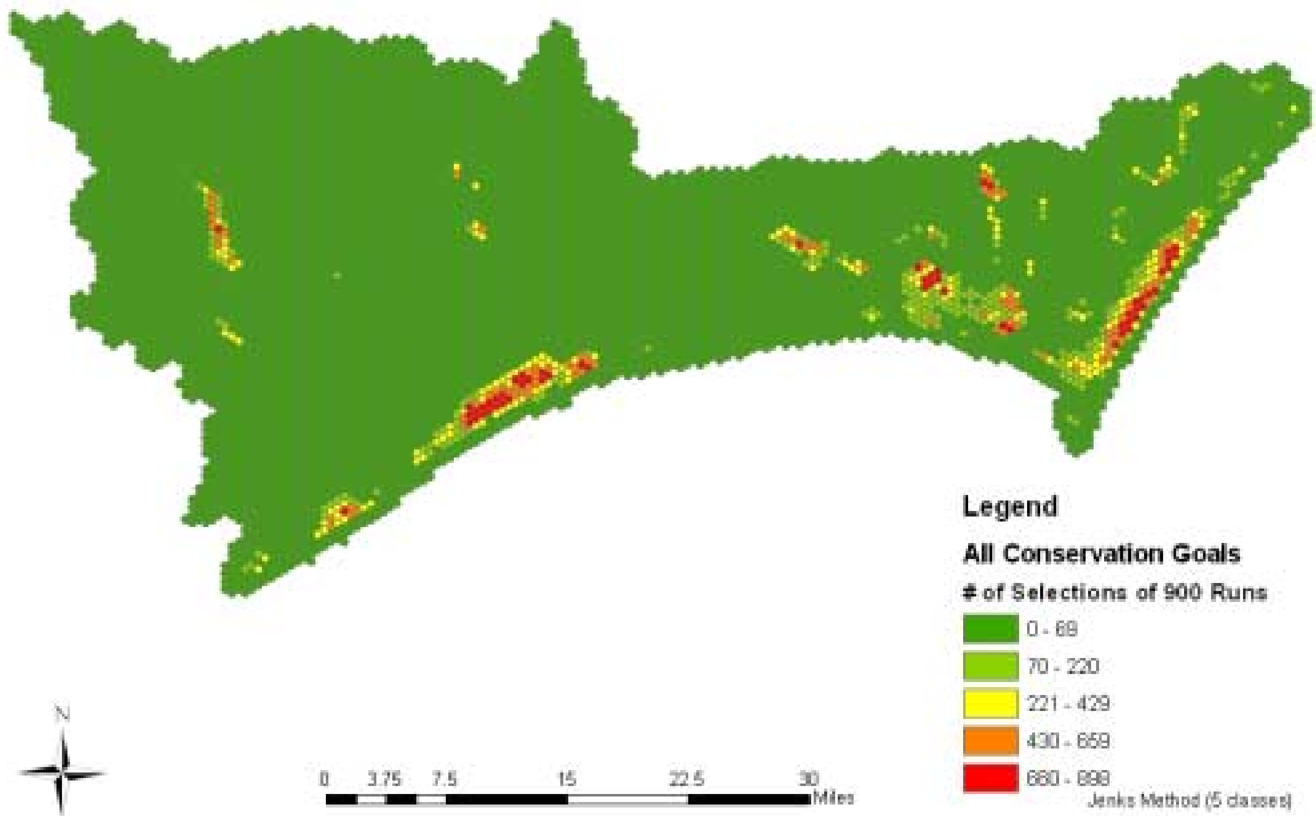


Figure 7: Sum of Irreplaceable Sites from All Scenarios

The irreplaceability analysis also provides an important tool for prioritization of "core" areas for conservation (Figure 8). While the number of irreplaceable sites varied across changing parameters, each scenario consistently selected eight core areas for inclusion in the reserve system (Figure 7). The core areas included: 1) the upper New River, 2) New River Inlet, 3) Bogue Inlet & Bear Island, 4) upper Newport River, 5) Newport Marshes, 6) upper North River, 7) lower North River, and 8) southeastern Core Sound (Appendix 1). According to the criteria set forth for the nine scenarios, these areas constitute the core locations for habitat conservation within the White Oak Basin.

In addition to the location of the irreplaceable sites, the habitats contained within these sites are important to consider. Of the top quantile of irreplaceable sites, estuarine wetlands were the most represented habitat type (mean of 75% of all habitats; Appendix 3). In 28 of the 57 sites a single habitat type comprised 85% or greater of all habitats within the site. Eleven of these sites contained 100% estuarine wetlands, and in 26 of these 28 sites, estuarine wetlands were the dominant habitat type. Fifteen of the 57 sites contained two habitats types that each represented at least 30% of total habitats for that site. Nine of the 57 sites contained three different habitat types.

A unique mix of habitats make up each of the eight complexes identified through the irreplaceability analysis (Table 3). Generally, each subwatershed has a habitat complex in its upper and lower reaches. The exception occurs in the White Oak River where a single large complex exists around Bogue Inlet and Bear Island but none in the upper White Oak. In the New and Newport Rivers, the complexes in the upper reaches are

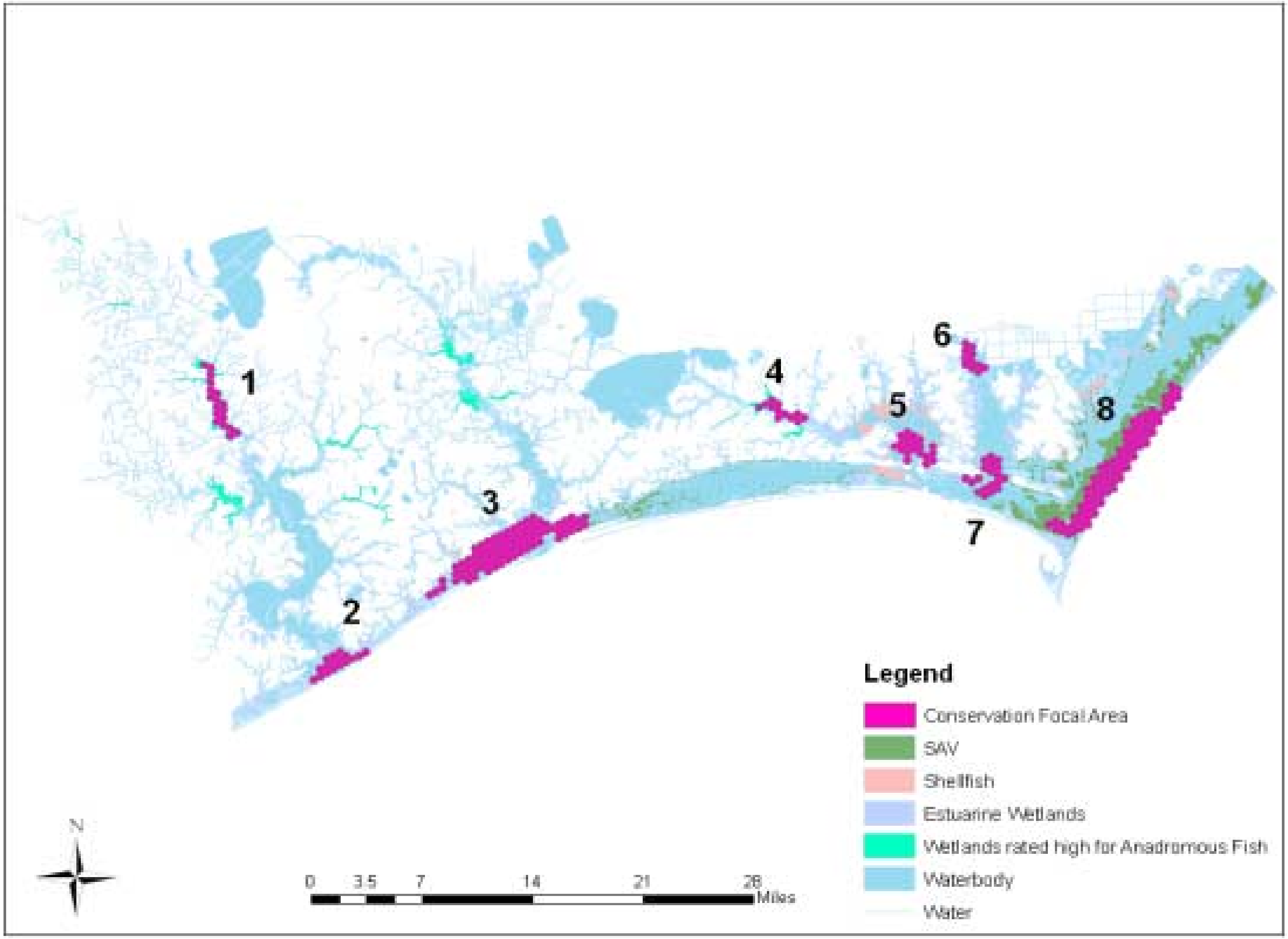


Figure 8: Focal areas determined by irreplaceability analysis in the White Oak Basin

primarily composed of anadromous fish habitat (complexes 1 & 4). Estuarine wetlands dominate complexes 2, 3, 6, and 7 (Table 3). Complex five is roughly split between estuarine wetlands and shellbottom. The primary habitat type in complex eight is SAV. Those complexes that exhibit homogeneity of habitats occur primarily in the upper reaches of the subwatersheds. The complexes closest to the open ocean have higher degrees of heterogeneity (Table 3; Figure 8).

