

Exploration of MARXAN for Utility in Marine Protected Area Zoning

By

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B.Sc., University of Victoria, 2001

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ABSTRACT

There is a lack of tools for zoning marine protected areas (MPAs). MARXAN is a popular tool for MPA siting, and this thesis explores its use for zoning. MPA managers and zoning practitioners were interviewed in order to determine the requirements of zoning. This, combined with a literature review, informed the testing of several MARXAN settings. This testing was necessary due to poor existing documentation and the uncertainty associated with many settings. Finally, different methods for creating and combining zones were also developed.

Due to the complexity of MARXAN it is not possible to develop specific guidelines for many of the settings tested in this research. However, general trends for several settings were determined, and applied within the context of MPA zoning.

Preliminary zones were developed and combined using MARXAN's summed solution output, the results of which are ready for zone refinement with stakeholders and MPA planners.

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LIST OF ACRONYMS

BLM	Boundary Length Modifier
CPAWS	Canadian Parks and Wilderness Society
DFO	Fisheries and Oceans Canada
GIS	Geographic Information System
HREC	Human Research Ethics Committee
ICZM	Integrated Coastal Zone Management
MCA	Multiple Criteria Analysis
MPA	Marine Protected Area
MSRM	Province of British Columbia Ministry of Sustainable Resource Management (now contained within the Ministry of Agriculture and Lands)
NGO	Non-Governmental Organization
NMCA	National Marine Conservation Area
SPF	Species Penalty Factor
SSOG	Southern Strait of Georgia

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DEDICATION

This thesis is dedicated to my late grandmother, Dorien Dodd, who has inspired many aspects of my life. Thank you, Dammy.

CHAPTER ONE

INTRODUCTION

1.1 MARINE PROTECTED AREAS AND ZONING

The oceans are in trouble. Not only are species and habitats declining, but there is also increasing human conflict over the use and exploitation of this traditionally 'open resource' (National Research Council, 2001). Marine protected areas (MPAs), and specifically marine protected area zoning, with its emphasis on avoiding conflict, can assist in addressing these problems.

Marine protected areas were defined by the 1988 IUCN General Assembly in Resolution GA17.38 as:

Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment (Kelleher & Kenchington, 1992).

As demonstrated by this widely quoted definition, MPA is a broad term that can include many types and levels of protection (Nicholls, 1998). An MPA can be an area of complete protection (Roberts, 2000), of very little protection, as in so-called 'paper parks' (Dearden, 2002), or a multiple use area of varying protection, such as the Great Barrier Reef Marine Park (Day 2002, Cocks 1984).

While the establishment of large no-take and no-entry reserves is attractive, they are often not feasible due to social pressures and logistical issues. In addition, no-take / no-entry reserves are generally single species or habitat oriented. Multiple use

MPAs focus on entire ecosystems and the sustainable management of resources, and therefore are generally larger (Agardy *et al.*, 2003; Lubchenco *et al.*, 2003). Zoning is applied in multiple use MPAs to set aside certain key areas, while regulating the use of surrounding areas in a manner that reduces conflict and promotes sustainability. These multiple uses can include fishing, recreation, shipping, traditional use, and scientific study. Typically, zones fall into three basic categories: core protection, buffer, and use.

The process of developing zoning is a complicated task, and an inherently spatial problem. Huge amounts of spatial data must be weighted and combined according to the priorities and goals of a given area, which makes geographic information systems (GIS) a suitable tool for assisting with zoning. According to Villa *et al.* (2002) the complexity of zoning is beyond the capabilities of common sense decision-making and a systematic approach, attainable through the use of GIS, is necessary.

Zoning can be characterized as an optimization problem; the goal is to find the best (i.e. optimal) solution to a problem given a set of inputs and constraints. GIS can be used to identify simple 'hot spots' based on overlaps among layers, but used alone it does not have the ability to obtain optimal solutions to complex problems such as zoning. For this, specialized optimization algorithms are required to work in conjunction with the GIS. One such algorithm that has been applied to reserve site selection is simulated annealing, available through MARXAN software. Although simulated annealing has been applied successfully for siting MPAs (McDonnell *et al.*, 2002; Oetting & Knight, 2003; Possingham *et al.*, 2000; Stewart *et al.*, 2003), its applicability to MPA zoning remains largely unexplored. Such an exploration is the focus of this research.

1.2 PROBLEM DEFINITION

The problem this research aims to solve can be broken into two components: the Zoning Problem and the MARXAN Problem. The Zoning Problem relates to the complexity of MPA zoning. Comprehensive science-based zoning requires a large amount of information in order to incorporate economic, social, and biophysical factors. Not only should zoning solutions be efficient and effective, but they should also be adaptable and transparent. Adaptability and transparency are particularly critical, as they affect a zoning plan's ability to respond to changing conditions and gain public acceptance, respectively. Ad hoc approaches to zoning have been unable to meet many of these goals (Gonzales *et al.*, 2003; Stewart *et al.*, 2003; Villa *et al.*, 2002). There is a need, therefore, for a consistent and rigorous zoning methodology. The Zoning Problem can therefore be stated as: *How can optimal zoning configurations be developed to incorporate large amounts of data and stakeholder opinions while being transparent, repeatable, and scientific?*

A tool that has been used for MPA siting that also has potential for solving some of the issues of The Zoning Problem is reserve selection software called MARXAN (Ball & Possingham, 2000; Possingham & Andelman, 2000). MARXAN has the power to incorporate large quantities of information and it is flexible, allowing for the examination and comparison of numerous scenarios. As a result, it has emerged as a popular tool for siting marine reserves (Airamé *et al.*, 2003; Banks *et al.*, 2005; Evans, 2003; Geselbracht & Torres, 2005; Leslie *et al.*, 2003; Sala *et al.*, 2002; Stewart *et al.*, 2003). However, using MARXAN also presents several difficulties. Not only are there many settings to be adjusted within the software, but the effects of these adjustments on the solution are mostly undocumented and possibly unknown. Due to these gaps in understanding, trial and error has played a significant role in past

MARXAN use (Ardron, 2005a; Fernandez, 2005). In order for MARXAN to be useful for zoning, the various software settings and the effects of changes to these settings must be explored and tested. The MARXAN Problem can be stated as: *Can the use of MARXAN be streamlined, thereby removing some of the guesswork associated with its use?*

The research objectives and questions related to the Zoning Problem and the MARXAN Problem are discussed in Section 1.3.

1.3 RESEARCH OBJECTIVES AND QUESTIONS

The main objective of this research is to explore the use of simulated annealing (through MARXAN software) for MPA zoning. More specifically to:

- Test for stability under various conditions;
- Determine how MARXAN can contribute to MPA zoning; and
- Assist managers in making use of this tool.

These objectives are explored through the following research questions:

1. What are the requirements (data, analytical and decision making) for MPA zoning?
2. What effect do the size and shape of planning units have on the results of simulated annealing?
3. What, if any, is the 'cost' of data gaps?
4. Can some of the 'guess work' be taken out of MARXAN settings? Specifically, can guidelines be created to address the following questions:
 - a) What are the effects of different boundary length modifier values under different data and spatial conditions?
 - b) How can cost values be used to assign weights to different planning units?
 - c) What effect do different species penalty factors have on solutions?
5. How can individual zones be identified and combined to form a zoning plan using MARXAN?

1.4 STUDY AREA

The study site that has been selected for this research is the proposed Parks Canada Southern Strait of Georgia (SSOG) National Marine Conservation Area (NMCA) located on the south west coast of British Columbia (Figure 1.1). Although only in a feasibility stage, this area was chosen because Parks Canada has amassed, and made available, large amounts of data. The SSOG NMCA also has an interest in the possibility of using MARXAN to help create zoning. It is important to note that the preliminary zones presented in this research are not meant in any way to be prescriptions for the SSOG; they are merely tests and should be treated as such. Nor is this work meant to preclude Parks Canada's zoning process.

Figure 1.1: General location of the proposed Southern Strait of Georgia NMCA. (Boundaries have not yet been defined)



1.5 THESIS ORGANIZATION

Chapter Two, the literature review, introduces the tools and concepts employed in this research. These include marine protected areas, zoning, GIS, and MARXAN / simulated annealing settings. Also included are examples of relevant research that has been conducted in each area.

Chapter Three describes the methods used in this research. It is divided into four sections: expert interviews, spatial data integration, MARXAN testing, and zoning development.

Chapter Four, the functional requirements study, presents an overview of the objectives and requirements for zoning, including data, analysis, users / participants, and decision support. This chapter is based on the results of interviews with zoning experts and the literature review.

Chapter Five presents and discusses the results of MARXAN testing including planning unit size and shape, data gaps, boundary length modifier, planning unit costs, and species penalty factors.

Chapter Six presents and discusses the results of testing three methods for developing and combining zones using MARXAN.

Chapter Seven is a discussion of MARXAN shortcomings. It also addresses the position of MARXAN within zoning, and potential directions for future research.

Chapter Eight concludes with an overview of key findings and contributions.

CHAPTER TWO

LITERATURE REVIEW

2.1 MARINE PROTECTED AREAS

This section introduces marine protected areas, describes how and why they are established, and presents some of the challenges associated with developing and managing them.

Marine protected areas have been variously described depending on purpose and level of protection (Agardy *et al.*, 2003). MPA terms include: marine park; marine reserve; fisheries reserve; closed area; marine sanctuary; nature reserve; ecological reserve; replenishment reserve; marine management area; coastal preserve; sensitive sea area; biosphere reserve; no-take area; coastal park; marine conservation area; and marine wilderness area.

From this point forward the term *MPA* will be defined as a multiple use marine area with varying levels of protection established through zoning. Included within the MPA will be a zone of complete protection, sometimes referred to as a reserve, or no-take area (Lam, 1998).

Marine protected areas are established for various scientific, economic, cultural and ethical reasons (Boersma & Parrish, 1999). These include: resolving conflicts, replenishing populations, conserving critical habitat, maintaining or restoring biodiversity, buffering against management error and environmental uncertainty, increasing the reproductive potential of economically important species, contributing to social and economic well-being, protecting heritage or traditional use

sites, and increasing educational, scientific, or tourist value (Agardy *et al.*, 2003; Allison *et al.*, 1998; Boersma & Parrish, 1999; Parsons *et al.*, 1998; Shirai & Harada, 2003; Villa *et al.*, 2002).

MPAs have been established around the world, and although many different processes and driving factors have contributed to their formation, public involvement is common to many (Airame *et al.*, 2003; Cowie-Haskell & Delaney, 2003; Great Barrier Reef Marine Park Authority, 2003b; etc...). Section 2.4.3 discusses the importance of stakeholder involvement in MPA siting and zoning processes.

One of the challenges of MPA establishment and management is the uncertainty associated with our understanding of marine processes (Grafton & Kompas, 2004). The ever-changing, permeable nature of the ocean makes it virtually impossible to fully understand the distribution of marine species and ecosystems. For this reason, the designation of an MPA should not be postponed due to incomplete data (Agardy, 2000; Kelleher & Recchia, 1998; Roberts, 2000; Salomon *et al.*, 2002.). Tools such as adaptive management can be used to refine boundaries and regulations once new data are discovered (Agardy *et al.*, 2003).

Guidelines for adaptive management, as well as the goals, objectives, and strategies for the MPA, are contained in a management plan (Gilman, 2002). A good management plan is critical for a successful MPA, and it should be tailored to address the specific ecological, cultural, and socio-economic problems an MPA is meant to address (Agardy, 2000). An important component forming the foundation of an MPA management plan is the zoning plan, which outlines zoning expectations (Kelleher, 1999; Salm *et al.*, 2000).

2.2 ZONING

Multiple use MPAs must balance a variety of uses and values including fishing, tourism, commerce, aquaculture, preserving natural features, conservation, biodiversity, cultural values, and historical features (Gilman, 2002). Some of these activities can co-exist, but others are more likely to conflict (Bohnsack, 1996). Zoning is a tool that can be used to separate conflicting uses, usually in space, but also in time, and to protect especially valuable/rare ecosystems within an MPA, while also supporting sustainability, conservation and cultural values (Agardy *et al.*, 2003; Day, 2002).

According to Kelleher & Kenchington (1992), the goals of MPA zoning are to:

- conserve the MPA in perpetuity;
- provide protection to critical/representative habitats, ecosystems, and ecological processes while allowing reasonable human uses;
- separate conflicting human activities and to minimize the effects of these uses on the MPA; and
- preserve certain areas of the MPA in their natural state, undisturbed by humans, unless for the purpose of research or education.

Salm *et al.* (2000) summarize these goals into three criteria for zoning: 1) sensitive habitats should be protected; 2) intensive uses should be confined to sites that can sustain them; and 3) incompatible activities should be separated.

There are three general categories of zones typically included in MPA zoning: core zones with a high level of protection; buffer zones that shield other zones from outside influences; and use zones, where human activities are allowed (Salm *et al.*, 2000).

Core zones are strictly protected areas where the objective is to preserve or restore the area to its natural state (Kelleher, 1999). These zones of complete protection are found in almost every multiple-use MPA, and it is generally recognized that they are the most important and should be delineated first (Salm *et al.*, 2000).

Buffer zones are transition areas of moderate protection (Day, 2002). They often surround core areas and attempt to minimize conflict between zones.

Use zones, which allow a range of human activities, typically offer lower levels of protection and fewer restrictions. Often they are separated into extractive and non-extractive uses such as tourism or recreation (Kelleher & Kenchington, 1992; Villa *et al.*, 2002), although traditional use, such as hunting and fishing, may also be included in these zones (Kelleher, 1999). Use zones are meant to allow opportunities for general use that do not interfere with the conservation goals of an MPA (Kelleher, 1999).

In addition to the three categories of spatial zones outlined above, temporal and vertical zoning have also been applied within MPAs (Day, 2002; National Research Council, 2001). Temporal zoning (also known as a seasonal closure) is applied when a temporary condition, such as breeding or spawning, requires that an area be protected (Clark, 1996). Vertical zoning has been applied in instances where the object being protected is located below a certain depth, allowing extractive uses to continue above that feature. An example is the application of depth restrictions on fishing gear to protect the Tasmanian Seamounts in Australia (Day, 2002).

Zoning schemes vary between MPAs, since each one is unique, both in form and purpose. There are, however, general guidelines for zoning that are applicable to any MPA:

- sudden transitions between zones (i.e. going from high protected to little protection) should be avoided (Day, 2002; Kelleher, 1999; Kelleher & Kenchington, 1992);
- zoning should be kept as simple as possible, by minimizing the number of zone types and by using easily understood names and descriptions for zones (Day, 2002; Kelleher & Kenchington, 1992; Villa *et al.*, 2002);
- core zones of full protection should be representative of the range of habitat types and marine communities in the area (Day, 2002; Franklin *et al.*, 2003; Turpie *et al.*, 2000); and
- stakeholders should be involved in the zoning process as this will more likely result in sustained public support (Day, 2002; Kelleher & Kenchington, 1992; Villa *et al.*, 2002).

There are many methods for developing zoning schemes (almost as many as there are different MPAs with zoning); some are based mainly on stakeholder opinion and/or visualization, some are based on scientific analysis, and others combine the two techniques. In all cases a set of criteria is used to determine the value of each area in the MPA, whether for recreation, fishing, scientific research, or protection purposes. Even when zoning is developed through stakeholder consensus rather than scientific modeling a set of criteria forms the basis for that decision. Some of the criteria that have been used include:

- Are there endangered species in the MPA? ^{1,2,4}
- Where are areas of high biodiversity (species and/or habitats)? ^{3,4}
- Are any areas used by key migrating species? ^{1,2,4}
- Where are key habitats? ^{1,2,3,4}
- Are there spawning grounds? ^{2,3}
- What is the direction of the prevailing ocean current? ³
- What species are being targeted by fisheries? ^{1,3}
- What yields are the fisheries obtaining? ^{1,2,3,4}
- Where are the most popular fishing/resource extraction spots? ^{1,3,4}
- What importance does an area hold economically? ³

- What areas are suitable/popular for tourist and recreation use? ^{2,4}
- Are there areas of historical / cultural significance (including fishing grounds)? ^{1,2,4}

¹ Klaus *et al.*, 2003

² Villa *et al.*, 2002

³ Horrill *et al.*, 1996

⁴ Great Barrier Reef Marine Park Authority, 2003a

Zoning is a complex problem that requires large amounts of data to encompass the range of factors that must be considered (see Appendix I for a list of data suitable for developing zoning). The majority of these data are spatial in nature. Geographic information systems (GIS), which are specifically geared towards spatial problem solving, are therefore well suited for zoning.

2.3 APPLICATION OF GEOGRAPHIC INFORMATION SYSTEMS TO MPA ZONING

Geographic information systems (GIS) are computer-based tools that aid in the display and analysis of geographically based (spatial) information (Clarke, 2001). GIS has been applied across disciplines and is viewed as a key tool for supporting spatial decision-making in the marine environment (Canessa & Keller, 2003; Cicin-Sain & Knecht, 1998; Fabbri, 1998).

According to Bartlett (1999), GIS is an ideal tool for marine planning for several reasons: it can handle large data sets; data can be shared easily; and it offers the ability to test, model, and compare strategies before implementation. While a non-GIS based approach may be able to obtain an answer to a question such as, *where is the best place for a given activity?*, it does not have the flexibility to explore 'what if' questions such as, *what if this area is included in a different zone?* (Wright *et al.*, 1998). GIS-based methods have the potential to provide a scientific robustness, transparency to stakeholders (Lewis *et al.*, 2003) and objectivity (Wright *et al.*, 1998)

that are not possible with ad-hoc methods (Stewart *et al.*, 2003). The term *ad hoc* is used here to refer to zoning processes that are typically not transparent and are based mostly on opinions and intuition. At the most extreme level this type of zoning is characterized by 'drawing circles on maps' to decide where zones should be located.

GIS has been used to aid in the development of MPAs around the world (Airamé *et al.*, 2003; Lieberknecht *et al.*, 2004; Scholz *et al.*, 2004; Villa *et al.*, 2002). A technique called multiple-criteria analysis, where different data layers are overlaid and weighted, has been used to create marine zones (Villa *et al.*, 2002), though it has been mostly used for terrestrial zoning (Gole, 2003; Hepcan, 2000; Trisurat *et al.*, 1990). For the most part, the role of GIS for zoning has been supportive. It has been used to display features and proposed zones (MacNab, 2004), and to develop models that were used in zoning (Parker, 2004). In these cases, the actual zones were developed through ad-hoc processes where experts and, to a lesser degree, stakeholders decided where zones should be located.

Recently a powerful GIS-based method for siting marine protected areas, which can also assist with zoning, was developed in Australia. Software called MARXAN, which works in conjunction with GIS, runs a site selection algorithm called simulated annealing. MARXAN can be thought of as a GIS extension since it cannot function independently. The GIS is used to demarcate planning units that divide the study area, to determine which data (called species) fall within each planning unit, and to set targets for the amount of each species to include in the solution. Once the GIS has been used to prepare the data MARXAN runs the simulated annealing algorithm which selects planning units that best meet targets. Simulated annealing is discussed in the next section.

2.4 SIMULATED ANNEALING FOR RESERVE DESIGN

Quickly emerging as a popular reserve siting method, an optimization algorithm called simulated annealing has been shown to select reserve locations superior to those identified through ad-hoc methods (Stewart *et al.*, 2003). In fact, simulated annealing achieves near-optimal results (Angelis & Stamatellos, 2004). Because of the complexity of reserve siting problems, the amount of time required to find optimal solutions would be prohibitive (Stewart *et al.*, 2003). Thus heuristic methods, which find good and often near-optimal solutions, are used (McDonnell *et al.*, 2002). Numerous MPA practitioners recognize simulated annealing as the superior heuristic algorithm for solving site selection problems (McDonnell *et al.*, 2002; Oetting & Knight, 2003; Possingham *et al.*, 2000; Stewart *et al.*, 2003). When compared with other heuristic algorithms, such as greedy and rarity based, simulated annealing provides consistently better (i.e. closer to optimal) solutions (Stewart *et al.*, 2003).

In 1953 Metropolis *et al.* developed a Monte Carlo-based algorithm that simulates the crystallization (annealing) process of a solid (Angelis & Stamatellos, 2004). In 1983 Kirkpatrick *et al.* introduced a general purpose optimization technique based on Metropolis' algorithm, called simulated annealing (SA), that is capable of finding exact or approximate solutions to diverse problems that are otherwise difficult to solve. The algorithm is modeled after the cooling process that brings a solid to a ground state of minimum energy (Angelis & Stamatellos, 2004). If the rate of cooling is controlled (i.e. slowed) the molecules in the solid will come to rest in an optimum configuration, resulting in a strong solid (Tang, 2004).

2.4.1 MARXAN and Simulated Annealing Components

2.4.1.1 Objective Function

The SA algorithm attempts to find the lowest possible value of an objective function, which is simply a combination of the cost of the selection and a penalty for not meeting targets (Ball & Possingham, 2000). The lower the value of the objective function, the better the solution (modified from Ball and Possingham, 2000):

$$\text{Objective Function} = \sum \text{Cost} + (\text{BLM} * \sum \text{Boundary}) + \sum (\text{SPF} * \text{Penalty}) \quad (1)$$

where

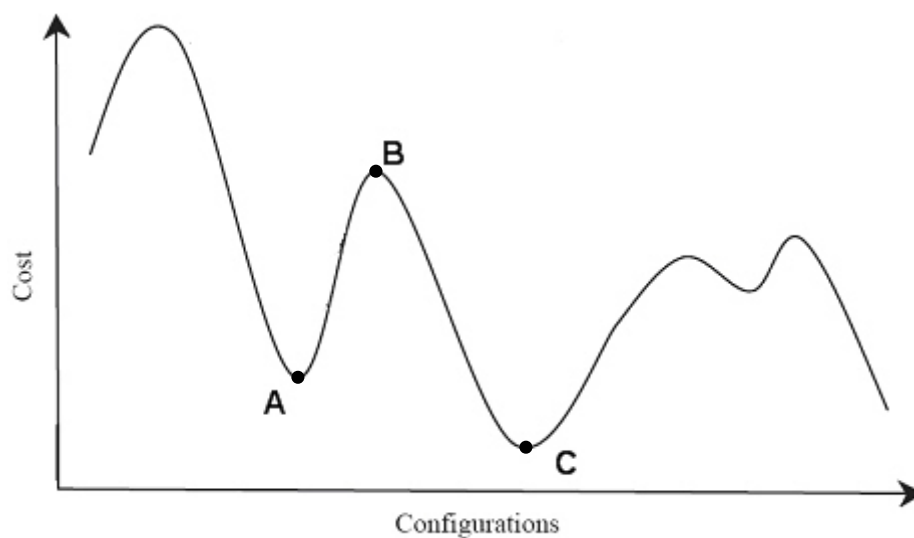
- **Cost** is the cost of the selected planning units, which can be measured as their combined area, an economic or social cost, or any combination of these (see Section 2.4.1.5).
- **BLM** is the boundary length modifier, which controls the importance of the boundary length relative to the cost of the selected units. If it is zero then the boundary length is not considered (see Section 2.4.1.6).
- **Boundary** is the length of the boundary surrounding the selected areas (perimeter)
- **SPF** is the species penalty factor, which controls the influence of the Penalty for not meeting the target for each species (see Section 2.4.1.7).
- **Penalty** is a value added to the objective function for every target that is not met. It is based on the additional boundary length and cost that would be needed to represent a species' target that is not met (see Section 2.4.1.7).

In most heuristic algorithms only downhill moves (those that move the solution towards lower objective function values) are accepted, and downhill movement is as fast as possible (Tang, 2004). While these algorithms are generally much faster than SA (Possingham *et al.*, 2000), which is sometimes referred to as a slow algorithm (Tang, 2004), they can get trapped in local optima (Angelis & Stamatellos, 2004). Because simulated annealing has the ability to escape from local optima (see Figure

2.1), it is generally recognized as the most effective algorithm available for site selection (Oetting & Knight, 2003).

Figure 2.1: Local optima.

Point A is an example of local optima. However, point C offers a better solution. Without the uphill move between A and B the solution at C would not have been discovered (Modified from Tang, 2004).



A run of the SA algorithm can be summarized by the following pseudocode (adapted from Ball & Possingham 2000; 2001):

1. Generate a random selection of planning units and evaluate the objective function value of the selection.
2. Choose a unit at random and swap it for another unit not included in the selection.
3. Evaluate the acceptability of the swap in step 2 (this depends on the progress of the algorithm – the closer you are to the end of an iteration, i.e. the lower the freezing parameter, the less likely it is to accept changes that increase the objective function value): if it is deemed acceptable, then the swap is maintained.
4. Repeat steps 2 and 3 for the set number of perturbations.
5. Decrease the freezing parameter and repeat steps 2 through 4 for a given number of iterations. (More information on simulated annealing including freezing parameters can be found in Appendix II)

The solution offered by simulated annealing is, in most cases, near-optimal (Angelis & Stamatellos, 2004). Because of the random element in the algorithm, each run (which is composed of multiple iterations of the algorithm) results in a slightly different solution (Lieberknecht *et al.*, 2004). For this reason, the algorithm is often run repeatedly in the same area, and the results of the runs are combined to produce a solution that approaches optimum. Summed solutions, which are a common way to evaluate combined runs, are discussed below.

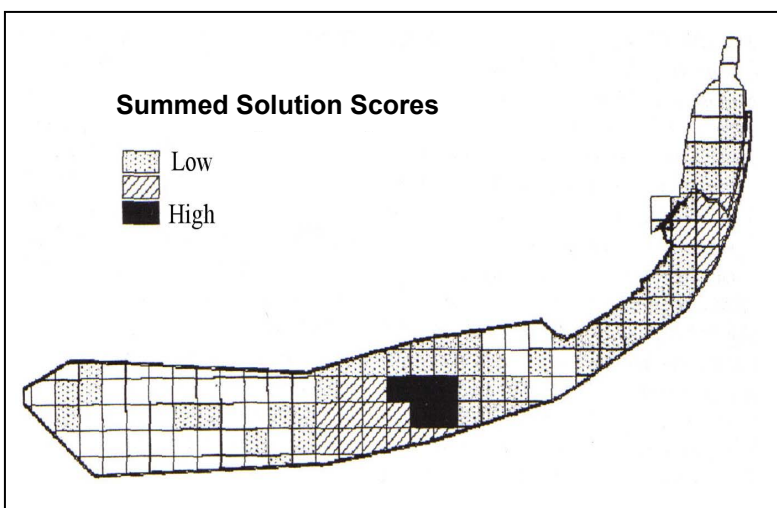
2.4.1.2 Summed Solutions

MARXAN provides two outputs from each analysis; the solution of the 'best' run (i.e. the one with the lowest objective function value), and a summed solution that shows the number of times each planning unit was included in a run solution. If, for example, the number of runs were set to 100, the summed solution would contain values ranging from 0 (never included in a run's solution) and 100 (included in all the 100 runs' solutions). Figure 2.2 shows a summed solution whose values have been divided into three categories; high, medium and low. Those planning units of high importance have the highest summed value, and are therefore the most important for meeting targets. These areas can be thought of as hotspots. Just because planning units are not included in the 'best' solution does not mean they do not have value and it is important to note that the high value units may or *may not* be part of the 'best' solution.

The summed solution is useful because, unlike the 'best' solution, it provides an indication of the relative importance of each planning unit by assigning each one a value.

Using summed solutions adds flexibility to the selection process. This allows reserve developers, including stakeholders, to visualize the locations of hotspots (high value planning units) and of units that can be swapped in and out of the reserve (medium and low value planning units). This creates more opportunities for negotiation and, ultimately, for consensus during stakeholder consultation and other processes.

Figure 2.2: Summed solution (modified from Leslie *et al.*, 2003). Units of high value are the most important for meeting targets.



2.4.1.3 Planning Units

Planning units are the building blocks of a reserve system. They are the units that MARXAN evaluates and selects to form solutions. Planning units can be based on natural, administrative, or arbitrary features (Pressey & Logan, 1998), and they can be of any shape or size.

Table 2.1 shows the range of planning unit shapes and sizes that have been used for past MARXAN applications.

Table 2.1: Shape and size of planning units from previous MARXAN applications.

Study Area	Study Area Size (km ²)	Planning Unit Size (km ²)	Planning Unit Shape	Details	Reference
Belize (Marine)	59,570	10	Hexagonal		Meerman, 2005
Channel Islands, USA (Marine)	4294	3.4 (1x1 nautical mile)	Square	1x1 minute grid follows Lat. Long. lines	Airamé <i>et al.</i> , 2003
Irish Sea (Marine)	Approx. 57,000	Variable size; none > 24.6	Square and irregular	Planning units based on marine 'landscape' units	Lieberknecht <i>et al.</i> , 2004
British Columbia Central Coast (Marine)	22,303	4.9	Hexagonal		CIT, 2003
Florida coast (Marine)	280,356	14.8	Hexagonal		Geselbracht & Torres, 2005
Southern Rockies, USA (Terrestrial)	165,589	9.8	Hexagonal		Miller <i>et al.</i> , 2003
Southern Australia (Marine)	77,975	25	Square		Stewart <i>et al.</i> , 2003
Florida coast (Marine)	136,014	2.17	Hexagonal	Size of planning units due to MARXAN limitation of 65,000	Oetting & Knight, 2005
Florida Keys (Marine)	9500	1	Square		Leslie <i>et al.</i> , 2003
South Okanagan, Canada (Terrestrial)	1,568	0.155, 2, and 10 (3 sizes tested)	Hexagonal		Warman, 2001

There are three equilateral shapes that can be joined together to form grids: triangles, squares and hexagons. Appendix III shows these grids, and demonstrates that shapes with more than six sides cannot be gridded evenly. The two most common shapes used for reserve planning are squares (for example; Airamé *et al.*, 2003) and hexagons (for example; Ardron *et al.*, 2002), although irregular polygonal shapes have also been used (for example; Lewis *et al.*, 2003).

The majority of MARXAN analyses have used hexagonal planning units (CIT, 2003; Geselbracht *et al.*, 2005; Meerman, 2005; Miller *et al.*, 2003; Oetting & Knight, 2005; Polasky *et al.*, 2000; Warman, 2001), though a good number have also used squares (Airamé *et al.*, 2003; Leslie *et al.*, 2003; Lieberknecht *et al.*, 2004; Stewart *et al.*, 2003). Scientific comparisons between the two shapes in the context of reserve siting have not been conducted. Rationales for the use of square units are not found in the literature, whereas they are often given when hexagonal units are used. The rationales given for using hexagons include: solutions appear more 'natural' (Geselbracht *et al.*, 2005); their shape approximates a circle, which has a low edge to area ratio (Miller *et al.*, 2003); they provide a relatively smooth output (*ibid*); and they have a smaller perimeter to area ratio than squares of the same area (Warman, 2001).

Several studies have used irregular planning units (for example Gonzales *et al.*, 2003; Sala *et al.*, 2002). However, problems arise when planning units of different sizes or shapes are used in the same analysis. For example, Warman (2001) found that large planning units were often selected over smaller units. The Coast Information Team, which also encountered this problem, prescribed the use of regular grids to remove this area bias (CIT, 2003). Irregular units are appropriate in areas where a large amount of information is available across the study area. However, according to

Groves (2003), a regular grid is more suited to areas where the planning situation is especially complex, or data are missing.

A situation where irregular planning units would be favourable is when a particular natural feature needs to be treated as a single unit in analysis. For example, in order to avoid fragmentation, the Coast Information Team (CIT, 2003) used linear shoreline units as planning units, and the Great Barrier Reef used coral reefs as planning units (Lewis *et al.*, 2003).

The size of planning units must also be decided. Many different rationales have been used to justify planning unit size choices (Warman *et al.*, 2004). Hardware limitations can mean that the number of planning units have to be decreased in order to run the software (see for example Meerman, 2005). The size of units has also been based on the distribution of natural features (Geselbracht & Torres, 2005; Lewis *et al.*, 2003). Open ocean areas where there are few features do not require the same level of planning unit detail as more complex coastal areas.

Data scale is the most frequent reason given for planning unit size choice (Airamé *et al.*, 2003; Evans, 2003; Meerman, 2005; Miller *et al.*, 2003). This ties in with conventional GIS wisdom, which dictates that combined data can only be used at the coarsest level (smallest scale), otherwise a level of detail is implied that is not present. Contrarily, Ardron (2005b) uses all data at the finest scale when conducting reserve design. He argues that over sampling a coarser feature (i.e. using a smaller planning unit size) will not adversely affect results, whereas under sampling (i.e. using a larger grid size) will cause information to be lost and produce inferior results. In fact, Pressey & Logan (1998) and Warman (2004) reported that smaller selection units found more efficient solutions than larger ones.

A factor that limits the planning unit size is the number of planning units that can be processed by MARXAN. Oetting and Knight (2005) found that MARXAN does not “function correctly” (p.16) when more than approximately 65,000 planning units were included in the study. Curiously, no other MARXAN literature mentions this limitation. This may be because most analyses are divided into regions that are processed separately. This was done in the Channel Islands where three bioregions were determined based on species distribution and sea surface temperature maps (Marine Reserves Working Group, 2000). Because each bioregion was processed separately, a much smaller planning unit size could be used than if the entire area was processed at once.

2.4.1.4 Targets

Targets are the amount of each species (this term includes any type of data, including physical features, habitats, organisms, economic data, public opinions, etc.) to be included in the solution. Several sources mention 20% as a target for the amount of each habitat that should be protected within an MPA (Boersma & Parrish, 1999; Franklin *et al.*, 2003; National Research Council, 2001; Roberts, 2000); however, according to Agardy *et al.* (2003), this 20% protection figure originated from one specific study of a particular fishery within a particular habitat, and is not applicable to a broader range of areas. Other scientists have suggested up to 50% as the amount that should be protected (Lauck *et al.*, 1998; Polacheck, 1990).

While 50% and even 20% protection represent significant levels of protection, Agardy *et al.* (2003) and Jamieson & Levings (2001) both warn against applying blanket targets such as these. Since we do not know enough about the marine

environment, applying arbitrary targets implies that only a given percentage of the area requires attention, and thus can be counterproductive to the goals of the MPA (Lauck *et al.*, 1998).

Despite arguments against using targets, they are a necessary input when using MARXAN. Often a range of targets is examined in a MARXAN analysis. For example, Airamé *et al.* (2003) examined targets of 30%, 40%, and 50% and Lieberknecht *et al.* (2004) looked at targets between 10 – 40%. These ranges allowed stakeholders to visualize solution sizes and configurations associated with target values. Targets are often varied based on the relative importance (rarity, vulnerability, etc.) of features (Geselbracht *et al.*, 2005). Rare or vulnerable features are often given a higher target as a greater proportion needs to be conserved. Smith (2005) suggests setting targets based on the original amount of each feature in the region before habitat loss, which ensures that transformed habitats are included in the solution.

The ability of a solution to meet targets influences the penalties assessed against the solution, and thus the overall solution cost. A penalty is added for any species whose target is not met in the solution (Lieberknecht *et al.*, 2004). Penalties are discussed in Section 2.4.1.7.

2.4.1.5 Costs

The costs assigned to individual planning units are used to calculate the overall solution (objective function) value in Equation 1, above. Cost can be based on planning unit area, economic or social cost, or combinations of these (Lieberknecht *et al.*, 2004). The higher the cost of a planning unit, the less likely it is to be included in

the final solution, as the objective is to minimize the overall solution value (Ball & Possingham, 2000). Many studies use the area of planning units as the cost value (Airamé *et al.*, 2003; Leslie *et al.*, 2003; Oetting and Knight, 2005).

Factors other than area often also influence the cost of planning units. The Coast Information Team (CIT, 2003) used a cost index that incorporated planning unit area and level of human impact on each planning unit. Miller *et al.* (2003) assigned cost values using an arbitrary scale according to the naturalness and human influence on planning units. Banks *et al.* (2005) used a method for calculating cost that takes into account adjacent uses. Units that come into contact with undesirable objects or uses were assigned a cost equal to the length of the undesirable object they touch. The rest of the units were assigned no cost.

Some studies assign arbitrary costs to all planning units. Stewart *et al.* (2003), for example, assigned a cost value of 1 to all planning units.

As can be seen by the multitude of values listed above, cost can be assigned virtually any value. However, it is important to note that its magnitude does influence the effectiveness of BLM (Ball, 2005). For example, the BLM used with costs measured in square metres will have to be greater by an order of 1,000 than the BLM used with costs measured in square kilometres. In other words, the magnitude of the two values is directly proportional.

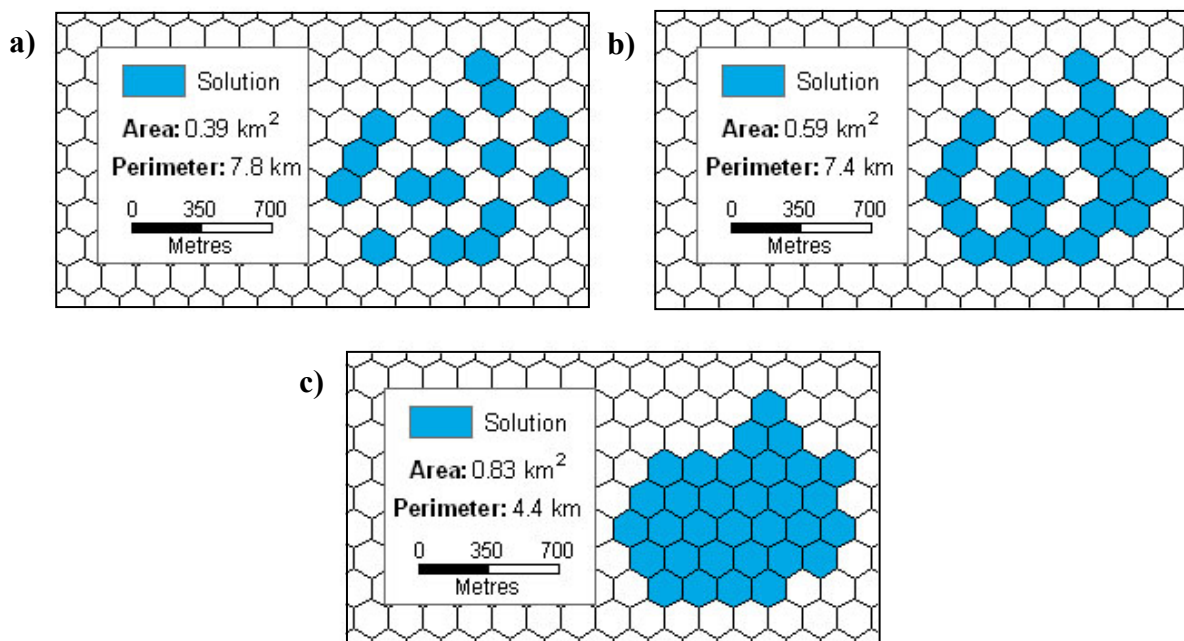
2.4.1.6 Boundary Length Modifier

The boundary length modifier (BLM) is a MARXAN setting that, when assigned a value greater than 0, acts to limit the perimeter of the solution. As the BLM is raised,

the value of the objective function increases (see Section 2.4.1.1). Because the goal is to minimize the value of the objective function, the solution will increasingly attempt to minimize boundary length by clustering planning units (Meerman, 2005). Clustered (compact) solutions are more viable for management purposes because they are easier to manage and monitor than highly fragmented areas (Geselbracht & Torres, 2005).

As the perimeter (boundary length) is decreased, the area of the solution increases because more planning units are typically needed to form contiguous clusters (Lieberknecht *et al.*, 2004). Figure 2.3 demonstrates the influence of increased clustering on the perimeter and area of solutions.

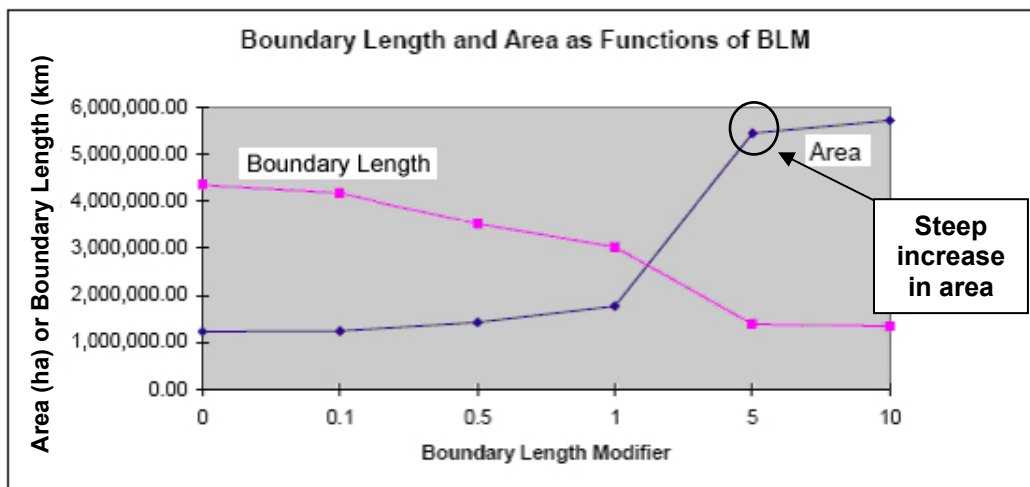
Figure 2.3: The effects of increasing clustering on solution area and perimeter. **a)** Scattered (typical of low BLM). **b)** Slightly more clustered (typical of medium BLM). The perimeter has decreased, and the area has increased. **c)** Highly clustered (typical of high BLM). The perimeter has decreased significantly and the area has increased.