1	2	3	4	5	6	7	8
900 ha	850 ha	4150 ha	600 ha	1000 ha	550 ha	950 ha	4200 ha
100% Anadromous Wetlands	96% Estuarine Wetlands	96% Estuarine Wetlands	77% Anadromous Wetlands	53% Shellbottom	100% Estuarine Wetlands	71% Estuarine Wetlands	63% SAV
	4% Shellbottom	2% SAV	23% Estuarine Wetlands	1% SAV		13% SAV	36% Estuarine Wetlands
		2% Shellbottom		46% Estuarine Wetlands		15% Shellbottom	1% Shellbottom

Table 3: Focal area habitat and area statistics

Discussion

The results of this analysis suggest several key issues to consider in the design of the Strategic Habitat Area network. First, using the boundary length modifier can improve the reserve design. Increasing the BLM can decrease the perimeter and increase the compactness of the network. Benefits from changing this parameter occur up to a certain threshold after which it may produce inefficient outcomes. This can be seen in this analysis when increasing the BLM from zero to 0.05. In this situation, the area within the network did not change but the perimeter decreased and the compactness increased. In this case, increasing the BLM improved the design of the reserve system by making its sites more compact and connected. A well-connected reserve design will be preferable for both biological and sociopolitical reasons and may reduce both enforcement and management costs (Roberts et al. 2003). However, increasing the BLM beyond the required threshold can result in an inefficient design. Increasing the BLM to an unreasonably high level will put emphasis on reducing boundary length at the expense of adding area. This expense may include adding sites that have no conservation value or adding more habitat than required under the conservation goals—over representing habitat. Both of these outcomes are inefficient in design as area within reserves must be used efficiently. Each scenario will require adjustment of the BLM to determine the appropriate threshold for balancing perimeter, area, and compactness.

As area-based conservation goals increase, the area included in the reserve system must increase given a fixed amount of habitat within the river basin. Thus, increasing conservation goals decreases the design flexibility of a network as an increasing number of sites become irreplaceable. Selecting a lower conservation goal allows for more flexibility in reserve design; many combinations of sites can achieve the conservation goal. As the conservation goal level increases, flexibility in spatial design decreases and the value of irreplaceable sites increases. While design flexibility should not dictate the levels for habitat conservation goals, it should be understood when making changes to these goals.

Finally, while levels of irreplaceability varied across changing scenario parameters, each scenario concentrated its selections on similar core areas within the study area. Certain sites became irreplaceable across all scenarios. The likelihood of these areas becoming

SHAs is high given the spatial and ecological criteria set forth in the experimental design. These areas should receive priority consideration in the SHA identification and designation process. The habitat composition of these irreplaceable sites can provide guidance for reserve design efforts. In the White Oak Basin, design efforts should use estuarine wetlands as an "anchor" habitat for the network. This habitat type dominates the irreplaceable sites and tends to be found in close proximity to shellbottom and SAV. Wetlands that perform functions for anadromous fish are, by nature of their salinity requirements, spatially removed from the other three habitat types. Thus, these wetlands will not likely be found in complexes with the other habitat types. Most of the sites selected for anadromous fish habitat will be homogeneous.

The surrogate identification method used in this analysis has proved to be effective in identifying SHA focal areas within the study site. Marxan provides an interface with which to incorporate spatial, ecological, and managerial criteria for the identification of potential SHA sites. While stakeholders, managers, and resources users could use similar criteria and identify focal areas manually, the process would be time consuming, use subjective decision criteria, and typically provide a single solution. Marxan allows for an explicit decision-making process and provides an "experimental" environment with which to alter various criteria to produce multiple solutions for consideration.

Recommendations for Using Marxan for Identifying SHAs

The process for achieving goal two of the CHPP, "Identify, designate, and protect Strategic Habitat Areas," could be potentially long and complex. The methods used in this project will help to incorporate various criteria and make the process more explicit. However, the model used in this project has a definite place and function in the overall SHA process. I have seven recommendations that will improve the use of this model in that larger process.

1. The methods used in this project should be applied to identify SHA focal areas for further consideration. Because this process produces a final output of specific locations, there may be a temptation to move forward with these sites without considering them within the context of other criteria. This temptation should be avoided. The process should comprehensively consider other biological, social, and economic criteria in order to effectively site Strategic Habitat Areas.
2. Stakeholders should be involved throughout the entire process. Stakeholder participation in the entire SHA network development process can have several potential benefits. Allowing stakeholders to participate in the process allows them to better understand resource management goals and objectives, in addition to an appreciation for the marine environment (Kessler 2004). Stakeholders that participate in the process are more likely to comply with regulations since they had a say (Kessler 2004). Perhaps most importantly, stakeholders can provide valuable local and traditional knowledge that might not otherwise receive consideration in the network development process. Managers of the process should weigh the benefits of various levels of stakeholder involvement and clearly

articulate to stakeholders how their input will be used (Bernstein et al. 2004). Given the current climate of limited enforcement resources for natural resource management efforts, resource user compliance with regulations can dramatically improve management efforts; stakeholder participation can contribute to desirable levels of compliance. Marxan is an effective tool for incorporating stakeholder participation as they can observe how various criteria factor into a specific solution.

3. The SHA process should identify areas based on biological criteria before considering socioeconomic criteria. As Crowder et al. (2000) suggest, identifying areas intended to improve biological processes based on social or political criteria will ultimately serve to defeat the purpose of protecting an area. For Strategic Habitat Areas to function effectively as fishery management tools, site evaluations should consider species abundance and diversity, local current and advection patterns, and larval dispersal and adult movement rates of species protected by the SHA. Larval dispersal and adult movement are essential factors in determining the effectiveness of a reserve in contributing to stocks outside reserve boundaries (Sladek-Nowlis & Friedlander 2005). Once biological factors receive full consideration, potential sites can be "filtered" using socioeconomic criteria.

4. Each site, as well as the network as a whole, should have specific, clearly-defined, measurable goals integrated with fishery management objectives to help determine the contribution of SHAs towards the achievement of fishery management improvements. While the CHPP generally implies that SHAs should

protect important habitats and the functions they provide, no clear goals have been set out with respect to habitat quantity and quality improvements. Goals should also be developed to measure the contribution of habitats within SHAs to the productivity of fishery stocks (Botsford et al. 2003; Hastings & Botsford 2003; Gerber et al. 2003).

5. An adaptive monitoring plan should be developed that analyzes site and network ability to achieve their goals. The monitoring plan should account for various time frames, including short- and long-term indicators, spatial and temporal changes, before- and after-effects of SHA implementation, and internal and external reserve effects on ecological and economic variables (NFCC 2004). The monitoring plan should be created with an adaptive management structure in mind. The use of marine reserves as a fisheries management tool is in its early stages. A good monitoring plan can provide data that will help determine the benefits and important design criteria for reserves as fishery management tools both in the SHA network and in the larger marine reserve effort worldwide.
6. DMF should initiate a data management effort that consolidates existing data and improves collection of data needed specifically for the evaluation of fishery stock improvements related to habitat enhancement and restoration. The Division of Marine Fisheries has initiated the Shellfish Habitat and Abundance Mapping Program which maps habitats in estuarine and nearshore waters. However, habitat classification within this effort is relatively coarse with respect to shellfish and plant species. Detailed habitat datasets should be produced frequently and updated often as habitat quantity and quality change due to various environmental

and human-induced factors. Detailed knowledge of habitat type, quantity, and quality will be essential in developing the SHA network going forward. Data should be shared across DENR divisions and other state agencies to develop a comprehensive source of data that can improve habitat analysis and protection efforts.