At some point, as clusters increase in size, area will increase dramatically (Figure 2.4). An 'ideal' BLM for most planning purposes is one that decreases boundary length, but does not cause an overly large increase in area, as this would increase the value of the objective function (Possingham *et al.*, 2000). In Figure 2.4 there is a steep increase in area above a BLM value of 1. Thus the use of a BLM of 1 (or lower, depending on the degree of flexibility desired) would be 'ideal' in this case.

BLM is an arbitrary value that will vary between study areas, and must therefore be derived through experimentation (CIT, 2003). The value chosen depends both on the 'landscape' of the study area (Possingham, 2005) and the purpose of the analysis. Several different rationales have been used to select BLM values. Lieberknecht *et al.* (2004) suggest using both graphs (similar to Figure 2.4) and maps of solutions to determine the ideal BLM value. Most studies look for a BLM that produces an efficient and compact solution (Airamé *et al.*, 2003; Stewart & Possingham; 2002; Stewart *et al.*, 2003); this is the 'ideal' value described by Possingham *et al.* (2000). Some studies use intentionally low BLM values to develop solutions that are not overly clustered, thus offering more freedom for planners when decisions are made (Meerman, 2005). Another reason for using lower BLM values is that although solutions are more fragmented, hotspots are more apparent (CIT, 2003). Other studies, for which increased clustering is more important than keeping the solution size to a minimum, use higher BLM values (Lieberknecht *et al.*, 2004).

Figure 2.4: Graph of boundary length vs. area (modified from Possingham *et al.*, 2000).



2.4.1.7 Penalties

Penalties are added to the objective function (OF) when a feature's target is not met. A penalty is equivalent to the amount of boundary length and cost needed to adequately represent a missing target (Ball and Possingham, 2000). The factor that controls the importance of penalties in the OF is the species penalty factor (SPF), also known as the conservation feature penalty factor. The SPF is a multiplicative factor based on the importance of each conservation feature / species. Setting a high SPF will increase the likelihood that a feature's target will be met, since the objective is to minimize the cost of the objective function (Smith, 2005).

According to the creators of MARXAN, the SPF should be the same for most values and lower for those "you don't really care about" (p.64) and "there is no good theory at the moment about what level achieves what effect" (p.64) (Ball and Possingham, 2000). They do suggest setting the SPF higher than 1 to increase the likelihood that the feature's target will be represented. However, this leaves a lot of room for

experimentation since the SPF can be assigned any value. For example, Smith (2005) suggests using a value of 100,000 to ensure targets are met.

2.4.2 Data Gaps

As mentioned above, many researchers feel that developing an MPA should not be postponed due to incomplete data (Agardy, 2000; Kelleher & Recchia, 1998; Roberts, 2000; Salomon *et al.*, 2002.). There are, however, several different ways to treat areas where data have not been collected. Unsampled areas can either be treated as having an absence of data, or a value can be assigned through probability of species presence/absence. The probability can be based on factors such as location of suitable habitat and number of observed occurrences (Polasky *et al.*, 2000). This approach is fairly simple and has been effective in terrestrial settings (Csuti *et al.*, 1997; Nicholls, 1989; Polasky *et al.*, 2000). The marine situation, however, is much more complex; not only is the completeness of data more difficult to ascertain, but habitat is also hidden and more difficult to assess.

In cases where species presence/absence is completely unknown and cannot be derived from other datasets, one has little choice when using reserve-siting software such as MARXAN other than to treat these areas as though there is an absence of species. When further data are collected these areas can be re-evaluated, through adaptive management, to incorporate new information (Agardy *et al.*, 2003). When faced with the issue of how to include areas containing no data in the analysis, the Coast Information Team treated the unknown areas as a species, for which they set targets to be included in the solution (Ardron, 2005c). This way unsampled, data-poor areas were not completely excluded from the selected areas.

2.4.3 Incorporating Public Participation

Several authors emphasize the need for stakeholder and community involvement in zoning and MPA siting, as this can significantly boost support and compliance with MPA regulations (Day, 2002; Gilman, 2002; Kelleher & Kenchington, 1992; Klaus *et al.*, 2003; Villa *et al.*, 2002). While several MPA siting exercises have incorporated stakeholder input following MARXAN analysis to reach consensus (Airamé *et al.*, 2003; Cowie-Haskell & Delaney, 2003), the Great Barrier Reef National Marine Sanctuary in Australia has integrated public input both within and following the MARXAN process (Great Barrier Reef Marine Park Authority, 2003b). More than 10,000 public submissions were received, converted into spatial data, and incorporated into the analysis as a species layer (Lewis *et al.*, 2003). Public review also took place following the development of draft zoning (Great Barrier Reef Marine Park Authority, 2003b).

Although the stakeholder consultation process may result in compromises to conservation goals (Dearden, 2002), such a process is often necessary to overcome differences between use and conservation values (Davis & Tisdell, 1995). In addition, consultation provides an opportunity to incorporate additional information and values that might be missing from the preliminary analysis. The initial MARXAN output should not be viewed as a final solution, but rather as a starting point that needs to be refined through consultation (Fernandez, 2005). For example, the summed solution output from MARXAN was used in the Channel Islands National Marine Sanctuary reserve siting process. Stakeholders used summed solution scores to swap planning units in and out of reserves, which gave them a clear idea of how their changes influenced conservation goals (Airamé *et al.*, 2003).

2.5 SUMMARY

GIS, combined with MARXAN, has the power and flexibility to greatly assist with the development of marine protected area zoning. However, despite previous use of MARXAN for MPA siting, there remains a great deal of uncertainty and guesswork associated with several settings. Every new application requires extensive testing because so few guidelines exist.

MARXAN is very complex. Many settings, especially those directly influencing the value of the objective function, are interrelated. MARXAN is also influenced by the characteristics of the study area. These factors make it very difficult, if not impossible, to suggest values for every setting, in every situation.

The research described in this thesis aims to find general guidelines that can better inform the use of MARXAN. It uses these results to examine potential methods for developing multiple zones using MARXAN. The following chapters outline and discuss the methods and results of the MARXAN testing and zoning development.

CHAPTER THREE

METHODOLOGY

The research described below can be divided into three sections: data collection through expert interviews and digital data acquisition; MARXAN testing, where software settings were examined; and zone development, where the information collected in the other two sections was applied in the context of zoning.

3.1 EXPERT INTERVIEWS

Marine protected area zoning practitioners and experts were interviewed between November 2004 and January 2005. The purpose of the interviews was to gather information on how MPA zoning has been developed and to determine zoning experts' opinions on GIS-based zoning methods. The interviews were necessary because most zoning processes are not published, and this research requires an in-depth understanding of past and future zoning efforts.

The University of Victoria requires that research involving human subjects be reviewed by its Human Research Ethics Committee (HREC). The interviews and questionnaires described below were approved and conducted in accordance with HREC's guidelines.

Participants were chosen based on literature reviews and through Internet searches. The goal was to include participants from the major Canadian marine protected areas, including Fisheries and Oceans Canada (DFO), Parks Canada, and Environment Canada, as well as a range of international experts. Participants were selected based on MPA zoning experience, or future involvement with zoning.

Sixteen people were approached, and eleven participated. Of these eleven, five had already participated in zoning, and six were preparing for the zoning process. Four were biologists/ecologists, and the remainder were managers. They represented ten different MPAs; Great Barrier Reef, Monterey Bay, Florida Keys, Endeavour, Scott Islands, Gwaii Haanas, Sable Gully, Saguenay St. Lawrence, Fathom Five, and the proposed Southern Strait of Georgia NMCA. A complete list of participants, including affiliations, can be found in Appendix IV.

Participants were initially contacted by letter (Appendix V), and followed up with a telephone call. A consent form, as required by the HREC, was included with the recruitment letter (Appendix VI). In order to participate this form had to be signed and returned.

A copy of the interview questionnaire (Appendix VII) was also included with the recruitment letter. Zoning experts were asked questions about their zoning experiences, or anticipated experiences if zoning had not yet occurred. Questions related to both the process and the outcome of zoning efforts. In addition, attitudes pertaining to the suitability of GIS-based site selection tools for zoning were probed. Two slightly different versions of the questionnaire were developed: one for those who have had zoning experience, and one for those who will be involved in zoning in the future. Participants were asked to respond to the appropriate questionnaire in writing. The submitted responses were then clarified and expanded through a telephone interview. A summary of responses can be found in Appendix VIII.

The information gathered from the interviews and MPA zoning literature was used to develop functional requirements for MPA zoning, to address the first research

question (Section 1.3). Chapter Four provides an in-depth discussion of the methodology and results of the functional requirements study.

3.2 SPATIAL DATA INTEGRATION

The data utilized for this research were obtained through a data sharing agreement with Parks Canada. Most of the data originated from other sources, including DFO, Environment Canada, Province of British Columbia, and non-governmental organizations (NGOs), and have been compiled by Parks Canada as part of the proposed Southern Strait of Georgia National Marine Conservation Area initiative.

Approximately ten gigabytes of data were obtained, however the majority were either duplicate layers or were unusable for a variety of reasons. Some were not applicable to marine zoning, such as the digital elevation model of the province, while others had more serious issues. Large amounts of data had very poor metadata, meaning that they contained little or no information on what the features were meant to represent. Some data were out of date, for example eelgrass surveys from the 1970s. Others, such as kelp layers, were obviously limited spatially, with some areas very well sampled and others completely empty. The scope of data was also limited. Species distributions and habitat information, and socio-economic data are data that should be included in zoning, but were severely under-represented.

Appendix IX shows the data that were used to test zoning development. All data were in ESRI shapefile and interchange (E00) formats.

3.3 MARXAN TESTING

Two GIS programs, ArcGIS 9.1 and ArcView 3.3 were used for the analysis described in this research. Although ArcGIS is the more powerful of the two, ArcView was used because it runs an extension, called CLUZ that interfaces with MARXAN (Smith, 2005). CLUZ is an excellent tool for reserve planning because it eliminates the need to work directly with MARXAN files, which are complicated and labour intensive to generate.

Trial and error and experimentation have been used to decide on many of the criteria used in MARXAN applications (Ardron, 2005a; Fernandez, 2005). This has been necessary due to the uncertainty associated with many of the variables that form MARXAN inputs, including planning unit specifications, the influence of data distribution and gaps, clumping factors, planning unit costs, and penalties. It would greatly assist MARXAN users if some guidelines could be developed for these variables, even if they are general and only serve to narrow the scope of experimentation. The methodologies for the testing of each variable are described below. Table 3.1 shows an overview of this testing, and lists the variables and values used for each one.

Table 3.1: Summary of MARXAN testing

Variable	Values Tested	Dependant Variable #1	Dependant Variable #2	Dependant Variable #3
Planning unit size	<ul style="list-style-type: none"> • 100 • 500 	<u>BLM:</u> <ul style="list-style-type: none"> • 0 • 1 • 10 • 100 • 1000 	<u>Spatial Configuration:</u> <ul style="list-style-type: none"> • Open Ocean • Inlets & Passages 	<u>Data Distribution:</u> <ul style="list-style-type: none"> • Continuous • Sparse
Planning unit shape	<ul style="list-style-type: none"> • Square • Hexagonal 	<u>BLM:</u> <ul style="list-style-type: none"> • 0 • 1 • 10 • 100 • 1000 	<u>Spatial Configuration:</u> <ul style="list-style-type: none"> • Open Ocean • Inlets & Passages 	<u>Data Distribution:</u> <ul style="list-style-type: none"> • Continuous • Sparse
Data gaps	<ul style="list-style-type: none"> • Continuous data • Sparse data 	<u>BLM:</u> <ul style="list-style-type: none"> • 0 • 1 • 10 • 100 • 1000 	<u>Targets:</u> <ul style="list-style-type: none"> • 20% • 5% 	
BLM	<ul style="list-style-type: none"> • 0 • 1 • 10 • 100 • 1000 	<u>Targets:</u> <ul style="list-style-type: none"> • 20% • 5% 	<u>Spatial Configuration:</u> <ul style="list-style-type: none"> • Open Ocean • Inlets & Passages 	<u>Planning Unit Shape:</u> <ul style="list-style-type: none"> • Square • Hexagonal
Costs	<ul style="list-style-type: none"> • 'Desirable' • 'Neutral' • 'Undesirable' Assigned combinations of values between 0 and 300 (See Table 3.3)	<u>Data Distribution:</u> <ul style="list-style-type: none"> • Data in 'desirable' area • No data in 'desirable' area 		
Species penalty factor	<ul style="list-style-type: none"> • 0.1 • 1 • 10 • 100 • 1000 • 10000 			

3.3.1 Planning Unit Size and Shape

Planning Unit Size

In order to compare the effects of different sized planning units, two uniform grids of hexagons and squares were created in two different sizes: 100 and 500. The 100 grid has a planning unit area of approximately 26,000 m² and the 500 grid has a planning unit area of approximately 650,000 m². The square and hexagon grids have the same unit area. Table 3.2 shows the difference in the areas and perimeters of the 100 and 500 grids. Originally, a 50 grid was used as the 'small' grid, but it resulted in more planning units than could be processed by MARXAN (see Section 2.4.1.3 and 7.1). The 100 grid was therefore the smallest planning unit size that could be used in the study area. The 500 grid was chosen as the 'large' grid because it is significantly larger than the 100 grid, yet it is still small enough to fit in most of the inlets and narrow passages of the Gulf Islands.

Table 3.2: 100 and 500 planning unit grid measurements.

Planning unit	Area (m ²)	Square perimeter (m)	Hexagonal perimeter (m)	Square Side Length (m)	Hexagon Side Length (m)
100	25,981	644	600	161	100
500	649,519	3223	3000	806	500

Three scenarios were tested for the two sizes of planning units: Open Ocean; Inlets and Passages; Inlets and Passages using Sparse Data.

Open Ocean: This is an area of uninterrupted planning units that is not connected to islands or land (Figure 3.1a). This was tested because it was observed, during initial exploration, that if large expanses of uninterrupted planning units (i.e. 'open ocean') were included with inlets and passages, the solution was more likely to be attracted to the open areas since clustering is easier in open areas. Three identical overlapping test 'data' layers were used that covered the entire area. Because the test layers span

the entire Open Ocean study area, the results of testing can be attributed solely to the influence of open areas on the algorithm, and not data distribution. This acts as a control, and allows the results of Open Ocean testing to be compared with the results from the Inlets and Passages scenario.

Inlets and Passages: This area is characterized by narrow inlets and passages between islands (Figure 3.1b). Large expanses of ocean are not present, unlike the Open Ocean scenario. As with the Open Ocean scenario, three overlapping test 'data' layers were used that cover the entire Inlets and Passages study area.

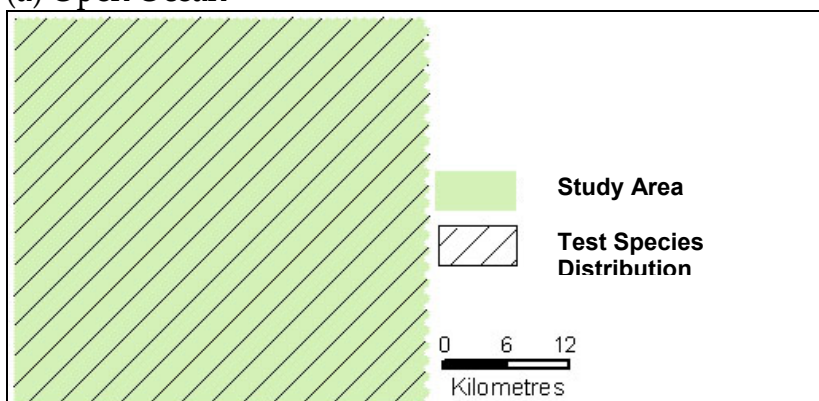
Inlets and Passages with Sparse Data: This covers the same area as the Inlets and Passages scenario, except in this scenario the data layers do not cover the entire study area. They are, in fact, real data layers that only cover sparse areas (Figure 3.1c). A total of seven different layers were used. The only difference between this scenario and the Inlets and Passages scenario is the distribution of data, which allows for a comparison of the influence of data on results.

The influence of different boundary length modifier (BLM) values was used as the benchmark to compare the two grid sizes. The BLM values covered a range of values: 0, 1, 10, 100, and 1000. This range was chosen based on literature searches and initial examinations of MARXAN.

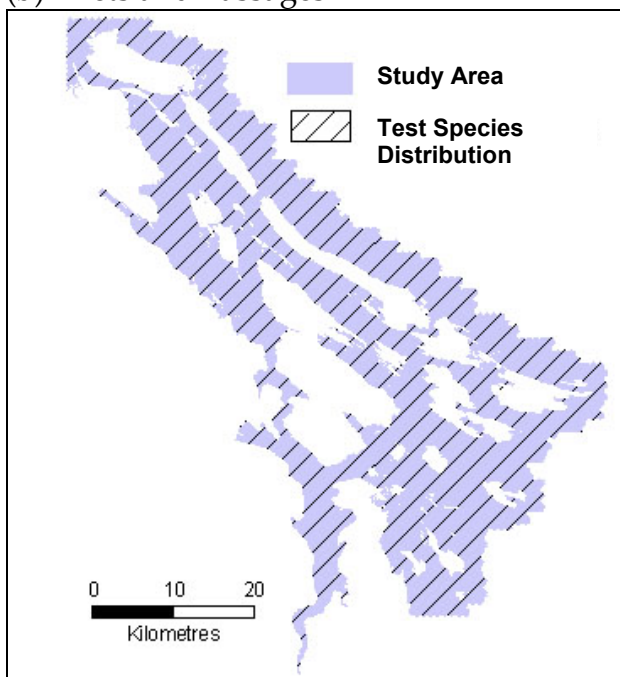
The five BLM values were applied to both grid sizes for each of the three scenarios. The results were compared using graphs of changes in solution area vs. perimeter. This allowed for a quantitative comparison of results.

Figure 3.1: Extents of test data layers.

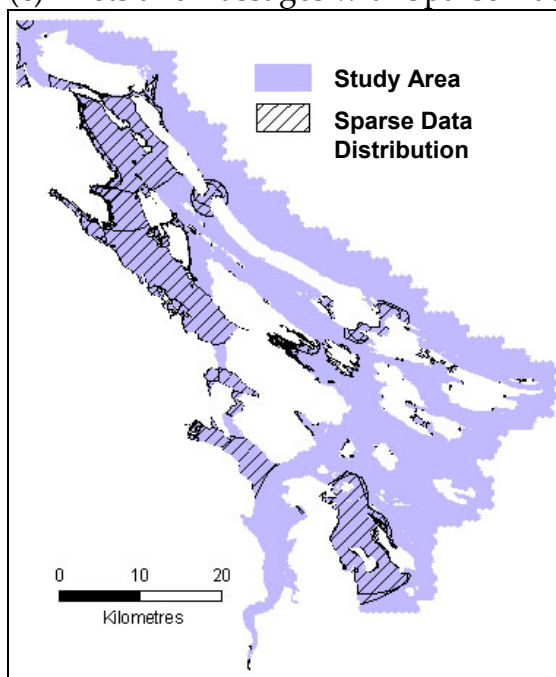
(a) Open Ocean



(b) Inlets and Passages



(c) Inlets and Passages with Sparse Data



Planning Unit Shape

Square and hexagonal grids were compared using the three scenarios described above: Open Ocean, Inlets and Passages, and Inlets and Passages with Sparse Data. The same range of BLM values (0, 1, 10, 100, and 1000) was used as the benchmark for comparison. The results (changes in perimeter and area) were graphed and formed the basis for comparison.

3.3.2 *Data Gaps*

Data gaps are areas where data are missing, either because data collection is incomplete, or because distributions are naturally patchy. This research question aims to discover what, if any, influence patchy data have on the ability of MARXAN to meet goals.

The influence of data gaps was examined by running MARXAN with continuous data (Figure 3.1b) and sparse data (Figure 3.1c). The continuous data are composed of three test layers that cover the entire study area. The sparse data are real data that are patchy and cover only a portion of the study area. Two target levels were tested: 5% and 20%. The 20% target was chosen because it is a value often used (Boersma & Parrish, 1999; Franklin *et al.*, 2003; National Research Council, 2001; Roberts, 2000). The 5% target was chosen in contrast with 20%, thus allowing for a comparison of the impact of data gaps on different targets. The results (changes in solution area and perimeter) of five different BLM values (0, 1, 10, 100 and 1000) were used to compare the solutions.

3.3.3 *Boundary Length Modifier*

The boundary length modifier (BLM) is a MARXAN setting that controls the influence of a solution's perimeter (i.e. boundary length) on the value of the objective function. The higher the BLM, the higher the value of the objective function. Solutions will, therefore, be increasingly clustered in an attempt to lower the boundary component of the objective function.

As discussed in Section 2.4.1.6, BLM values are determined through experimentation. The choice of BLM depends on both the characteristics of the study area as well as the data being used for analysis. It would be useful to have some guidelines, even if they are only general, for the influence of BLM under various conditions. The influence of five different BLM settings (0, 1, 10, 100, and 1000) on different targets (5% and 20%) and spatial study area arrangements (Inlets and Passages, and Open Ocean scenarios) was examined. The area and perimeter of the solutions were used to compare results of each BLM value.

3.3.4 *Planning Unit Costs*

Planning unit cost is a MARXAN parameter that can be based on any number of factors, including planning unit area, economic costs, and arbitrary values. These costs are associated directly with a planning unit, and can therefore be used to incorporate additional spatial information that may not lend itself to use as a data layer in the analysis. Costs can be thought of as a way to nudge a solution in a particular direction without actually setting targets or excluding areas and thereby forcing a certain outcome.

The question is: *what range of costs should / can be used to incorporate both 'desirable' and 'undesirable' areas?* To answer this question, a simple set of test data layers (Figure 3.2) was developed within a small section of planning units. The planning units were divided into three groups: 'desirable' areas were desirable for inclusion in the solution; 'neutral' areas were neither good nor bad; and 'undesirable' areas were not ideal for inclusion in the solution. The 'desirable' areas are those planning units 200 metres offshore of an imaginary 'desirable' terrestrial site. For example, it might be desirable to locate core conservation areas adjacent to existing protected areas. The

'undesirable' units are those within 200 metres of an 'undesirable' terrestrial site. An example of an undesirable site could be an industrial area. The 'neutral' areas are the remaining planning units.

Two different scenarios were tested: one where the 'desirable' area contained species (Figure 3.2), and one where the 'desirable' area did not contain species (Figure 3.3). The second scenario simulates what would happen if species data do not happen to fall within 'desirable' areas.

A range of costs was tested (Table 3.3) with each scenario, and the results were compared qualitatively. The objective was to find a range of costs that avoided bad areas and was attracted to good areas, while not ignoring the distribution of species data.

Table 3.3: Cost values.

Costs		
'desirable' areas	'neutral' areas	'undesirable' areas
0	0	0
100	100	100
0	1	2
0	5	10
0	10	20
0	50	100
0.1	0.2	0.3
1	2	3
1	50	100
2	4	6
2.5	5	7.5
0.5	1	1.5
5	10	15
10	20	30
20	40	60
25	50	75
100	200	300

Figure 3.2: Cost testing data layers.

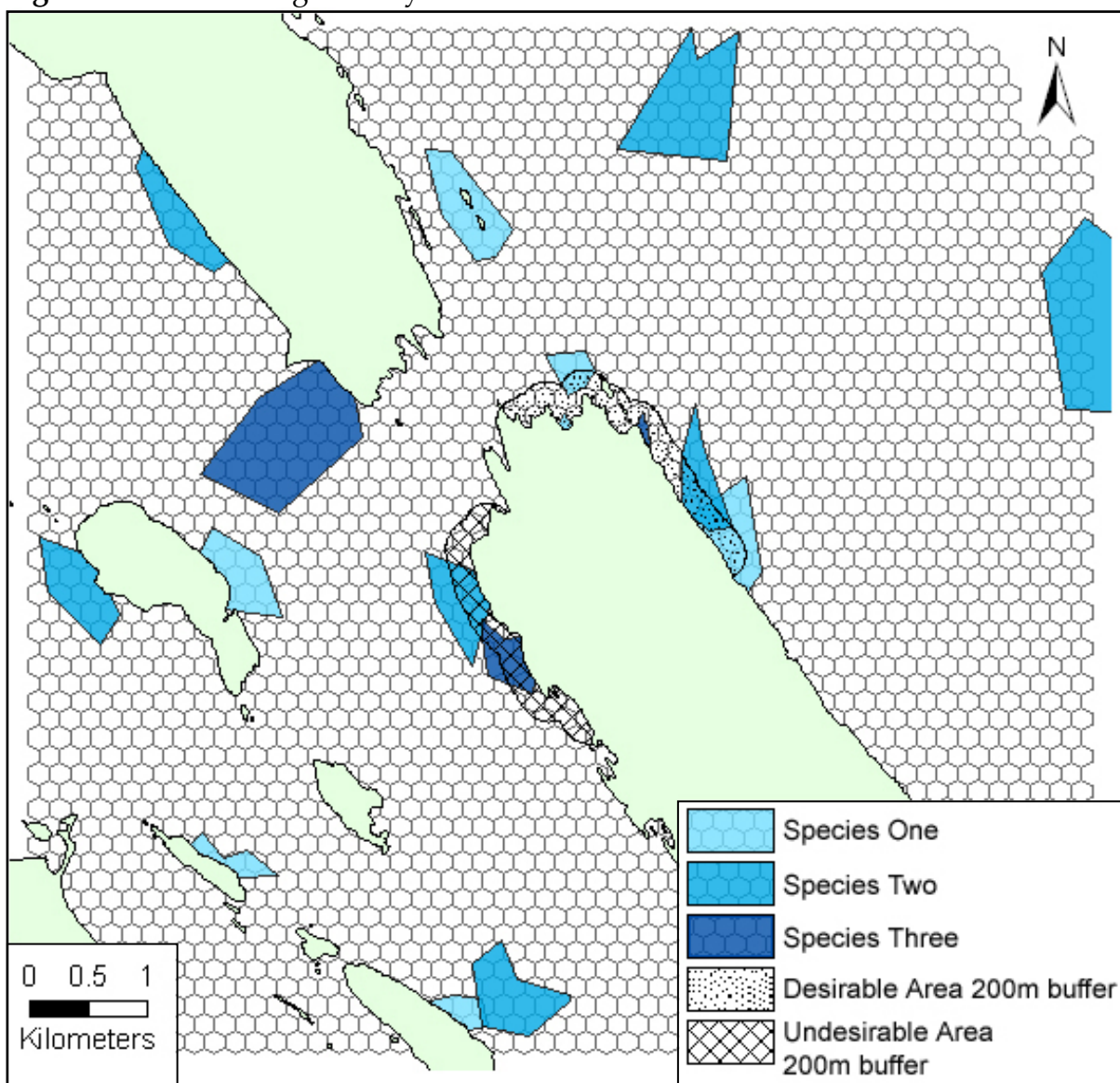
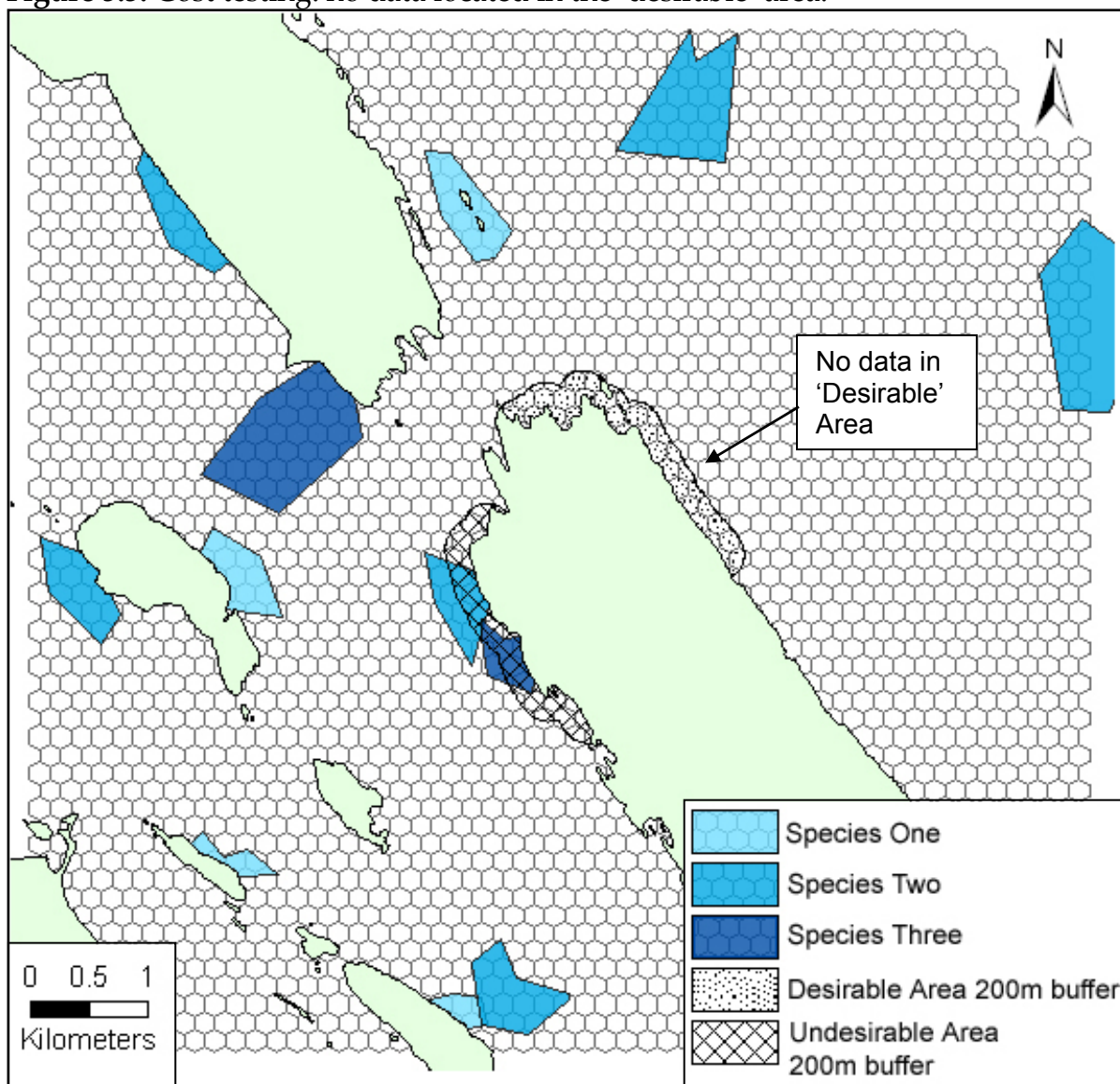


Figure 3.3: Cost testing: no data located in the 'desirable' area.



3.3.5 Species Penalty Factor

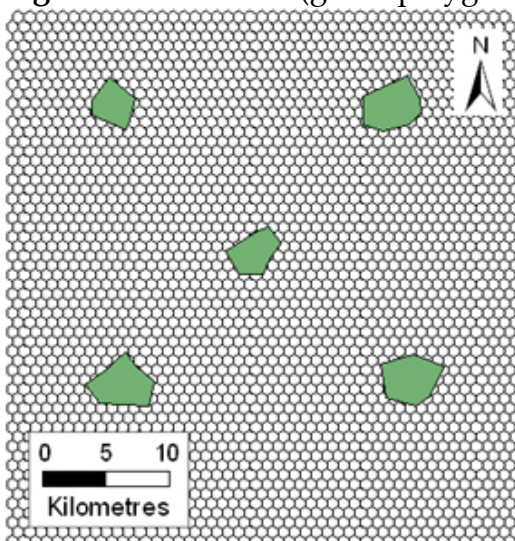
The species penalty factor (SPF) relates to the importance of meeting species' targets. The higher the SPF, the higher the objective function value will be if targets are not met. While some general guidelines exist, they are both conflicting and vague. While Ball and Possingham (2000) suggest using SPF values above 1, Smith (2005) suggests the use of a "large value" (p.10) of 100,000. The question, therefore, is what effect do

different SPF values have on solutions, and are there any advantages to using particular values?

The influence of the species penalty factor (SPF) was tested using a hexagonal grid with a planning unit area of 25,981 m², and a fabricated species layer composed of five patches (Figure 3.4). This patchy data configuration, which makes it harder for the algorithm to meet species targets, was chosen after initial experimentation determined that SPF only has an effect on solutions if targets are difficult to reach. A range of SPF values (0.1, 1, 10, 100, 1000, and 10000) were tested. This range was chosen based on the values suggested by Ball and Possingham (2000) and Smith (2005). A BLM of 1000 was used for all testing. Using a constant BLM value allowed for comparison between tests, and the high BLM resulted in clumped solutions, which are easier to interpret than highly fragmented ones.

The results were compared based on a number of factors, including ability to meet targets, size of the solution, and the amount of non-target species planning units included in the solution.

Figure 3.4: Test data (green polygons) used to test SPF



3.4 IDENTIFYING AND COMBINING ZONES

MARXAN has been primarily used to design networks of conservation areas. Multiple use MPAs present an additional challenge because they comprise different types of zones. Each zone must be developed separately in MARXAN and then combined, as the software does not have the ability to develop multiple zones simultaneously. Despite literature reviews and interviews with zoning experts, guidelines for developing and combining zones using MARXAN could not be found. For this reason, several methods are examined.

3.4.1 *Developing Zones*

Through interviews with zoning practitioners (Section 4.2) and literature reviews (Section 2.2), it was discovered that it is beneficial to keep the number of zones low (three or four), as this is easier to monitor and interpret. Therefore, a four-zone model, based on the zones likely to be used for the Southern Strait of Georgia NMCA (Henwood, 2005), was used here. The zones are: conservation, recreation, general use, and facilities. The facilities zone will be based on the locations of existing infrastructure, such as ferry terminals and marinas. Because no complicated decisions have to be made regarding the zone's location (either infrastructure exists or it does not), MARXAN is not needed for developing this zone. The multiple use zone also does not require the use of MARXAN. This zone is typically 'left over' after the other zones have been developed (see Section 4.2); i.e., they are formed by default. The development of the remaining two zones, conservation and recreation, is based on large amounts of complex data, and does require the use of MARXAN. The conservation and recreation zones are therefore the two zones that are developed and combined here. It is important to note that the steps followed here

are not specific to the conservation or recreation zones, and could be applied to any combination of zones.

The data used to develop the conservation and recreation zones were based on information gathered from interviews with zoning practitioners and literature reviews (see Table 4.1 for a list of data suggested for zoning). Many of the suggested data layers, namely those concerned with species distributions, fishing efforts, and socio-economic factors, were unavailable for the study area (see Section 3.2).

Although it is important to note this fact, it is of no real consequence, as it is the zoning process, not the actual zones, that is important in this study. The conservation zone included data such as habitat, ecologically important areas, endangered species, etc. The recreation zone included data such as tourism, boating, sport fishing, etc. The specific data layers used to develop each zone are listed in Appendix IX.

In accordance with the results of planning unit size (Section 5.2.1) and shape testing (Section 5.2.2), square planning units with an area of 25,921 m² (the '100' grid) were used for the analysis. Costs, based on the results of Section 5.4, were used to assign value to planning units and to incorporate adjacent land uses and activities in zoning. 'Undesirable' areas were assigned a cost of 3, neutral areas were assigned a cost of 2, and 'desirable' areas were assigned a cost of 1. Table 3.4 lists the data used to identify 'desirable' and 'undesirable' areas for the conservation zone, and Table 3.5 lists the data used to add costs for the recreation zone. The extents of the 'desirable' and 'undesirable' data for the conservation zone are shown in Figure 3.5. The 'desirable' and 'undesirable' layers used for the recreation zone are shown in Figure 3.6. Because small cost values were used a correspondingly small BLM of 0.1 was used (Section 2.4.1.5 explains the relationship between BLM and cost values).

Targets are study area specific and should be set in conjunction with biologists and other experts. Given the time frame and scope of this research, hypothetical target values were used. A target of 20% was used for all species, habitats, and uses. This is based on the findings of Section 5.3, which indicated that in situations where sparse data are used, such as this research, a higher target facilitates clustering and results in fewer superfluous units in the solution.

Table 3.4: ‘Desirable’ and ‘undesirable’ area data layers used for the development of the conservation zone.

‘Desirable’ area data, cost = 1	‘Undesirable’ area data, cost = 3
100m buffer around adjacent terrestrial parks	Islands Trust ‘Development’ zoning
Existing marine protected areas (under provincial and DFO jurisdiction)	Fisheries and shellfish closures due to anthropogenic pollution or anchorage
	Finfish and shellfish aquaculture tenures and harvesting
	Vessel traffic lanes
	Water discharge points

Table 3.5: ‘Desirable’ and ‘undesirable’ area data layers used for the development of the recreation zone.

‘Desirable’ area data, cost = 1	‘Undesirable’ area data, cost = 3
100m buffer around terrestrial parks	Finfish and shellfish aquaculture tenures and harvesting
	Vessel traffic lanes

Figure 3.5: Extents of the 'desirable' (low cost) and 'undesirable' (high cost) areas for the conservation zone

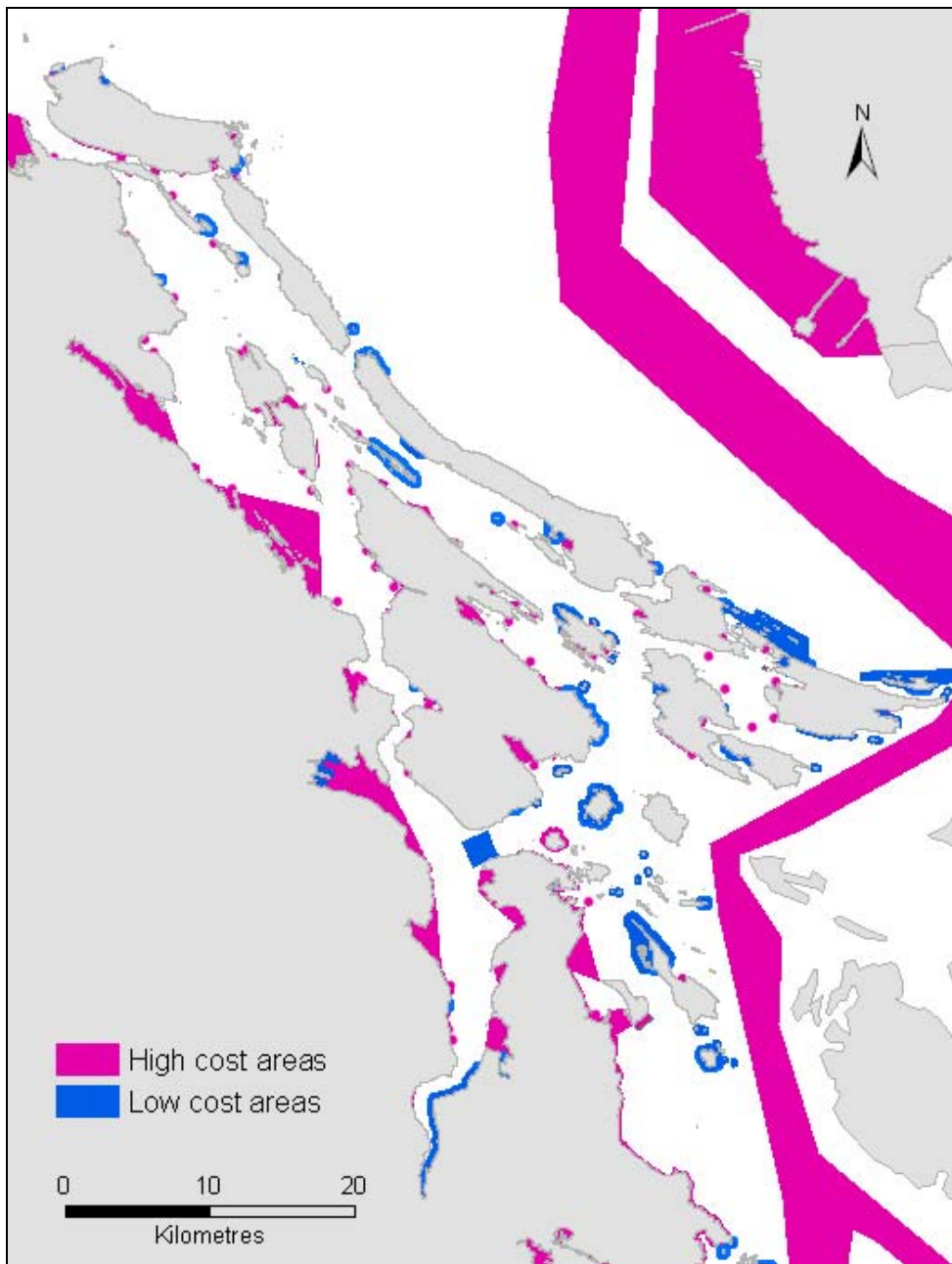
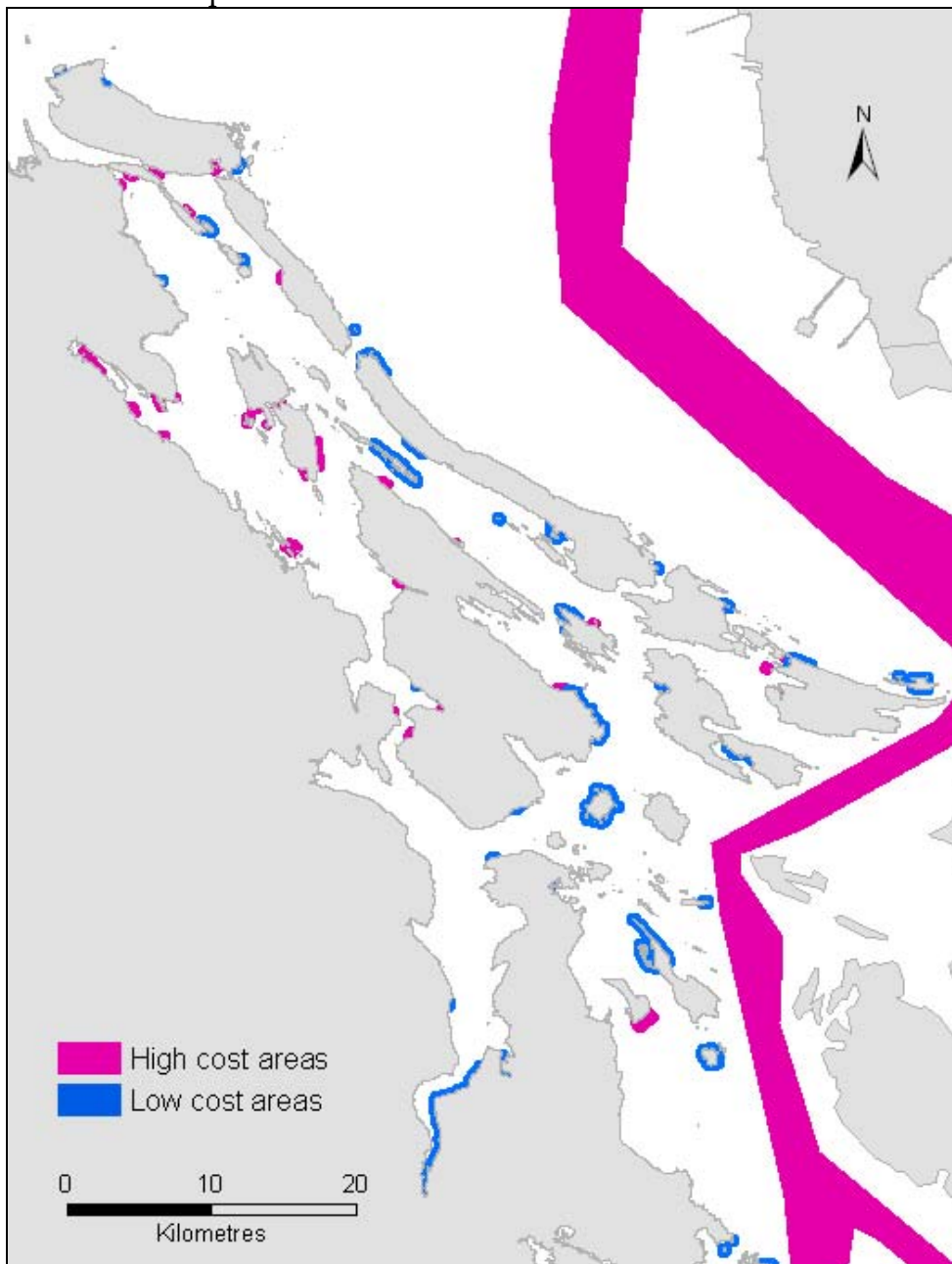


Figure 3.6: Extents of the 'desirable' (low cost) and 'undesirable' (high cost) areas used to develop the recreation zone



3.4.2 Combining Zones

Three methods for combining the conservation and recreation zones were explored:

- 1) **Zones developed separately:** The zones were developed separately in MARXAN, then overlaid using GIS. Areas of overlap were flagged and rated according to their importance for each zone.
- 2) **Two step process excluding areas:** The conservation zone was developed first. Then, when the recreation zone was developed, areas of high and medium value (Table 3.6) for the conservation zone were set off limits (excluded from the recreation zone analysis). The conservation and recreation zones were then overlaid in the GIS. As in method one, areas of overlap were flagged and rated according to their importance for each zone.
- 3) **Two step process using cost:** The conservation zone was developed first. Those areas (i.e. planning units) that were of high or medium value (Table 3.6) for the conservation zone were then given a higher cost (three) when the recreation zone was developed. This higher cost made the areas less likely to be selected for the recreation zone. The two zones were then overlaid using GIS, with areas of overlap flagged and rated according to their importance for each zone.

MARXAN's summed solution output, which shows the number of times each planning unit was included over the runs of the software, was used for each of the three methods described above. This output was chosen because it provides information on the relative importance of planning units for each zone. This was used to rate areas of overlap when the zones were overlaid in the GIS.

To simplify comparison of the two zones, the top half of the summed solution values for each zone was divided into three categories: high value, medium value, and low value (Table 3.6). The bottom half of the summed solution values were excluded from the analysis because they are of little importance to the zones and removing them allows for more focus on important areas. High and medium value units for

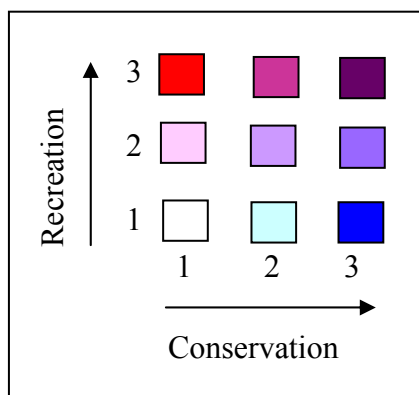
the conservation zone were used in methods two and three (above) for developing the recreation zone.

When the conservation and recreation zones were overlaid in the GIS, the three categories of summed solution values were used to assign importance to overlap areas. The range of colours used to visualize the overlap areas are shown in Figure 3.7. This method allows decision makers and stakeholders to not only visualize both zones simultaneously, but also to compare the importance of overlapping planning units for each zone and to make decisions accordingly.

Table 3.6: Divisions used to divide the conservation and recreation zone summed solution values into three categories.

Zone	Range of Values	High Importance	Medium Importance	Low Importance
Conservation	0 - 451	376 - 451	301 - 375	250 - 300
Recreation Scenario 1	0 - 466	297 - 466	255 - 296	233 - 254
Recreation Scenario 2	0 - 436	294 - 436	253 - 293	218 - 252
Recreation Scenario 3	0 - 432	293 - 432	253 - 292	216 - 252

Figure 3.7: Summed solution zone overlap areas matrix.
(1 = low value, 2 = medium value, 3 = high value)



CHAPTER FOUR

FUNCTIONAL REQUIREMENTS STUDY

4.1 INTRODUCTION

A review of literature revealed a paucity of available published information on specific approaches to MPA zoning. Therefore, to acquire an understanding of past and future zoning efforts, MPA zoning practitioners and experts were interviewed during the winter of 2004/2005. The results of the interviews, combined with literature reviews, form the basis for the functional requirements study.

A functional requirements study (FRS) is an exercise often carried out during software development. An FRS identifies what a system is intended to do, and what is necessary to perform the desired functions (Adams *et al.*, 2000). Martin (1990) defines a functional requirement as “a functional-level capability or business rule which is necessary to solve a problem or achieve an objective” (p.465).

In GIS literature, an FRS is often referred to as a user needs assessment, and it is within this context that the FRS described below was conducted. The purpose was twofold: to identify requirements for MPA zoning and to provide guidance for zoning development.

The FRS described here can be divided into the following categories:

- Zoning objectives
- Users and participants of zoning
- Data
- Analysis
- Decision support

4.2 ZONING OBJECTIVES

In interviews with zoning practitioners, conservation and conflict minimization were the two main reasons given for developing zones. This is consistent with zoning literature (Day, 2002; Kelleher, 1999; Kelleher & Kenchington, 1992). Specific goals and requirements for the formulation of zones were also discussed and are listed below.

Size: Most interviewees indicated that there were no guidelines or restrictions for zone sizes. In most cases, zones were simply made as large as necessary to incorporate a particular feature or use. Only one interviewee indicated that minimum zone sizes were used in an effort to avoid the creation of small, fragmented zones. As discussed in zoning literature, small zones can be difficult for officials to monitor and users to comply with (Geselbracht & Torres, 2005).

The relative sizes of zones were also discussed in the interviews. Zones of complete protection (e.g. conservation zones) and limited protection (e.g. recreation zones) are generally smaller than general use zones. This is not, however, due to size restrictions; it is simply how these zones have tended to be developed

Number of zones: The importance of keeping the number of zones low for ease of understanding and monitoring was mentioned by both survey respondents and in zoning literature (Day, 2002; Kelleher & Kenchington, 1992; Villa *et al.*, 2002). As one respondent said, "Having only three zones... is simple[r] to interpret and apply." Most interviewees had, or were planning to have, three or four zones. The two MPAs with more than four zones (Great Barrier Reef with seven, and Florida Keys

with five) were also the largest. It may be that larger MPAs require more zones than smaller MPAs, as their increased size makes them likely to include more diverse conditions, leading to greater management requirements.

Identifiability: Four interviewees mentioned the importance of creating easily identifiable zone boundaries. As indicated by one respondent, zones should be something that users can “comply with easily.” This is related in part to the size and number of zones, as small, complex zones are more difficult to interpret. It is also related to the positioning of zone boundaries (Day, 2002). The use of easily recognizable natural or nautical features enables the public to know if they are in a zone or not. Zoning enforcement has similar requirements and, as one respondent stated, simple boundaries “translate well for surveillance.”

Protection: Both interviews and literature reviews revealed that the presence of a zone of complete protection is a vital component of MPA zoning (Salm *et al.*, 2000). As mentioned above, areas of protection are often one of the main reasons for the establishment of an MPA, and for this reason they are often given the highest priority when developing zones (*ibid*).

Priority of zones: Eight respondents indicated that conservation zones were given the highest priority *whenever possible* when creating zones. Logistical issues, public opinion, and conflict with existing uses were some factors that supplanted the priority of the conservation zone. In most cases, draft zones were formulated with conservation as a priority, but were then altered when stakeholder input was incorporated. The priority of the conservation zone is also discussed in zoning literature (Salm *et al.*, 2000). Through discussions with zoning experts it became clear that multiple use zones (i.e., those that allow for resource extraction) are sometimes

initially created by default, made up of areas remaining after other zones have been developed.

Conflicts: One of the key roles of zoning is to separate conflicting human uses and to minimize their influence on the MPA (Kelleher & Kenchington, 1992). In other words, not only should incompatible uses be separated, they should also be confined to sites that can sustain them (Salm *et al.*, 2000). Despite its importance in zoning literature, only three interview respondents actually used the term *conflict* during interviews, while two others expressed this concept as a need to “balance use.”

Existing uses: Related to conflicting uses is the problem of how to treat existing use in the zoning process. One approach described by an interview respondent is to, “stay away from conflicts,” and allow existing uses to remain intact. A less extreme version that attempts to avoid, but does not preclude, disrupting existing uses was described by the majority of the remaining respondents. The Great Barrier Reef zoning policy, which aims to, “minimiz[e] impacts on existing uses,” (p.7) is an example of this (Great Barrier Reef Marine Park Authority, 2003b). Information on existing uses can be difficult to obtain, therefore this aspect of zoning can be incorporated during public participation.

Public opinion: The complete failure of a zoning process in Florida due to lack of public support, described by one respondent, is a testament to the importance of public opinion on the success of a zoning plan. This process, also described by Cowie-Haskell & Delaney (2003), did not incorporate stakeholder input and it resulted in a “lack of community acceptance” (p.69). Subsequent efforts, which involved stakeholder input throughout the process, resulted in the successful

completion of a zoning network (*ibid*). All interview respondents indicated the importance of public input when developing zones.

4.3 ZONING USERS AND PARTICIPANTS

We can distinguish several groups involved in zoning: planners and managers; biophysical and social scientists; spatial analysts; and stakeholders. Each plays a different, yet complementary, role in zoning development.

Planners and managers oversee the zoning process. They are responsible for developing the policies and strategies governing zoning, as well as the continued management of zones.

Zoning decisions made by planners and managers are informed partly by biophysical and social scientists. This group offers input and expertise that can help ensure that a zoning process is scientific.

Spatial analysts (i.e., GIS technicians who run MARXAN) play a major supporting role in GIS-based zoning, but were not mentioned either by respondents or the literature. This group is responsible for translating the requirements of managers into actual zones, and represents an important link between policy and zone delineation. Concepts such as boundary length modifiers, penalties, and costs are not commonly considered by MPA managers (as can be seen from their absence in Section 4.2), so it falls upon spatial analysts to facilitate the translation of zoning objectives into software commands.

Another group that provides input is stakeholders. As mentioned above, all survey participants stressed the importance of public participation in the zoning process. Stakeholders offer valuable local knowledge, and their inclusion builds trust and creates more opportunities for consensus. Stakeholders were, or will be, involved in all of the respondents' zoning processes. In most cases, stakeholders' input was incorporated after a zoning scheme had already been developed. This involved a give-and-take process with consensus as a goal.

Another method that was used by one of the questionnaire respondents and mentioned by several others involves a two-step process: stakeholders' comments were entered directly into the analysis as a data layer before zoning is proposed, and then again when a draft plan was released. This method of public participation is appealing because it incorporates input before zoning is developed, which should result in fewer changes to the proposed plan. In addition, experience with MPAs has shown that the more public input is incorporated, the more likely it is there will be sustained public support (Day, 2002; Villa *et al.*, 2002).

4.4 DATA

Zoning is increasingly data driven and requires the integration of biophysical and socio-economic data. Table 4.1 lists a broad range of data listed in zoning literature, that were, or should be, used for zoning. Survey respondents did not provide the same level of detail when describing data that had been, or would be, used for zoning. Instead, they mentioned general categories, such as 'socioeconomic' and 'recreational use.'

Table 4.1: Zoning data requirements (Great Barrier Reef Marine Park Authority, 2003b; Kelleher, 1999; Marine Reserves Working Group, 2000).

Fauna & Flora	Fishing	Historic Use	Recreation	Physical Characteristics	Other
distribution of fish and benthic communities	trawling	traditional uses and rights	tourist developments & uses	complexity	sites used for research & scientific study
eel-grass and kelp forest communities	pelagic fishery	historic places	diving	coastline type	navigation, shipping and defence areas
significant colonies of breeding birds	demersal fishery	native claims	sport fishing	sediment type	adjacent land use
endangered, rare or protected species distribution and significant sites	netting		marinas	emergent rocks	boat ramps
marine mammal haulouts	mariculture / fish farming		moorings and anchorages	oceanographic characteristics	
	fishing closures			estuaries	

Probably the most common data problem in the marine environment is data availability, and, perhaps more importantly, data gaps (Possingham *et al.*, 2000). The three-dimensional, shifting nature of the ocean makes it difficult for humans to have a good or even fair understanding of what is occurring below the surface. This is an area of GIS research that is directly applicable to MPAs, since as one questionnaire

respondent said, “we need to use the 3rd dimension more in interpreting the underwater world.”

Through the questionnaires it became apparent that the role of GIS in past Canadian MPA zoning has been mostly for visualizing zone boundaries. The main reason was a lack of spatial data when zoning was conducted. One respondent, who was involved in a ‘manual’ zoning process, stated that he “seriously doubt(ed) that (they) could have automated or optimized zones with something like MARXAN,” mostly due to the time required to digitize the data used for zoning. The same respondent did feel that MARXAN and GIS would probably be better suited for data rich areas where extensive surveys have taken place and information is already in digital format.

Data gaps are especially problematic when dealing with large MPAs. Data are often patchy and incomplete, or out of date. One solution has been to set the site selection algorithm (MARXAN) so that areas with no data are chosen randomly to be part of the final solution (Ardron, 2005c). Another solution, presented by a questionnaire respondent, is to extrapolate features into continuous surfaces, so that unknown areas are assigned values. Another respondent suggested that, “Intuition has a role in zoning, mostly to make up for lack of data...” Although there is a chance with all of these solutions that the ‘unknown’ areas being selected will have some value, the uncertainty makes it difficult to justify the inclusion of these areas, especially in conservation zones. It is important, however, to re-evaluate zones as additional data are acquired through field surveys and suitability modelling. Local knowledge gained through stakeholder input (described above) can also help fill data gaps.

While data availability is important, data quality was also recognised. As one survey respondent said, “The better the data, the more (the zoning process) will be trusted.” Several problems may arise in association with data, often compounded by the use of data collected from other sources. Information may be out of date, which is of concern when dealing with the constantly shifting ocean environment. Data may be of variable quality, or may have been collected during different time periods, making it difficult to make comparisons between layers. In addition, data may have been collected at different scales, or may be of unknown accuracy, and not all organizations follow thorough metadata standards.

4.5 ANALYSIS

When asked about the analysis required for zoning, the majority of questionnaire respondents, who had previously been involved in zoning, described visualization, manual data examination, and judgment as the key methods used to examine data. Spatial analysis did not figure prominently. Those who will be involved in future zoning indicated that GIS and MARXAN would be used for analysis, but did not yet have a clear idea of specific roles.

MARXAN is well suited to delineating conservation zones, as it was initially developed to establish marine reserves, and several case studies exist (Airamé *et al.*, 2003; Gonzales *et al.*, 2003; Leslie *et al.*, 2003). For zoning, however, the complexity of the problem is increased because different zones need to be developed. One questionnaire respondent, who was involved in a ‘manual’ zoning process, described an iterative process where three zones were developed simultaneously. Data layers were examined one by one, and all three zones were altered according to how zoning practitioners’ perceived the importance of the data. There is currently

no way to develop zones simultaneously in MARXAN, however a new version is planned for release in late 2006 that will better facilitate zoning (Ball, 2005).

There appears to be a methodological divide between zoning practice, zoning literature, and available software. While conducting the interviews, it became obvious that certain issues that were important in MARXAN, and mentioned in zoning literature, were not issues for those who had been, and would be, conducting zoning. Targets are an example. MARXAN does not function without targets, since they are the basis for selecting areas. Targets are also discussed in the zoning literature, and it is not clear if this is a result of a desire to make MPA siting and zoning more systematic and scientific, or if software such as MARXAN has created a need to think in terms of targets. Only one interview respondent indicated that targets were used as a guideline for zoning. The others indicated that zones were made as large as possible, or as large as required. In many situations if there was a feature to be protected, the zone was established around that feature, instead of using an arbitrary target. As one respondent said, "zones were simply made big enough to fit the feature in question."

Fragmentation (small, dispersed zones) is frequently considered in terrestrial parks, but has proven to be more challenging with respect to MPAs. It is an important issue, and as one respondent said, "Fragmented use zoning does not work in a marine system." Despite this, few respondents seemed to understand the concept of fragmentation, and even fewer indicated that it was, or would be, a factor when developing zoning. Respondents tended to confuse fragmentation with replication, and therefore viewed it as a positive force that should be included in zoning. Replication is the act of locating a given zone in more than one site within the MPA, and acts as a type of insurance policy. One respondent summarized this concept as

the “don’t keep all your eggs in one basket” approach. This confusion has arisen because fragmentation is not a factor with ‘manual’ zoning where clustering is inherent to the process. This is an example of another MARXAN term that is not instantly understood by MPA managers.

Zone adjacency is another issue that is discussed in the literature, often with the role of separating use zones from conservation zones with buffer zones. Adjacency has also been applied in the context of fisheries yields, where fishing areas are located to take advantage of the fish leaving protection areas, in what is known as the spillover effect (Guidetti, 2002). Most of the survey respondents who had been involved with zoning indicated that intuition / common sense was used to site zones, and that adjacency was not specifically addressed. Those who will be involved with zoning in the future indicated that adjacency would “probably be taken into account,” but that it was too early to specify how it would be done.

4.6 DECISION SUPPORT

Those six respondents who had not yet participated in zoning were much more enthusiastic regarding the role of GIS for supporting zoning decisions. They did, however, indicate that GIS alone should not be used to generate final solutions. Rather, it should function more as a support tool that assists decision makers and stakeholders by generating alternative options. This is partly due to the often-incomplete nature of available data, as discussed in Section 4.4. Several respondents indicated that socio-economic data are lacking, which has the potential effect of excluding local knowledge and values from the process. As a result, compromises and ‘tweaking’ of GIS results are common, and several respondents indicated that

this process should involve public input, for which GIS / MARXAN outputs can provide a starting point.

4.7 SUMMARY

The functional requirements study has highlighted a number of interesting differences and similarities between the zoning requirements listed in the literature and by interview participants.

The majority of the zoning objectives listed in Section 4.2 is common to zoning literature and interview respondents. Both agreed that it is important to minimize the complexity of zoning, by limiting the number of zones (to three or four), as well as by using easily identifiable features as zone boundaries. This aids with both the compliance and monitoring of zones, and is one of the reasons why a four-zone model (though only two were actually developed) formed the basis for the zoning experimentation described in Section 3.4 and Chapter Six.

The importance of the zone of complete protection was mentioned by both respondents and in the literature. This zone was developed first and given priority, whenever possible, during zoning processes. In keeping with these findings, the zoning process described in Section 3.4 and Chapter Six has the conservation zone developed first. Two methods that experiment with ways to assign more weight to the conservation zone during the development of other zones were also tested (Section 3.4.2).

Both the zoning literature and interview participants agreed that existing uses should be accommodated in zoning as much as possible. Because use data was

largely unavailable for the SSOG study area, this aspect of zoning was not explored. This is an area where stakeholder input, the importance of which was also stressed by all sources, can be applied.

A difference between the zoning literature and interview respondents involves zone size and the minimization of conflicts between uses. The need for minimum zone sizes is mentioned in zoning literature, but only one respondent indicated that it was a factor when developing zones. The remaining zoning practitioners made, or were planning to make, zones as large as needed and/or possible. The size of zones is not a factor for the zoning described in Chapter Five, as it only shows preliminary hotspots for each zone.

The role of spatial analysts in GIS-based zoning development was not mentioned by interview respondents. Based on the interviews it seems obvious that spatial analysts must act as an important link between the policy developed by zoning experts and the execution of GIS/MARXAN for developing zoning.

The importance of detailed, high quality data was stressed by many interview participants. Although several methods for dealing with data gaps are discussed, the uncertainty associated with their use meant they were not included in the zoning described in Chapter Five.

Probably the most valuable contribution of the FRS is that it frames the zoning process, including the applicability of GIS, and MARXAN, from the viewpoint of zoning practitioners. It provides the users of GIS and MARXAN (spatial analysts) with an understanding of the requirements of zoning practitioners, and helps bridge the gap between the software and the requirements of zoning. The results of the FRS

were used to inform the software testing and zoning development components of the research, whose results are provided in Chapter Five and Six.

CHAPTER FIVE

RESULTS: MARXAN TESTING

5.1 INTRODUCTION

The complexity of MARXAN software is exacerbated by the uncertainty surrounding many of the settings and related decisions. Because few guidelines exist, extensive experimentation and trial and error have played a major role in the use of MARXAN (Ardron, 2005a; Fernandez, 2005). There is a need, therefore, for more direction regarding several MARXAN components, including planning unit specifications, the influence of data distribution and gaps, clustering factors, planning unit costs, and penalties. Methods for testing each of these factors were outlined in Section 3.3, and the results are presented and discussed in this chapter.

5.2 PLANNING UNIT SIZE AND SHAPE

5.2.1 *Planning Unit Size*

Two sizes of planning unit were compared: 100 (area of 25,981 m²) and 500 (area of 649,519 m²) in three scenarios: Open Ocean, Inlets and Passages, and Inlets and Passages using Sparse (real) Data. The results are summarized in Table 5.1, and graphs showing percentages of change in perimeter vs. area are provided in Appendix X. Percentage of change from a BLM of 0, rather than absolute values, is used to evaluate results throughout this research. Not only does standardizing the results as percentages facilitate interpretation, but some results are also on different scales, which makes absolute comparison invalid.

Table 5.1: Planning unit size testing results.

BLM	Grid Size	Open Ocean		Inlets and Passages		Inlets and Passages with Sparse Data	
		% Area Increase	% Decrease Perimeter	% Area Increase	% Decrease Perimeter	% Area Increase	% Decrease Perimeter
1	100	0	1.5	0	1.3	0.7	-0.5
	500	0	6.3	1	0.7	-0.5	2.2
10	100	0	4.9	0	4.1	-0.4	3.4
	500	0	6.1	0.3	-1.1	-0.6	4.7
100	100	0	36	0	30.3	-1.1	30.1
	500	0	22.4	-0.2	21.5	-7.1	29
1000	100	0	74	0	68.2	9.7	56
	500	0	90.2	-0.2	81.4	-12.4	67

In all three scenarios, with BLMs of 1, 10, and 100, the 100 grid showed very similar, and often greater, percentages of perimeter change (as compared to BLM 0) than the 500 grid. However, when the BLM jumped to 1000, the 500 grid perimeter showed a greater percentage of change for all scenarios (between 11% and 17% more than the 100 grid). This shows that BLM has more effect on perimeter change with larger size (500) units. This is expected, since there are fewer units in the study area, making it easier to find combinations. This accounts for why the 500 grid experienced larger changes in perimeter with a BLM of 1000; fewer units means easier clustering.

Changes in area with increasing BLM were very similar between the 100 and 500 grids, however there was a difference with the Inlets and Passages scenario with Sparse (real) data. With increasing BLM, the 100 grid results had increasingly higher areas (Appendix X c), whereas the areas of the 500 grid results decreased (Appendix X d). This was surprising because typically increasing BLM produces either no change or an increase in solution area. The creators of MARXAN were unable to explain this phenomenon (Ball, 2005). The following is offered as a possible explanation: the Sparse Data combined with the large (500) planning units resulted in a very limited range of possible solutions. As the BLM was increased, MARXAN

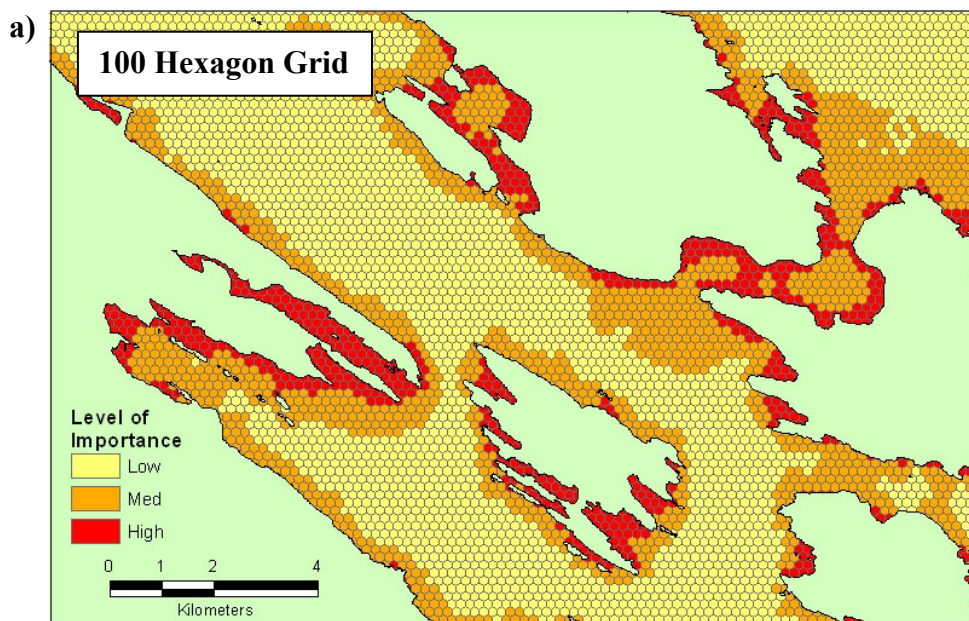
included fewer units in the solution as a way to reduce perimeter. Perhaps this was necessary because there were no alternative configurations of planning units available that did not cause overly large increases in area. The 100 grid, however, had additional unit configurations to select from, and did not have to remove units from the solution in order to decrease perimeter.

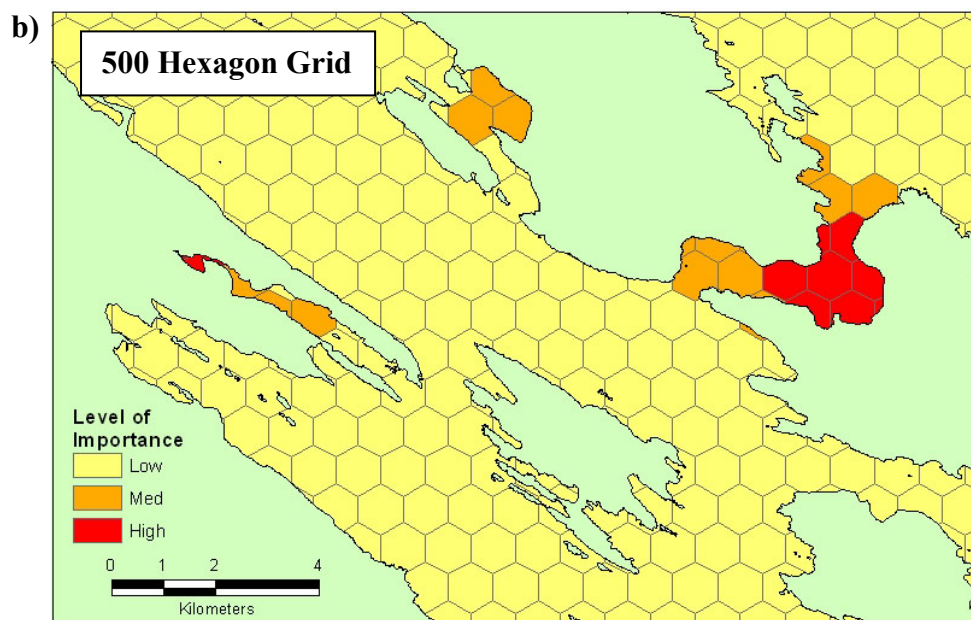
As expected, the 100 planning units are better at highlighting fine-scale variations in data than the 500 (Figure 5.1). When the summed solution results were compared, hotspots occurred in similar locations for both grid sizes, however the smaller sized units showed more variation within those hotspots.

Figure 5.1: Summed solution values for 100 and 500 grids.

a) 100 grid, b) 500 grid

(The term *level of importance* (see legends) refers to the number of times each cell was included in a run solution. 'High' values, for example, were included in more solutions.)





5.2.2 Planning Unit Shape

100 unit size (area of 25,981 m²) square and hexagonal grids were compared under three scenarios: Open Ocean, Inlets and Passages, and Inlets and Passages with Sparse Data. Table 5.2 summarizes the results of the planning unit shape testing, and Appendix XI shows graphs comparing area and perimeter changes.

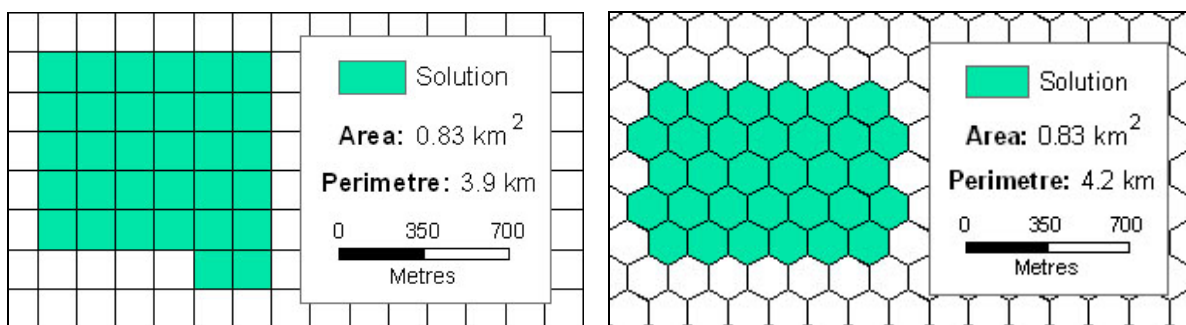
Table 5.2: Planning unit shape testing results.

BLM	Grid Shape	Open Ocean		Inlets and Passages		Inlets and Passages with Sparse Data	
		% Area Increase	% Decrease Perimeter	% Area Increase	% Decrease Perimeter	% Area Increase	% Decrease Perimeter
1	Square	0	2.3	0	3.5	-0.5	2.2
	Hexagon	0	1.5	0	1.3	0.7	-0.5
10	Square	0	7.6	0	5.8	-0.8	4.5
	Hexagon	0	4.9	0	4.1	-0.4	3.4
100	Square	0	41.1	0	36.5	-0.9	36.4
	Hexagon	0	36	0	30.3	-1.1	30.1
1000	Square	0	74.5	0	70.9	-1.3	65.3
	Hexagon	0	74	0	68.2	9.7	56

In most cases, there was negligible difference in the area and perimeter changes between the square and hexagonal results. The only difference was with the Inlets and Passages scenario with Sparse Data with a BLM of 1000 (Appendix XI c, d). The hexagonal grid solution experienced a sharp increase in area, which indicates that a very large number of planning units had to be selected in order to lower perimeter. With the same BLM the square grid experienced no such increase in area, and the percentage of perimeter decrease was also larger than that of the hexagonal grid.

Several studies cite reasons why hexagons should perform in a superior fashion to squares (Geselbracht *et al.*, 2005; Miller *et al.*, 2003; Warman, 2001). However, the opposite of this assumption was observed upon testing the two shapes. Although the two performed similarly with lower BLM values, the squares showed more clustering, without increased area, than the hexagons with higher BLM values. This is because although individual hexagons have a lower boundary to area ratio than squares, squares cluster together more efficiently because they have fewer sides than hexagons. Figure 5.2 demonstrates this phenomenon. The two solutions are composed of the same number of planning units, and cover the same area. Note the smaller perimeter with the square solution.

Figure 5.2: Comparison of hexagonal and square planning unit clusters.



5.3 DATA GAPS

The purpose of data gap testing is to determine how two different data configurations, one containing gaps and one that is continuous, react to different boundary length modifiers, and whether this reaction is influenced by targets. Table 5.3 summarizes the results of the tests. Appendix XII shows graphs of area and perimeter changes.

Perimeter changes were very similar between the sparse and continuous data configurations, with BLM values of 1, 10, and 100. However, with a BLM of 1000, the Inlets and Passages scenario (continuous data) lowered the solution perimeter by 12% more than the Inlets and Passages with Sparse Data scenario, for both the 5% and 20% targets. This is because sparse data has fewer planning unit configuration options, and therefore, less ability for clustering than continuous data.

Table 5.3: Data gap testing results.

BLM	Data Configuration	5% Target		20% Target	
		% Area Increase	% Decrease Perimeter	% Area Increase	% Decrease Perimeter
1	Continuous	0	1	0	1.3
	Sparse	-0.1	2.5	0.7	-0.5
10	Continuous	0	1.3	0	4.1
	Sparse	-0.6	2.3	-0.4	3.4
100	Continuous	0	13.2	0	30.3
	Sparse	-1.8	17.3	-1.1	30.1
1000	Continuous	0	66.6	0	68.2
	Sparse	36	53.2	9.7	56

Area changes were also very similar between the two data configurations with BLM values of 1, 10, and 100. With a BLM of 1000, however, the sparse data solution area increased while that of the continuous data remained constant. The solution area for the 20% target increased by 9%, and the 5% target increased by 36%. This is a

significant difference, and it indicates that sparse data combined with a low target is forced to include large quantities of superfluous planning units to achieve clustering with high BLM values.

Sparse data (i.e. with gaps) does not offer as many configuration options for solutions as continuous data. Therefore, when high BLM values induce clustering, there are fewer choices of contiguous units containing data. This creates a situation where non-data (superfluous) units must be included in the solution to decrease perimeter and cluster results, which creates a larger solution area. This suggests that lower BLM values might be slightly more efficient with sparse data, though the difference between sparse and continuous solutions is only about 10%.

Targets also affect the influence of BLM on sparse data. The higher the target, the easier it is for a solution to achieve clustering, which results in the inclusion of fewer superfluous units. Although debates continue in the literature regarding appropriate targets, these results show that in MARXAN there is a benefit to using higher target values with sparse data.

5.4 BOUNDARY LENGTH MODIFIER

The influence of boundary length modifier within different study area configurations and target values was examined. The results of this testing are presented in Table 5.4. These results are also shown graphically in Appendix XIII for the study area configurations component, and in Appendix XIV for the target component.

Table 5.4: Boundary length modifier testing results.

BLM	Study Area Configuration	5% Target		20% Target	
		% Area Increase	% Decrease Perimeter	% Area Increase	% Decrease Perimeter
1	Open Ocean	0	0.8	0	1.5
	Inlets and Passages	0	1	0	1.3
10	Open Ocean	0	2.2	0	4.9
	Inlets and Passages	0	1.3	0	4.1
100	Open Ocean	0	13.5	0	36
	Inlets and Passages	0	13.2	0	30.3
1000	Open Ocean	0	73.4	0	73.5
	Inlets and Passages	0	66.6	0	68.2

Study Area Configuration (Open Ocean vs. Inlets and Passages)

During preliminary examination of MARXAN, it was observed that solutions tended to gravitate towards large open expanses of planning units. Based on this observation it was hypothesized that open areas might react differently to BLM. Therefore, two different study area configurations were tested with different BLM values. These are: Open Oceans, which contains only uninterrupted planning units; and Inlets and Passages, which contains only small groups of contiguous planning units.

With low BLM values (1 and 10) the percentage of perimeter decrease was very similar for the Open Ocean and Inlets and Passages scenarios. However, with high BLM values (100 and 1000), the Open Ocean scenario experienced perimeter decreases approximately 5% greater than the Inlets and Passages scenario. For both the Inlets and Passages and Open Ocean scenarios there was no change in solution area between the different BLM values.

BLM had a larger clustering influence on the Open Ocean scenario than on the Inlets and Passages scenario. This is because the Open Ocean scenario contains more adjacent planning units, which made clustering easier to achieve. The difference between Open Ocean and Inlets and Passages scenarios is very small, which makes it unlikely that they would require the use of different BLM values. They should, however, be run in separate analyses.

Targets (5% vs 20%)

The influence of BLM depends partly on the characteristics of the data being used for analysis. Related are the targets set for each species (i.e. data layer). The influence of two target values, 5% and 20%, were examined with the Open Ocean and Inlets and Passages scenarios. The results are shown in Appendix XIV.

For both scenarios (Open Ocean, Inlets and Passages) the 20% target solution experienced higher decreases in perimeter than the 5% target solution. With low BLMs (1 and 10) the difference was small (between 1-2%), with a BLM of 100 the difference was much larger (between 13% and 23%), and with a BLM of 1000 the difference was small again (less than 2%).

Solution areas were the same (0% change) for all BLM values.

For each of the three scenarios, BLM has more clustering influence on higher targets than on lower targets. However, when the BLM value reaches a certain point (1000), the difference between the targets is small. Because more units are selected with a higher target, there is more choice when developing the solution, and therefore more opportunities for clusters. There is, however, a limit to the number of choices,

which is why the results with a BLM of 1000 are similar. This result shows that higher targets will achieve more clustering than lower targets.

5.5 PLANNING UNIT COSTS

Planning unit costs are values assigned to a particular area that are used in the calculation of the value of the objective function. Since the goal is to minimize the value of the objective function, the higher a unit's cost the less likely it is to be selected.

Because BLM and cost are interrelated (Section 2.4.1.5), a BLM value of 0 was used for cost testing, which removed the boundary length component from the objective function. Targets were set to 20% for all tests. Controlling for these factors meant that any difference between solutions could be attributed to costs alone. Two different scenarios were tested; scenario 1 contains data in both the 'desirable' and the 'undesirable' areas, and scenario 2 does not contain data in the 'desirable' area.

Table 5.5 provides a summary of results and Appendix XV shows the spatial configurations of solutions. Only a selection of results is included, since many solutions were identical. This is discussed below.

Table 5.5: Planning unit cost testing results.