7. Finally, the Strategic Habitat Area concept should incorporate larger conservation efforts across the land-sea interface. As implied in the CHPP document, cooperative efforts should be pursued between different divisions of DENR and various non-profits to ensure that SHAs are managed and protected in an ecosystem context. The presence and proximity of nearshore SHAs should drive the placement of other conservation efforts including Clean Water Management Trust Fund acquisitions, Ecosystem Enhancement Program restoration and preservation projects, and private land trust and significant natural heritage acquisitions.

If implemented successfully, the SHA network in North Carolina could be one of the first of its kind in the nation—a network of sites that protects fisheries habitat while improving fishery stocks. Given its uniqueness, the design process, implementation, and management efforts should be studied and monitored to help build capacity for similar future efforts in other states and nations.

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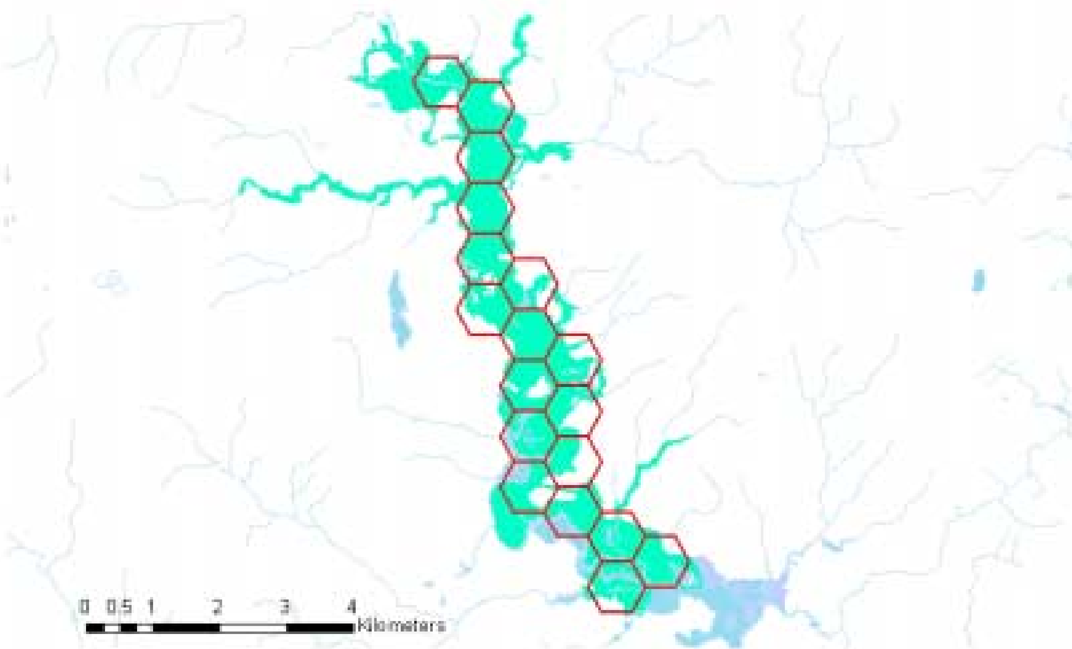
Appendix 1
White Oak Basin Focal Areas

Focal Area 1



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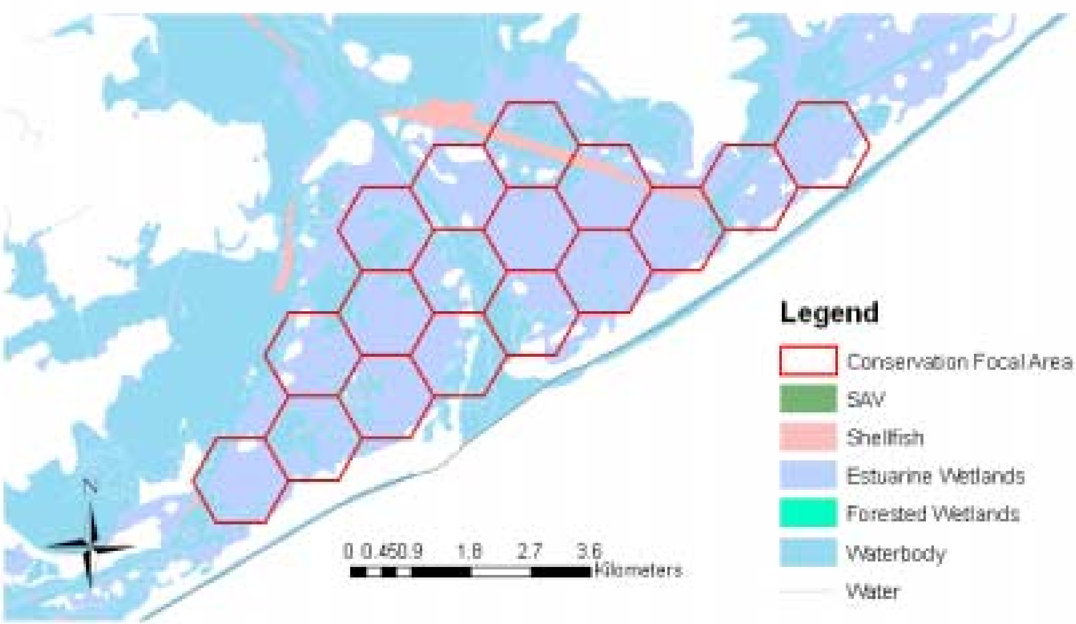

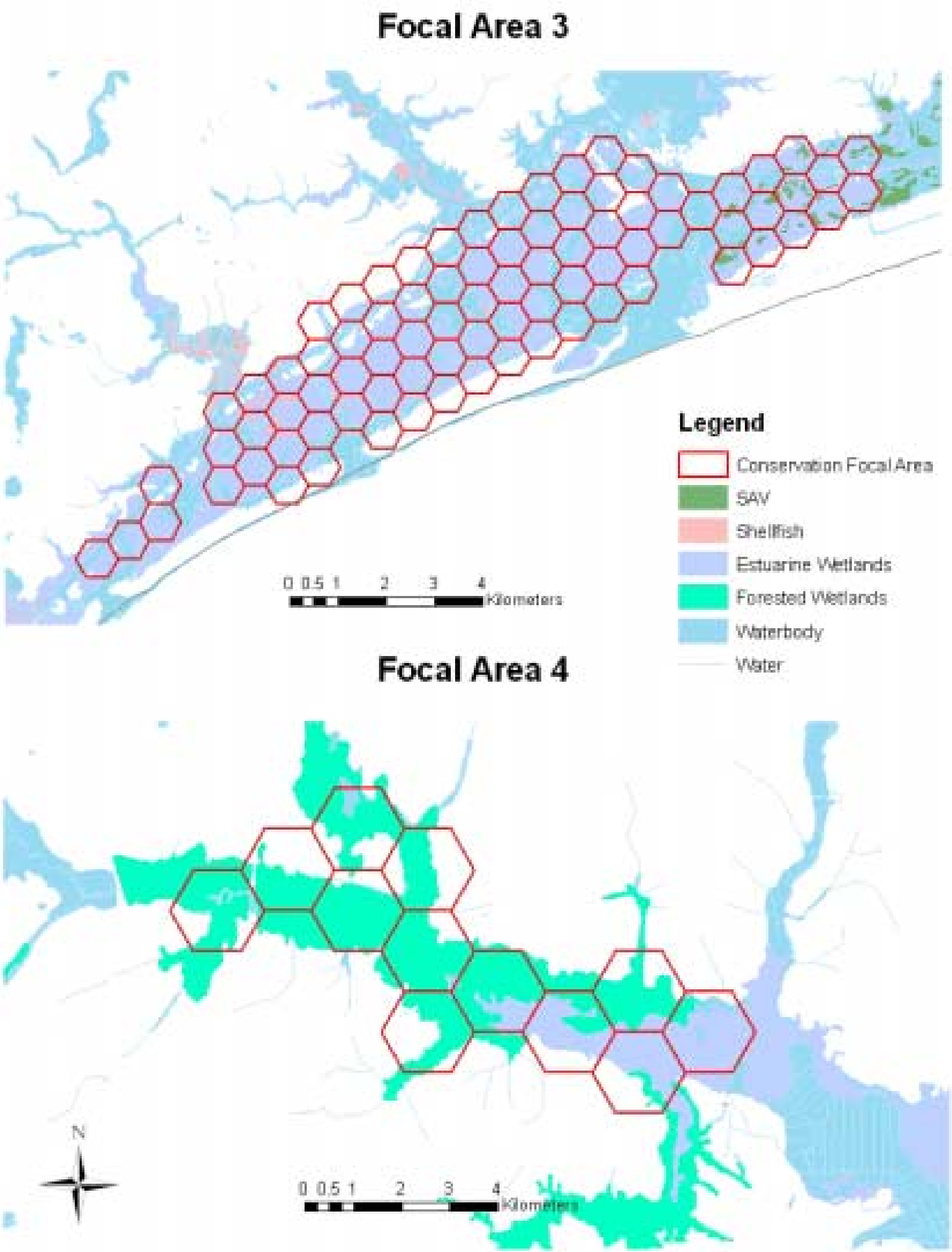
Focal Area 3
0 0.5 1 2 3 4
Kilometers
Legend
Conservation Focal Area
SAV
Shellfish
Estuarine Wetlands
Forested Wetlands
Waterbody
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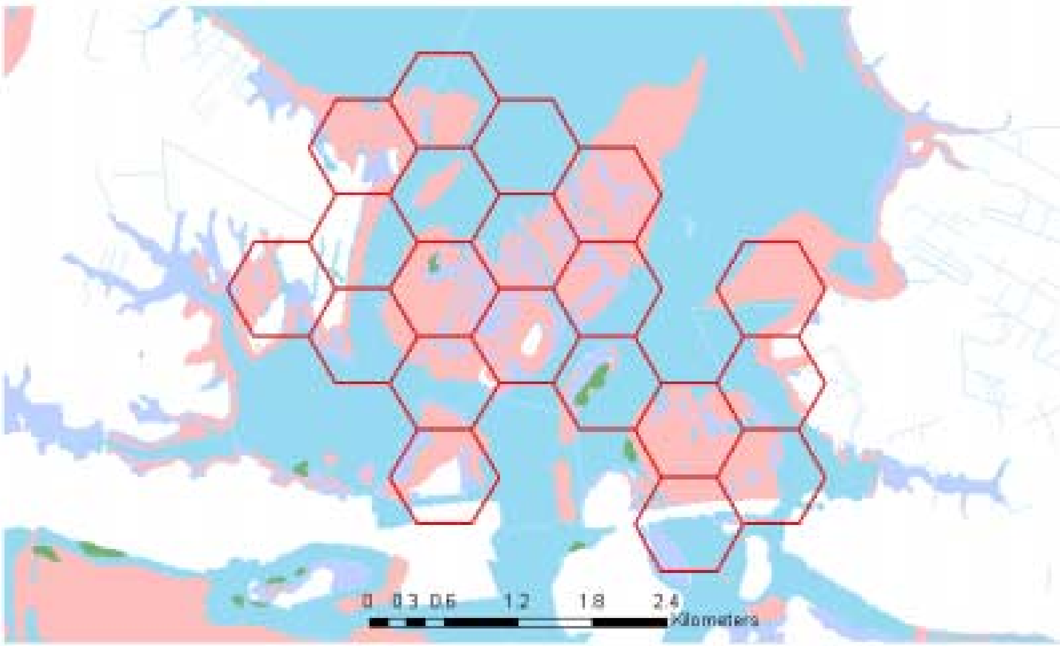
Focal Area 4
N
0 0.5 1 2 3 4
Kilometers