Data Scenario	Costs			Summed Solution Area (km ²)			
	Desirable	Neutral	Undesirable	High	Medium	Low	Total
Scenario 1	0	0	0	6.2	41.0	8.3	55.5
	100	100	100	0.08	2.5	4.4	6.98
	0	1	2	0.4	0.5	4.6	5.5
	0	50	100	0.4	0.5	4.6	5.5
	0.1	0.2	0.3	0.2	0.05	6.3	6.55
	1	2	3	0.2	0.08	6.2	6.48
	25	50	75	0.2	0.08	6.4	6.68
	100	200	300	0.2	0.08	6.2	6.48
Scenario 2	0	0	0	15.0	38.8	1.7	55.5
	100	100	100	0.1	3.0	2.9	6
	0	1	2	0.1	2.9	3.0	6
	0	50	100	1.0	2.8	3.2	7
	0.1	0.2	0.3	1.0	2.8	3.3	7.1
	1	2	3	0.5	2.5	2.9	5.9
	25	50	75	0.2	2.8	3.1	6.1
	100	200	300	0.2	2.8	3.1	6.1

Scenario 1: Data in both ‘desirable’ and ‘undesirable’ areas

When the cost of every planning unit in the study area was set to 0, the solutions were scattered randomly across the study area, and were unrelated to target species’ distributions (Appendix XV a). When all planning units were assigned a cost of 100 (or any other value above 0), the solutions were clustered within the planning units that contained target data (Appendix XV b).

When ‘desirable’ areas were assigned a value of 0, the solutions were clustered around these areas regardless of the costs assigned to the ‘neutral’ and ‘undesirable’ areas (Appendix XV c, d). When the ‘desirable’ area was assigned a value above 0 (values between 0.1 and 100 were tested), the solutions were still concentrated in the

'desirable' area (Appendix XV e, f, g, h). However, fewer planning units from the 'desirable' area were selected than when the 'desirable' area was assigned a cost of 0.

The 'undesirable' areas were excluded from all of the solutions, regardless of the range of planning unit costs being used.

The selection of 'neutral' areas varied with costs. More of the 'neutral' areas containing species data were included in solutions when the 'desirable' area was assigned a value above 0 (Appendix XV e, f, g, h), than when the 'desirable' area was assigned a value of 0 (Appendix XV c, d).

Scenario 2: No data in the 'desirable' area

When no data were located in the 'desirable' area and all planning unit costs were set to 0 and 100, the results were the same as when data was contained in the 'desirable' area (Appendix XV i, j). The other tests, however, yielded different results.

When the 'desirable' areas were assigned a cost of 0, the solutions were very attracted to those areas, but the 'neutral' areas containing data were also selected more times than they were when data was included in the 'desirable' area (Appendix XV k, l).

When the 'desirable' area was assigned a value above 0, it was not included in the solution and a slight attraction to the 'undesirable' areas was apparent (Appendix XV m, n, o, p).

Although it is intuitive to assign 'desirable' areas a cost value of 0, doing so makes the solution gravitate overly towards these areas, especially when there is no data

within them. For this reason it is best to set the cost of all planning units above 0, since there is a possibility that ‘desirable’ areas may be void of data. It is better to include some ‘undesirable’ areas in the solution, which can be examined and/or removed easily after analysis, than to have a solution that is based only on the location of ‘desirable’ areas. A balance between ‘desirable’ areas and data distribution is ideal. This can be achieved using a wide range of costs (except 0), and there was very little difference between the solutions described above. Because the solutions are very similar it was necessary to select a range of costs randomly for developing zoning (Section 3.4.1). The cost range of 1, 2, 3 (1 for ‘desirable’ areas, 2 for ‘neutral’ areas, and 3 for ‘undesirable’ areas) was selected.

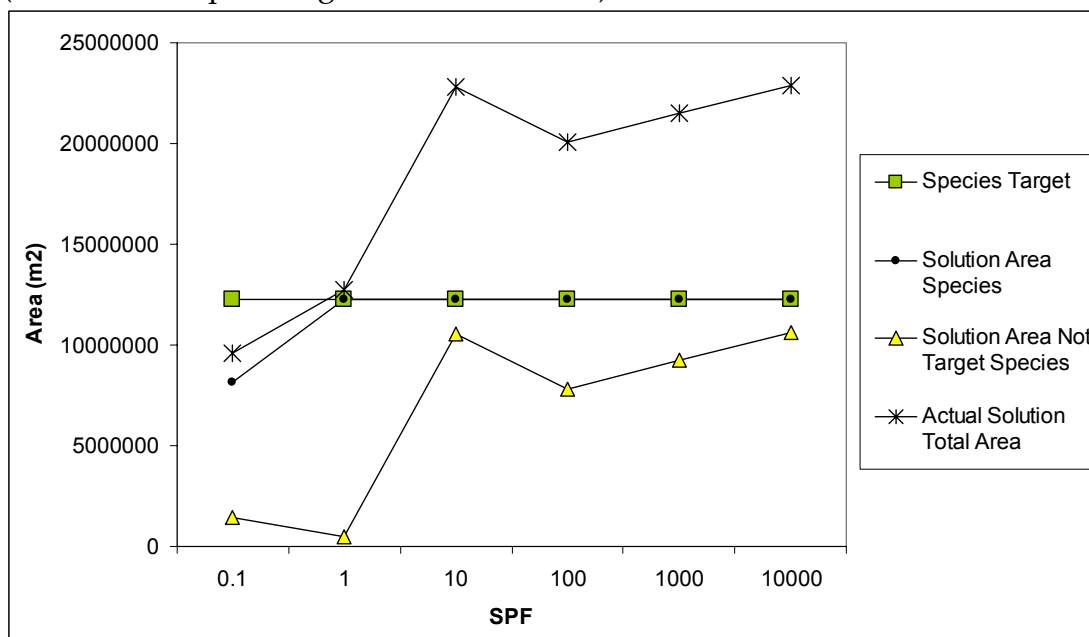
5.6 SPECIES PENALTY FACTOR

The species penalty factor (SPF) controls the importance of meeting data layers’ targets in solutions. The higher the SPF, the more likely a target is to be met. A range of SPF values (0.1, 1, 10, 100, 1000, and 10000) were tested (Section 3.3.5), and the results are presented here. Table 5.6 lists the results of SPF testing, which are shown spatially in Appendix XVI. Figure 5.3 shows the results as a graph.

Table 5.6: Results of species penalty factor testing.

SPF Value	Solution Area (m2)	Species Target (m2)	Target Met?	% Solution Area Containing Target species	% Solution Area NOT Containing Target Species
0.1	9586901	12259303	No	84.8	15.2
1	12730573	12259303	Yes	96.3	3.7
10	22837090	12259303	Yes	53.7	46.3
100	20057148	12259303	Yes	61.1	38.9
1,000	21538052	12259303	Yes	56.9	43.1
10,000	22863071	12259303	Yes	53.6	46.4

Figure 5.3: Species penalty factor testing results.
(BLM = 0, and planning unit costs = 25,981)



Lower species penalty factors (SPF) resulted in solutions with smaller areas and perimeters than higher SPF values. In fact, the solution for SPF of 0.1 was so small it did not meet species targets. The other SPF solutions (1 through 10,000) all contained the same amount of target species, and the increased area was due to the addition of increasing amounts of planning units not containing target species.

The higher the SPF value the larger the solution area will be. This is due to the addition of increasing amounts of non-target species planning units to the solution with higher SPF values.

Ball & Possingham (2000) suggest using an SPF value above 1, which correlates with the discovery that a small SPF value (0.1) can result in targets not being met.

It is likely that the magnitude of difference between different SPF values varies depending on the study area, penalties, costs, and data being used. Testing of these

factors was beyond the scope of this research, which only touched on a small sample of potential SPF combinations. Although a general trend of increasing area with increasing SPF was apparent, it was impossible to make suggestions for the use of different SPF values based on these results.

In theory it is possible to use different SPF settings to assign importance to different species, however in most situations, targets are used to set species importance (Geselbracht *et al.*, 2005). Variations in SPF value might be useful if the data distribution is such that it is very difficult to obtain a clustered solution that meets targets. In these cases, the SPF of less 'important' layers could be lowered, which might facilitate finding a solution.

More experimentation is needed to look at the use of different SPF values based on the importance of data layers. This could then be compared with the effect of using different targets.

5.7 SUMMARY

Between the two sizes of planning unit tested (100, with an area of 25,981 m², and 500, with an area of 649,519 m²) the smaller 100 planning unit grid was able to reduce perimeter of solutions without having to also decrease area. The 100 unit grid could also better highlight variations in the data than the 500 grid, and provided more possible configurations of units. The more choices there are for configurations, the better MARXAN will be able to find solutions. It was therefore concluded that smaller planning units are better, regardless of the scale of data collection and other factors that have influenced past decisions on planning unit size.

Two shapes of planning units that have been used in past MARXAN analyses were compared: squares and hexagons. Despite their popularity (Geselbracht *et al.*, 2005; Miller *et al.*, 2003; Warman, 2001), hexagons did not perform better than squares. In fact, although performance was very similar between the two, squares actually clustered more with higher BLM values than hexagons. Because squares react more efficiently to BLM they are better suited for MARXAN analysis.

The influence of the distribution of data on MARXAN solutions was also examined. Two data configurations were tested: one that is continuous, and one with gaps. Data with gaps does not provide as many possible configurations as continuous data, and was therefore more difficult to cluster. With a higher target (20%) the influence of the gaps on the clustering of the solution was less noticeable than at a lower target (5%). This indicates that the clustering limitations of data with gaps can be lessened with a larger target.

Two study area configurations were compared: Open Ocean, and Inlets and Passages. As suspected, Open Ocean areas reacted faster to BLM (i.e. clustered more) than the Inlets and Passages areas. This indicates that the two areas should be separated when running MARXAN analyses, otherwise, with high BLM values, solutions will gravitate towards the Open Ocean areas.

Costs, which can be used to incorporate study area characteristics into a MARXAN analysis, were tested in two scenarios: data in 'desirable' areas, and no data in 'desirable' areas. The main finding was that a cost of 0 creates a solution that centres around the area that has a cost of 0, ignoring the distribution of data. Combinations of costs (above 0) resulted in very similar solutions, all of which balanced the presence of data with the 'desirable' and 'undesirable' areas.

Several species penalty factor (SPF) values between 0.1 and 10,000 were compared. It was found that the low SPF value (0.1) was not able to reach targets, and that the size of solutions increased with SPF. The increases were composed mainly of non-target species planning units, and it was only with an SPF of 1 that the solution area was composed almost entirely of target species. However, this finding is not enough to suggest the use of a particular SPF value over another, as other important factors such as study area configuration, costs, and input data were not examined.

CHAPTER SIX

RESULTS: IDENTIFYING AND COMBINING ZONES

6.1 INTRODUCTION

The methods for developing and combining zones were informed by the results of the MARXAN testing (Chapter Five) and the functional requirements study (Chapter Four).

It is important to note that the preliminary zoning suggestions presented in this chapter should not be perceived as a prescription for the Southern Strait of Georgia. It is the theory, not the physical zones, that is of importance.

Three different cost values (1, 2, and 3) were applied to planning units during zoning based on the findings of Section 5.5. 'Desirable' areas were assigned a cost value of 1, 'neutral' areas were assigned a value of 2, and 'undesirable' areas were assigned a value of 3. Desirable areas are those whose inclusion in the solution is potentially beneficial, and are therefore assigned the lowest cost. Undesirable areas are those whose inclusion is potentially harmful, or simply not desired, and they are assigned the highest cost. In between are the neutral areas, which make up the remainder, and the majority, of the study area. See Section 3.4.1 for a list of the data used for the desirable and undesirable areas.

Three different zoning methods were tested. For each, the conservation zone was developed first, followed by the recreation zone. The same conservation zone was used for the three methods. In the first method, each zone was developed separately,

then joined. In the second method, areas of importance for the conservation zone were excluded when developing the recreation zone, then the two zones were joined. In the third method, areas of importance for the conservation zone were assigned a cost of 3 when developing the recreation zone, then the two zones were joined. For each of the three methods, an overlay was used to join the two zones, and areas of overlap were flagged and rated according to their importance for each zone.

The summed solution output from MARXAN was used to show the relative level of importance of planning units for each zone. Section 3.4.2 describes how the three levels, high, medium and low, were determined.

The results for developing, as well as joining, the zones are presented for each of the three methods, followed by a discussion and summary of the results.

6.2 METHOD ONE – Zones developed separately, then combined

The conservation zone solution was influenced by both the distribution of data and the location of 'desirable' areas. 'Desirable' areas containing species data were selected most often, which was the desired outcome. The influence of the 'desirable' areas on the solution can be seen by comparing Figure 6.1 (shows the summed solution when all planning unit costs were set to 1), to Figure 6.2 (shows the summed solution when costs of 1, 2, and 3 were applied). Similar areas were highlighted by both solutions due to data distributions, and these areas were selected more where they intersected with 'desirable' areas (Figure 6.2). Most of the 'undesirable' areas were avoided by the solution when costs were set to 1, 2, and 3.

However, in cases where a given species was only found in ‘undesirable’ areas it was included in the solution, as shown in Figure 6.2.

The recreation zone solution was based on much less data than the conservation zone, so the influence of data distribution is much more obvious. Figure 6.3 shows the recreation solution when all planning unit costs are set to 1. The hotspots selected with costs of 1, 2, and 3 (Figure 6.4) are very similar to those selected when all costs were set to 1. This is because most of the recreation data is located close to shore, and the ‘desirable’ areas are also contiguous to the coastal areas. There are, however, a few slight differences, which are highlighted in Figure 6.4.

When the two zones were combined, there were 786 overlapping planning units, the majority of which were of low or medium importance for both zones. Table 6.1 summarizes the distribution of overlaps between the two zones. Figure 6.5 and 6.6 show the spatial distribution of overlapping units.

Table 6.1: Method One number and importance of overlapping planning units.

		Recreation Zone Importance			Total
		1 (low)	2 (medium)	3 (high)	
Conservation Zone Importance	1 (low)	413	79	2	494
	2 (medium)	166	53	1	220
	3 (high)	41	28	3	72
Total		620	160	6	786

Figure 6.1: Conservation zone summed solution with all costs set to 1.

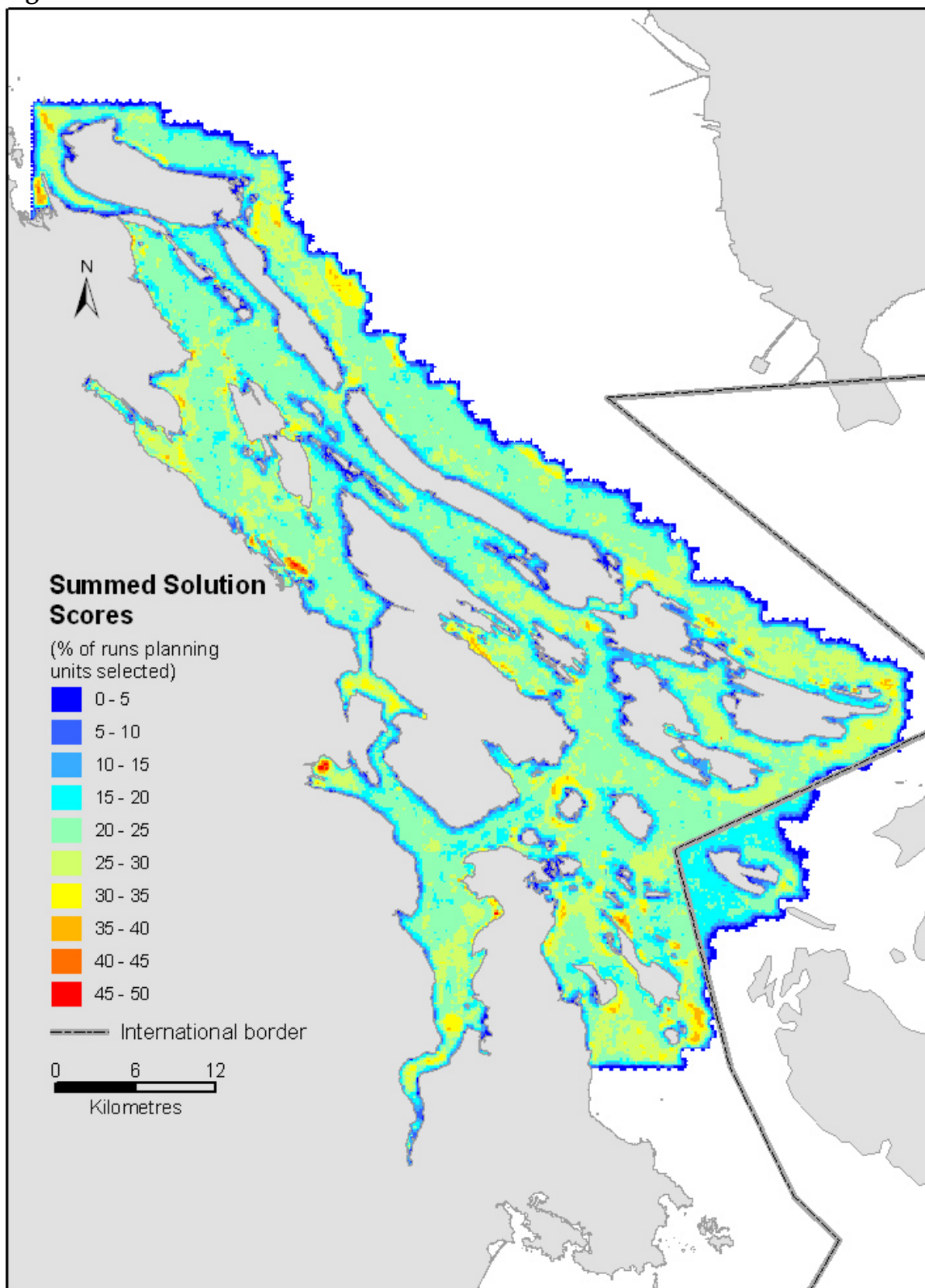


Figure 6.2: Conservation zone summed solution with costs of 1, 2, and 3.

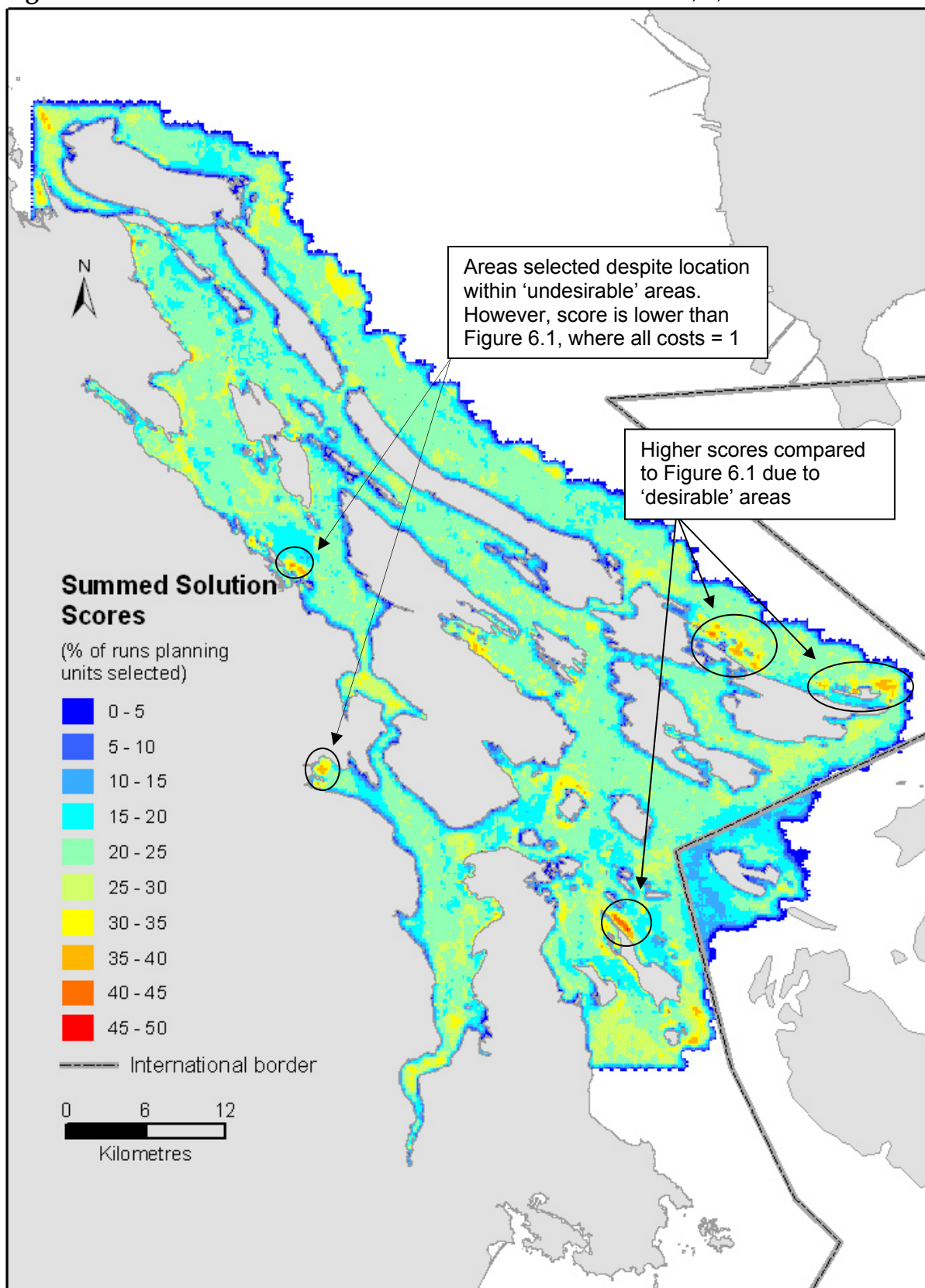


Figure 6.3: Recreation zone summed solution with all costs set to 1.

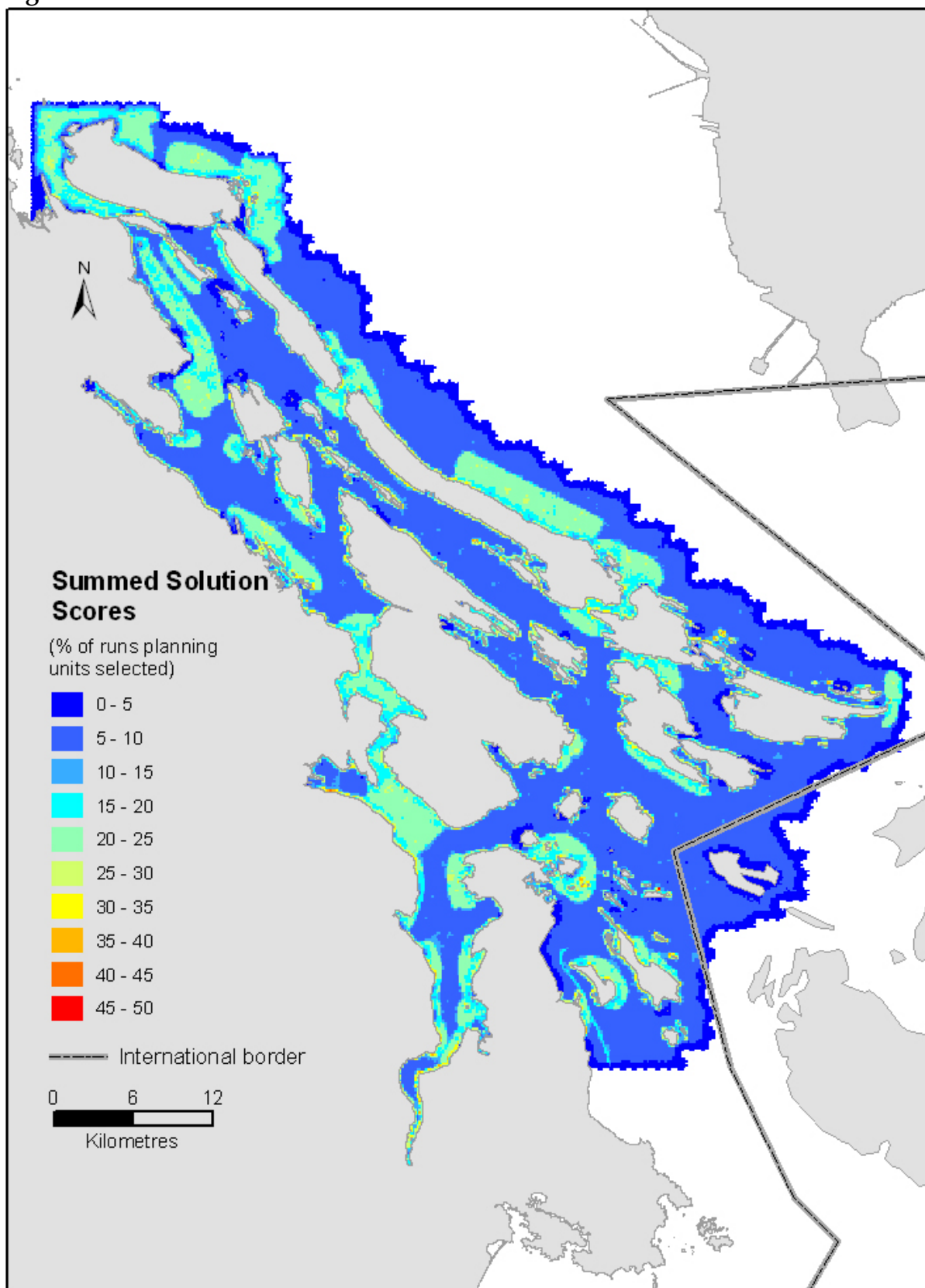


Figure 6.4: Recreation zone summed solution with costs of 1, 2, and 3.

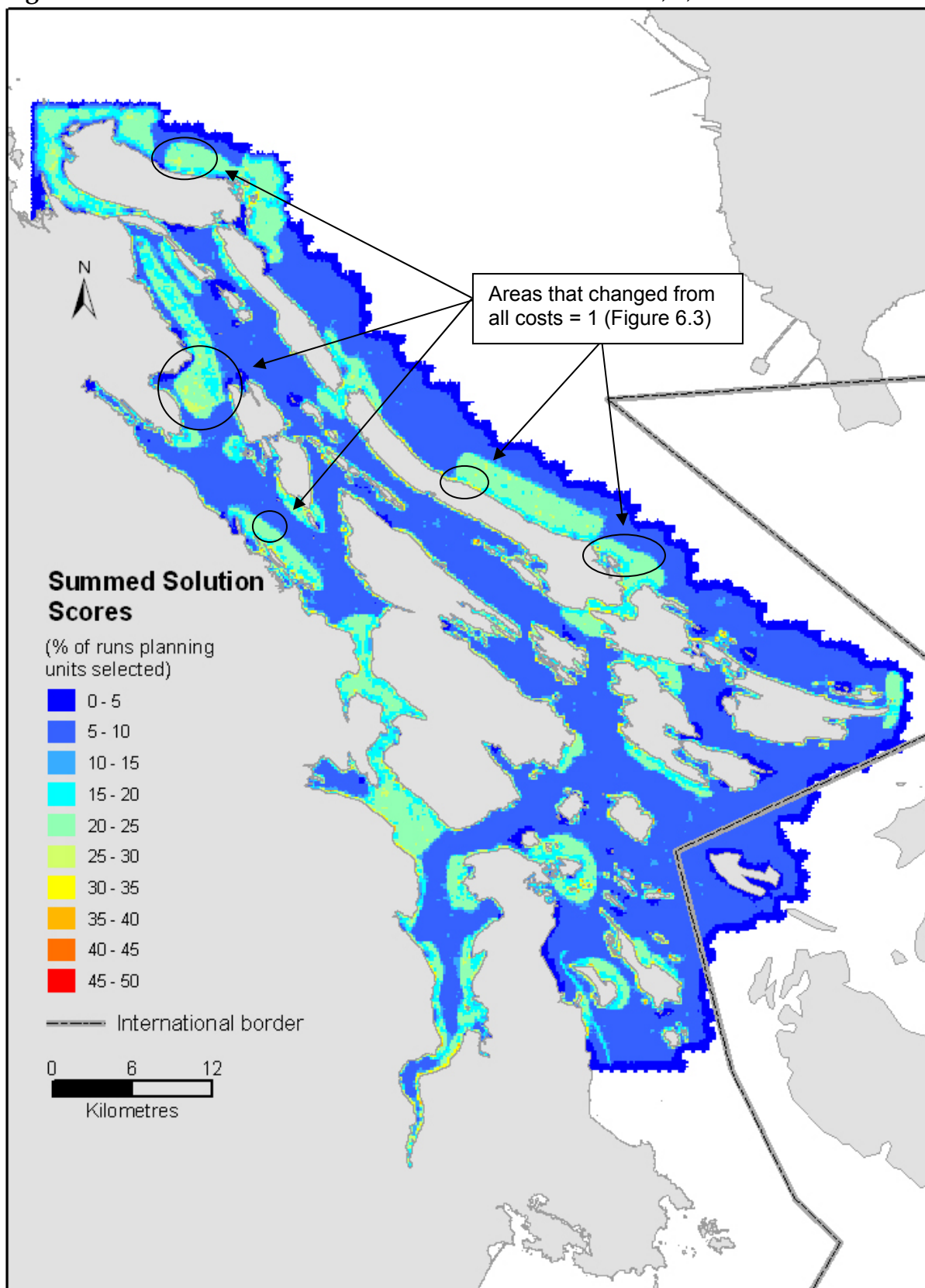


Figure 6.5: Method One combined conservation and recreation zones.

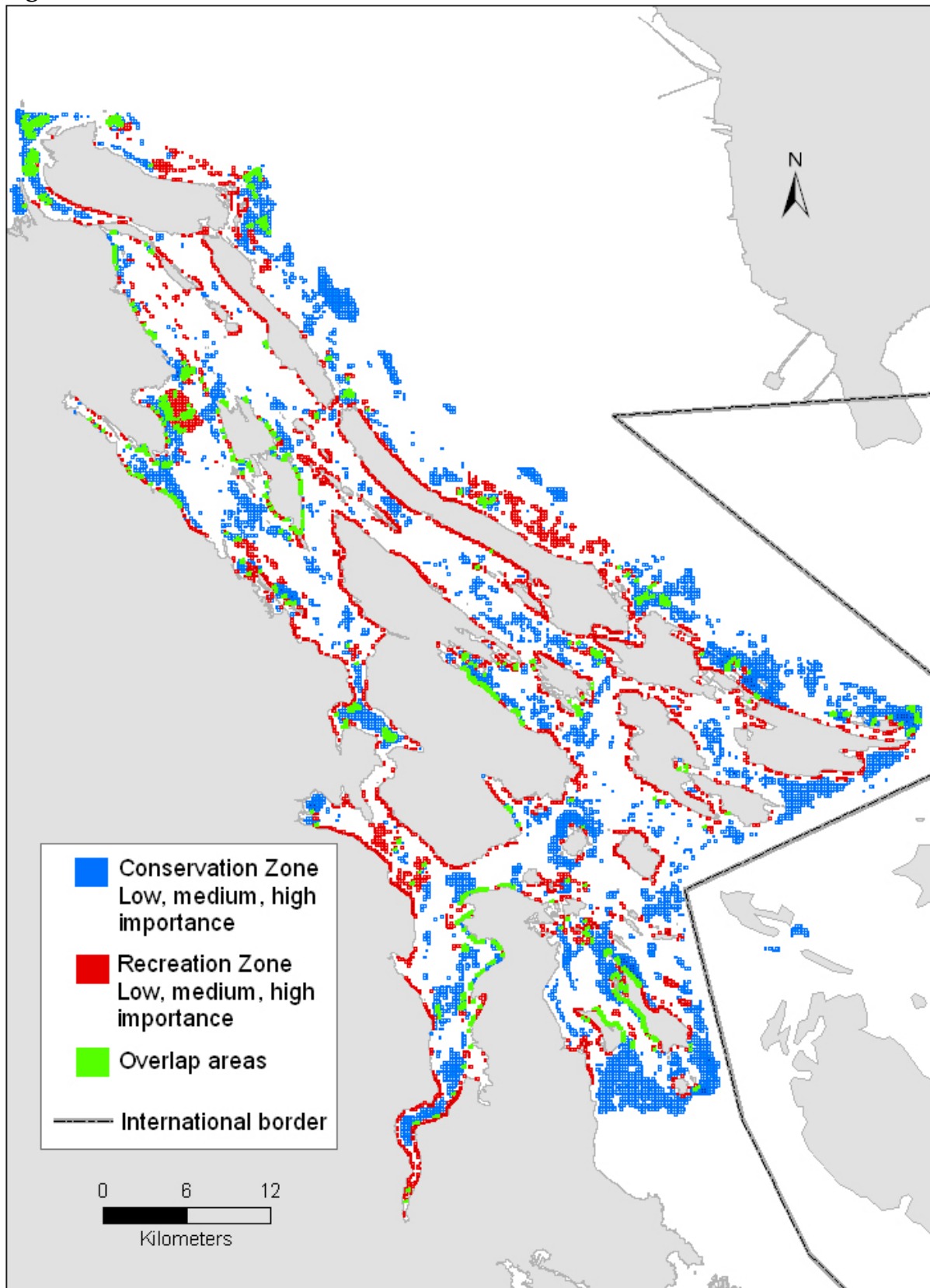
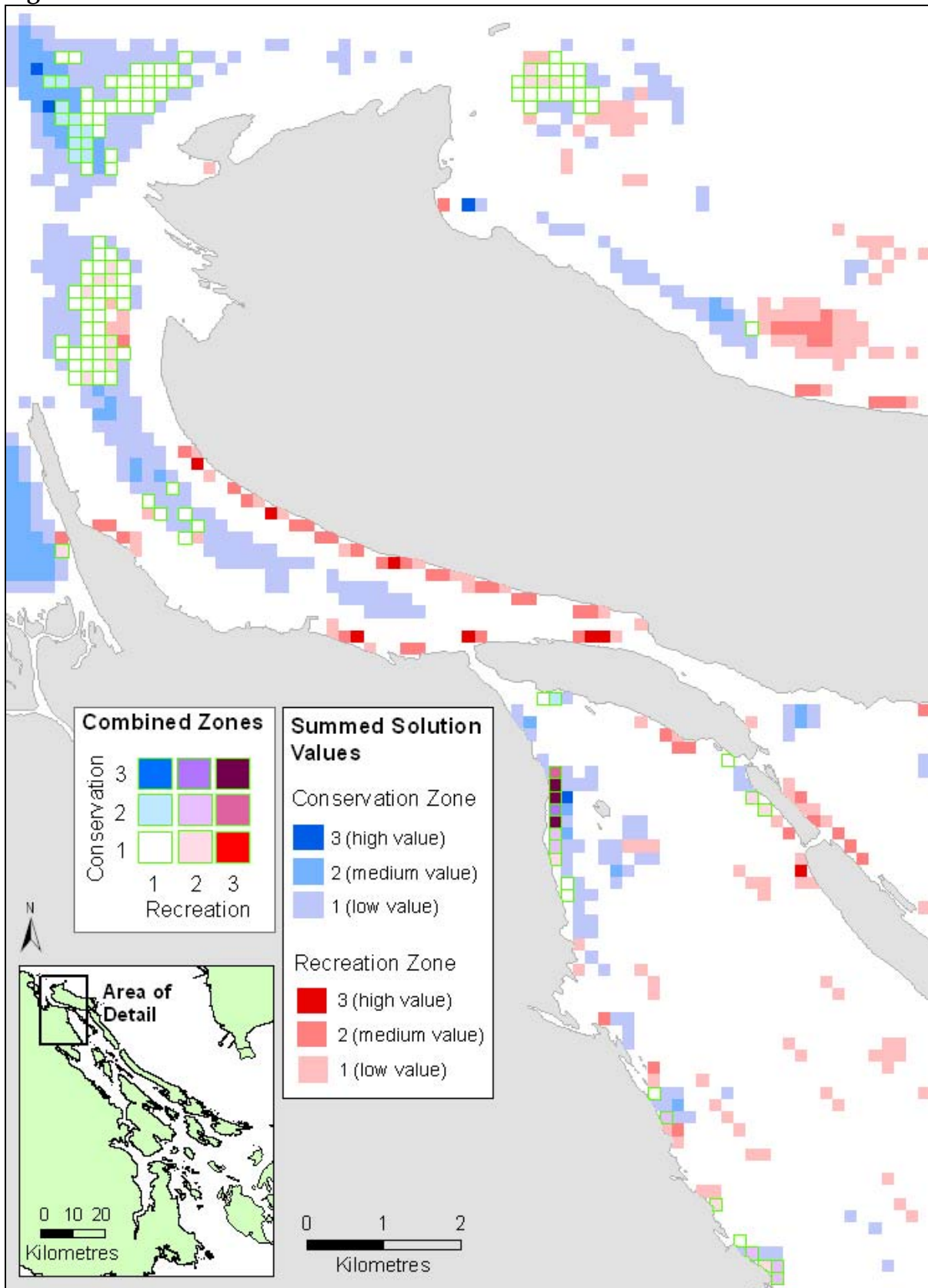


Figure 6.6: Area of detail from Method One combined zones.



6.3 METHOD TWO – High value conservation zone areas set off limits when developing the recreation zone

Figure 6.7 shows the recreation zone solution when high value conservation zone areas were excluded from the solution. This result is clearly different from that of Method One. The excluded ('off limits') areas, of medium and high importance to the conservation zone, were not included in the development of the recreation zone. Other planning units, of lesser importance for the recreation zone, were selected instead. Despite avoiding the medium and high overlaps, the solution resulted in 996 planning unit overlaps between the two zones, which is an increase of 27% over the number of overlapping units in Method One.

The distribution of overlaps between the two zones is summarized in Table 6.2. The spatial distribution of overlapping units is shown in Figure 6.8 and 6.9.

Table 6.2: Method Two number and importance of overlapping planning units.

		Recreation Zone Importance			Total
		1 (low)	2 (medium)	3 (high)	
Conservation Zone Importance	1 (low)	708	250	38	996
	2 (medium)	0	0	0	0
	3 (high)	0	0	0	0
Total		708	250	38	996

Figure 6.7: Method Two recreation zone summed solution.

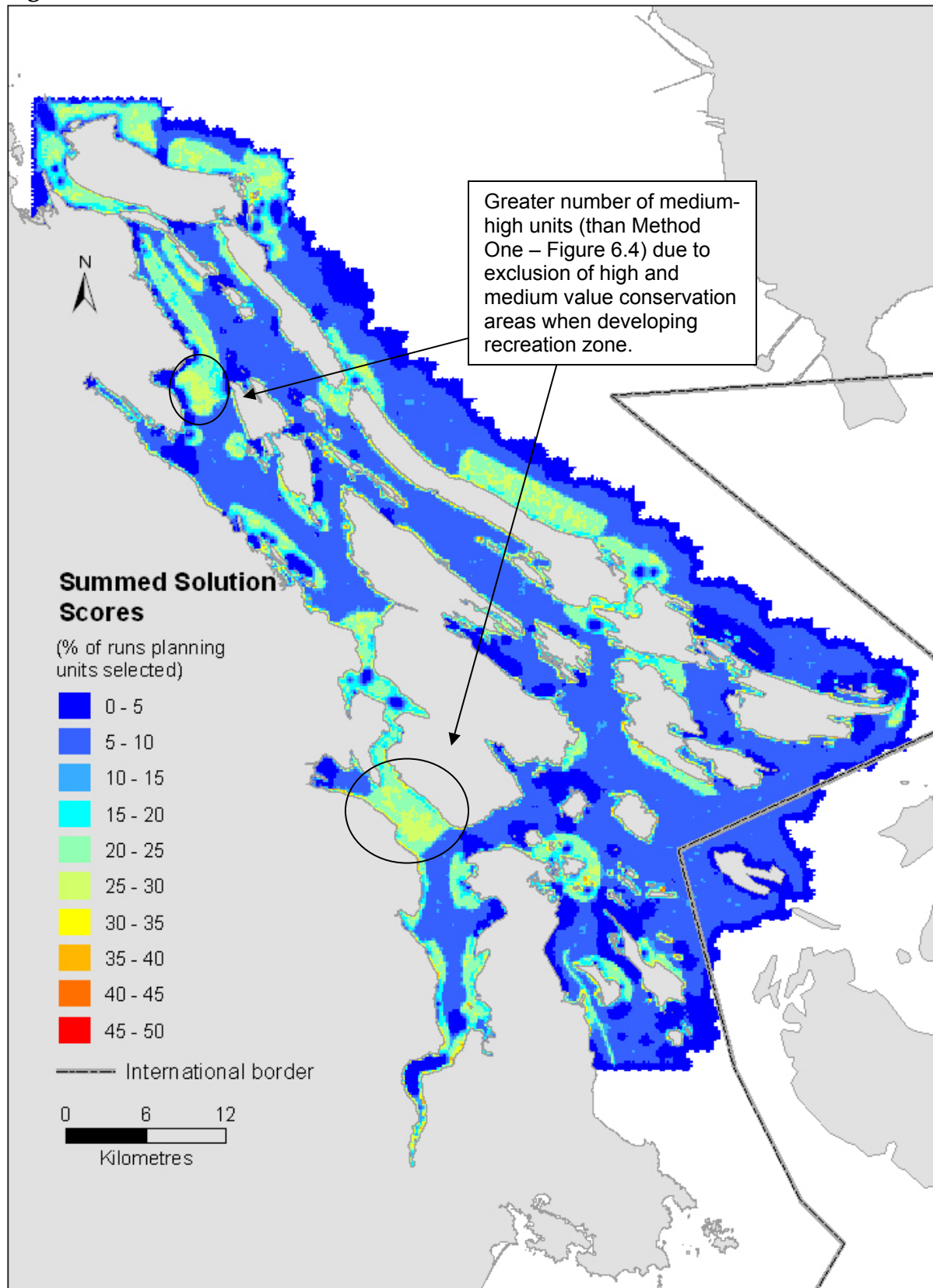


Figure 6.8: Method Two combined conservation and recreation zones.

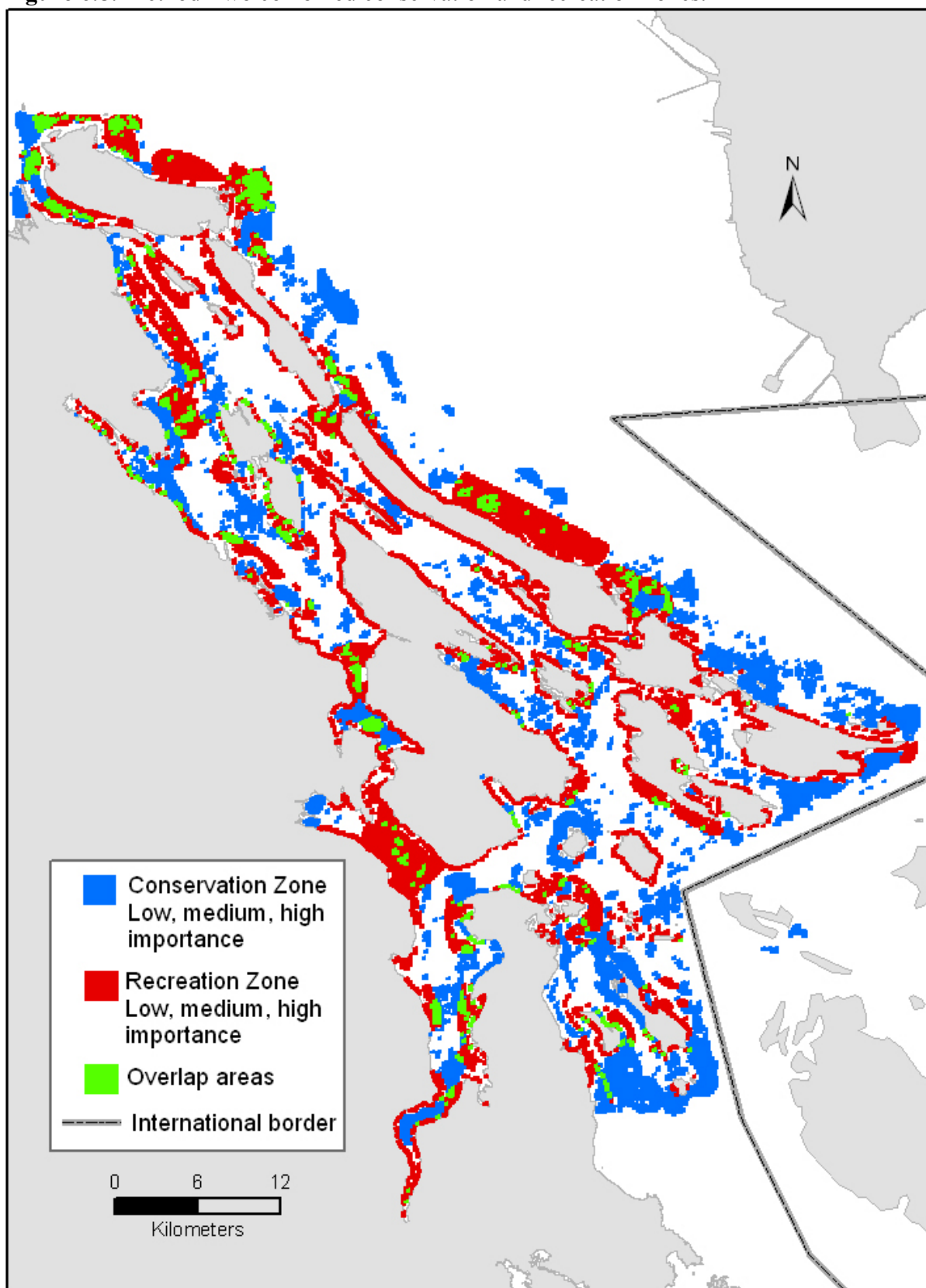
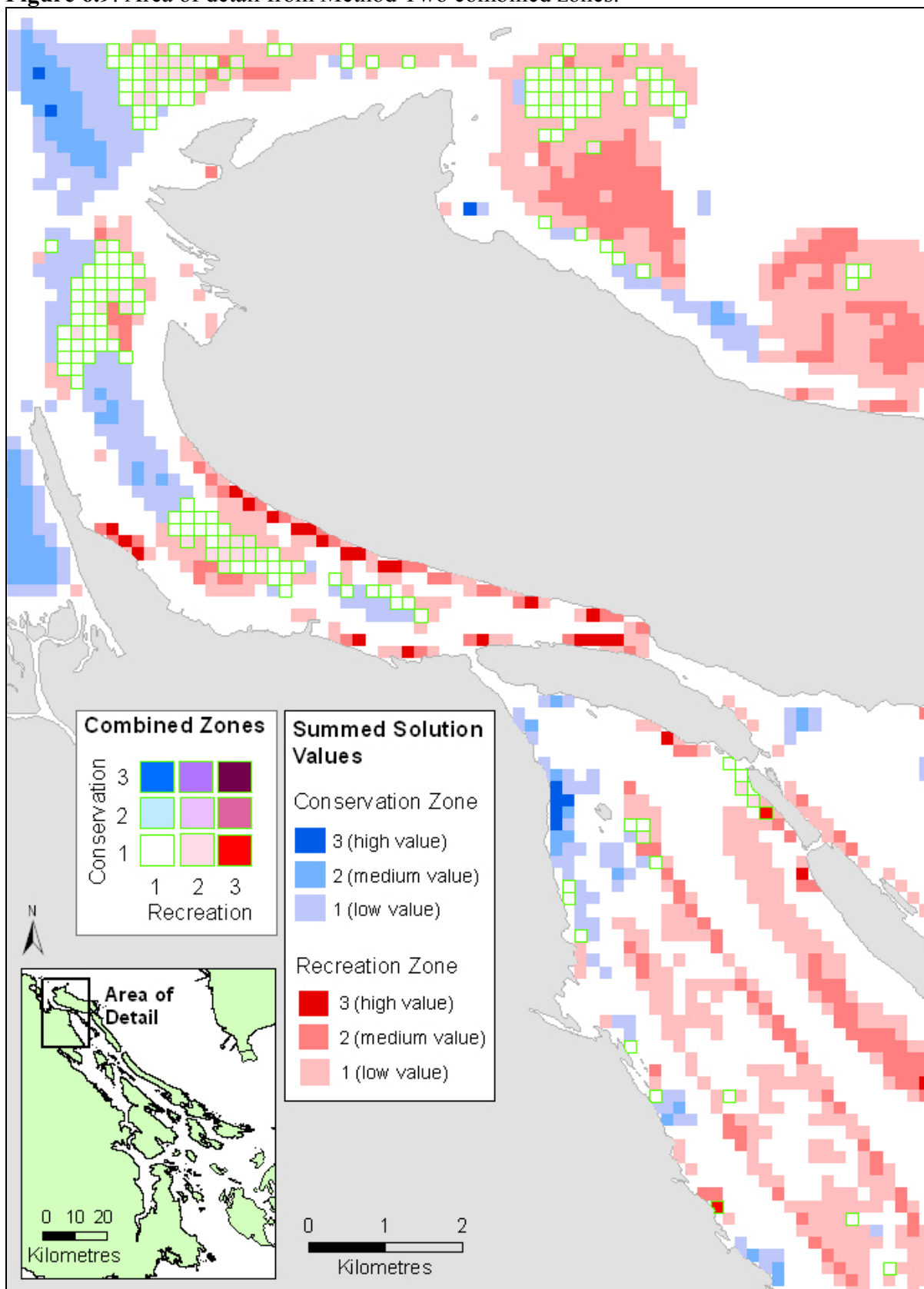


Figure 6.9: Area of detail from Method Two combined zones.



6.4 METHOD THREE – High value conservation zone areas given high cost when developing recreation zone.

When high value conservation zone areas were given a high cost (3), other planning units with lower costs in the recreation zone were selected more often. There was a less dramatic difference than with Method Two, but similar changes to the solution occurred. Figure 6.10 shows the recreation zone solution when high value areas from the conservation zone were given a cost of 3.

When the Method Three recreation zone solution was joined with the conservation zone solution, there were dramatically more areas of overlap than with Method One. 1,295 planning units overlapped, which is an increase of 65% over Method One. Most of the overlaps are in low importance conservation areas, so the higher cost was effective in avoiding overlaps in medium and high importance conservation areas.

The distribution of overlaps between the two zones is summarized in Table 6.3. Figure 6.11 and 6.12 show the spatial distribution of overlapping units.

Table 6.3: Method Three number and importance of overlapping planning units.

		Recreation Zone Importance			Total
		1 (low)	2 (medium)	3 (high)	
Conservation Zone Importance	1 (low)	946	155	48	1149
	2 (medium)	78	46	16	140
	3 (high)	2	4	0	6
Total		1026	205	64	1295

Figure 6.10: Method Three recreation zone summed solution.

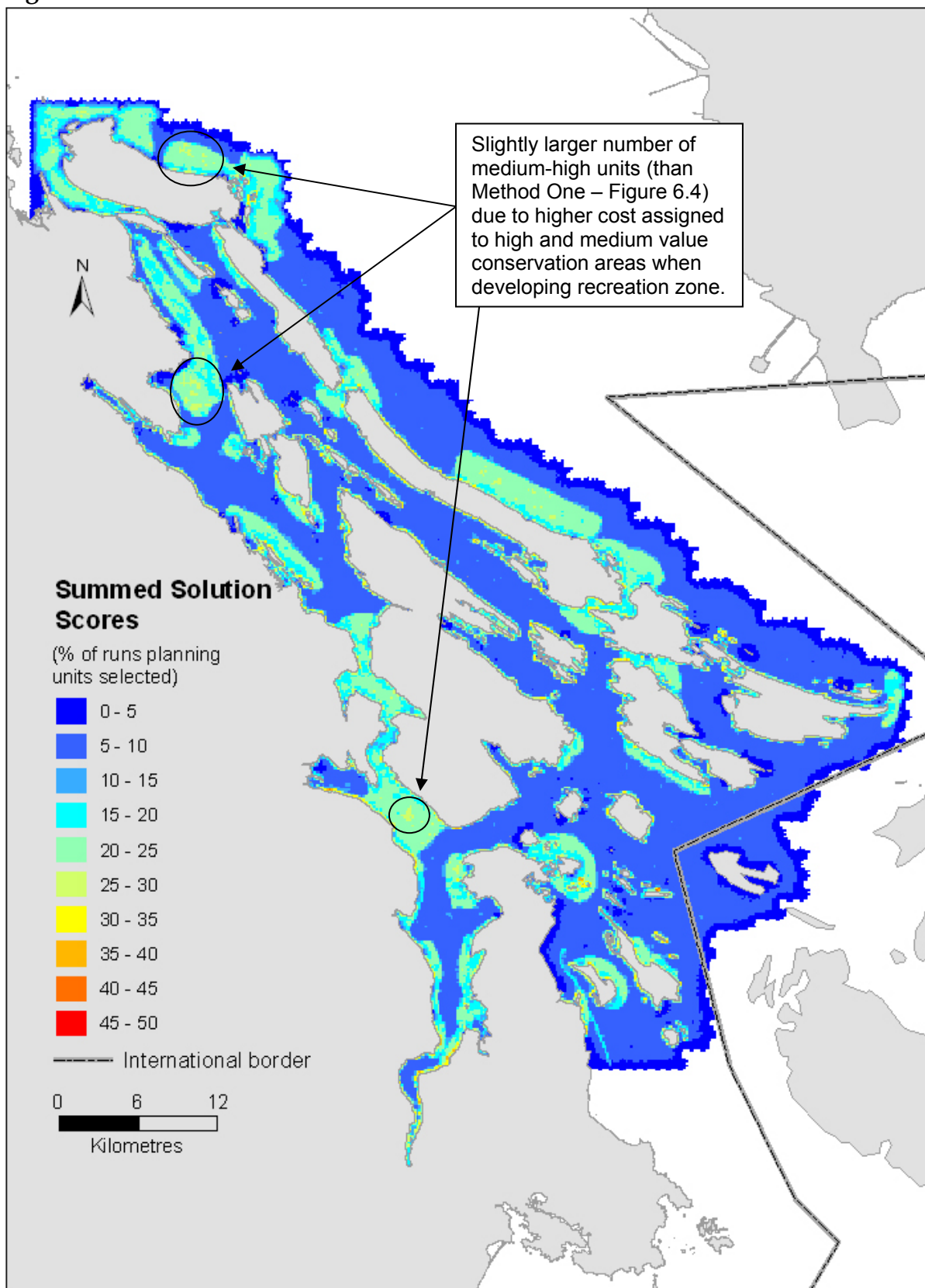


Figure 6.11: Method Three combined conservation and recreation zones.

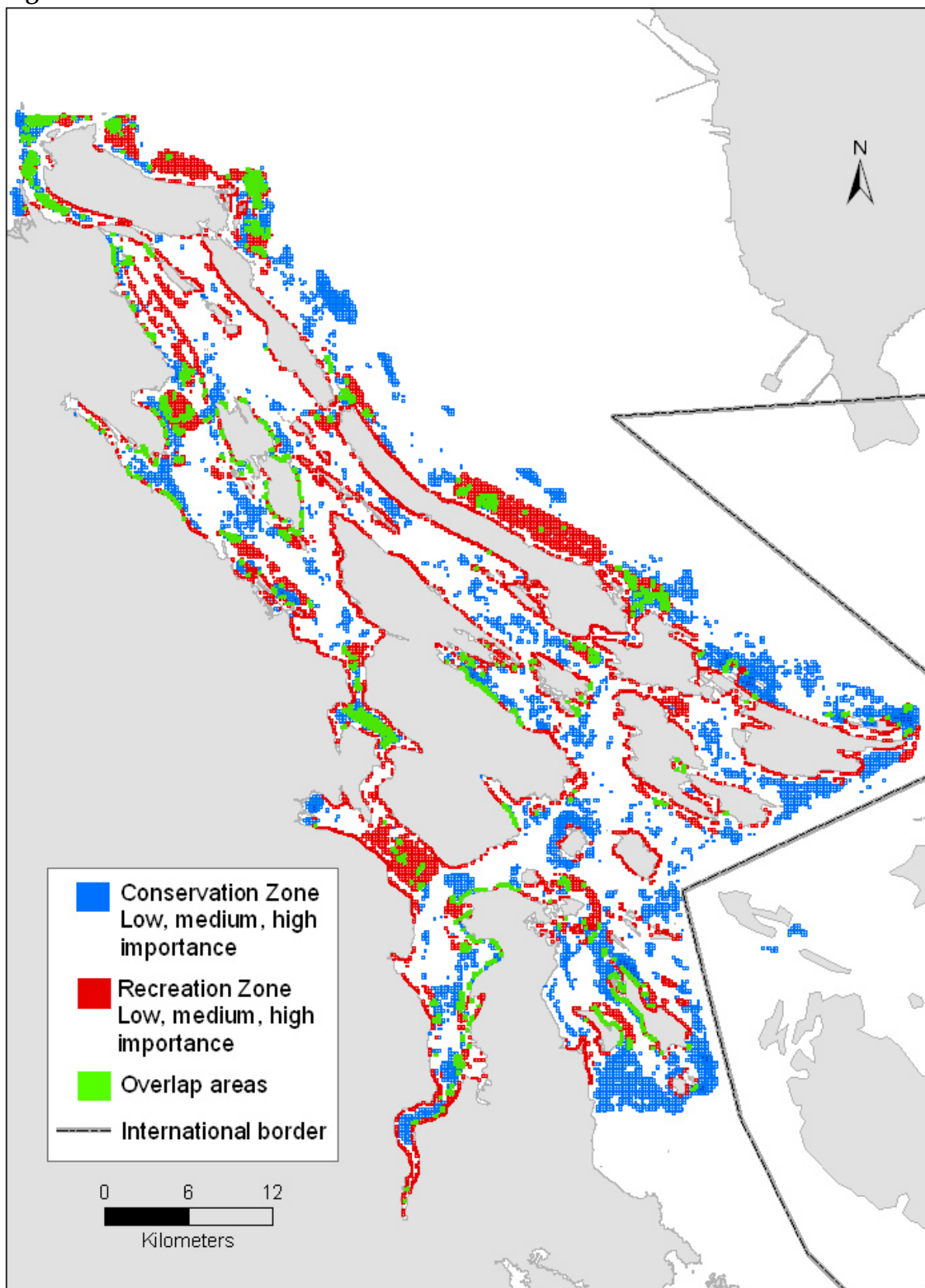
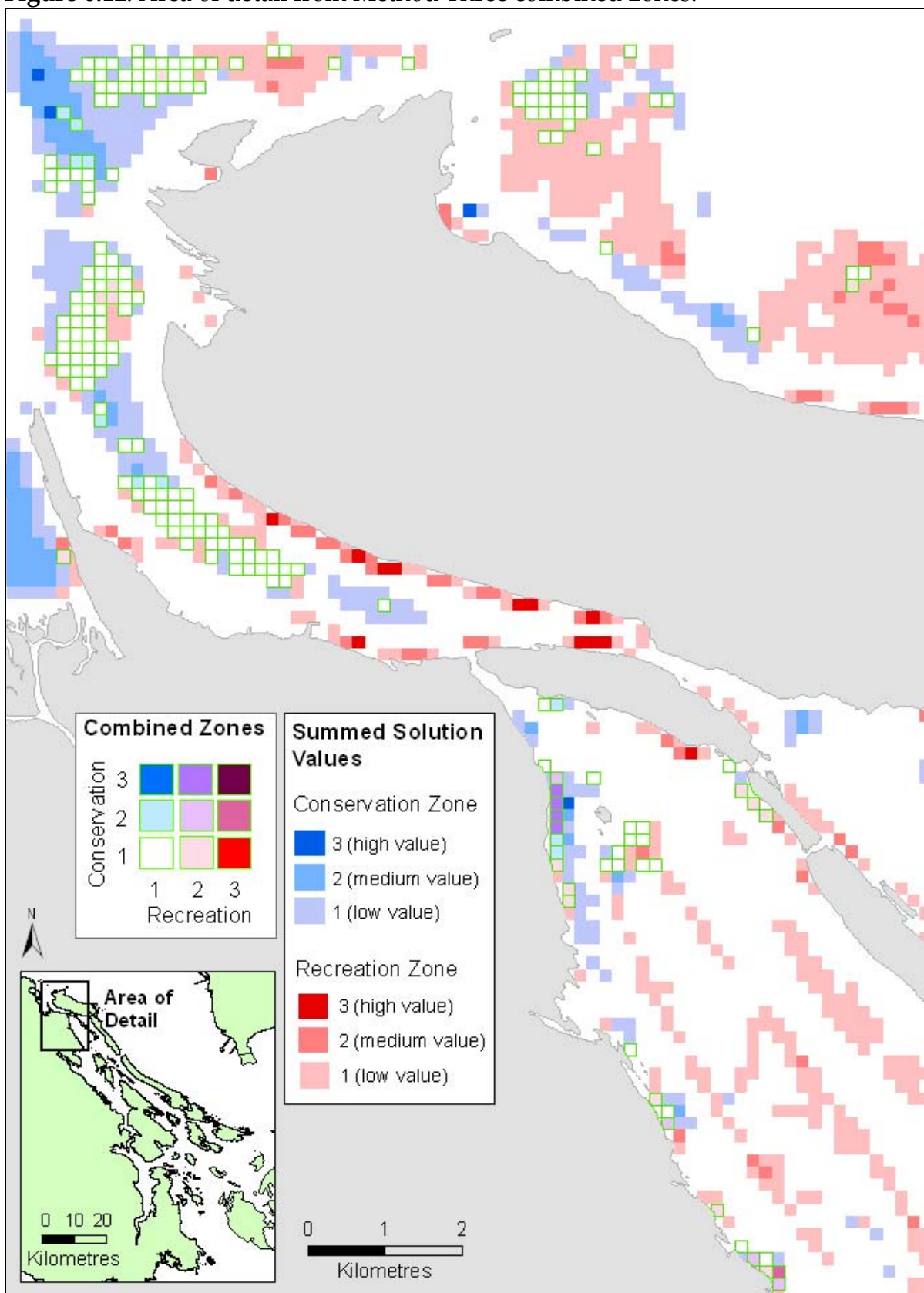


Figure 6.12: Area of detail from Method Three combined zones.



6.5 SUMMARY

Although the results of Method One had fewer overlapping planning units between the two zones, 37% of these overlaps were in areas of high or medium value for the conservation zone. Methods Two and Three were designed to avoid overlaps between the recreation zone and areas of high value for the conservation zone. Method Two was the most successful with 0% of the recreation solution's units overlapping with high value conservation areas. Method Three, with 11% of overlapping units in high value conservation areas, was also able to reduce the amount of overlap. However, each of these methods did result in a higher overall number of overlapping planning units than Method One; 27% more with Method Two, and 65% more with Method Three.

The suitability of these methods depends on the nature of the problem being addressed. Method One gives stakeholders an opportunity to decide what areas of overlap should be attributed to the conservation or recreation zone, rather than applying overall rules before the zones are combined. However, if priority of the conservation zone is a given, Method Three would be useful because it incorporates this priority into the development of the recreation zone. This creates fewer areas of high value conflict with the conservation zone when the two zones are combined. Unlike Method Two, where high value areas were excluded from the recreation zone, Method Three uses costs to `nudge` the recreation zone away from areas of importance for the conservation zone, without forcing a given output.

Regardless of the method chosen to combine zones, the outputs shown in Figures 6.5, 6.6, 6.8, 6.9, 6.11, and 6.12 are ready to be used for a zone refinement process.

CHAPTER SEVEN

DISCUSSION

7.1 INTRODUCTION

While previous chapters have explored specific aspects of MARXAN and the zoning process, this chapter sets MARXAN, and this research, in a wider context. This involves a discussion of the limitations of the software that came to light during this research, as well as the position of MARXAN within the zoning process. Also included are suggestions for future research opportunities.

7.2 MARXAN LIMITATIONS

Several difficulties with the use of MARXAN were encountered in this research. These include; the influence of cost settings on the effectiveness of BLM, the limit to the number of planning units that can be processed by MARXAN, and the influence of edges on solution configurations. While the second issue was reported in grey literature, none of the three are mentioned in other literature or in the MARXAN user manual.

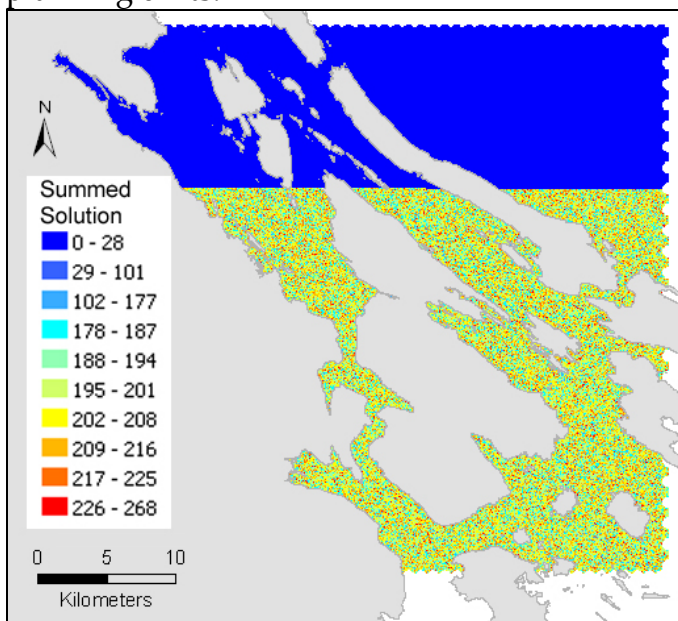
As discussed in Section 2.4.1.5, the magnitude of cost settings influences the effectiveness of BLM values. This fact is not mentioned in the MARXAN manual, and it was only discovered when explorations of BLM settings yielded results that were significantly different from those of other studies. BLM values ranging between 0.02 and 1 have been used to achieve clustering in other applications of MARXAN (Airamé *et al.*, 2003; CIT, 2003; Lieberknecht *et al.*, 2004; Meerman, 2005; Stewart *et al.*, 2003; Stewart & Possingham; 2002). For this research, however, a BLM

of 0.1 had no effect on solution clustering, and it was not until much larger values (above 100) were reached that significant clustering was apparent. Upon consultation with Ian Ball (2005), one of the MARXAN creators, it was discovered that the influence of the BLM value is sensitive to the magnitude of planning unit costs being used. Converting the costs, which were based on planning unit size, to kilometres from metres brought BLM influence into line with the results of other testing. Appendix XVII shows graphs of the kilometre and the metre scale costs. The kilometre scale graphs show an immediate and significant decrease in perimeter with a BLM value of 0.1, which was the BLM value used in this research during zone development. When area, in meters, is used as the cost factor the boundary length modifier that is required to significantly decrease perimeter is very high (above 1000). When area in kilometres is used as the cost factor the BLM needed to reach the same optimal point is much lower, in the range of 0.1 to 1.

Another issue that is not mentioned in the MARXAN manual or peer reviewed literature is MARXAN's planning unit limit. Oetting and Knight (2005) found that MARXAN did not function correctly, independently of hardware processing power, with a study area containing more than approximately 65,000 planning units. This result was confirmed in the research described here. After exactly 65,678 planning units the software stopped selecting planning units, and multiple tests produced identical results. Figure 7.1 shows a solution from an analysis that contained too many planning units for MARXAN. The blue area is above the 65,678 planning unit limit and therefore went unprocessed and unselected in the solution. The remainder of the solution appears normal, and were it not for this limitation of MARXAN, it would have been usable. This problem is significant because the size of planning units, and potentially the scale of MARXAN analysis, is limited. Two options are possible to solve this issue: use larger planning units, thus changing the scale of the

analysis, or divide the study area into smaller areas for separate analyses. The former is less preferable, as coarser planning units are less able to highlight variations in data (Section 5.2.1), and therefore result in less detailed solutions. However, the latter option also presents some challenges, as the boundaries for dividing the analysis must be determined. This can be simple if distinct areas, such as ecoregions, have been identified in the study area. Otherwise more subjective, and potentially arbitrary, divisions would have to be developed. The divisions can greatly change the outcome of a MARXAN analysis, so the choice of boundaries is an important consideration.

Figure 7.1: Summed solution produced by MARXAN with more than 65,678 planning units.



Another issue with MARXAN is the 'edge effect' that is apparent in summed solution results. The results from zoning development (Chapter Six) show a clear avoidance of edges. See, for example, Figure 6.1. The dark blue border, which represents planning units that were not included in solutions, along the outside edge of the study area and the coastline is caused by the software, not data

distribution. This edge effect is due to the higher boundary length of coastal planning units, and the difficulty of perimeter planning units to create clusters. This effect is not mentioned in literature, or in the MARXAN manual. It was, however, encountered by the Great Barrier Reef Marine Park Authority, who overcame this difficulty by multiplying coastal boundaries by a factor that decreased their influence on solutions (Lewis, 2006). This factor was determined through experimentation, and along extremely convoluted coastlines it was increased as necessary. In Figure 6.1 there are some areas along the coast where there is no dark blue (areas that were not included in solutions). This is because the distribution of data in those areas was such that the 'edge effect' was overcome. This shows that the 'edge effect' can be cancelled out, or at least tempered, by input data. Further tests would be useful to determine how much respective influence 'edge effect' and data distribution have on solution distribution.

When examining the results from Chapter Six (see Figure 6.1 as an example), it is apparent that the entire coastline is not avoided. In some areas the solution touches the coastline, which indicates that the presence of data can over-ride the edge effect. For this reason a factor such as that used by the GBRMPA was not used in this research. It is not known, however, how much influence the edge effect had on results. Further experimentation is needed, and MARXAN users should at least be made aware of this phenomenon.

In addition to the MARXAN issues discussed above, broader limitations of the software were observed. Terms such as efficient, adaptable, systematic, effective, scientific, and transparent have been used to describe ideal zoning tools and processes (Lewis *et al.*, 2003; Villa *et al.*, 2002). Through this research it became apparent that MARXAN only offers some of these characteristics. While it has the

power to incorporate large amounts of information, and to quickly adapt to changing requirements, MARXAN is deficient in other areas. Because there are many interrelated settings with few specific guidelines, 'tweaking' plays a large role in MARXAN use (Ardron, 2004; Fernandez, 2005). The guesswork and manipulation of settings dilutes the systematic and scientific potential of MARXAN, and in this aspect make it similar to *ad hoc* methods. In addition, true transparency is almost impossible with the software. While the settings used to develop zoning can be shared, with stakeholders for example, it would be very difficult for those unfamiliar with MARXAN to evaluate the appropriateness and motivation for using a given set of settings.

Finally, MARXAN is not an easy program to learn or use. Even for experienced GIS users the learning curve is steep. Sparse documentation and the need to experiment with settings exacerbate this problem. There is a danger of using settings without fully understanding the implications. In addition, it is very difficult to evaluate a given output because of the variation in possible outcomes. There are no 'wrong' answers, only different ones. This is partly because the workings of MARXAN are essentially a black box and it can be difficult to discover why a particular area was selected over another, especially when complicated input data was used.

7.3 POSITION OF MARXAN IN THE MPA ZONING PROCESS

Despite the limitations described above, MARXAN has an important, supportive, role to play in the MPA zoning process. This role lies mainly in data processing; the flexibility and power of MARXAN when dealing with complex spatial data was apparent throughout this research. MARXAN provides a mechanism through which zoning goals can be applied to large quantities of spatial data. MARXAN outputs

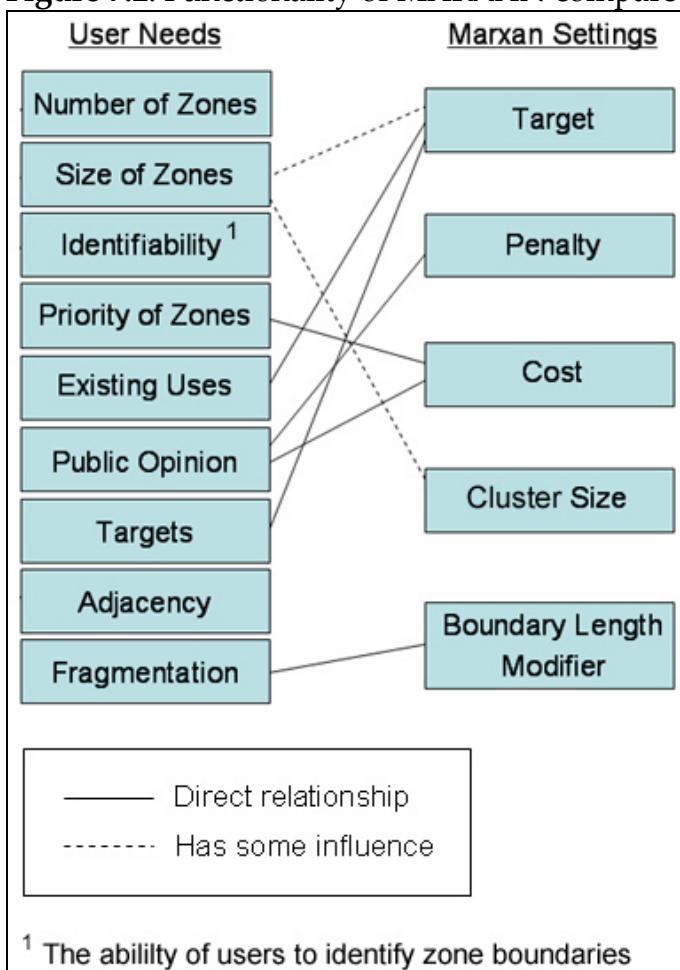
are not, however, suitable for immediate application as zones. The 'best' solution from a set of MARXAN runs is of limited usefulness, as it gives no indication of the relative importance of planning units. In addition, since every solution contains a random element (section 2.4.1.1), there is no guarantee that the areas selected for the best solution are actually of highest value. It is far better, therefore, to use the summed solution output, which serves to identify hotspots, and also provides an indication of the relative value of each planning unit. These outputs are preliminary, and bear little resemblance to zones. Refinement and boundary development are the next steps in developing zones.

Although MARXAN does not have the ability to develop multiple zones simultaneously, zoning can be developed in steps as demonstrated here. Developing zones separately, joining them, and then manually examining the areas of overlap using maps such as Figure 6.6 is a potential way to include stakeholder input in the zoning process. The summed solution output of MARXAN, which shows the relative importance of areas for zones, could be used to facilitate consensus development. A give-and-take approach, where units are swapped in and out of the solutions, could be used. The ability of stakeholders to visualize the relative values of planning units for each zone would facilitate such a trade-off analysis. The visualization of conflicts between zones is a key contribution to the usefulness of MARXAN for zoning.

Probably the biggest challenge for MPA managers and zoning practitioners when using MARXAN is translating zoning goals into specific software settings. For example, while most interview participants indicated that zones covered as much space as was feasible, MARXAN requires specific targets, in percentages, for every data layer. Costs and species penalty factors are other settings that require a shift in

how MPA managers traditionally approach zoning. Figure 7.2 shows the range of zoning user needs compared with the range of functions available in MARXAN. Several requirements for zoning identified by questionnaire participants and zoning literature are included in MARXAN settings. These include the avoidance of fragmentation, the incorporation of existing uses and public opinion, and the inclusion of certain amounts (targets) of particular features in solutions. Other areas, such as the number, identifiability, and adjacency of zones, are not supported by the present functionality of MARXAN. The size of zones is somewhat controllable through MARXAN, though if the summed solution output is used the size is ultimately determined by the person who refines the zone boundaries.

Figure 7.2: Functionality of MARXAN compared with user needs for zoning.



Most of the user-specified settings in MARXAN are quantitative, and every decision depends not only on the study area, but also on the goals of the specific zoning plan. The range of possible settings and necessary experimentation mean that MPA managers cannot hand off requirements to GIS technicians and walk away. Rather they should work closely with spatial analysts to advise the use of MARXAN throughout the zoning process.

7.4 FUTURE RESEARCH OPPORTUNITIES

Although many MARXAN settings were examined in this research, there are others that also require attention. The simulated annealing settings, such as the initial energy level and freezing parameter (see Appendix II), which were set to default values for this research, can all be altered. Little is known about the influence of these parameters on solutions, and it would be beneficial to further examine these settings.

As mentioned above in Section 5.5 the species penalty factor requires further testing to determine its usefulness for applying relative importance to different data layers.

The influence of data on the solutions produced using MARXAN is another area that requires further investigation. It would be interesting to see how solutions react when individual data layers are removed or added. The influence of physical, socio-economic, and biological data could also be compared, which would give an indication of what type of data is driving solutions.

Marine zoning is a relatively recent activity, whose theories and practices are still evolving. Perhaps the difficulty of translating objectives into software is partly a

result of a need for more work on the theories behind zoning. One questionnaire respondent said, “most of the challenges associated with marine zoning are conceptual rather than technical in nature... I would suggest that we need more work on the theoretical basis for marine zoning.” As the theoretical aspect of marine zoning progresses it will likely become easier to apply tools such as MARXAN.

Finally, research is needed that further studies the integration of MARXAN in the zoning process. Specifically it would be beneficial to continue where this research ended, and to look at stakeholder input and zone refinement. Three methods for combining zones were developed here, and a stakeholder consultation process is needed to compare the effectiveness of these methods for group decision-making.

7.5 SUMMARY

MARXAN has certain limitations related to both its functioning and functionality. Limited instructions available through the MARXAN manual combined with the uncertainty associated with several settings increase the difficulty of using the software. These same factors along with the inter-related nature of the settings make it impossible to create specific guidelines and parameters that can be applied in different study areas and zoning situations. There is, however, currently a role for MARXAN within the zoning process. This involves the refinement of large amounts of data into a form (the summed solution) that is useable by MPA planners and stakeholders. This is one of several areas where further research is needed.

CHAPTER EIGHT

CONCLUSION

This research aimed to answer two questions: the Zoning Question, *How can zoning configurations be developed to incorporate large amounts of data and stakeholder opinions while being transparent, repeatable, and scientific?*; and the MARXAN Question, *Can the use of MARXAN be streamlined, thereby removing some of the guesswork associated with its use?*

In response to the MARXAN Question, several settings and conditions were tested; planning unit size and shape, data gaps, study area configuration, boundary length modifier (BLM), planning unit cost, and species penalty factor.

It was discovered that smaller grids are preferable as they provide more possible configurations of planning units. Square planning grids are also preferable, as they cluster slightly more efficiently than hexagons.

Data gaps were found to adversely affect the clustering ability of MARXAN, though with higher targets this was less apparent. This indicates that higher targets should be used with sparse data.

Of the study area configurations tested, the Open Ocean reacted more to BLM than the Inlets and Passages scenario. This result confirmed that Open Ocean and Inlets and Passages areas should be separated for MARXAN analyses.

The cost testing showed that solutions gravitate towards areas with a cost of 0 and that data distribution has little influence on these solutions. It is better, therefore, to use cost values above 0, though the magnitude has little effect on results.

The species penalty factor (SPF) testing conducted in this research was preliminary, and more testing is needed to examine the relationship between SPF and other factors. It was discovered, however, that with increasing SPF the solution size increases, the majority of which is composed of non-target species planning units.

The results of these tests, outlined in detail in Chapter Five, help provide a clearer understanding of MARXAN. It is possible, however, that these results would be different in other study areas, as it was beyond the scope of this research to examine all possible configurations. The inter-related nature of many settings, such as BLM and cost, also became apparent through testing. For example, a change in one requires a change in the other to maintain similar levels of clustering. In addition, the subjective nature of MARXAN inputs means that the need for experimentation cannot be completely eliminated. Because the values used for MARXAN settings are inter-related, and depend on the study area and zoning objectives, it is almost impossible to provide guidelines that would be applicable across different applications. Experimentation is a necessary component of MARXAN use.

A number of factors that are integral to the functioning of MARXAN are absent from the manual and literature. These include the relationship between cost and BLM mentioned above, the limit to the number of planning units that MARXAN can process, and the 'edge effect' exhibited when BLM is used. The 65,678 planning unit limit is an important limitation of the software, as it controls the size of planning units that can be used. Dividing the study area into separate analyses is a simple

way to address this problem, however users should be made aware of it. The edge effect, where MARXAN solutions avoid study area edges and coastlines, may have an adverse influence on solution configurations, and more work is needed to explore this phenomenon. Expanding the documentation to include these topics would greatly assist MARXAN users, and help remove some of the guess-work associated with the software. It should be noted that MARXAN is free software that was not developed commercially. This is probably the main reason for the gaps in the documentation.

The second part of this research aimed to answer the Zoning Question, which was based partly on the findings of the MARXAN testing, and informed by expert interviews and literature reviews. In interviews with zoning practitioners it became apparent that there is a divide between the required inputs of MARXAN and the way that zoning has been approached. Terms such as BLM, species penalty factors, and even targets in some cases, are not concepts that are applied in non-MARXAN-base zoning development. In fact, GIS-based methods were viewed by many participants who had been previously involved in zoning as having a mainly supportive role. Those who were preparing for a zoning process were more enthusiastic about GIS-based methods. There was some interest specifically in using MARXAN for developing zoning, though only one participant had an understanding of the workings of MARXAN.

There was a perception by some participants that the systematic approach offered by GIS and MARXAN would lend transparency and scientific rigour to the zoning process. There is, however, as discussed above, a large amount of subjectivity that forms the use of the software. There is a danger, as with any solution developed by a computer, of perceiving the results as impartial, scientific and perfect. Simply

recording settings is not sufficient to make the process transparent and there is a need, as one interview respondent stated, to have the “bias of the zoning process identified up front.” It became clear through this research that it is the underlying purpose of zones, whether for conservation or for fisheries development, that determines MARXAN settings and outputs. This is important, as an emphasis on conservation goals will produce a very different result from a process that emphasizes economic values. Unless specifically stated it would not be possible for a non-MARXAN user to identify this bias.