Focal Area 5



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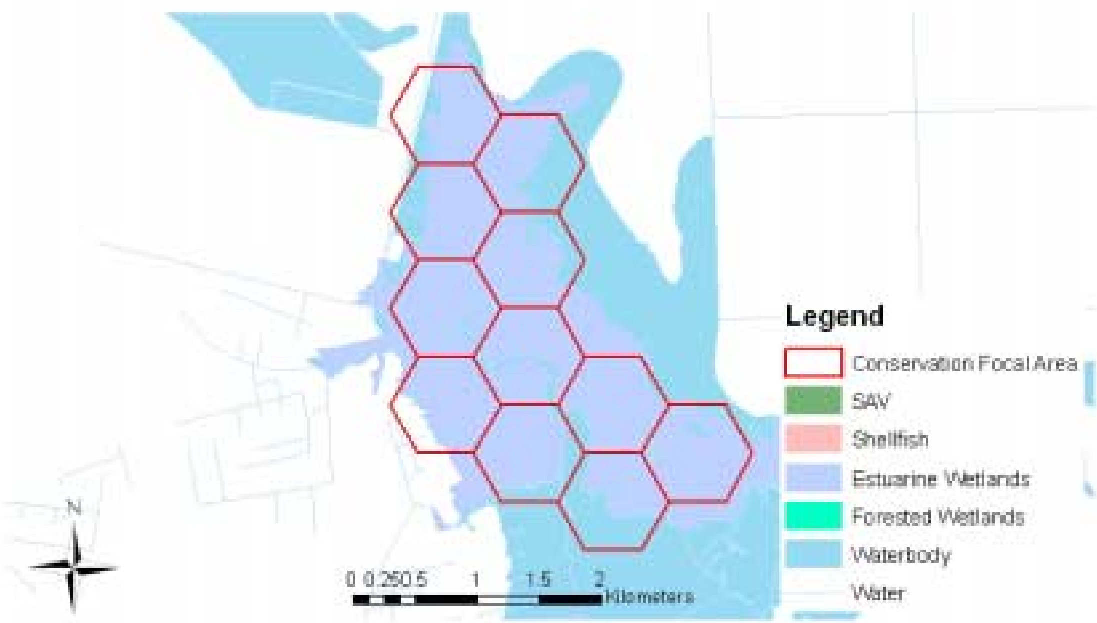

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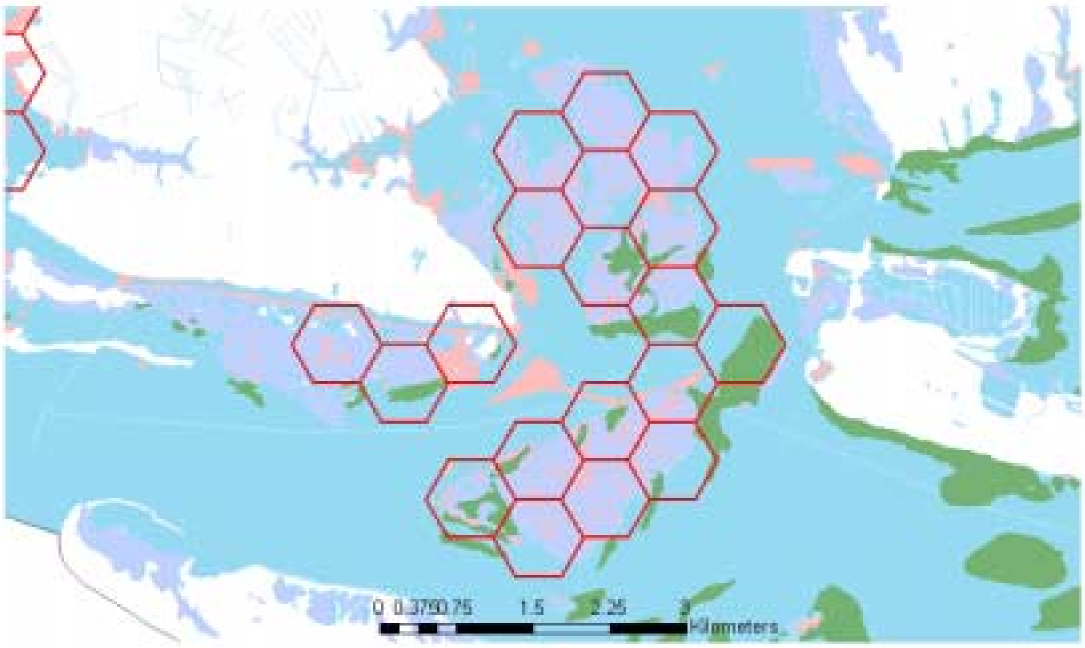
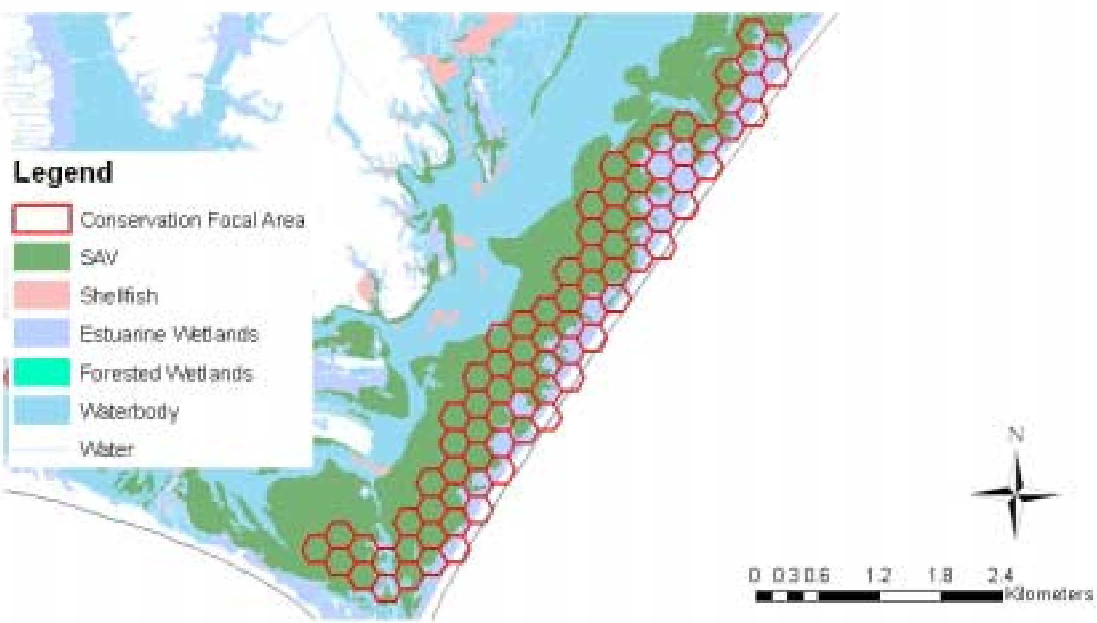