Despite the limitations listed above, the actual outputs provided by MARXAN have great potential to facilitate zoning development, particularly involving stakeholders. The summed solution output not only identifies hotspots for each zone, but it also indicates the relative importance of planning units for each zone. This creates a starting point and provides alternatives that have the potential to help stakeholders reach consensus. Through an iterative process of give-and-take stakeholders and MPA planners could use summed solution outputs to develop and refine zone boundaries.

Three methods for combining zones using the summed solution were developed in this research. They identify areas of overlap between zones, and the relative importance of these overlap areas for each zone. It is anticipated that these methods could help stakeholders and zoning practitioners develop multiple zones simultaneously. Practical testing of these methods is needed to determine their usefulness.

MARXAN has attained an exalted status in the field of reserve development. This is partly because it is a computer-based tool, which lends an aura of scientific

legitimacy, and also because it uses simulated annealing, a heuristic algorithm that achieves near-optimal results. The results are, however, only as good as the inputs, which include software settings as well as data. The research described here shows that both the spatial distribution and completeness of data influence MARXAN outputs. In addition, the uncertainty surrounding many MARXAN inputs, combined with limited documentation, create a situation where subjectivity influences results.

There is no easy solution to the challenges associated with MARXAN. Even the removal of certain settings from user control, such as the species penalty factor and the simulated annealing settings, would have little impact on the complexity of the software. The removal of settings such as BLM, costs, targets, etc. would severely limit usefulness, but these settings are also major contributors to the uncertainty associated with MARXAN.

One reason why MARXAN is valued highly is because it runs the simulated annealing algorithm, which finds near-optimal results. A thousand runs of a million iterations is impressive, but what is lacking is a connection between the different runs. The algorithm does not successively improve with each run; each begins randomly and is unconnected to the others. Perhaps some added efficiency could be added by connecting the runs.

MARXAN lacks a fundamental requirement for many zoning situations: transparency. While the multitude of settings and the powerful simulated annealing algorithm seem initially advantageous, the complexity and uncertainty associated with MARXAN cancel out the benefits of a 'near optimal' solution. It is important to

have a solid, defensible output that will stand up to stakeholder scrutiny. Such results were not apparent in this research.

The two factors that contribute most to the usefulness of MARXAN are its ability to synthesize large amounts of data and its summed solution output. Most GIS packages contain this functionality, and a raster sum of multiple runs would essentially duplicate the summed solution. The reason MARXAN is so attractive for zoning and reserve design is because it comes as a packaged tool that contains reserve-specific functions. There is a demand for such a tool, and MARXAN has been applied to fill this demand. However, the complexity of MARXAN settings and uncertainty associated with its use give reason to consider returning to less complex methods of developing zoning. One such method is GIS-based multiple criteria analysis (MCA), that has been used to develop both terrestrial (Gole, 2003; Hepcan, 2000; Trisurat *et al.*, 1990), and marine (Villa *et al.*, 2002) zoning.

A GIS extension based on multiple criteria analysis could be developed to facilitate the development of zoning. Overlays between layers could be used to determine hotspots for different zones. If outputs were displayed like summed solutions, showing levels of importance of each planning unit for each zone, zones could then be combined. The simultaneous development of multiple zones could also be included in this tool. Emphasis should be placed on user-friendliness; ideally zoning planners with limited GIS knowledge could use the tool. MARXAN is so complex that even experienced GIS users are faced with a steep learning curve. A tool with fewer functions would therefore be easier to understand, yet still meet the analytical requirements of MPA planners.

As zoning continues to gain recognition as an effective management tool for multiple use areas the tools and theories supporting zoning will continue to advance. The present version of MARXAN has served as an excellent starting point, but it is time to move forward. Perhaps advances will take the form of a modified MARXAN, and perhaps they will turn to less complex methods such as multiple criteria analysis. In the mean time, a certain amount of *caveat emptor* should accompany the use of MARXAN should it be applied to marine protected area zoning.

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APPENDIX I: DATA SUGGESTED FOR ZONING

Kelleher (1999) provides a comprehensive list of data to incorporate into a zoning plan:

- distribution of fish and benthic communities;
- endangered, rare or protected species distribution and significant sites;
- significant colonies of breeding birds;
- sea-grass and kelp forest communities;
- trawling;
- pelagic fishery (e.g. mackerel, cod);
- demersal fishery (commercial, recreational);
- netting (gill and drift, bait);
- diving;
- sites used for research and scientific study;
- tourist developments including camping;
- charter vessels and aircraft;
- adjacent land uses (eg. National Park, trust land, industrial use, agriculture);
- navigation, shipping and defense areas;
- mariculture/fish farming; and
- traditional uses and rights;

Additional data used by the Great Barrier Reef Marine Park Authority (2003) to site protection zones included:

- recreational fishing;
- interview data on resource use and values;
- boat ramps;
- moorings and anchorages;
- historic shipwrecks;
- recreational use; and
- tourism settings.

APPENDIX II: SIMULATED ANNEALING ALGORITHM

The analogy of the cooling of a solid is often used to explain the simulated annealing algorithm. This convention is followed here. The algorithm begins by selecting a random set of parameters with an initial 'energy level' $f(0)$, which is the cost of the selection (this is different from the Cost in formula (1) above). Cost represents how different the selected configuration is from the ideal solution (Ball & Possingham, 2000). Within each perturbation of the algorithm selected units are swapped, and each time a change is made the energy level of the selection changes (Angelis & Stamatellos, 2004). The initial energy level $f(0)$ is compared to the new energy level $f(1)$ and if $f(1)$ is smaller than $f(0)$ the changes in $f(1)$ are automatically accepted. If $f(1)$ is larger (has a greater cost) than $f(0)$ then $f(1)$ is accepted based on a probability, P (McDonnell *et al.*, 2002). The probability of acceptance, $P(\text{accept change})$, is given by the equation (Aerts & Heuvelink, 2002):

$$P(\text{accept change}) = \exp\left(\frac{f(0) - f(1)}{s_0}\right) \quad (2)$$

where s_0 is a 'freezing parameter' that controls the rate of cooling. At each freezing parameter value a user set number of perturbations (swaps) is allowed before moving to the next iteration of the algorithm (Angelis & Stamatellos, 2004). The freezing parameter is decreased with each iteration; the smaller s_0 the less likely that an increase in energy (cost) will be accepted (Aerts & Heuvelink, 2002). It has been found that the slower the freezing parameter is decreased (the smaller the increments of s_0), the better the final solution (Aerts & Heuvelink, 2002), since the solution is more likely to escape from local optima (Oetting & Knight, 2003). As the algorithm progresses and the freezing parameter gets smaller the magnitude of acceptable increase in cost decreases (Possingham *et al.*, 2000). By the end of a run

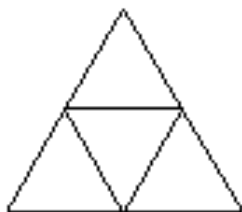
the algorithm only accepts changes that decrease cost. The freezing parameter, s_0 , is decreased according to the equation:

$$s_0 = r * s_i \quad (3)$$

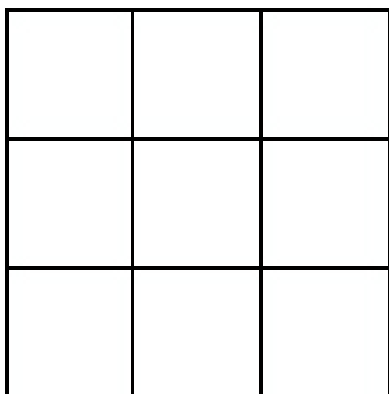
where r is a constant multiplication factor between 0 and 1 and s_i is the initial freezing parameter. Aerts & Heuvelink (2002) suggest using an r -value between 0.8 and 0.98 (the closer the r -value is to 1 the slower the cooling process) for optimal results. Aerts & Heuvelink (2002) also suggest that the freezing parameter should be set so as to accept about 80% of the changes that increase the cost function.

APPENDIX III: PLANNING UNIT GRIDS

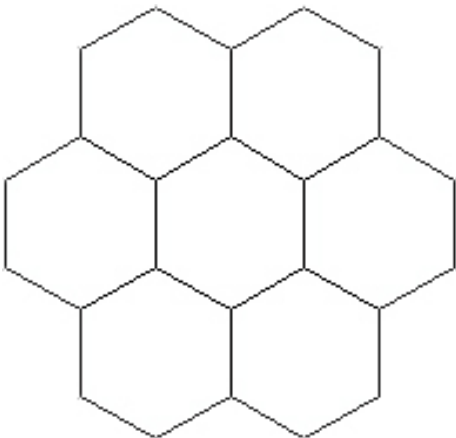
Triangles: a maximum of three joins are possible with each cell



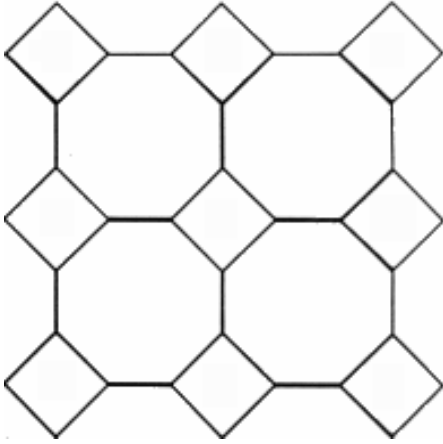
Squares: a maximum of four joins are possible with each cell



Hexagons: a maximum of six joins are possible with each cell



Octagons (and other shapes with more than six sides): cannot be tiled unless another shape (e.g. diamond) is inserted. Thus these shapes cannot be used for regular (i.e. uniform) planning unit grids.



APPENDIX IV: SURVEY PARTICIPANTS

Respondent	MPA	Position	Organization
Marc Pagé & Nadia Menard	Saguenay-St. Lawrence Marine Park	Biologist	Parks Canada
Norm Sloan	Gwaii Haanas (proposed NMCA)	Marine Ecologist / Ecosystem Coordinator	Parks Canada
Cliff Robinson	N/A	Marine Ecologist	Parks Canada
Bill Henwood	Southern Strait of Georgia (proposed NMCA)	Senior Planner	Parks Canada
Scott Parker	Fathom Five National Marine Park	Park Ecologist	Parks Canada
Kevin Conley	Endeavour		DFO
Paul Macnab	Sable Gully	Biologist	DFO
Michael Dunn	Scott Islands	Senior Habitat Conservation Coordinator	Environment Canada
Brian Keller	Florida Keys National Marine Sanctuary	Science Coordinator	Florida Keys National Marine Sanctuary
Huff McGonigal	Monterey Bay National Marine Sanctuary	Environmental Policy Specialist	Monterey Bay National Marine Sanctuary
Leanne Fernandes	Great Barrier Reef Marine Park	Manager, Representative Areas Program	Great Barrier Reef Marine Park Authority

APPENDIX V: LETTER OF INTRODUCTION

Dear Participant,

My name is Sarah Maxwell, and I am a graduate student at the University of Victoria. I am conducting a research project entitled "Zoning Marine Protected Areas Using GIS: A Comparison of Methods." The goal of this research is to systematically examine different GIS-based methods for zoning MPAs, and to work towards a decision support tool. Your participation in this research has the potential to assist yourself and other zoning practitioners in future zoning activities, since its goal is to contribute to the development of systematic, analytical approaches to zoning, in the form of decision support tools that complement public input.

The purpose of this letter is to ask if you are willing to participate in my research. I am seeking the input of people who have been, are, or will be involved in MPA zoning. I will be gathering data on how zoning has been conducted, which will allow me to set up a test zoning scenario in as realistic a fashion as possible. This scenario will be used to develop and compare GIS-based zoning methods.

If you do not have experience with zoning and will not be participating in zoning please let me know. If there is someone else who you believe would be able to provide input to the research based on their MPA zoning experience could you please pass his or her name on to me and feel free to forward this letter on to him or her.

Participation will be in the form of two telephone interviews, one to gather input on your approach to MPA zoning and potential needs for a GIS-based zoning tool and a second to obtain your feedback on my results. It is anticipated that each interview will last approximately 30 minutes.

I am obliged, under the University of Victoria's Human Research Ethics Committee, to obtain your consent to participate in my research. Attached you will find a consent form outlining details of the research. If you wish to participate please sign and return the last page of the consent form. Attached you will also find a copy of the questions I will be asking. If you plan to participate please read through the questions before the interview. The submission of written answers prior to the interview is requested since it will allow me to focus the telephone interviews on elaborating on your written responses. I will be contacting you by phone to confirm that you received this letter. At that time, if you are willing to participate, I will also set up a time for a phone interview. I hope you can find time to participate.

Thank you very much,
Sarah Maxwell

APPENDIX VI: CONSENT FORM

You are being invited to participate in a study entitled “Zoning Marine Protected Areas Using GIS: A Comparison of Methods” that is being conducted by Sarah Maxwell. Sarah is a graduate student in the Department of Geography at the University of Victoria and you may contact her if you have further questions by emailing her at smaxwell@uvic.ca, or by telephone at (250) 472-4624.

As a graduate student, I am required to conduct research as part of the requirements for a Master’s degree in Geography. It is being conducted under the supervision of Dr. Rosaline Canessa, whom you may contact at (250) 721-7339 or rcanessa@mail.geog.uvic.ca.

The purpose of this research project is to develop and compare geographic information system (GIS) based zoning methods. Before GIS analysis can be conducted, information needs to be collected surrounding the needs of zoning practitioners and past zoning experiences. This background information will provide the context to develop a realistic zoning scenario upon which to test and compare several GIS-based zoning methods.

You are being asked to participate in this study because your insight and/or experience with marine protected area zoning will help improve the effectiveness of my research design.

If you agree to voluntarily participate in this research, your participation will include two telephone interviews lasting approximately 30 minutes each. The first interview will be used to gather data surrounding different approaches to MPA zoning. This information will help me set up my zoning model. The second interview will be a follow up, where I will show you the results of my research and ask for feedback and suggestions.

There are no known or anticipated risks to you by participating in this research. Your participation in this research has the potential to assist yourself and other zoning practitioners in future zoning activities, since its goal is to contribute to the development of systematic, analytical approaches to zoning, in the form of decision support tools, that complement public input.

Your participation in this research must be completely voluntary. If you do decide to participate, you may withdraw at any time without any consequences or any explanation. If you do withdraw from the study your data will be removed from the study and destroyed, unless you wish it to remain in the study.

To make sure that you continue to consent to participate in this research, I will ask for consent again before commencing the second interview.

You will be asked at the start of the interviews if you wish to have your name omitted from publications (including theses) resulting from this research. If you wish to remain anonymous your name will not be published in conjunction with this research. No other personal information apart from your name, position, and professional affiliation will be gathered.

Your confidentiality and the confidentiality of the data will be protected. Only myself and those immediately involved in the research (my supervisor) will have access to the interview transcripts. All transcripts of interviews will be stored in a locked filing cabinet. All database files that include interview data will be kept secure.

Data from this study will be stored securely for 10 years to ensure that the research can be verified if asked to do so.

It is anticipated that the results of this study will be shared with others in the following ways: thesis, conference presentation(s), and published article(s).

In addition to being able to contact the researcher and supervisor at the above phone numbers, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Associate Vice-President, Research at the University of Victoria (250-472-4362).

Your signature below indicates that you understand the above conditions of participation in this study and that you have had the opportunity to have your questions answered by the researcher.

Name of Participant _____

Signature _____

Date _____

Please keep a copy of this consent form and fax a copy of this page to the researcher (Sarah Maxwell) at (250) 721-6216.

APPENDIX VII: QUESTIONNAIRES

Questions for those who have been involved with MPA zoning

Privacy questions:

Do you wish to remain anonymous? To what degree? Can I use your name and/or position in publications?

Zoning questions:

1. What MPA are/were you involved with?
2. How large is the MPA? When was it designated?
3. What uses take place in the MPA?
4. What stakeholders have an interest in the MPA?
5. What were the key issues (e.g. conflicts, resource issues) addressed in the zoning plan?
6. When did zoning take place?
7. How many and what type of zones were developed?
8. Has there been a re-evaluation of zoning and why did it take place? How was the re-evaluation undertaken and what was the outcome?
9. What was the main driving force behind how zoning was decided? (i.e. data driven vs. stakeholder input or expert opinion.) What was the rationale behind that choice?
10. How was zoning developed:
 - a. What tools were used?
 - b. What analysis was used?
 - c. What data were used and why?
 - d. Were there any activities that had to be accommodated within the MPA?
 - e. Was there a target percentage of habitat / ecosystem protection?
 - f. Was public input sought? How was it incorporated in the zoning process?
11. Why was zoning developed the way it was? (i.e. is it outlined in legislation, or through some other authority?)
12. In some zoning processes an effort is made to minimize the number of separate areas of the same zone type, known as fragments, within a reserve. Was this a factor in the zoning process you were involved with? How was it addressed?
13. Were there any guidelines for determining which zones should be adjacent to each other? How was adjacency addressed?
14. Were there any size restrictions for zones? Desired minimum sizes? Or a desired ratio of sizes between zones?

15. What was the priority of zones? (i.e. if there was an overlap between potential areas for multiple zones which zones would be given the highest and lowest priorities. Were any tradeoffs or compromises to accommodate different uses?)
16. In your opinion, what constitutes a successful zoning plan?
17. What tools would be useful for zoning?
18. Would a methodology for using GIS to zone MPAs be helpful? Why or why not?
19. Can you think of any factors or methods that would make zoning easier?
20. Any other comments?

Questions for those who will be / are involved in MPA Zoning

Privacy questions:

Do you wish to remain anonymous? To what degree? Can I use your name and/or position in publications?

Zoning questions:

1. What MPA are / will you be involved with?
2. How large is the MPA? When was it designated? (Or when do you anticipate it will be designated?)
3. What uses take place in the MPA?
4. What stakeholders have an interest in the MPA?
5. When is zoning scheduled to take place?
6. How many and what type of zones are to be developed?
7. What is the main driving force behind how the zoning will be decided? (i.e. data driven vs. stakeholder input or expert opinion.) What is the rationale behind that choice?
8. How will zoning be developed (as best as you can anticipate):
 - a. What tools will be used?
 - b. What analysis will be used?
 - c. What data will be used and why?
 - d. Are there any activities that have to be accommodated within the MPA?
 - e. Is there a target percentage of habitat / ecosystem protection?
 - f. Will public input be sought? How will it be incorporated in the zoning process?
9. Why will zoning be developed the way it will be? (i.e. is it outlined in legislation, or through some other authority?)
10. In some zoning processes an effort is made to minimize the number of separate areas of the same zone type, known as fragments, within a reserve. Will this be a factor in the zoning process you are / will be involved with? How will it be addressed?

11. Are there any guidelines for zone adjacency? How will adjacency be addressed?
12. Are there any size restrictions for zones? Desired minimum sizes? Or a desired ratio of sizes between zones?
13. What is the priority of zones? (i.e. if there is an overlap between potential areas for multiple zones, which zones would be given the highest and lowest priorities? Is it likely that tradeoffs or compromises will be made to accommodate different uses?)
14. In your opinion, what constitutes a successful zoning plan?
15. What tools would be useful for zoning?
16. Would a methodology for using GIS to zone MPAs be helpful? Why or why not?
17. Can you think of any factors or methods that would make zoning easier?
18. Any other comments?

Appendix IX: Questionnaire Responses

Already Zoned

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
MPA size (km ²)	94	113	9,844	344,400	2,364
Designation date	2003	1987	1990, Tortugas added 2001	1975	2004
Designation reason	Unique hydrothermal vents	Representative of Georgian Bay ecoregion. Preserve shipwrecks.	Unique coral ecosystems	Great Barrier Reef – protection of this world heritage site.	Endangered bottlenose whale
Uses	Mostly research. Perhaps mining interest, and tourism.	Mostly recreational tourism, e.g., tourboats, SCUBA diving, hiking/day use on islands, kayaking, sailboats. Also limited commercial and recreational fisheries	Tourism, recreational boating, diving, fishing (recreational and commercial), snorkelling	Range of commercial, traditional and recreational uses (i.e. boating, diving, snorkelling, collecting and fishing.)	Shipping, research, monitoring, fishing by hook and line.

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Stakeholders	Researchers, funding agencies, tourism operators, and mineral exploration interests	First Nations, Chamber of Commerce, Dive & Boat charters, Ferry, Fishers, private boaters, Coast Guard, adjacent private landowners	Fishers, Tourists, Residents, Government, ... Conservation Organizations, Commercial (Dive Operators, Charter Boats, Fishing Guides)	Tourists, commercial and recreational fisheries, recreational users, research institutions, government agencies, indigenous communities	Other government departments, province of Nova Scotia, fishing industry, oil and gas industry, conservation groups, scientists, academics, Canadian public.
Key issues for zoning plan	Attempt to balance conservation of the novel ecosystem with maintaining research opportunities across disciplines and use levels (e.g. sampling research vs research that would require intact natural ecosystems for observational purposes).	User conflicts (divers and tourboats), shoreline alterations (docks, filling), protecting shipwrecks, environmentally sensitive sites (nearshore wetlands), and sites of scientific interest (submerged waterfalls)	Assist in the protection of biological diversity. Disperse resource uses to reduce user conflicts and lessen concentrated impacts on marine organisms at heavily used reefs. Focus management efforts on a small portion of the sanctuary while addressing water quality and habitat degradation in the broader, unzoned portions of the area.	Less than 5% of the Marine Park is currently in no-take areas; the existing areas are largely confined to coral reefs or the remote far north of the marine park; and the coverage of no-take areas in many of the 70 bioregions in the Great Barrier Reef is minimal or non-existent.	Marine ecosystem protection, conservation objectives as outlined in the Gully Conservation Strategy (will send this 1998 document), fisheries bycatch and entanglement issues, bottom disturbance, marine mammal protection, species-at-risk, deep sea coral, anthropogenic noise, contaminants.

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Date of zoning	2001	1997	1997, 2001 Tortugas	2004 rezoning	2002
Number of zones	Four zones with three different treatments for levels of activities.	Three zones, plus environmentally sensitive sites.	Five	Seven marine and one terrestrial.	Three
Zone 1	Manage the Salty Dawg vent field to reserve it as an observational research site – deterring intrusive activities.	No harvesting , usually does not allow visitor entry	Wildlife Management Areas (27): Important wildlife areas into which access is restricted to varying degrees (speed restrictions, no wake, no access, no motor, etc). minimize disturbance to especially sensitive wildlife populations and their habitats, e.g. , bird nesting, resting, or feeding areas and turtle nesting beaches.	Preservation Zone: ‘no go’ area for the general public. Entry only with special permission. Research may occur, but only if it is a priority for management and cannot be conducted elsewhere. This zone makes up less than 1% of the Park.	Deep Canyon. Complete ecosystem protection. Research permitted, all extractive uses restricted.

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Zone 2	Manage the High Rise vent field to reserve it for projects focused on education/outreach—detering more intrusive activities.	Buffer zone , some resource harvesting.	Ecological Reserves (2): All activities that do not damage or remove of marine life or resources will be allowed. Objective is to protect fish and marine life. encompass large, contiguous and diverse habitats to provide natural spawning, nursery, and permanent residence areas to protect and preserve all habitats and species, particularly those not protected by fishery management regulations. Allow areas to evolve in a natural state with a minimum of human influence.	Marine National Park Zone: ‘no-take’ areas. Only non-extractive activities such as boating, swimming, snorkelling and sailing are allowed. Travel is not restricted, as long as fishing gear is stowed. Anchoring is also allowed, however in high use and sensitive areas, use of a mooring may be necessary. This zone makes up about 33% of the Park.	Between 300 and 600m , most activities restricted. Only longline fishing permitted.

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Zone 3	Manage the Mothra vent field to reserve it for research projects, including those involving moderate sampling.	consumption and recreation	Sanctuary Preservation Areas (18): All activities that do not damage or remove of marine life or resources will be allowed. Objective is to protect shallow, heavily used reefs where conflicts occur between user groups and where concentrated visitor activity leads to resource degradation.	Scientific Research Zone: provide areas, primarily around scientific research facilities, that allow studies to occur in areas relatively undisturbed by extractive activities. This zone makes up less than 1% of the Park.	Banks adjacent to zone 2. (Shallow areas). Activities allowed that are within bounds of natural levels of disruption (i.e. trawling allowed since storms regularly disturb bottom). New activities must apply for approval.

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Zone 4	Manage the Main Endeavour vent field to reserve it for research projects, including those involving moderate sampling.	environmentally sensitive areas (basically a way of "dealing" with difficult & potentially conflict producing areas)	Existing Management Areas (21): Existing protected areas managed by other agencies where restrictions already exist, e.g., State parks, aquatic preserves, and other restricted areas.	Buffer Zone: provides for the protection and conservation of areas in their natural state, while allowing the public to appreciate and enjoy the relatively undisturbed nature of the area. Trolling for pelagic fish is allowed, however most other forms of extractive activities are prohibited. This zone makes up approximately 2.9% of the park.	

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Zone 5			<p>Special Use Areas (4; all Research-Only): Scientific research, monitoring, restoration and education. set aside areas for scientific research and educational purposes, restoration, monitoring, or to establish areas that confine or restrict activities such as commercial personal watercraft operations and establish live-aboard mooring fields.</p>	<p>Conservation Park Zone: Protection and conservation, while providing opportunities for reasonable use and enjoyment, including limited extractive use. This zone makes up approximately 1.5% of the Park.</p>	

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Zone 6				<p>Habitat Protection Zone: provides for the conservation of areas by protecting and managing sensitive habitats and ensuring they are generally free from potentially damaging activities. Most uses are allowed, some only by permit. Trawling is the only use not permitted. This zone makes up about 28% of the Park.</p>	
Zone 7				<p>General Use Zone: provides opportunities for reasonable use, while still allowing for the conservation of these areas. All activities allowed, some only through permits.</p>	

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Has there been a re-evaluation?	No. Evaluation is envisioned for five years post designation (2008)	Nothing scheduled	No evaluation of zoning yet - The 5 year update of the Management Plan excluded zoning in order to streamline the review process. Zoning will be addressed in a separate process in the near future.	Yes. The purpose was to increase the amount of no-take areas (green zones). The outcome was 33% protection, and examples of each habitat type being protected.	Not yet. Expect a 5-7 year review. Still preparing management plan.

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
What was driving force behind zoning?	Based on delineating known vent fields as individual management areas. This was primarily through stakeholder input/expert opinion.	For the most part it was expert opinion, however the site possessed considerable data / information and that was applied to protect specific sites. The zoning was developed during the management plan process and this involved considerable public consultation.	During the original Florida Keys zoning process (1997), the process was very data driven. Stakeholders felt that zoning was being imposed and that they did not have enough input, and that too much economically important areas were going to become no-take, and as a result there was a lot of discord during the process, and the plan was changed and the Tortugas area was not included in the original zoning plan. The Tortugas zoning process in 2001 was much more successful since public input was included from the start.	Both data and stakeholder driven.	The zones were derived by DFO personnel (professional planners/managers) It was an expert led planning process informed by a large volume of information, (ecological and socio-economic data, stakeholder input received prior to the zoning exercise, ad-hoc risk assessment and pre-existing zones). Different data was balanced using common sense combined with a knowledge of the area. It was iterative process that built up the zones by adding in different factors. The results were analyzed to detect possible problems.

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
What tools were used?	Background reports	GIS was used.	GIS	GIS, Marxan	Paper maps, nautical charts, mylar, drawing implements, GIS was mostly used to display boundaries and refine their locations.
What analysis was performed?	Mostly just judgement - used scientific information and stakeholder input to identify vent fields. Boundaries were developed based on this info	GIS: A shoreline model (basically an inventory of shoreline habitat, wave exposure, cultural features, and geology) was used to identify levels of risk and importance. Result was a restriction of where people were allowed to alter the shoreline.	GIS	Used Marxan to identify protection areas	Examination of maps, existing studies and assessments. Some visual on-screen comparison of thematic elements. Mental and literal checklists of criteria, considerations, restrictions, limitations and opportunities.

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
What data were used?	Largely stakeholder input	Biophysical, resources, setting. There is no set data that needs to be used, so used what was available at the time. Now have archeology, bathymetry, and fisheries data too.	Biophysical, social, economic, stakeholder input	Large number of public submissions, biological, social and economic info were used to revise zoning plan.	Multibeam bathymetry, interpolated contours, interpreted seabed geology, multidisciplinary Gully Science Reviews, Gully Ecosystem Report, Socio-Economic Assessment, Fisheries Assessment, Minerals Assessment, Hydrocarbon Assessment, acoustic predictions from the Environmental Assessment for Seismic on the Scotian Shelf, input and oral proposals.

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Any mandatory activities?	Research, however there is a recognition that not all of the areas can be used, and that preservation must take place	Fishing	Fishing and non-destructive public use.	The park supports a diverse range of traditional, commercial and recreational interests: i.e. boating, diving, snorkelling, collecting and fishing.	No, but existing uses were assessed against conservation objectives. Tried to stay on the conservation side - the conservation was based on bottlenose whales, and needed to provide complete protection. This was more important to existing uses that conflicted with whales.
Target percentages?	No	No. I think things would be different now since we know a lot more about the lake bottom. We probably would not have a target, but more would be protected.	No - initially 20% was considered, but this was rejected by community	Generally aimed for 20% protection of habitats. External experts gave biophysical targets.	No. Wanted to protect as much bottlenose whale habitat as possible.

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Public input?	A stakeholder advisory team was developed and represented principle public input. Broader interests were consulted in formulating recommendations into an interim management guidelines report. Two workshops were held with broader representatives invited and participating.	During Management Plan process open forums were held to discuss issues with the public.	Public input was sought. Comments were addressed or explained to the public. It was a "give and take" process. Some uses were allowed (for example bait fishing in 4 SPAs) because of public comments. During the Tortugas 2000 process public input was incorporated from the start. The working group of stakeholders reached a consensus, which involved trade-offs, give and take, from both sides.	Yes. Community participation in 2002 to get info from community to help form zoning draft. Then public was invited to submit comments on the draft plan. Each submission was recorded in detail.	Public input/comments was considered during the process and information was used to verify data used for zoning. Once we developed the draft zoning scheme and regulatory intent, both were presented to interested groups and organizations. Feedback received at this point did not fundamentally change the zones, but it did influence things like the cost-benefits analysis in the RIAS (e.g., predicted effects on displaced fisheries).

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Why was zoning developed how it was?	At a management level zoning is considered important. It is not required in the legislation.	We were required by Parks Canada policy to develop a zoning scheme in the management plan. It was principally based on the terrestrial national park zoning approach / policy at that time. Created depth related zoning to deal with the challenge of 3-D zoning	Zoning is part of the Florida Keys National Marine Sanctuary Act. Public participation is required by the National Environmental Policy Act.	The process is outlined in the GBRMPA Act from 1975. The level of public participation was greater than required.	Many reasons. The Oceans Act allows us to create zones so there is a legislative basis for zoning in DFO MPAs. We also have the history, practical experience and precedent for spatial controls under the Fisheries Act. We don't have narrow or highly prescriptive guidelines for zoning DFO MPAs as of yet, so with the Gully we were able to do what worked.

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Fragmentation	Not a factor.	Not a factor	There was an attempt to disperse resource use - zones are broken up into many small areas (~60) scattered throughout Sanctuary.	Yes this was a factor. There were requirements for replication and minimum sizes.	Not really. Although Zone 3 is split into two parts, we did not see this as a complicating factor. Most people seem to have understood that the shallow, sandy banks on either side of the canyon are quite different from the deep water. For a time we may have considered a Zone 3a and 3b, 3West and 3East, or a Zone 3 and Zone 4, but ultimately we decided that the areas and pressures were similar enough to comprise one management zone.

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Adjacency	Not applicable	No, intuition was used	Adjacency was not an issue (in fact almost none of the zones come close to touching each other).	not especially	Not applicable. Zones were based on topography / habitat.
Zone size restrictions?	No. Sizes are based on size of vents.	No size restrictions - zones were simply made big enough to fit the feature in question	No	Applied minimum size requirements as far as possible	We had no hard and fast guidelines for or restrictions on zone size

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Priority of zones?	Not applicable	This did not come up in the zoning process. We stayed away from conflicts - zone 1 did not remove any areas that were already in use.	Sanctuary Preservation Areas given priority over Existing Management Areas, with compromise during the initial process.	Depended on a lot of factors - there was no one rule. Generally bioregional targets "won," though they were examined case-by-case.	Zone 1, the core of the MPA and the zone with the most restrictions, might appear to be the highest priority, however, Zone 2 has a tremendous diversity of habitat types and greater use pressures than Zone 1 and is thus a greater priority for immediate management. The three zones were developed at the same time. They were divided based on breaking points (continental shelf, depth, ecosystems).

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
What is successful zoning plan?	It would successfully lay out zones and management actions that best achieve ecosystem conservation, allowing sustainable development in the broader regional perspective.	Effective at protecting and conserving ecological and cultural integrity. Simple to interpret and apply - i.e. having only 3 zones. Wise.	Public acceptance and ecosystem changes caused by reduced exploitation (in this case).	Adequate levels of protection for every kind of habitat that is successfully implemented and compiled with	Ecologically defensible, supported by science and well justified. Balances use and conservation. Incorporates all perspectives and all available knowledge on the marine area in question. Something that users understand, support and can comply with easily. Supported in regulations or by some other means to have the force of law. Translates well for surveillance and monitoring, fisheries management and contemporary marine geomatics (e.g., GPS, ECDIS, GIS, satellite based vessel monitoring systems etc.).

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
What tools useful for zoning?	Detailed framework or step-by-step process for zoning	Inventory maps - these allow the public to make informed decisions. Data. Ecosystem models are very good for conceptualizing what's going on.	Simulation models, GIS-based information management systems and decision support tools.	Public input in the form of submissions	If all the spatial bits of ecological, socio-economic, cultural and TEK sources can be displayed overtop of zoning proposals, jurisdictional lines etc, the task would be made that much easier. Don't see GIS as useful for developing zoning schemes because of data problems - the decision rules are not good/precise enough. The statistical confidence is not there.

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Would GIS methods be useful?	Mostly to visualize the data	Yes, however I think we need to use the 3rd dimension more in interpreting the underwater world	Yes, to allow visualizations of different zoning scenarios for various stakeholders and staff.		GIS was essentially a decision support, depiction and refinement tool for us, but it was really the time knowledgeable experts spent in discussion that led to the zoning decisions for the Gully. I seriously doubt whether we could have automated or optimized the Gully zones with something like Marxan. It would have taken inordinately longer by the time all of the information was entered and processed with a series of programmed decision rules, irreplaceable units and Marxan runs. And even then, the zone solutions (Continued next page)

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Would GIS methods be useful? (Continued)					<p>would still need smoothing/conversion to something that would be feasible for management, for example, a straight-line fisheries license condition. All that said, I'd be very keen to see such an attempt made in a data rich benthic setting like Brown's Bank where multibeam, backscatter, optical sampling and geological and ecological classifications all exist at a level of detail and scale well suited for more computer and data driven approaches. Could see it used for developing possible schemes for stakeholder input.</p>

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Other suggestions for easier zoning?	Some way of balancing data with stakeholder opinions. A framework for zoning. Taking a risk-management approach to deal with data gaps. Some process that models the level of consensus between different data - i.e. displays the level of agreement between stakeholders and scientific data. This would be a way to gauge progress.	Public support. GIS	Good enforcement	No	I believe that most of the challenges associated with marine zoning are conceptual rather than technical in nature. decision-making about what goes into the zone will probably come before the zones is actually drawn. We need more work on the theoretical basis for marine zoning. We also have some serious problems with semantics and the collective understandings and misunderstandings of zoning. Negative connotations persist for user groups and participants. Zoning equals preservation and restriction rather than permission for many, and when (Continued next page)

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Other suggestions for easier zoning? (Continued)					<p>you're trying to design an MPA, this is especially troubling for some sectors. Expanding the discussion beyond zones for conservation (need more socio-economic inputs) strikes me as a positive first step. When developing zoning make it more collaborative - get lots of input, go out with possible scenarios and get comments - stakeholders need to have a sense of ownership and engagement in order to "buy in."</p>

	Endeavour Hydrothermal Vents MPA	Fathom Five National Marine Park	Florida Keys National Marine Sanctuary	Great Barrier Reef National Marine Park	Gully MPA
Other comments		<p>The zoning process was good (they did what they could with the data they had). Intuition has a role in zoning, mostly to make up for lack of data, and also reflects the bias of zoning developers. The better the data, the more it will be trusted. Precautionary principle should be used in areas that require further study.</p>	<p>The Tortugas process is one of the best models for zoning in existence.</p>	<p>Apart from technical issues, Marxan is a good starting point. It is not a solution. Used tweak and fiddle process of incorporating stakeholder opinion to reach consensus</p>	<p>We are working on a compilation of factors that influenced our zoning scheme for the Gully MPA. This will be an internal piece initially, but we will try to get a public version to you when it becomes available.</p>

Not Yet Zoned

	Proposed Southern Strait of Georgia NMCA	Saguenay-St. Lawrence Marine Park	Monterey Bay National Marine Sanctuary	Scott Islands Marine Wildlife Area	Gwaii Haanas National Park Reserve & Haida Heritage Site
MPA size (km ²)	Approximately 900	1,138	13,000	27,000	3,400
Designation date	2008	1988	1992	18 months to 2 years	Boundaries confirmed in 1993
Designation reason	Representative ecoregion	Beluga Whale Protection	Unique environment. Zoning will be taking place because the public said, during the management review, that they wanted to see areas of no-take, and areas that limited human use.	Significant sea bird habitat	Existing land park, representative of ecoregion
Uses	Commercial and sport fishing, boating of all kinds, other forms of tourism, public transit (ferries), facilities such as marinas, docks, etc.	Extraction of resources, Tourism and leisure, Navigational	Fishing, diving, tourism, scientific research	Fisheries, including hook and line, trap, and trawling. Heavily used by commercial shipping (cruise ships, tug, barges). Research interest. Potential oil and gas.	Fishing, tourism, recreation, First nations commercial and food fishing.

	Proposed Southern Strait of Georgia NMCA	Saguenay-St. Lawrence Marine Park	Monterey Bay National Marine Sanctuary	Scott Islands Marine Wildlife Area	Gwaii Haanas National Park Reserve & Haida Heritage Site
Stakeholders	Commercial and sport fishers, tour operators, boaters, commercial shipping, coastal land owners, divers, naturalists	Municipalities, tourism industry, fishing industry, recreational boaters, hunters, commercial boaters, research and educational groups, other federal or provincial government agencies	Fishers, divers, environmentalists, public, tourists, scientists	Government of BC, First Nations, fishing industries, local communities, tug & barge operators, cruise ships, shipping interests, Federal Agencies, conservation organizations, and fishermen	First Nations, NGOs, communities, Federal agencies, tourists, commercial fishers, tourism operators.
Date of zoning	Conceptually 2006, implemented 2008	Around 2007	In 2-4 years	Not zoning – management through permits	Don't know
Number of zones	4	4	Not sure yet. Definitely no extraction zone	Currently they are not planning on developing zoning, rather to implement a management regime that uses permits to regulate uses within the MPA	At least 2 (as required in the NMCA Act; use and non-use) and probably other zones as well.
Zone 1	High protection: perhaps no access.	Integral preservation. No access. Specifically for the protection of Beluga whales			Use

	Proposed Southern Strait of Georgia NMCA	Saguenay-St. Lawrence Marine Park	Monterey Bay National Marine Sanctuary	Scott Islands Marine Wildlife Area	Gwaii Haanas National Park Reserve & Haida Heritage Site
Zone 2	Wilderness / Recreation: mid range of protection, includes recreation, perhaps limited harvesting.	Specific protection (recreation zone)			Non-use
Zone 3	Natural environment (multiple use, including harvesting)	General recreation zone			
Zone 4	Facilities: Existing infrastructure such as marinas, ferry terminals.	General use / navigation zone - to keep boats within specified areas			
What is driving force behind zoning?	Driving force will vary with zone: science and the identification of marine values will be the driving force for zones 1 and 2; stakeholder interest will be driving force behind zones 3 and 4; presence of existing facilities will also drive zone 4.	Process is Data driven. Stakeholder consultation will serve to gather additional information. Activities have already been considered, so opposition is not anticipated. The park objectives are more important than stakeholder opinion (if the two differ)	Zoning will be developed based on a combination of stakeholder input, expert opinion, and data	Canada wildlife act does not allow zoning – only permits. Conservation of bird habitat is driving force.	Hard to say. Would like to see it mostly data driven, but a combo data and stakeholder is likely

	Proposed Southern Strait of Georgia NMCA	Saguenay-St. Lawrence Marine Park	Monterey Bay National Marine Sanctuary	Scott Islands Marine Wildlife Area	Gwaii Haanas National Park Reserve & Haida Heritage Site
What tools will be used?	GIS, Marxan or some other decision tool; public consultation / local aspirations.	GIS may be used to refine boundaries. No other tools so far. Only literature review, expert consultation and staff knowledge.	Computer models (for example model to incorporate public input and evaluate levels of agreement), GIS, interviews	Unknown	GIS
What analysis will be performed?	GIS / Marxan	47 sites of interest were selected based on collected information. These were rated according to 4 factors (endangered species, structure of area, function of area, value of area)	Level of fishing effort, habitat degradation trends,	Unknown	GIS
What data will be used?	Many data sets including distribution of marine life, oceanographic characteristics, full range of human uses, pollution sources	Spatial data includes oceanographic measures and whale distribution (no fishing or recreation data). Local knowledge forms the majority of data used.	Habitat, socio-economic, oceanographic factors.	Pelagic seabird surveys, and telemetry surveys which form the basis for the study area boundary	Recreational use, First Nations use, Animals, have requested fisheries info from DFO

	Proposed Southern Strait of Georgia NMCA	Saguenay-St. Lawrence Marine Park	Monterey Bay National Marine Sanctuary	Scott Islands Marine Wildlife Area	Gwaii Haanas National Park Reserve & Haida Heritage Site
Any mandatory activities?	Fishing, tourism, shipping can continue; only exploration of non-renewable resources is prohibited.	Many of the current uses must be accommodated (i.e. shipping) Effort was made to allow most uses to continue, but to mitigate their impacts	No	Existing fisheries and first nations access. Currently negotiating oil and gas access.	No
Target percentages?	Not a numerical target, but aiming for a network that protects representative habitats as well as "special / sensitive" features	No targets. Sizes of zones are limited by practicality - can't put marker buoys in the middle of a channel, so zones limited to nearer to shore areas (natural features as markers)	Not sure yet. Depends if habitat protection or biodiversity is the goal.	Unknown	No preset targets yet - they will have to be defensible and withstand public consultation

	Proposed Southern Strait of Georgia NMCA	Saguenay-St. Lawrence Marine Park	Monterey Bay National Marine Sanctuary	Scott Islands Marine Wildlife Area	Gwaii Haanas National Park Reserve & Haida Heritage Site
Public input?	Yes, this is integral part. Science will drive identification of zones 2 and 3, and they will be modified according to stakeholder and public input.	In several phases - committees, working groups in 2005, and public hearings in 2006. The purpose of these is to gather additional information from the public.	Stakeholder working group of 20 people will develop the plan and then the public will have a chance to comment on it.	Public input will be sought through direct consultation of affected and interested parties either on an individual basis or collectively. All feedback and input will be assessed and where appropriate become part of the management requirements for the Marine Wildlife Area.	Creating the NMCA would not be possible without public involvement. Don't know how much of a role it will have.
Why will zoning be developed the way it will be?	The process is not defined in legislation; we can develop our own process which is still unfolding.	Zoning obligation from the Act that created the Marine Park. Also, there is no sense not involving stakeholders - every major issue in the park goes through their review.	Nothing specifically asks for zoning - Sanctuaries Act states that ecosystems should be protected. The public asked for zoning.	The Canada Wildlife Act does not explicitly allow for a zoning model, but instead deals with permitted uses. The length of permits can be variable and/or seasonal.	NMCA Act says zoning must take place

	Proposed Southern Strait of Georgia NMCA	Saguenay-St. Lawrence Marine Park	Monterey Bay National Marine Sanctuary	Scott Islands Marine Wildlife Area	Gwaii Haanas National Park Reserve & Haida Heritage Site
Fragmentation	It is likely that zones two and three will be larger contiguous areas that surround zone ones.	Fragmentation will be addressed, so as to make the zones less complex and easier to find. This will be done by "logic" (by eye, in a manner that makes sense)	Common sense will probably be used to limit the number and complexity of zones	N/A	Don't know. Thinks the GBR model is good - "don't put all your eggs in one basket" - i.e. rather than have one big area for a zone, break it up into separate areas to ensure protection
Adjacency	No, but wherever possible highly protected zones will be buffered from areas of high or disruptive activity, but this is not always possible.	Adjacency will not be taken into account.	Will probably look at this, but more to make sure that MBNMS zones match up (or are compatible with) adjacent state zoning.	N/A	Too early. Buffer zones are a possibility.

	Proposed Southern Strait of Georgia NMCA	Saguenay-St. Lawrence Marine Park	Monterey Bay National Marine Sanctuary	Scott Islands Marine Wildlife Area	Gwaii Haanas National Park Reserve & Haida Heritage Site
Zone size restrictions?	It is likely that zone ones will be smaller than zone twos, which in turn will be smaller than zone threes.	No. The area covered by the zones will depend on both the area covered by a habitat that needs protection as well practical issues such as navigational routes that cannot be obstructed, the ease of recognizing a zone (presence of easily recognizable natural or nautical features) which will enable the public to know if they are in a zone or not.	Not yet developed	N/A	Too early to tell

	Proposed Southern Strait of Georgia NMCA	Saguenay-St. Lawrence Marine Park	Monteray Bay National Marine Sanctuary	Scott Islands Marine Wildlife Area	Gwaii Haanas National Park Reserve & Haida Heritage Site
Priority of zones?	Difficult to say at this time. But it is hoped that zone one and two will be given priority until objectives are met; it is inevitable that compromises will have to be made.	Tradeoffs have already been made in certain areas, for example at the mouth of the Saguenay River, which is the center of the beluga whale distribution, it is impossible to shut off the navigational corridor. We are protecting what is feasible.	No take, or restricted use will be #1 priority	Protecting bird populations	This will occur. The first priority will be the two zones outlined in the act (no take and use), and it is possible that First Nations use will be a priority. Areas that are currently closed (ie rockfish conservation areas) are also likely to be priorities. The priority will also depend on the strength of the lobby behind it - an activity that brings in lots of money, or that is traditional use, or that originates from the Queen Charlottes will have more weight in the process.

	Proposed Southern Strait of Georgia NMCA	Saguenay-St. Lawrence Marine Park	Monterey Bay National Marine Sanctuary	Scott Islands Marine Wildlife Area	Gwaii Haanas National Park Reserve & Haida Heritage Site
What is successful zoning plan?	High level protection for representative habitats and species groups; replication of habitats; recognition of special habitats; minimize conflicting uses; include recreation and tourism areas; include permissible commercial activities – fishing, shipping, tourism; facility requirements.	One with good data, clear objectives and excellent justifications, a good communication strategy and constructive public input	Achieving mandates with early stakeholder involvement, and ownership over the process	Few zones. Clear rationale for zones. Penalties must be explicit and the zones themselves must be simple enough as to be represented accurately on charts for shipping and other marine users. The key as well, is that these zones are not static and that regular reviews of their efficacy must be included. User groups must be aware that boundaries could change over time. All classifications must make sense and be relevant to users and public.	Sufficiently high percentage of no take areas and good relations with the commercial sector.

	Proposed Southern Straight of Georgia NMCA	Saguenay-St. Lawrence Marine Park	Monteray Bay National Marine Sanctuary	Scott Islands Marine Wildlife Area	Gwaii Haanas National Park Reserve & Haida Heritage Site
What tools useful for zoning?	GIS mapping, decision support tools such as Marxan, public and stakeholder consultation.	First you need a solid legislative tool, then you need an effective means of collecting, grouping and analyzing data which ideally can be presented in an easy to understand form.	Computer models, GIS, interviews, effective enforcement, monitoring	Accurate positioning of boundaries, communication (local presence or contact person) and outreach tools with user groups.	GIS, good consultation process.

	Proposed Southern Strait of Georgia NMCA	Saguenay-St. Lawrence Marine Park	Monterey Bay National Marine Sanctuary	Scott Islands Marine Wildlife Area	Gwaii Haanas National Park Reserve & Haida Heritage Site
Would GIS methods be useful?	Yes. Overlay analyses are very useful so as to be able to combine a theoretically limitless number of values. It would be particularly useful to be able to apply different importance ratings for individual data sets so that combinations could be run with different weightings for various values. Numerous runs with different combinations of values and different weightings could lead to better zoning decisions.	It could be helpful as long as it can be adapted to the various situations	Using GIS is critical, but more for modeling the pros and cons of developing the model a certain way - to determine economic impacts of no-take areas, for example	A methodology that helps define zones based on spatial analysis of a suite of physical / biological factors would be useful during the consultation phases. User and other commercial uses of the area of interest would be necessary to provide possible interaction information. Zones that are defined using minimum viability analyses or other such algorithms would also help with defining different zones.	Yes.

	Proposed Southern Straight of Georgia NMCA	Saguenay-St. Lawrence Marine Park	Monteray Bay National Marine Sanctuary	Scott Islands Marine Wildlife Area	Gwaii Haanas National Park Reserve & Haida Heritage Site
Other suggestions for easier zoning?	Not at this time	More awareness of marine zoning among stakeholders	No	Using fewer larger zones rather than trying to carve up marine areas to accommodate all uses. Fragmented use zoning does not work in a marine system.	Best possible data
Other comments	Not at this time			The bias of the zoning process should be identified up front (i.e. where is the model going - is it for regulating intensity/ location of uses or is it for permitting, or is it for conservation?	

APPENDIX IX: DATA USED TO DEVELOP ZONES

Conservation Zone

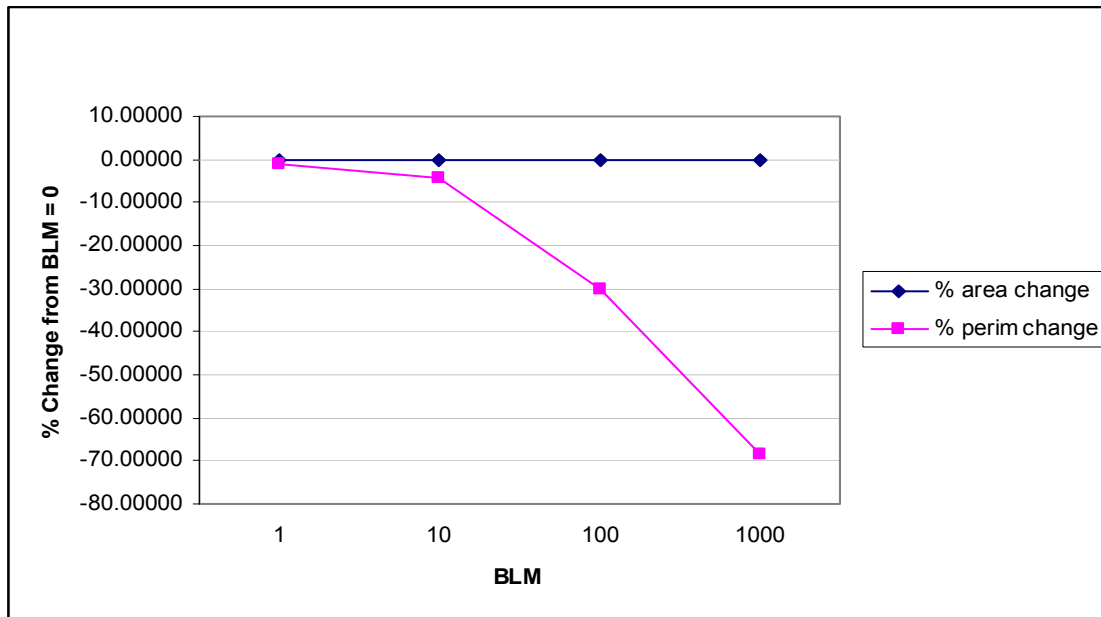
- Kelps
- Mudflats estuaries
- Important Bird Areas
- Eelgrass
- Bird colonies
- Sea lion haulouts
- Conservation Data Centre non sensitive occurrences
- Good clam aqua areas
- Good oyster aqua areas
- Conservation Data Centre points
- Rockfish conservation area
- Critical fish wildlife habitat
- Highly mixed areas
- High capability birds mammals
- Sea floor complexity (developed based on Ardron, 2002).
- 13 pelagic categories
- 35 benthic categories
- High value whales
- Herring spawning
- Salmon spawning rivers
- Salmon migration routes
- Productive herring areas
- Conservation zoning (Gulf Islands)
- CPAWS hotspots
- Puget Sound hotspots
- Nature Conservancy hotspots

Recreation Zone

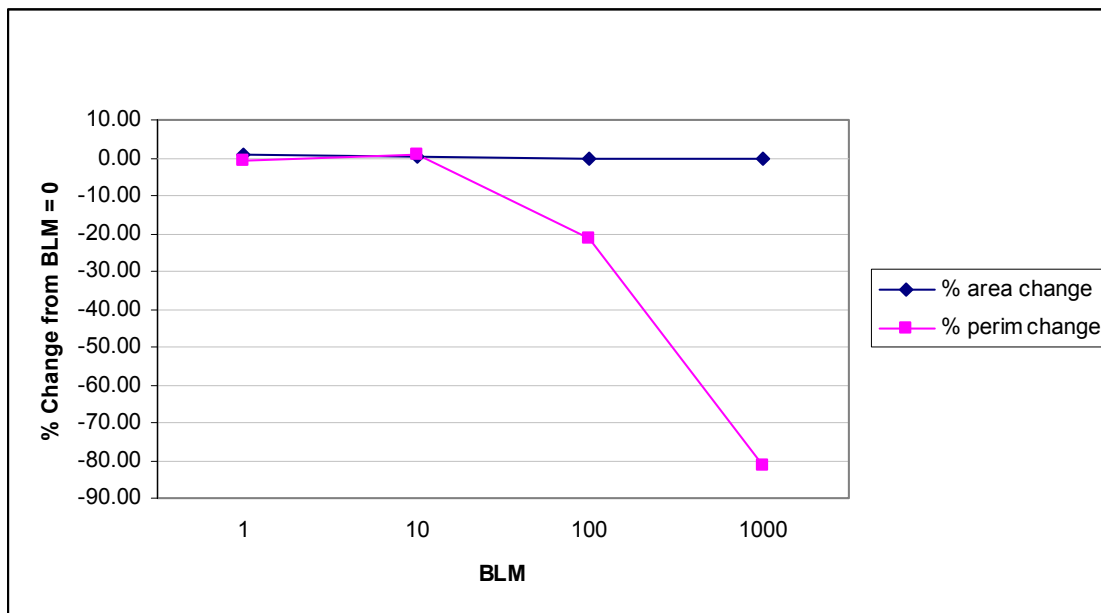
- Harbours
- Mooring bouys
- Sea kayaking areas
- Sport fishing areas
- Angling areas
- Boating areas
- Anchorage sites
- Artificial reefs

APPENDIX X: PLANNING UNIT SIZE TESTING RESULTS

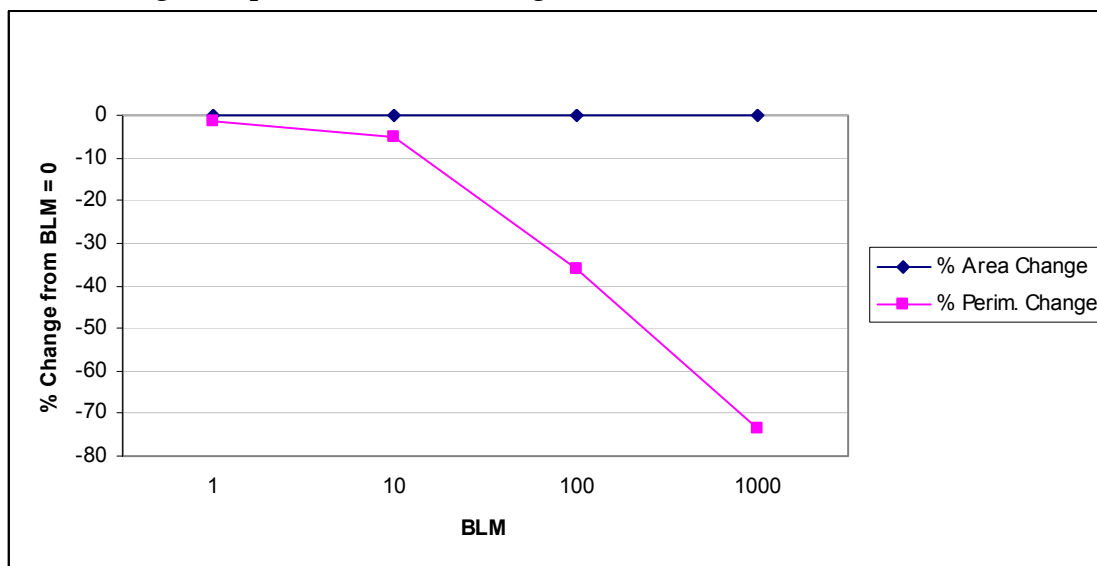
a) 100 hexagon, Inlets and Passages, 20% Target



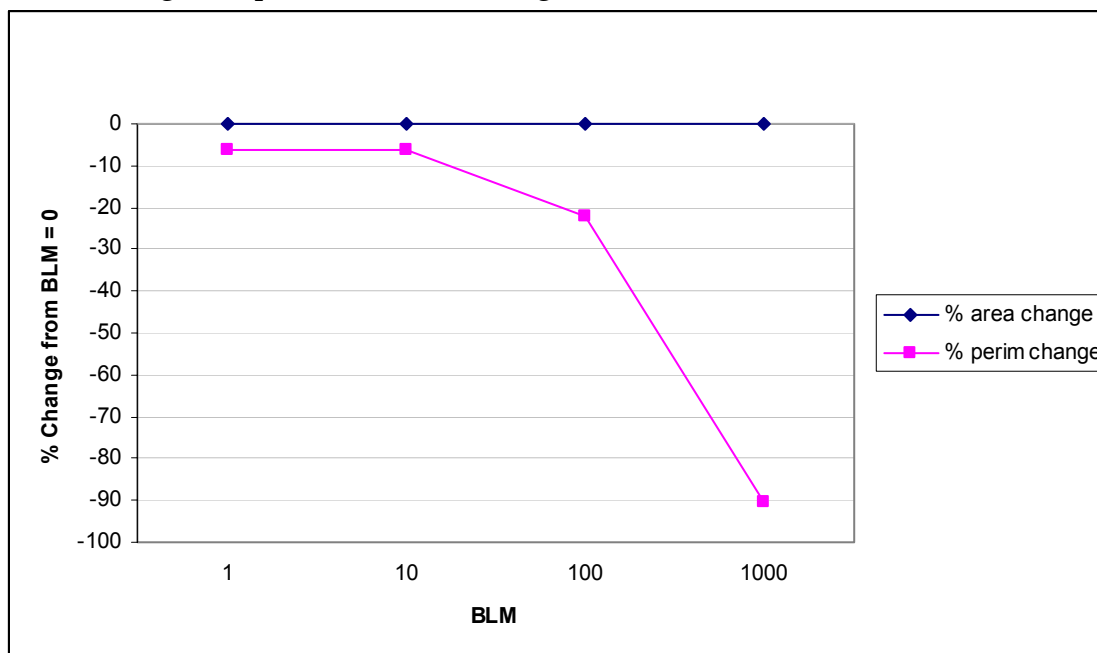
b) 500 hexagon, Inlets and Passages, 20% Target



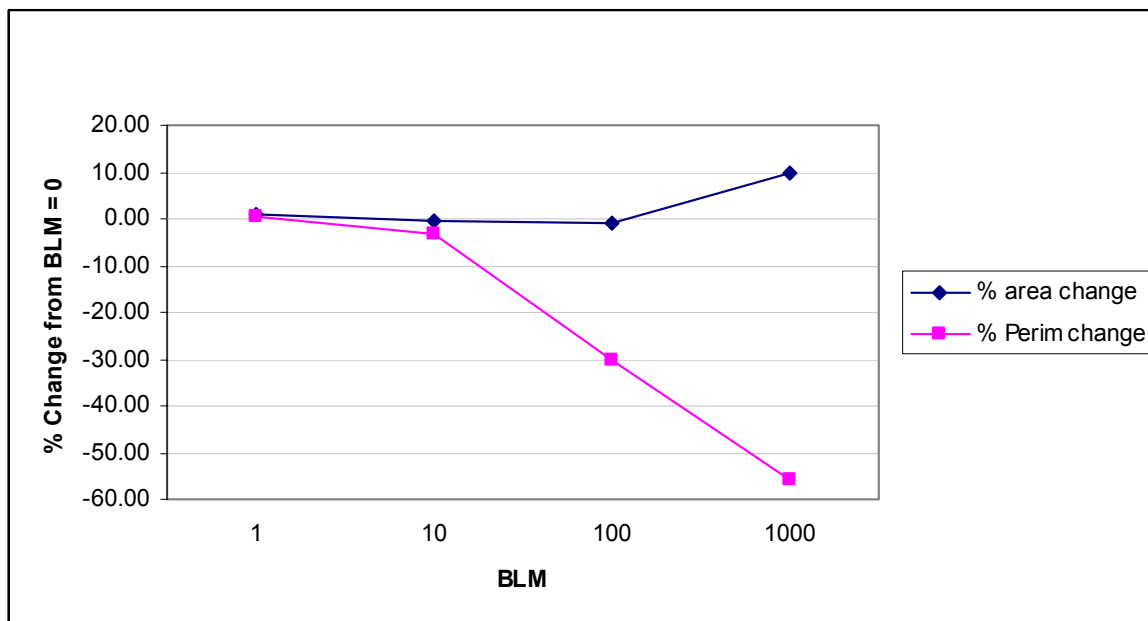
c) 100 hexagon, Open Ocean, 20% Target



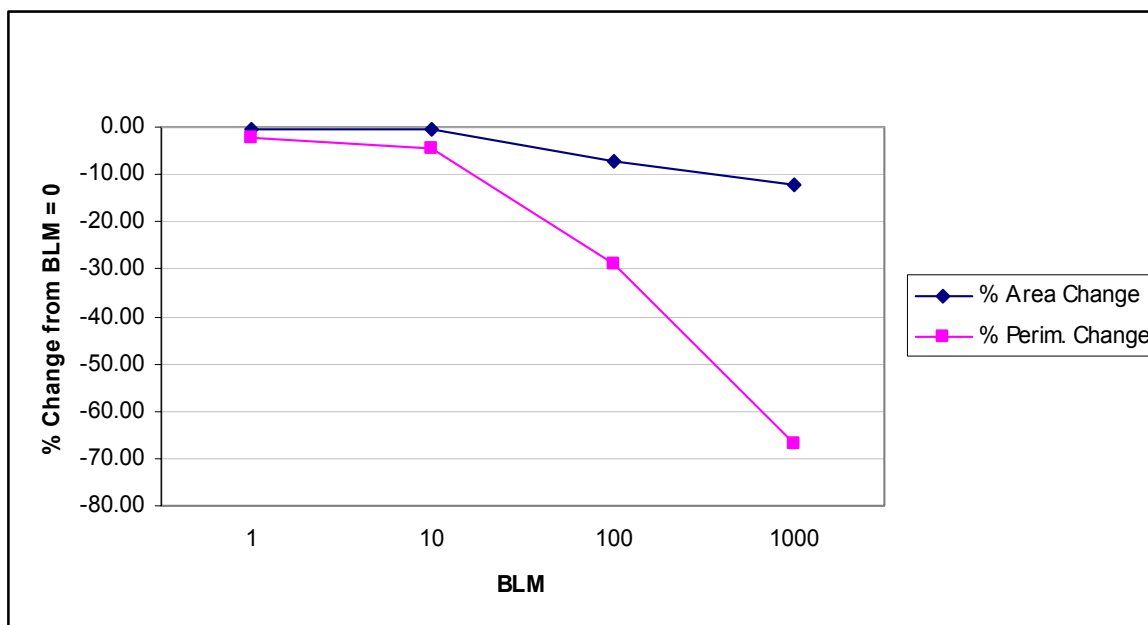
d) 500 hexagon, Open Ocean, 20% Target



e) 100 hexagon, Inlets and Passages with Sparse Data, Target 20%

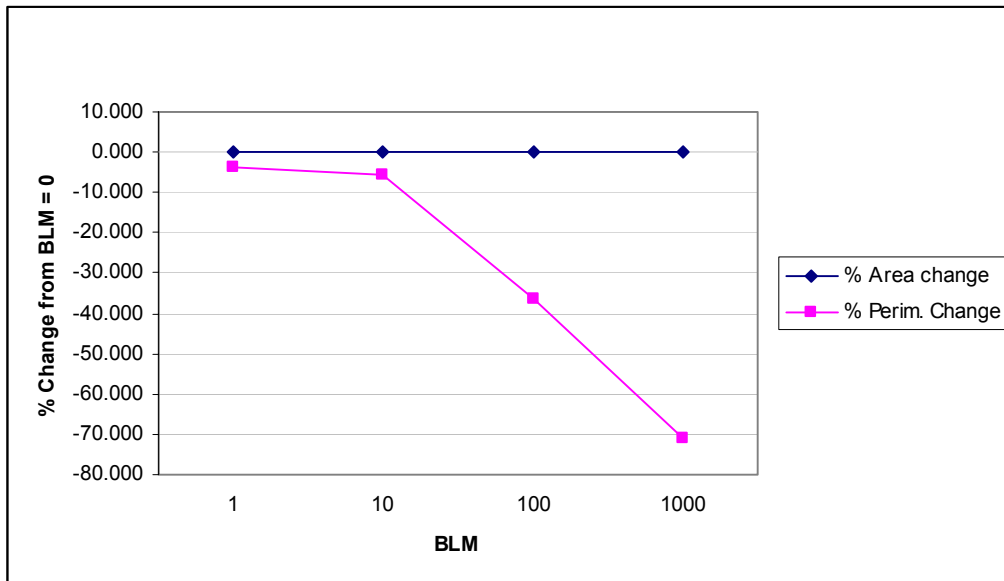


f) 500 hexagon, Inlets and Passages with Sparse Data, 20% Target

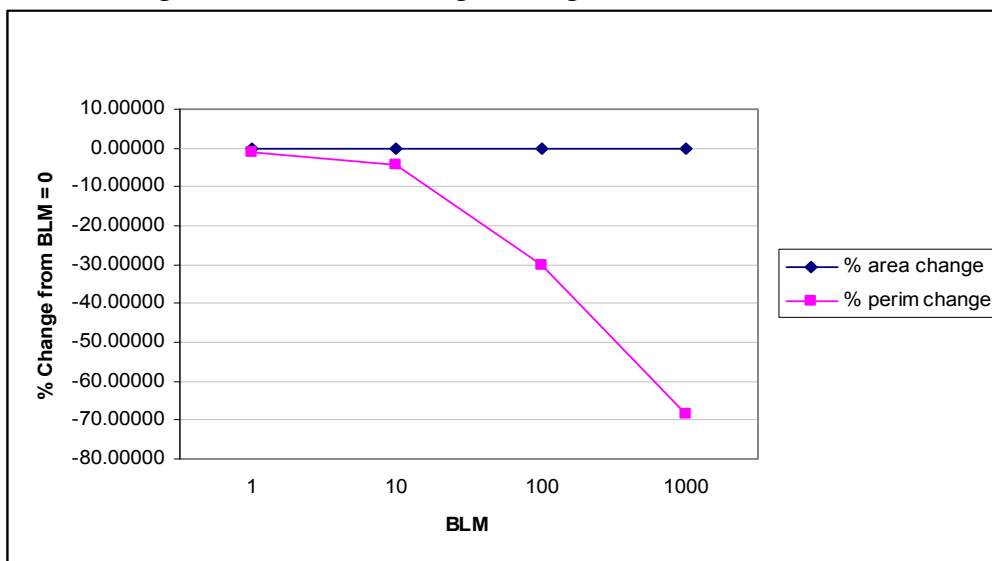


APPENDIX XI: PLANNING UNIT SHAPE TESTING RESULTS

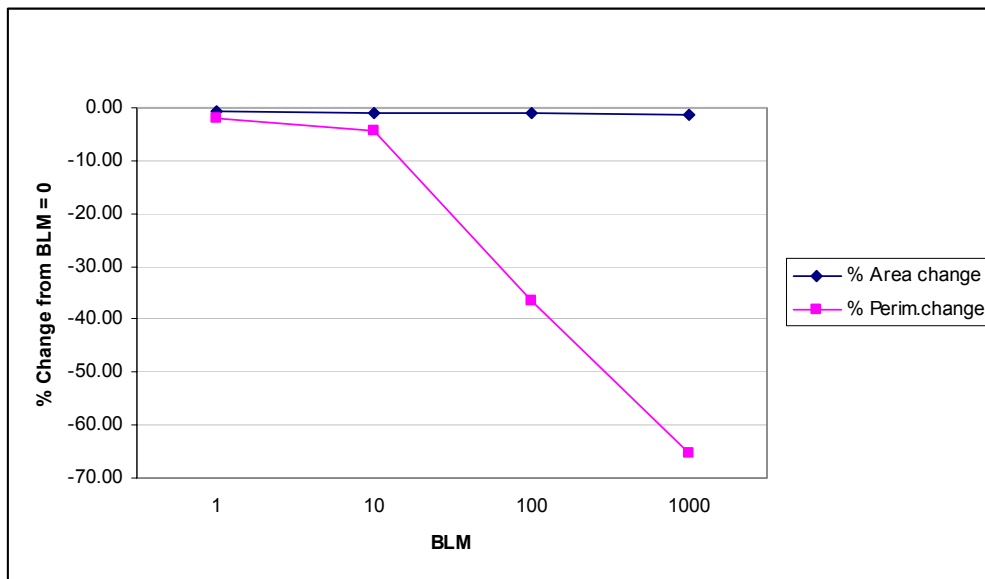
a) 100 square, Inlets and Passages, Target 20%



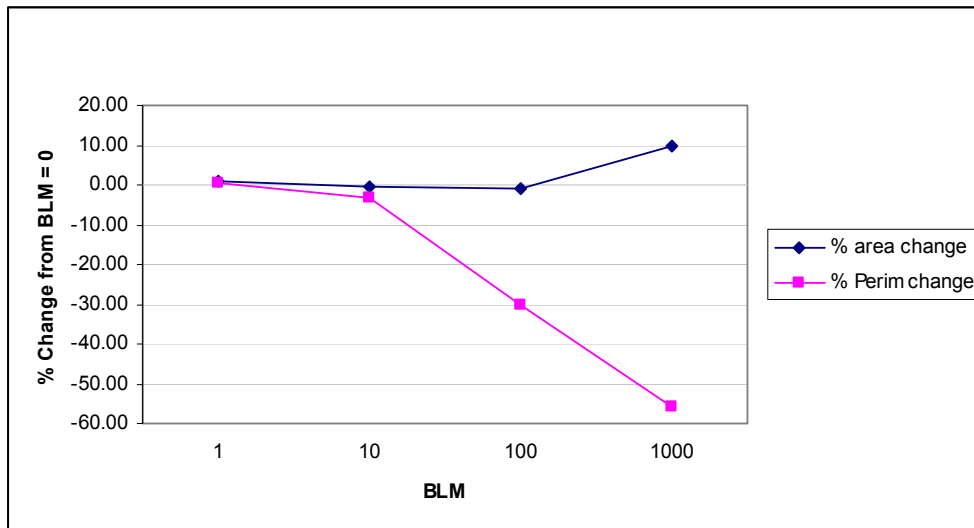
b) 100 hexagon, Inlets and Passages, Target 20%



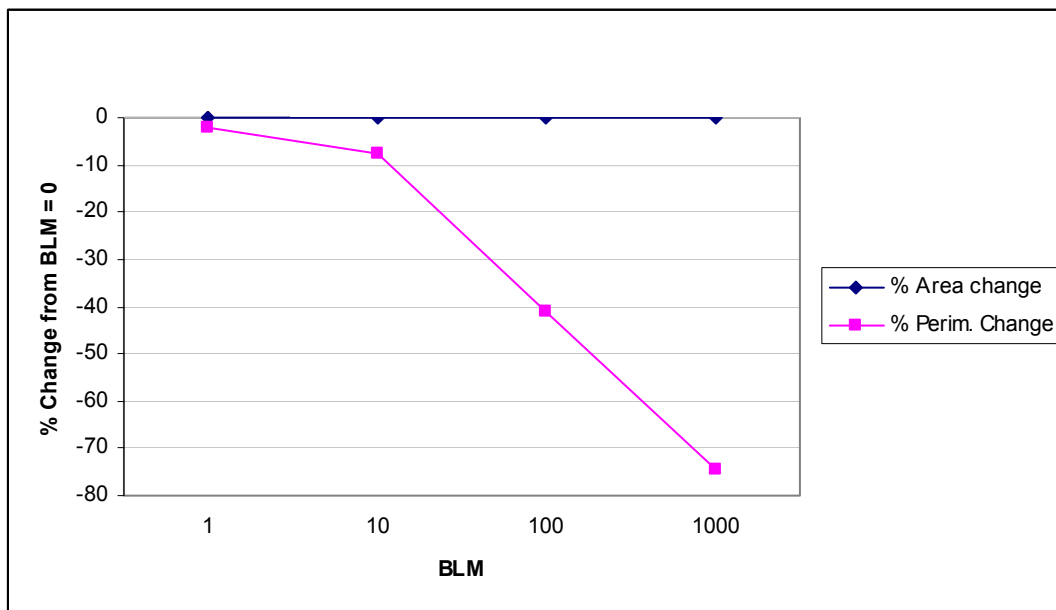
c) 100 square, Inlets and Passages with Sparse Data, Target 20%



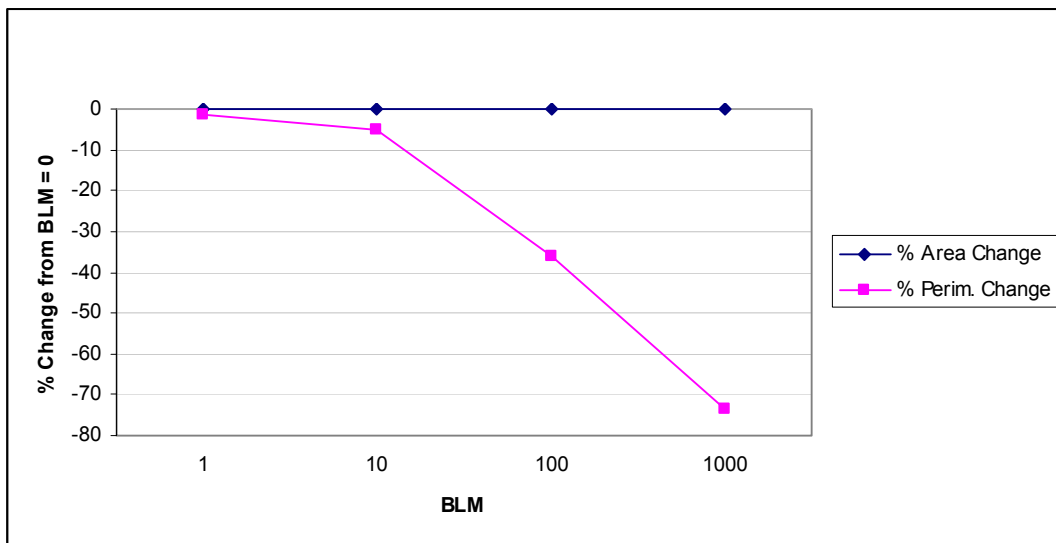
d) 100 hexagon, Inlets and Passages with Sparse Data, Target 20%



e) 100 square, Open Ocean, Target 20%

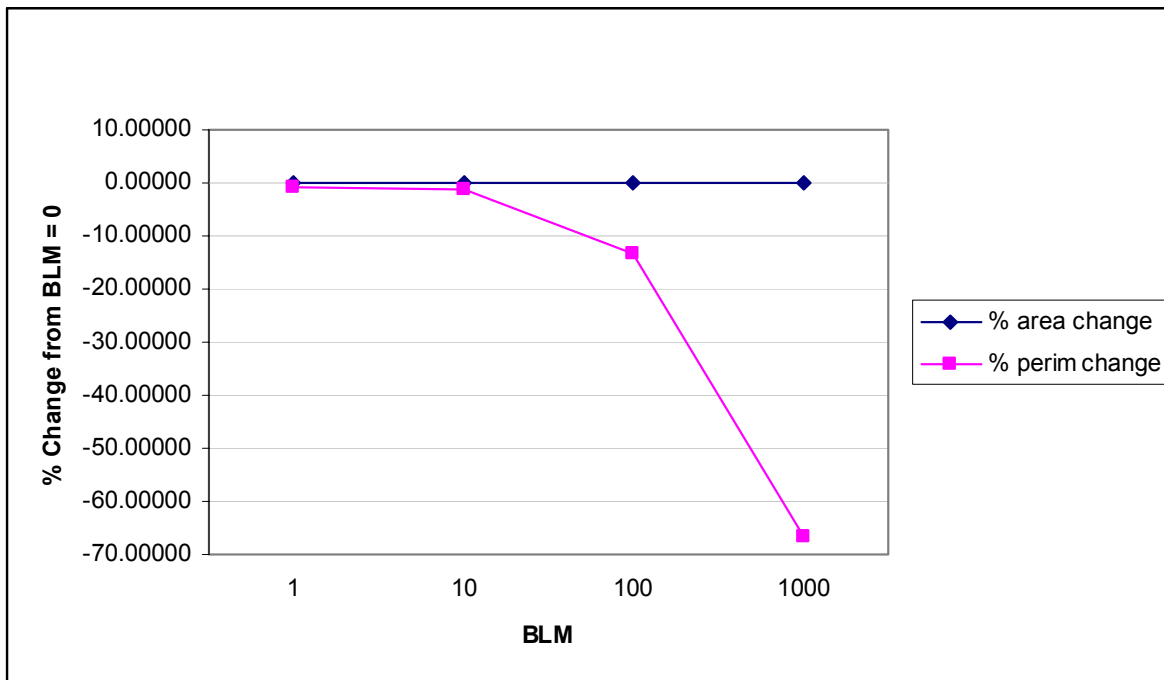


f) 100 hexagon, Open Ocean, Target 20%

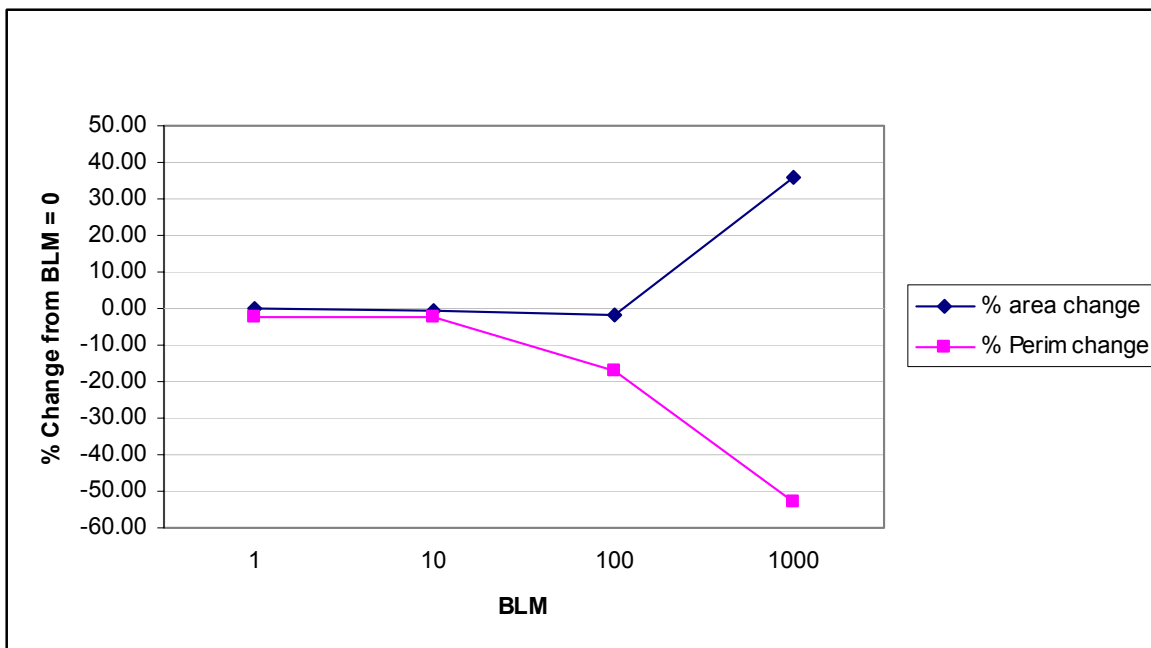


APPENDIX XII: DATA GAP TESTING RESULTS

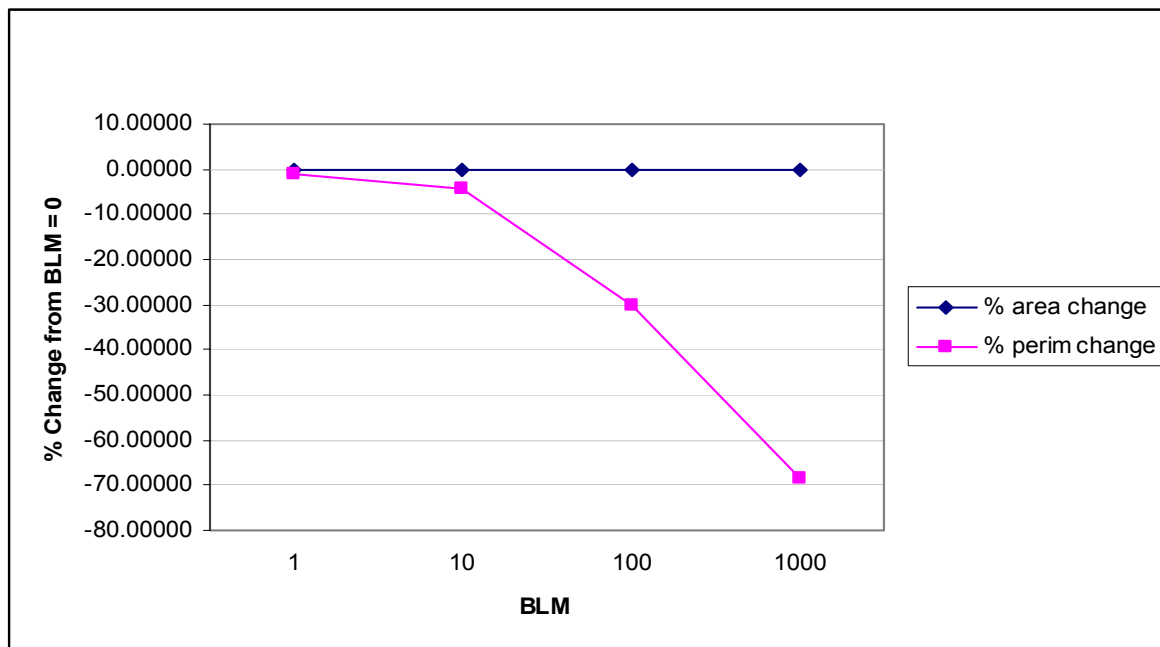
a) 100 hexagon, Inlets and Passages, Target 5%