Focal Area 8



Appendix 2
Scenario Statistics

Scenario	BLM	Goal %	# Habitats	Simulated Annealing?	Hueristic	Cost?
1	0	10	4	yes	sum irreplacability	yes
Conservation Feature	**Feature Name**	**Target**	**Amount Held**	**% Held**	**Occurrences Held**	**Target Met**
6666	Anadromous wetlands	3817975.4	3818273	100.01%	11	yes
5555	Estuarine Wetlands	22050243.5	22053897	100.02%	68	yes
3333	Shellbottom	2887000.6	2900979	100.48%	41	yes
2222	SAV	9676048.3	9739934	100.66%	41	yes
Min. Area (ha)	**Max. Area (ha)**	**Best Area (ha)**	**Min. Perimeter (km)**	**Max. Perimeter (km)**	**Best Perimeter (km)**	
3950	4150	3950	162.315	187.759	167.58	

Scenario	BLM	Goal %	# Habitats	Simulated Annealing?	Hueristic	Cost?
2	0.05	10	4	yes	sum irreplacability	yes
Conservation Feature	**Feature Name**	**Target**	**Amount Held**	**% Held**	**Occurrences Held**	**Target Met**
6666	Anadromous wetlands	3817975.4	3877393	101.56%	10	yes
5555	Estuarine Wetlands	22050243.5	22090997	100.18%	68	yes
3333	Shellbottom	2887000.6	2958829	102.49%	33	yes
2222	SAV	9676048.3	9680397	100.04%	38	yes
Min. Area (ha)	**Max. Area (ha)**	**Best Area (ha)**	**Min. Perimeter (km)**	**Max. Perimeter (km)**	**Best Perimeter (km)**	
3900	4200	3950	107.04	132.484	108.795	

Scenario	BLM	Goal %	# Habitats	Simulated Annealing?	Hueristic	Cost?
3	1	10	4	yes	sum irreplacability	yes
Conservation Feature	**Feature Name**	**Target**	**Amount Held**	**% Held**	**Occurrences Held**	**Target Met**
6666	Anadromous wetlands	3817975.4	3827049	100.24%	13	yes
5555	Estuarine Wetlands	22050243.5	22068628	100.08%	86	yes
3333	Shellbottom	2887000.6	2922450	101.23%	54	yes
2222	SAV	9676048.3	9961634	102.95%	28	yes
Min. Area (ha)	**Max. Area (ha)**	**Best Area (ha)**	**Min. Perimeter (km)**	**Max. Perimeter (km)**	**Best Perimeter (km)**	
5000	6000	5550	70.19	75.454	70.19	

Scenario	BLM	Goal %	# Habitats	Simulated Annealing?	Hueristic	Cost?
4	0	20	4	yes	sum irreplacability	yes
Conservation Feature	**Feature Name**	**Target**	**Amount Held**	**% Held**	**Occurrences Held**	**Target Met**
6666	Anadromous wetlands	7635950.8	7640195	100.06%	21	yes
5555	Estuarine Wetlands	44100487	44119806	100.04%	146	yes
3333	Shellbottom	5774001.2	5781911	100.14%	83	yes
2222	SAV	19352096.6	19396970	100.23%	83	yes
Min. Area (ha)	**Max. Area (ha)**	**Best Area (ha)**	**Min. Perimeter (km)**	**Max. Perimeter (km)**	**Best Perimeter (km)**	
8600	9000	8600	306.206	357.094	307.961	

Scenario	BLM	Goal %	# Habitats	Simulated Annealing?	Hueristic	Cost?
5	0.05	20	4	yes	sum irreplacability	yes
Conservation Feature	**Feature Name**	**Target**	**Amount Held**	**% Held**	**Occurrences Held**	**Target Met**
6666	Anadromous wetlands	7635950.8	7669444	100.44%	23	yes
5555	Estuarine Wetlands	44100487	44107791	100.02%	147	yes
3333	Shellbottom	5774001.2	5823094	100.85%	86	yes
2222	SAV	19352096.6	19412725	100.31%	79	yes
Min. Area (ha)	**Max. Area (ha)**	**Best Area (ha)**	**Min. Perimeter (km)**	**Max. Perimeter (km)**	**Best Perimeter (km)**	
8650	9100	8700	209.694	236.893	219.345	

Scenario	BLM	Goal %	# Habitats	Simulated Annealing?	Hueristic	Cost?
6	1	20	4	yes	sum irreplacability	yes
Conservation Feature	**Feature Name**	**Target**	**Amount Held**	**% Held**	**Occurrences Held**	**Target Met**
6666	Anadromous wetlands	7635950.8	7653691	100.23%	34	yes
5555	Estuarine Wetlands	44100487	44107043	100.01%	186	yes
3333	Shellbottom	5774001.2	5824252	100.87%	116	yes
2222	SAV	19352096.6	19375259	100.12%	89	yes
Min. Area (ha)	**Max. Area (ha)**	**Best Area (ha)**	**Min. Perimeter (km)**	**Max. Perimeter (km)**	**Best Perimeter (km)**	
11150	13200	12400	138.626	149.154	140.381	

Scenario	BLM	Goal %	# Habitats	Simulated Annealing?	Hueristic	Cost?
7	0	30	4	yes	sum irreplacability	yes
Conservation Feature	**Feature Name**	**Target**	**Amount Held**	**% Held**	**Occurrences Held**	**Target Met**
6666	Anadromous wetlands	11453926.2	11478582	100.22%	34	yes
5555	Estuarine Wetlands	66150730.5	66168738	100.03%	234	yes
3333	Shellbottom	8661001.8	8671483	100.12%	128	yes
2222	SAV	29028144.9	29106152	100.27%	128	yes
Min. Area (ha)	**Max. Area (ha)**	**Best Area (ha)**	**Min. Perimeter (km)**	**Max. Perimeter (km)**	**Best Perimeter (km)**	
14050	14450	14050	438.691	485.192	456.238	

Appendix 2
Scenario Statistics

Scenario	BLM	Goal %	# Habitats	Simulated Annealing?	Hueristic	Cost?
8	0.05	30	4	yes	sum irreplacability	yes
Conservation Feature	**Feature Name**	**Target**	**Amount Held**	**% Held**	**Occurrences Held**	**Target Met**
6666	Anadromous wetlands	11453926.2	11529493	100.66%	35	yes
5555	Estuarine Wetlands	66150730.5	66240266	100.14%	242	yes
3333	Shellbottom	8661001.8	8686796	100.30%	137	yes
2222	SAV	29028144.9	29096881	100.24%	130	yes
Min. Area (ha)	**Max. Area (ha)**	**Best Area (ha)**	**Min. Perimeter (km)**	**Max. Perimeter (km)**	**Best Perimeter (km)**	
14350	14750	14400	327.263	350.075	335.159	

Scenario	BLM	Goal %	# Habitats	Simulated Annealing?	Hueristic	Cost?
9	1	30	4	yes	sum irreplacability	yes
Conservation Feature	**Feature Name**	**Target**	**Amount Held**	**% Held**	**Occurrences Held**	**Target Met**
6666	Anadromous wetlands	11453926.2	11464237	100.09%	52	yes
5555	Estuarine Wetlands	66150730.5	66170323	100.03%	388	yes
3333	Shellbottom	8661001.8	10207739	117.86%	268	yes
2222	SAV	29028144.9	36826543	126.86%	183	yes
Min. Area (ha)	**Max. Area (ha)**	**Best Area (ha)**	**Min. Perimeter (km)**	**Max. Perimeter (km)**	**Best Perimeter (km)**	
19100	29700	29700	189.514	231.628	189.514	

Appendix 3
Irreplaceable Sites--Top Quantile
(area in square meters)

Site	Forested Wetlands	% Forested	Estuarine Wetlands	% Estuarine	SAV	% SAV	Shellfish	% Shellfish	Total Habitat	Site Cost
2253	0	0%	447870	100%	0	0%	0	0%	447870	145
3059	0	0%	351745	78%	101570	22%	0	0%	453315	135
3158	0	0%	463314	98%	11413	2%	0	0%	474727	135
3338	0	0%	426589	53%	0	0%	377250	47%	803839	150
3355	0	0%	206658	39%	323616	61%	4161	1%	534435	135
3436	0	0%	465825	56%	9482	1%	357372	43%	832679	143
3437	0	0%	283698	57%	0	0%	216939	43%	500637	150
3535	0	0%	233390	52%	0	0%	211668	48%	445058	150
3651	0	0%	417497	78%	115451	22%	0	0%	532948	135
3749	0	0%	159969	29%	398220	71%	0	0%	558189	135
3848	0	0%	237549	42%	331462	58%	0	0%	569011	130
3947	0	0%	307665	53%	271611	47%	0	0%	579276	130
4036	0	0%	372005	78%	34729	7%	68316	14%	475050	130
4045	0	0%	155257	28%	405048	72%	1822	0%	562127	130
4144	0	0%	407894	76%	120333	22%	10128	2%	538355	130
4499	0	0%	452438	79%	119980	21%	1143	0%	573561	140
4595	0	0%	416846	100%	0	0%	1599	0%	418445	140
4692	0	0%	403657	99%	0	0%	2428	1%	406085	133
4693	0	0%	339302	100%	0	0%	0	0%	339302	140
4694	0	0%	492235	99%	0	0%	2811	1%	495046	140
4889	0	0%	495912	100%	0	0%	0	0%	495912	140
4987	0	0%	500000	98%	0	0%	11968	2%	511968	140
4988	0	0%	445164	98%	0	0%	10968	2%	456132	140
5085	0	0%	473534	85%	0	0%	85523	15%	559057	143
5086	0	0%	355973	95%	0	0%	17037	5%	373010	140
5184	0	0%	414960	96%	0	0%	18245	4%	433205	143
6362	0	0%	488392	100%	0	0%	1657	0%	490049	140
9557	0	0%	472417	100%	0	0%	0	0%	472417	148
10087	453586	100%	0	0%	0	0%	0	0%	453586	165
10327	382286	77%	112063	23%	0	0%	0	0%	494349	160
10453	0	0%	460314	97%	16487	3%	0	0%	476801	135
10551	0	0%	290768	63%	172690	37%	0	0%	463458	135
10630	0	0%	264505	48%	0	0%	281514	52%	546019	143
10649	0	0%	417119	90%	46370	10%	0	0%	463489	135
10729	0	0%	328697	59%	0	0%	227614	41%	556311	150
10827	0	0%	351449	59%	0	0%	241484	41%	592933	150
10926	0	0%	365771	49%	0	0%	388150	51%	753921	150
10942	0	0%	320135	73%	90104	21%	25475	6%	435714	135
11039	0	0%	317682	49%	334893	51%	1493	0%	654068	135
11137	0	0%	440499	83%	88709	17%	0	0%	529208	135
11234	0	0%	84087	14%	498205	86%	0	0%	582292	130
11332	0	0%	376771	71%	156465	29%	0	0%	533236	130
11421	0	0%	412421	83%	1381	0%	83330	17%	497132	130
11430	0	0%	282266	52%	245075	46%	10498	2%	537839	130
11625	0	0%	328870	60%	202230	37%	17054	3%	548154	130
11879	0	0%	379227	82%	79430	17%	2365	1%	461022	140
11972	0	0%	450844	100%	0	0%	0	0%	450844	140
11974	0	0%	499334	98%	0	0%	9747	2%	509081	140
12070	0	0%	429379	100%	0	0%	0	0%	429379	140
12264	0	0%	500000	100%	0	0%	1209	0%	501209	140
12265	0	0%	379538	100%	0	0%	1004	0%	380542	140
12360	0	0%	291847	84%	0	0%	55872	16%	347719	143
12361	0	0%	377851	97%	0	0%	10658	3%	388509	140
12362	0	0%	479037	98%	0	0%	10036	2%	489073	140
12458	0	0%	323846	86%	0	0%	50659	14%	374505	143
12459	0	0%	317647	96%	0	0%	14093	4%	331740	140
12556	0	0%	449458	100%	0	0%	0	0%	449458	143

Appendix 3
Irreplaceable Sites within Focal Areas
(area in square meters)

Site	Forested Wetlands	% Forested	Estuarine Wetlands	% Estuarine	SAV	% SAV	Shellfish	% Shellfish	Total Habitat	Site Cost	Focal Area
2055	0	0%	300648	100%	0	0%	0	0%	300648	155	6
2154	0	0%	396398	100%	0	0%	0	0%	396398	148	6
2253	0	0%	447870	100%	0	0%	0	0%	447870	145	6
2293	421364	100%	0	0%	0	0%	0	0%	421364	170	1
2352	0	0%	374881	100%	0	0%	0	0%	374881	145	6
2353	0	0%	460187	100%	0	0%	0	0%	460187	145	6
2392	434940	100%	0	0%	0	0%	0	0%	434940	170	1
2491	428343	100%	0	0%	0	0%	0	0%	428343	170	1
2590	401019	100%	0	0%	0	0%	0	0%	401019	165	1
2665	0	0%	176690	52%	164045	48%	0	0%	340735	130	8
2689	306063	100%	0	0%	0	0%	0	0%	306063	165	1
2763	0	0%	141724	23%	465808	77%	0	0%	607532	135	8
2764	0	0%	300078	100%	0	0%	0	0%	300078	130	8
2789	324988	100%	0	0%	0	0%	0	0%	324988	165	1
2831	241145	100%	0	0%	0	0%	0	0%	241145	160	4
2832	224793	100%	0	0%	0	0%	0	0%	224793	160	4
2862	0	0%	326740	49%	334884	51%	0	0%	661624	135	8
2888	285581	100%	0	0%	0	0%	0	0%	285581	165	1
2931	407880	100%	0	0%	0	0%	0	0%	407880	160	4
2960	0	0%	17290	3%	492616	97%	0	0%	509906	135	8
2961	0	0%	244085	49%	258696	51%	0	0%	502781	135	8
2987	231965	100%	0	0%	0	0%	0	0%	231965	165	1
3030	264731	100%	0	0%	0	0%	0	0%	264731	160	4
3031	120618	32%	257456	68%	0	0%	0	0%	378074	155	4
3032	42497	10%	367786	90%	0	0%	0	0%	410283	155	4
3058	0	0%	117260	23%	387604	77%	0	0%	504864	135	8
3059	0	0%	351745	78%	101570	22%	0	0%	453315	135	8
3086	316557	100%	0	0%	0	0%	0	0%	316557	165	1
3157	0	0%	83702	16%	448538	84%	0	0%	532240	135	8
3158	0	0%	463314	98%	11413	2%	0	0%	474727	135	8
3186	349026	100%	0	0%	0	0%	0	0%	349026	165	1
3238	0	0%	193292	47%	0	0%	216421	53%	409713	150	5
3255	0	0%	0	0%	500000	100%	0	0%	500000	138	8
3256	0	0%	162677	32%	344107	68%	0	0%	506784	135	8
3257	0	0%	168247	99%	1942	1%	0	0%	170189	138	8
3337	0	0%	69874	42%	0	0%	97969	58%	167843	150	5
3338	0	0%	426589	53%	0	0%	377250	47%	803839	150	5
3354	0	0%	0	0%	500000	100%	0	0%	500000	138	8
3355	0	0%	206658	39%	323616	61%	4161	1%	534435	135	8
3435	0	0%	217283	56%	0	0%	170650	44%	387933	140	5
3436	0	0%	465825	56%	9482	1%	357372	43%	832679	143	5
3437	0	0%	283698	57%	0	0%	216939	43%	500637	150	5
3438	0	0%	55002	14%	0	0%	349433	86%	404435	150	5
3453	0	0%	0	0%	500000	100%	0	0%	500000	138	8
3454	0	0%	258104	54%	211063	44%	10424	2%	479591	135	8
3535	0	0%	233390	52%	0	0%	211668	48%	445058	150	5
3536	0	0%	82667	48%	35956	21%	53873	31%	172496	150	5
3537	0	0%	112617	46%	0	0%	130489	54%	243106	150	5
3552	0	0%	90060	17%	436163	83%	0	0%	526223	135	8
3634	0	0%	157933	49%	0	0%	165285	51%	323218	150	5
3636	0	0%	155668	43%	0	0%	202510	57%	358178	150	5
3640	0	0%	236942	85%	0	0%	40421	15%	277363	143	7
3641	0	0%	275051	89%	0	0%	33447	11%	308498	150	7
3650	0	0%	0	0%	500000	100%	0	0%	500000	135	8
3651	0	0%	417497	78%	115451	22%	0	0%	532948	135	8
3739	0	0%	347574	85%	0	0%	63512	15%	411086	150	7
3740	0	0%	279635	70%	44934	11%	75727	19%	400296	150	7
3748	0	0%	0	0%	467019	100%	0	0%	467019	133	8
3749	0	0%	159969	29%	398220	71%	0	0%	558189	135	8
3750	0	0%	267967	100%	0	0%	0	0%	267967	135	8
3839	0	0%	227103	55%	169374	41%	19120	5%	415597	136	7
3847	0	0%	0	0%	500000	100%	0	0%	500000	133	8
3848	0	0%	237549	42%	331462	58%	0	0%	569011	130	8
3936	0	0%	204661	66%	74894	24%	28781	9%	308336	133	7
3938	0	0%	138568	57%	28852	12%	75053	31%	242473	130	7
3946	0	0%	20125	4%	486852	96%	0	0%	506977	130	8
3947	0	0%	307665	53%	271611	47%	0	0%	579276	130	8
4036	0	0%	372005	78%	34729	7%	68316	14%	475050	130	7
4037	0	0%	265659	74%	42439	12%	51255	14%	359353	130	7
4044	0	0%	0	0%	500000	100%	0	0%	500000	130	8
4045	0	0%	155257	28%	405048	72%	1822	0%	562127	130	8
4046	0	0%	116254	80%	27074	19%	1194	1%	144522	130	8
4135	0	0%	295253	78%	35757	10%	45233	12%	376243	123	7
4143	0	0%	41229	8%	500000	92%	0	0%	541229	130	8

Appendix 3
Irreplaceable Sites within Focal Areas
(area in square meters)

4144	0	0%	407894	76%	120333	22%	10128	2%	538355	130	8
4242	0	0%	53929	10%	500000	90%	0	0%	553929	130	8
4243	0	0%	242851	61%	124862	32%	27727	7%	395440	130	8
4341	0	0%	198433	33%	402268	67%	0	0%	600701	130	8
4397	0	0%	218446	96%	0	0%	9399	4%	227845	140	3
4400	0	0%	320707	85%	55411	15%	0	0%	376118	140	3
4401	0	0%	230347	79%	58300	20%	3639	1%	292286	140	3
4439	0	0%	0	0%	498877	99%	2866	1%	501743	133	8
4440	0	0%	118153	19%	409133	67%	83487	14%	610773	130	8
4495	0	0%	121571	93%	0	0%	8558	7%	130129	140	3
4496	0	0%	208961	99%	0	0%	2275	1%	211236	140	3
4497	0	0%	300067	100%	0	0%	0	0%	300067	140	3
4498	0	0%	300974	89%	38261	11%	0	0%	339235	140	3
4499	0	0%	452438	79%	119980	21%	1143	0%	573561	140	3
4500	0	0%	395362	93%	24314	6%	6107	1%	425783	140	3
4536	0	0%	76735	13%	500000	86%	1890	0%	578625	130	8
4537	0	0%	95034	18%	442533	82%	1205	0%	538772	130	8
4538	0	0%	27669	6%	440335	94%	0	0%	468004	130	8
4539	0	0%	249520	75%	60045	18%	21374	6%	330939	130	8
4593	0	0%	121206	94%	0	0%	7506	6%	128712	133	3
4594	0	0%	297237	100%	0	0%	0	0%	297237	140	3
4595	0	0%	416846	100%	0	0%	1599	0%	418445	140	3
4596	0	0%	226999	99%	0	0%	2687	1%	229686	140	3
4597	0	0%	188415	80%	48225	20%	0	0%	236640	140	3
4598	0	0%	359172	90%	41044	10%	0	0%	400216	140	3
4636	0	0%	98714	17%	483973	83%	2102	0%	584789	130	8
4637	0	0%	83982	18%	375688	82%	0	0%	459670	130	8
4691	0	0%	44353	100%	0	0%	0	0%	44353	133	3
4692	0	0%	403657	99%	0	0%	2428	1%	406085	133	3
4693	0	0%	339302	100%	0	0%	0	0%	339302	140	3
4694	0	0%	492235	99%	0	0%	2811	1%	495046	140	3
4696	0	0%	212920	69%	95299	31%	2356	1%	310575	140	3
4789	0	0%	121555	100%	0	0%	0	0%	121555	136	3
4790	0	0%	203357	100%	0	0%	0	0%	203357	133	3
4791	0	0%	247456	93%	0	0%	18437	7%	265893	140	3
4792	0	0%	244634	99%	0	0%	1343	1%	245977	140	3
4793	0	0%	53036	100%	0	0%	0	0%	53036	140	3
4888	0	0%	240112	100%	0	0%	0	0%	240112	140	3
4889	0	0%	495912	100%	0	0%	0	0%	495912	140	3
4890	0	0%	339930	97%	0	0%	9966	3%	349896	140	3
4891	0	0%	289924	99%	0	0%	2705	1%	292629	140	3
4986	0	0%	299118	90%	0	0%	34592	10%	333710	143	3
4987	0	0%	500000	98%	0	0%	11968	2%	511968	140	3
4988	0	0%	445164	98%	0	0%	10968	2%	456132	140	3
4989	0	0%	197300	97%	0	0%	5812	3%	203112	140	3
5084	0	0%	156292	80%	0	0%	40008	20%	196300	140	3
5085	0	0%	473534	85%	0	0%	85523	15%	559057	143	3
5086	0	0%	355973	95%	0	0%	17037	5%	373010	140	3
5087	0	0%	107972	96%	0	0%	4139	4%	112111	140	3
5183	0	0%	301524	100%	0	0%	0	0%	301524	143	3
5184	0	0%	414960	96%	0	0%	18245	4%	433205	143	3
5281	0	0%	264124	100%	0	0%	0	0%	264124	140	3
5282	0	0%	323192	100%	0	0%	0	0%	323192	143	3
5283	0	0%	130618	100%	0	0%	0	0%	130618	150	3
5380	0	0%	336108	100%	0	0%	0	0%	336108	143	3
5478	0	0%	319412	100%	0	0%	0	0%	319412	140	3
6263	0	0%	115941	59%	0	0%	79564	41%	195505	140	2
6265	0	0%	352705	100%	0	0%	0	0%	352705	140	2
6361	0	0%	263373	98%	0	0%	5180	2%	268553	140	2
6362	0	0%	488392	100%	0	0%	1657	0%	490049	140	2
6363	0	0%	408896	93%	0	0%	33020	7%	441916	140	2
6460	0	0%	389883	100%	0	0%	894	0%	390777	140	2
6461	0	0%	213909	100%	0	0%	0	0%	213909	140	2
6559	0	0%	375744	99%	0	0%	4530	1%	380274	140	2
6657	0	0%	353047	100%	0	0%	0	0%	353047	140	2
9361	0	0%	317873	100%	0	0%	0	0%	317873	155	6
9459	0	0%	377171	100%	0	0%	0	0%	377171	155	6
9557	0	0%	472417	100%	0	0%	0	0%	472417	148	6
9596	346798	100%	0	0%	0	0%	0	0%	346798	170	1
9655	0	0%	401972	100%	0	0%	0	0%	401972	148	6
9656	0	0%	443778	100%	0	0%	0	0%	443778	145	6
9754	0	0%	224737	100%	0	0%	0	0%	224737	145	6
9965	0	0%	161650	31%	356765	69%	0	0%	518415	130	8
9989	236168	100%	0	0%	0	0%	0	0%	236168	165	1
10063	0	0%	252379	56%	197881	44%	0	0%	450260	135	8

Appendix 3
Irreplaceable Sites within Focal Areas
(area in square meters)

10087	453586	100%	0	0%	0	0%	0	0%	453586	165	1
10130	295470	100%	0	0%	0	0%	0	0%	295470	160	4
10161	0	0%	369378	84%	70632	16%	0	0%	440010	138	8
10185	388389	100%	0	0%	0	0%	0	0%	388389	165	1
10227	335458	100%	0	0%	0	0%	0	0%	335458	160	4
10228	408083	100%	0	0%	0	0%	0	0%	408083	160	4
10259	0	0%	276481	99%	2937	1%	0	0%	279418	138	8
10283	315657	100%	0	0%	0	0%	0	0%	315657	165	1
10327	382286	77%	112063	23%	0	0%	0	0%	494349	160	4
10328	299176	86%	47398	14%	0	0%	0	0%	346574	155	4
10355	0	0%	196546	38%	318321	62%	0	0%	514867	135	8
10356	0	0%	78149	20%	314336	80%	0	0%	392485	135	8
10381	283890	100%	0	0%	0	0%	0	0%	283890	165	1
10426	42839	13%	277443	87%	0	0%	0	0%	320282	155	4
10452	0	0%	0	0%	500000	100%	0	0%	500000	138	8
10453	0	0%	460314	97%	16487	3%	0	0%	476801	135	8
10454	0	0%	198359	79%	51761	21%	0	0%	250120	135	8
10480	376929	100%	0	0%	0	0%	0	0%	376929	165	1
10550	0	0%	0	0%	500000	100%	0	0%	500000	138	8
10551	0	0%	290768	63%	172690	37%	0	0%	463458	135	8
10578	313272	100%	0	0%	0	0%	0	0%	313272	165	1
10630	0	0%	264505	48%	0	0%	281514	52%	546019	143	5
10631	0	0%	0	0%	0	0%	3399	100%	3399	150	5
10648	0	0%	0	0%	500000	100%	0	0%	500000	138	8
10649	0	0%	417119	90%	46370	10%	0	0%	463489	135	8
10728	0	0%	28360	22%	0	0%	100706	78%	129066	143	5
10729	0	0%	328697	59%	0	0%	227614	41%	556311	150	5
10746	0	0%	0	0%	500000	100%	0	0%	500000	135	8
10747	0	0%	161159	97%	4144	3%	0	0%	165303	135	8
10826	0	0%	147861	54%	0	0%	125675	46%	273536	143	5
10827	0	0%	351449	59%	0	0%	241484	41%	592933	150	5
10843	0	0%	0	0%	500000	100%	0	0%	500000	138	8
10844	0	0%	108642	18%	456613	76%	33930	6%	599185	135	8
10926	0	0%	365771	49%	0	0%	388150	51%	753921	150	5
10931	0	0%	346185	90%	0	0%	39427	10%	385612	150	7
10941	0	0%	76327	13%	494744	87%	0	0%	571071	135	8
10942	0	0%	320135	73%	90104	21%	25475	6%	435714	135	8
11024	0	0%	175302	63%	0	0%	104418	37%	279720	143	5
11029	0	0%	322672	87%	955	0%	48169	13%	371796	150	7
11038	0	0%	0	0%	500000	100%	0	0%	500000	138	8
11039	0	0%	317682	49%	334893	51%	1493	0%	654068	135	8
11127	0	0%	238979	63%	105974	28%	33346	9%	378299	143	7
11136	0	0%	39983	7%	500000	93%	0	0%	539983	130	8
11137	0	0%	440499	83%	88709	17%	0	0%	529208	135	8
11223	0	0%	379419	87%	2262	1%	52364	12%	434045	140	7
11224	0	0%	138608	47%	6970	2%	151549	51%	297127	133	7
11226	0	0%	156910	38%	252910	62%	0	0%	409820	133	7
11233	0	0%	0	0%	500000	100%	0	0%	500000	133	8
11234	0	0%	84087	14%	498205	86%	0	0%	582292	130	8
11235	0	0%	206767	95%	11234	5%	0	0%	218001	130	8
11323	0	0%	291155	68%	44768	10%	92762	22%	428685	130	7
11331	0	0%	0	0%	500000	100%	0	0%	500000	133	8
11332	0	0%	376771	71%	156465	29%	0	0%	533236	130	8
11420	0	0%	217770	55%	126311	32%	49874	13%	393955	123	7
11421	0	0%	412421	83%	1381	0%	83330	17%	497132	130	7
11429	0	0%	72564	13%	500000	87%	0	0%	572564	130	8
11430	0	0%	282266	52%	245075	46%	10498	2%	537839	130	8
11527	0	0%	90190	15%	500000	85%	0	0%	590190	130	8
11624	0	0%	21313	4%	500000	96%	0	0%	521313	130	8
11625	0	0%	328870	60%	202230	37%	17054	3%	548154	130	8
11722	0	0%	0	0%	500000	97%	17896	3%	517896	130	8
11723	0	0%	238866	81%	42098	14%	14762	5%	295726	130	8
11777	0	0%	213697	100%	0	0%	0	0%	213697	140	3
11778	0	0%	175049	99%	0	0%	1652	1%	176701	143	3
11780	0	0%	235436	91%	22171	9%	0	0%	257607	140	3
11781	0	0%	287518	93%	21548	7%	0	0%	309066	140	3
11818	0	0%	29492	6%	500000	94%	0	0%	529492	130	8
11820	0	0%	0	0%	500000	74%	178776	26%	678776	130	8
11874	0	0%	105495	99%	0	0%	1210	1%	106705	140	3
11875	0	0%	275193	100%	0	0%	0	0%	275193	140	3
11876	0	0%	317471	99%	0	0%	3413	1%	320884	140	3
11877	0	0%	133026	100%	0	0%	0	0%	133026	140	3
11878	0	0%	346492	86%	54596	14%	0	0%	401088	140	3
11879	0	0%	379227	82%	79430	17%	2365	1%	461022	140	3
11916	0	0%	181963	26%	500000	70%	28101	4%	710064	130	8

Appendix 3
Irreplaceable Sites within Focal Areas
(area in square meters)

11917	0	0%	113562	33%	219262	63%	14244	4%	347068	130	8
11918	0	0%	156417	37%	262488	62%	5413	1%	424318	130	8
11971	0	0%	35652	89%	0	0%	4339	11%	39991	133	3
11972	0	0%	450844	100%	0	0%	0	0%	450844	140	3
11973	0	0%	281721	100%	0	0%	0	0%	281721	140	3
11974	0	0%	499334	98%	0	0%	9747	2%	509081	140	3
11976	0	0%	322638	89%	35471	10%	2841	1%	360950	140	3
12015	0	0%	186416	48%	181841	47%	17257	4%	385514	130	8
12068	0	0%	35519	100%	0	0%	0	0%	35519	133	3
12069	0	0%	116969	96%	0	0%	4491	4%	121460	133	3
12070	0	0%	429379	100%	0	0%	0	0%	429379	140	3
12071	0	0%	280443	100%	0	0%	0	0%	280443	140	3
12072	0	0%	124385	100%	0	0%	0	0%	124385	140	3
12165	0	0%	63775	100%	0	0%	0	0%	63775	140	3
12166	0	0%	279845	100%	0	0%	0	0%	279845	140	3
12167	0	0%	164877	97%	0	0%	4610	3%	169487	140	3
12168	0	0%	315627	100%	0	0%	1181	0%	316808	140	3
12169	0	0%	6768	100%	0	0%	13	0%	6781	140	3
12263	0	0%	133658	94%	0	0%	8109	6%	141767	140	3
12264	0	0%	500000	100%	0	0%	1209	0%	501209	140	3
12265	0	0%	379538	100%	0	0%	1004	0%	380542	140	3
12266	0	0%	170639	97%	0	0%	5629	3%	176268	140	3
12360	0	0%	291847	84%	0	0%	55872	16%	347719	143	3
12361	0	0%	377851	97%	0	0%	10658	3%	388509	140	3
12362	0	0%	479037	98%	0	0%	10036	2%	489073	140	3
12363	0	0%	154949	96%	0	0%	6359	4%	161308	140	3
12458	0	0%	323846	86%	0	0%	50659	14%	374505	143	3
12459	0	0%	317647	96%	0	0%	14093	4%	331740	140	3
12460	0	0%	51250	99%	0	0%	760	1%	52010	140	3
12556	0	0%	449458	100%	0	0%	0	0%	449458	143	3
12557	0	0%	119103	100%	0	0%	0	0%	119103	143	3
12750	0	0%	275323	100%	0	0%	0	0%	275323	140	3
13624	0	0%	297904	100%	0	0%	0	0%	297904	140	2
13625	0	0%	357880	85%	0	0%	60870	15%	418750	140	2
13626	0	0%	330710	99%	0	0%	3079	1%	333789	140	2
13722	0	0%	169442	100%	0	0%	0	0%	169442	140	2
13723	0	0%	443241	100%	0	0%	0	0%	443241	140	2
13819	0	0%	326334	100%	0	0%	0	0%	326334	140	2
13820	0	0%	220722	100%	0	0%	0	0%	220722	140	2
13917	0	0%	265127	98%	0	0%	5623	2%	270750	140	2