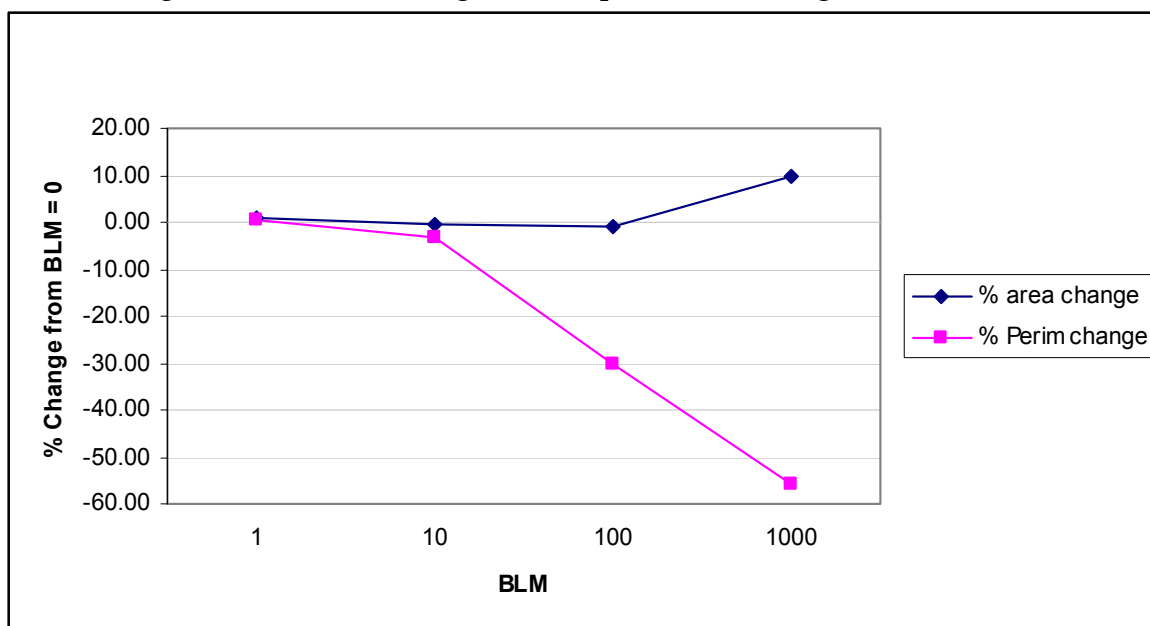
b) 100 hexagon, Inlets and Passages with Sparse Data, Target 5%



c) 100 hexagon, Inlets and Passages, Target 20%

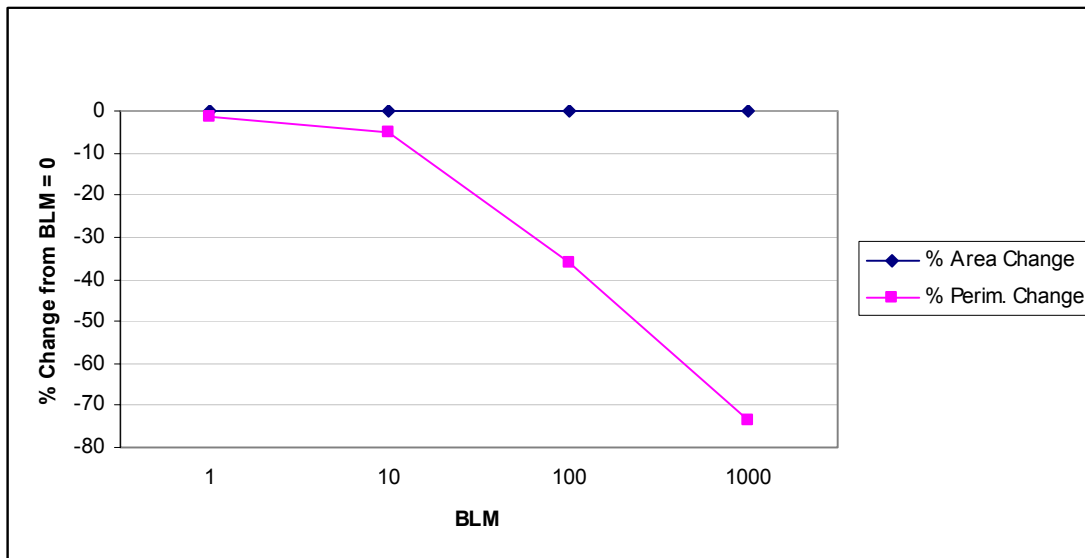


d) 100 hexagon, Inlets and Passages with Sparse Data, Target 20%

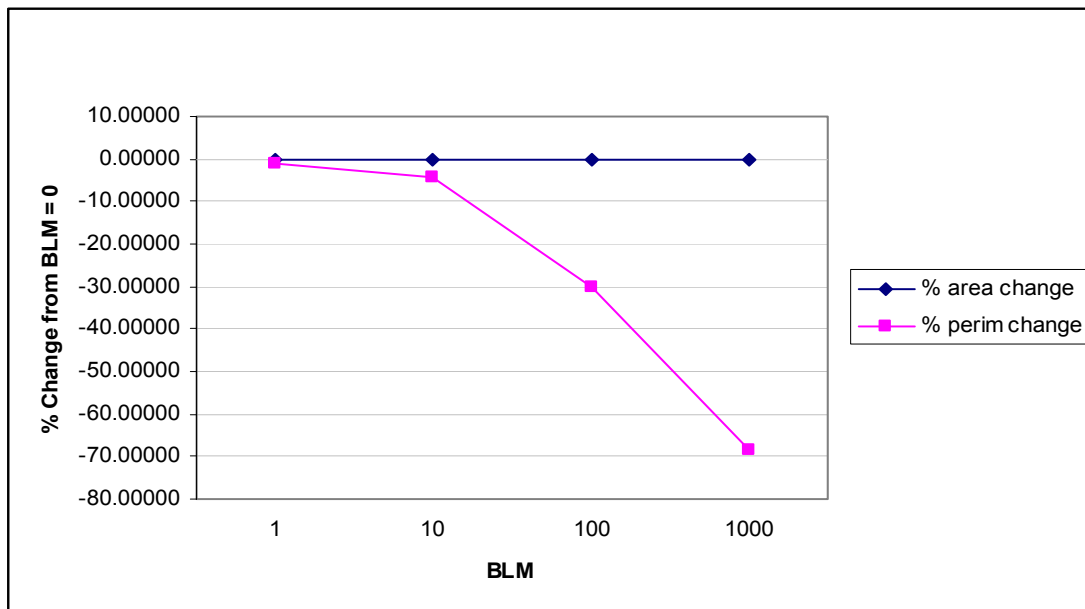


APPENDIX XIII: OPEN OCEAN VS INLETS AND PASSAGES (BLM TESTING)

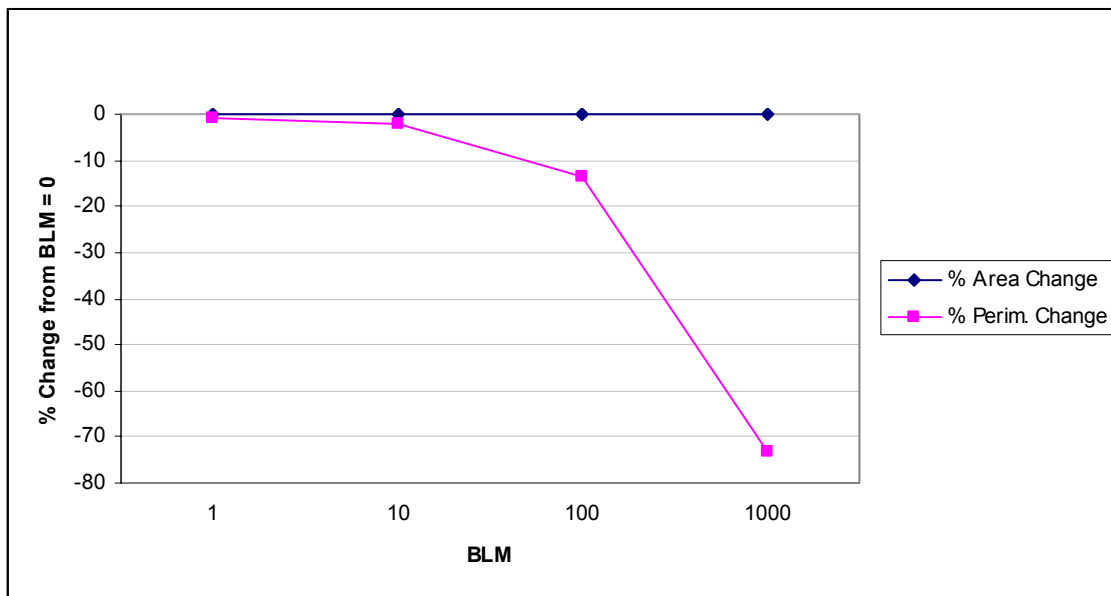
a) 100 hexagon Open Ocean 20% Target,



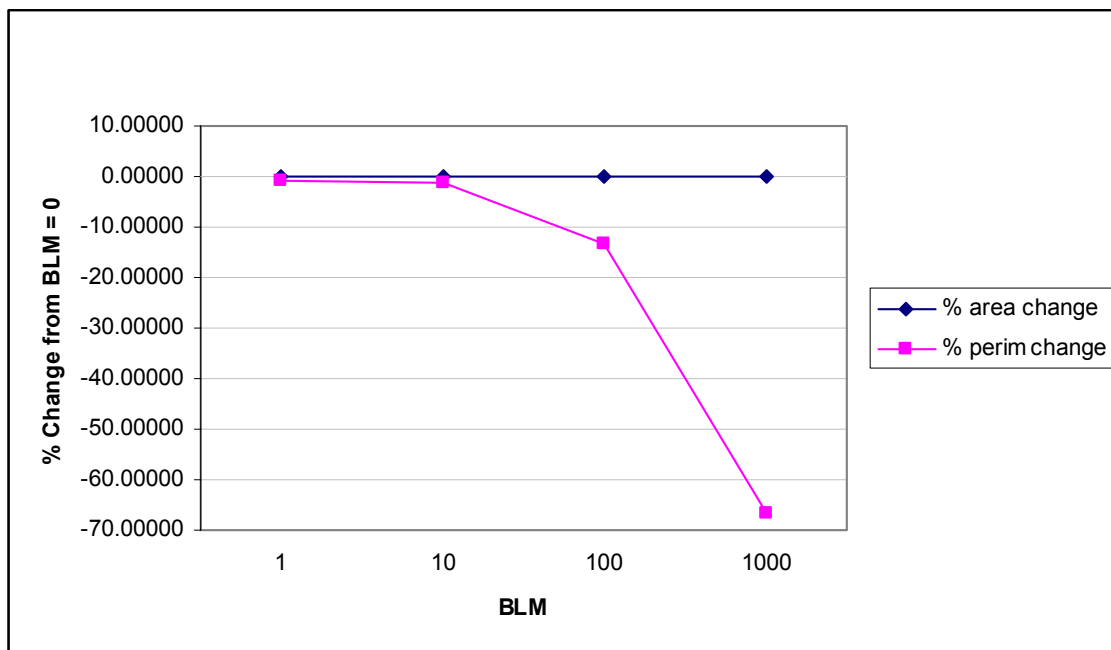
100 hexagon, Inlets and Passages, 20% Target



b) 100 hexagon, Open Ocean, 5% Target

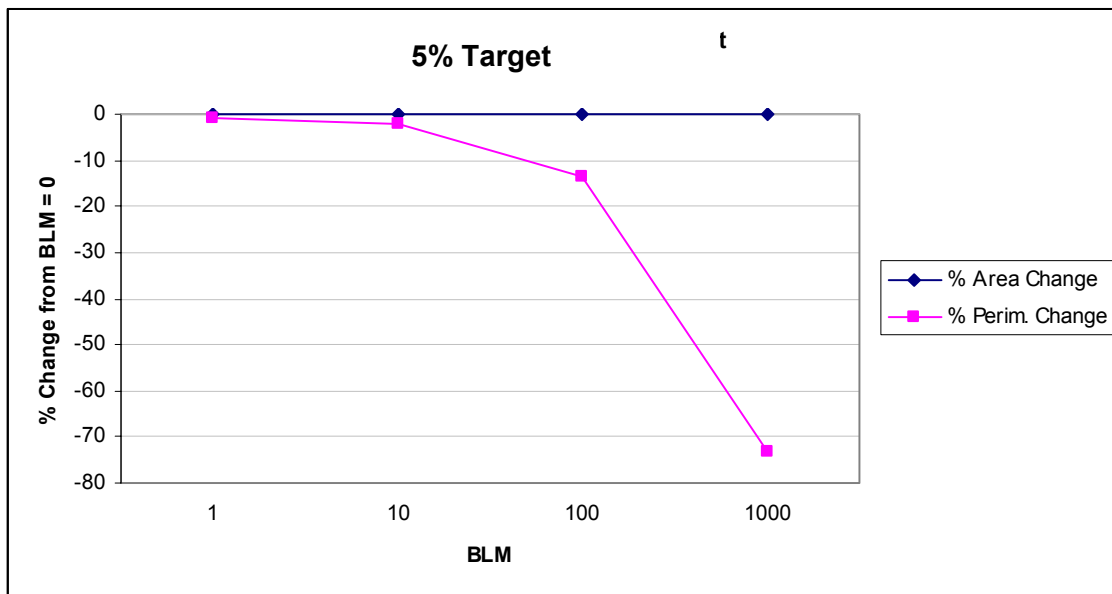
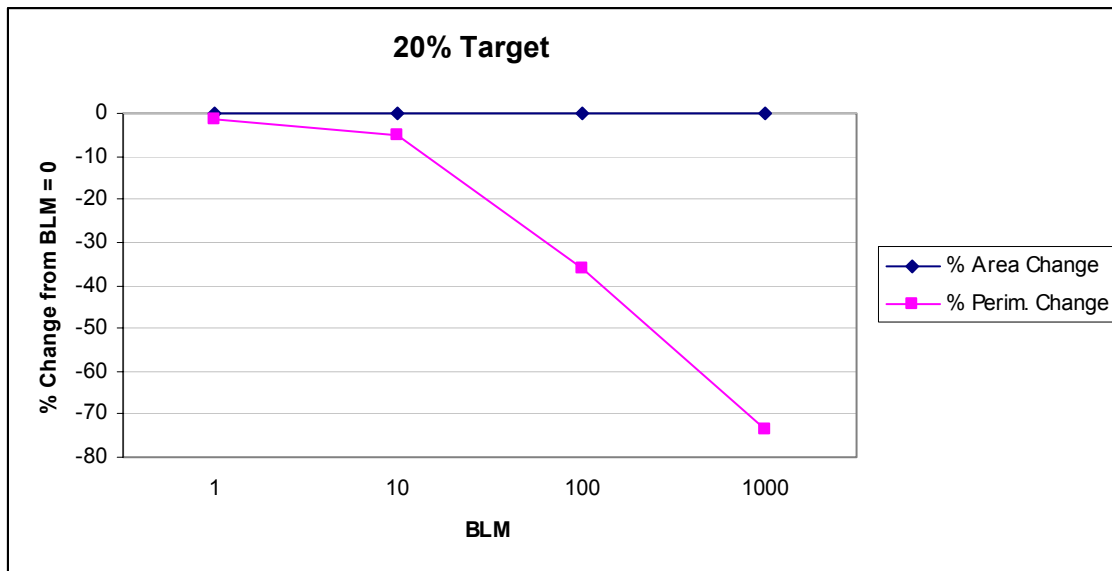


100 hexagon, Inlets and Passages, 5% Target

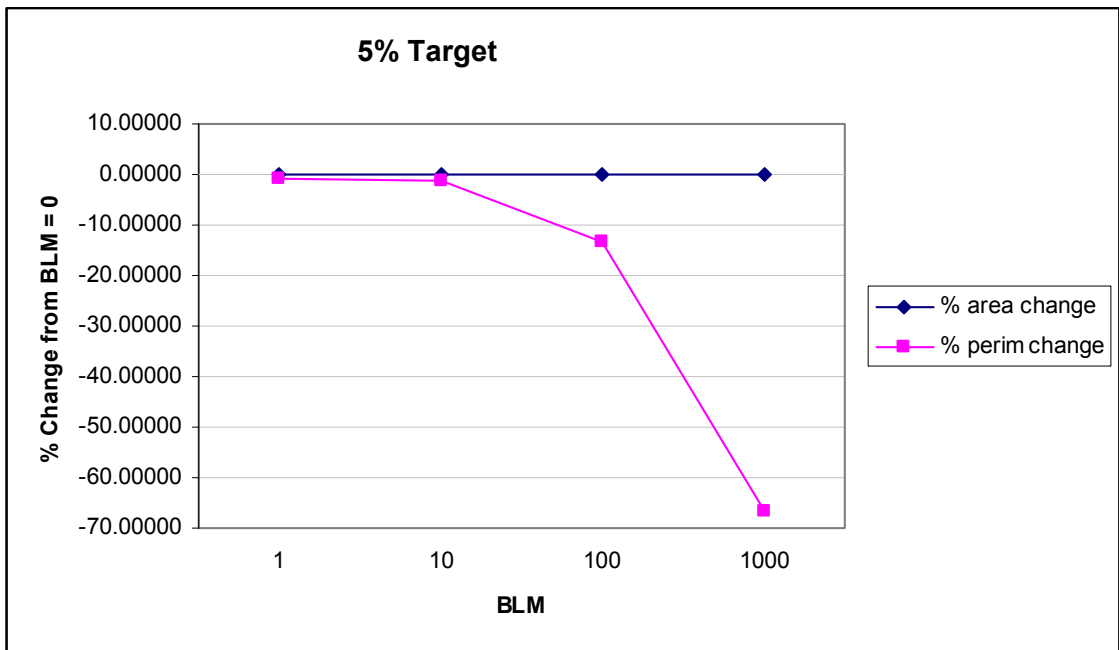
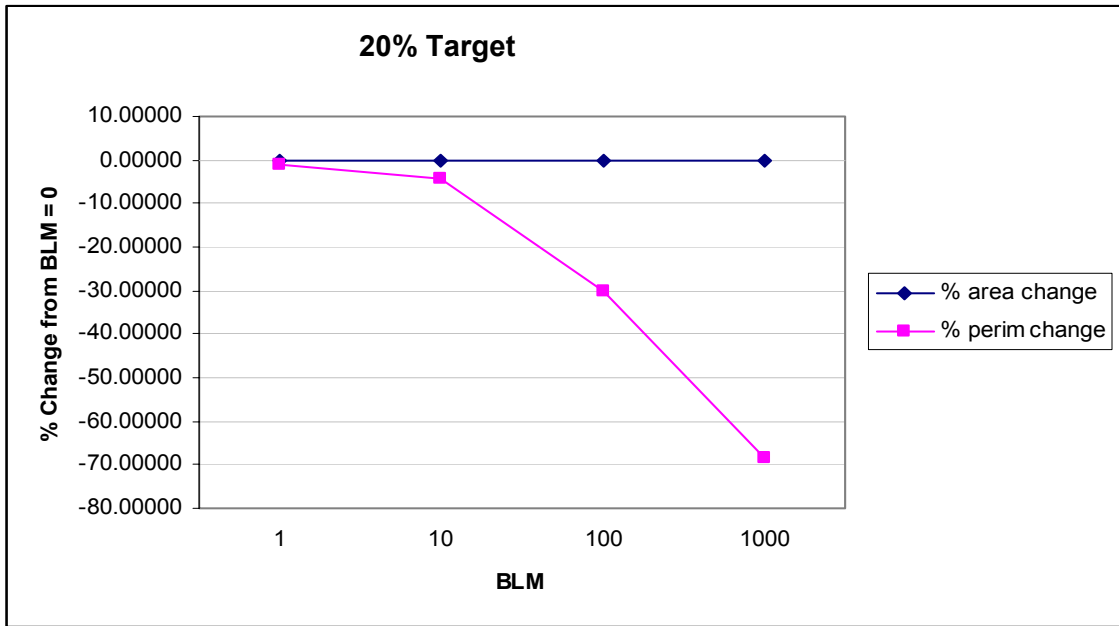


APPENDIX XIV: BLM TESTING - TARGETS

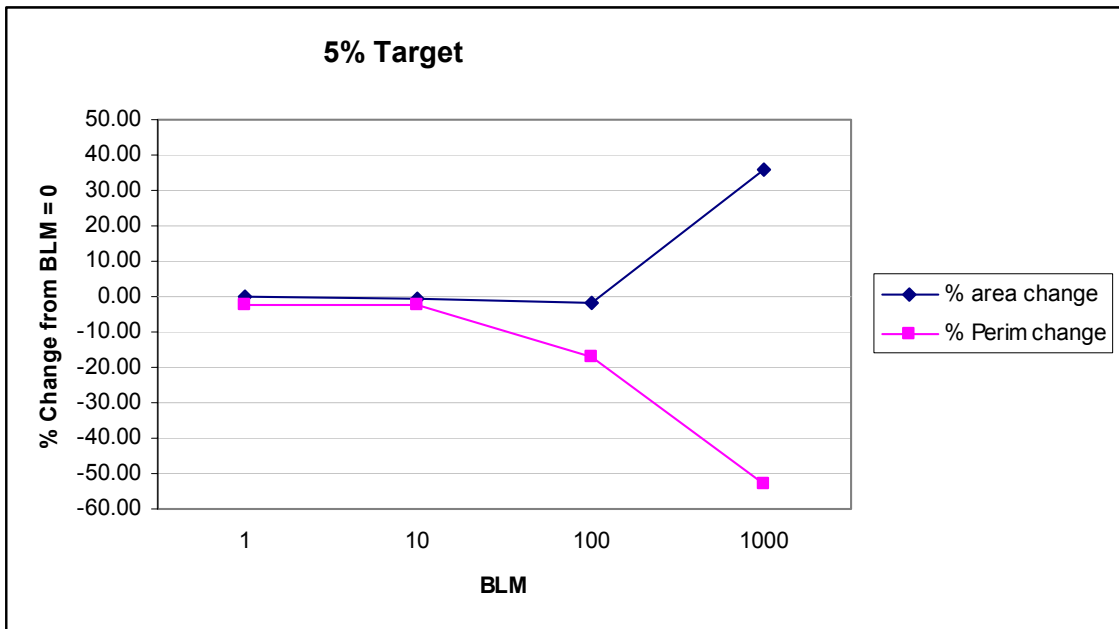
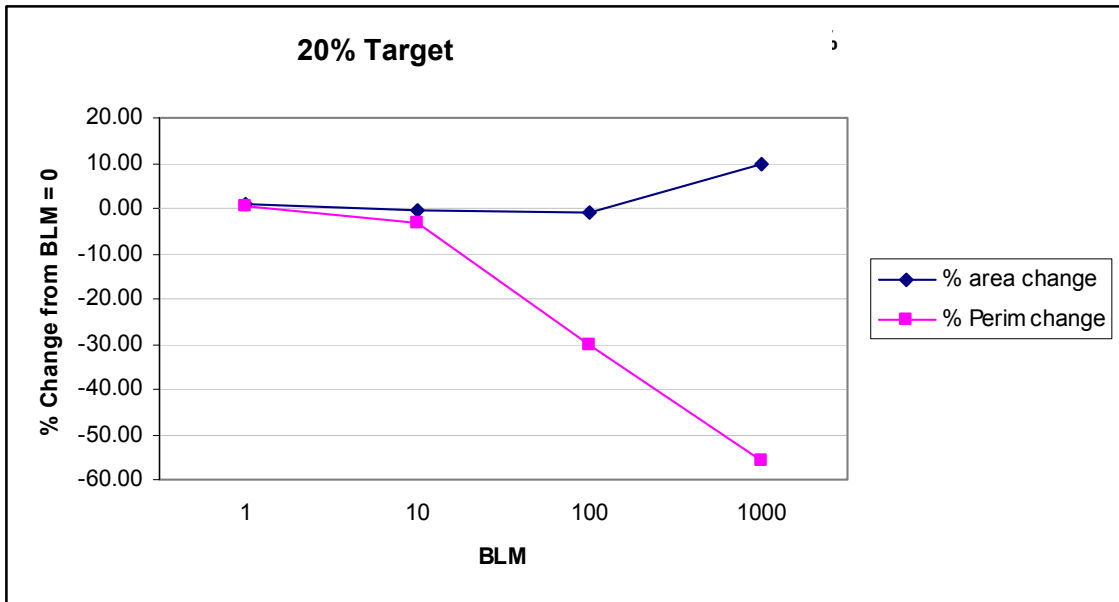
a) 100 hexagon, Open Ocean



b) 100 hexagon, Inlets and Passages



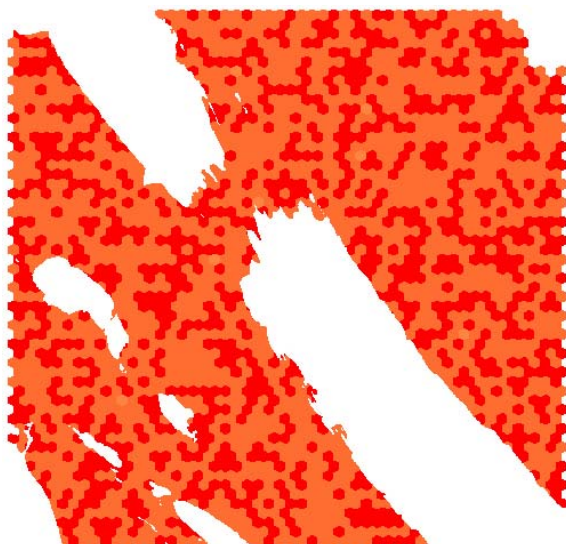
c) 100 hexagon, Inlets and Passages with Sparse Data



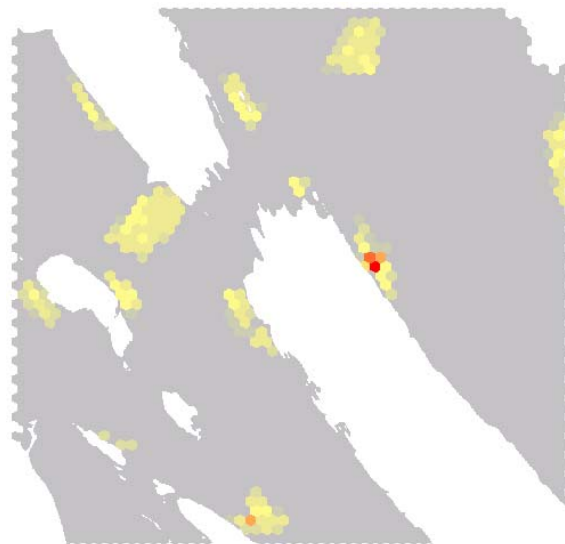
APPENDIX XV: COST TESTING

Data in both 'desirable' and 'undesirable' areas

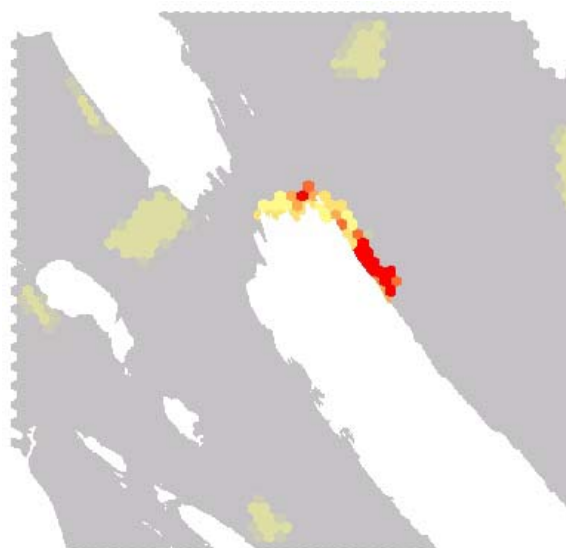
a) All planning unit costs = 0



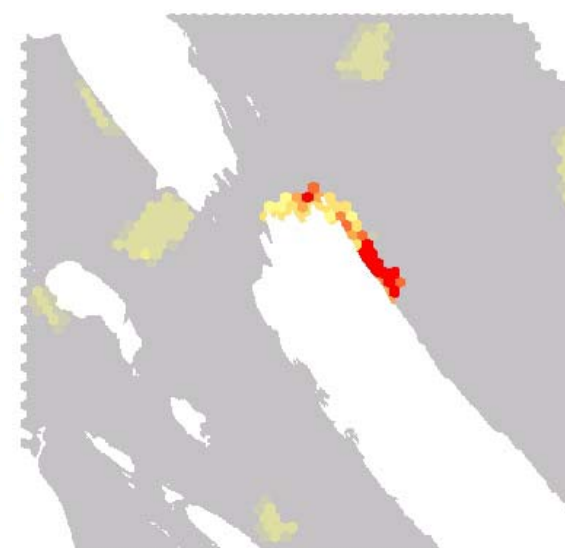
b) All planning unit costs = 100



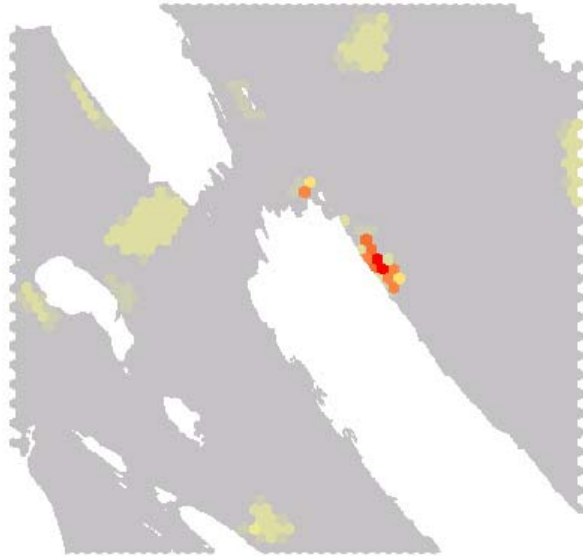
c) 'Desirable' 0, 'Neutral' 1,
'Undesirable' 2



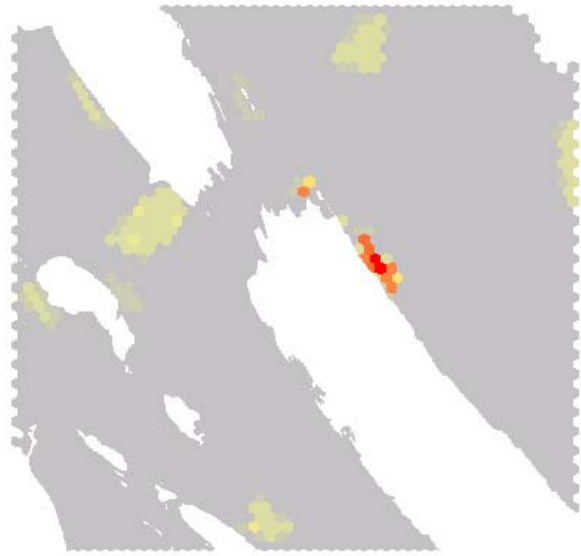
d) 'Desirable' 0, 'Neutral' 50,
'Undesirable' 100



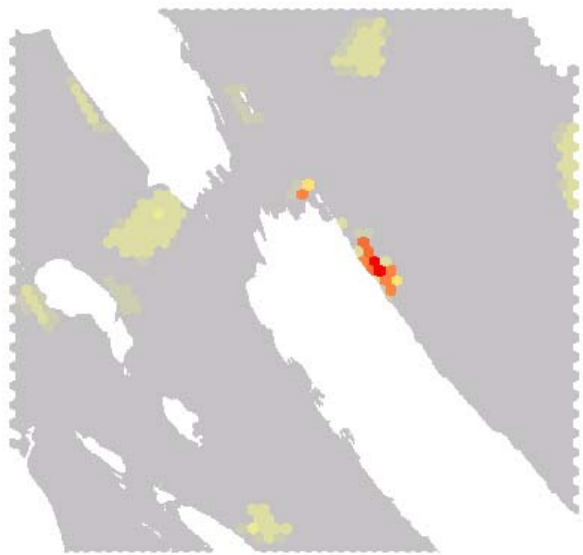
e) 'Desirable' 0.1, 'Neutral' 0.2,
'Undesirable' 0.3



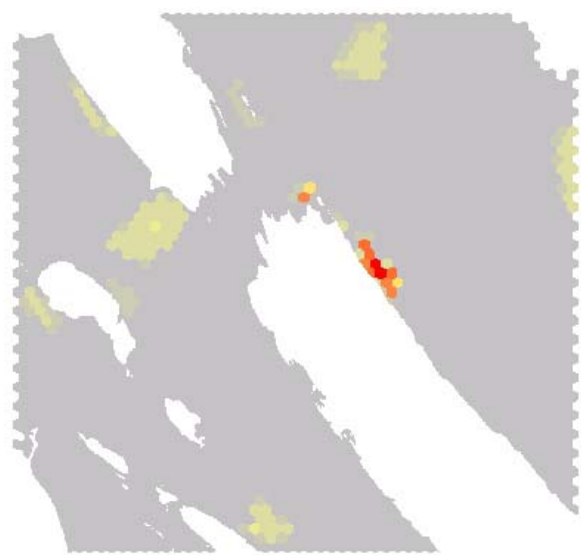
f) 'Desirable' 1, 'Neutral' 2,
'Undesirable' 3



g) 'Desirable' 25, 'Neutral' 50,
'Undesirable' 75

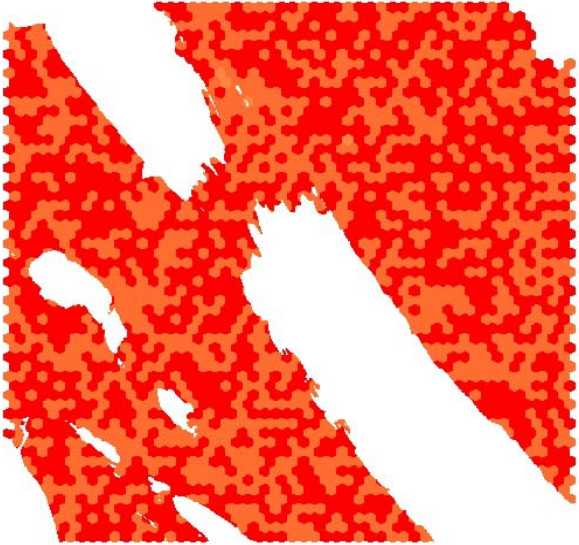


h) 'Desirable' 100, 'Neutral'
200, 'Undesirable' 300

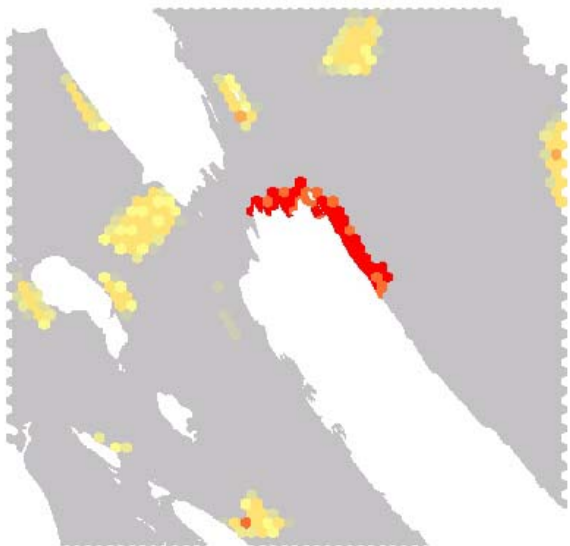
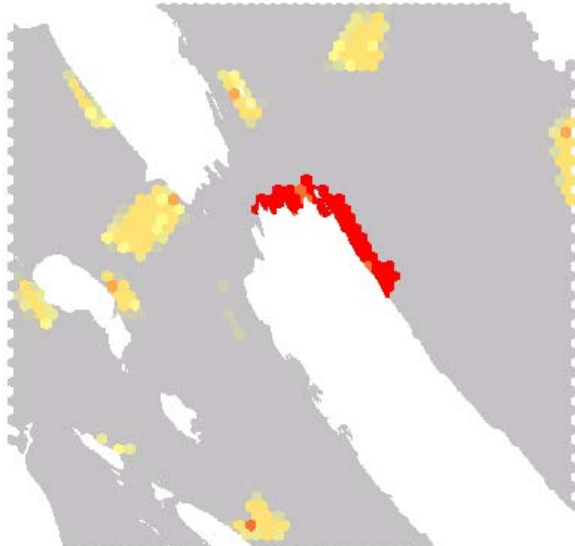


No data in 'desirable' area

i) All planning unit costs = 0



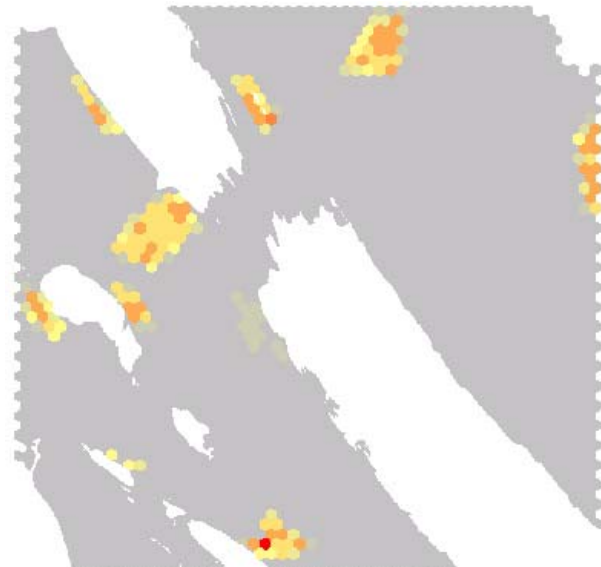
j) All planning unit costs = 100

k) 'Desirable' 0, 'Neutral' 1,
'Undesirable' 2l) 'Desirable' 0, 'Neutral' 50,
'Undesirable' 100

m) 'Desirable' 0.1, 'Neutral' 0.2,
'Undesirable' 0.3



n) 'Desirable' 1, 'Neutral' 2,
'Undesirable' 3



o) 'Desirable' 25, 'Neutral' 50,
'Undesirable' 75

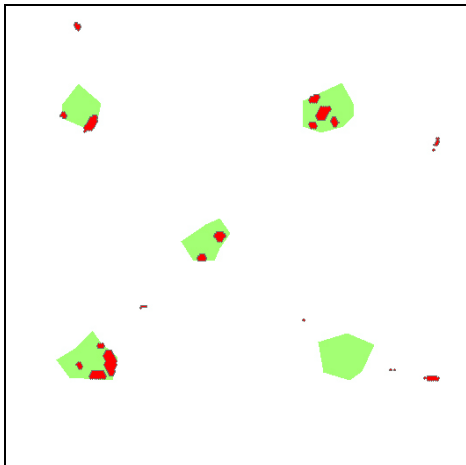


p) 'Desirable' 100, 'Neutral'
200, 'Undesirable' 300

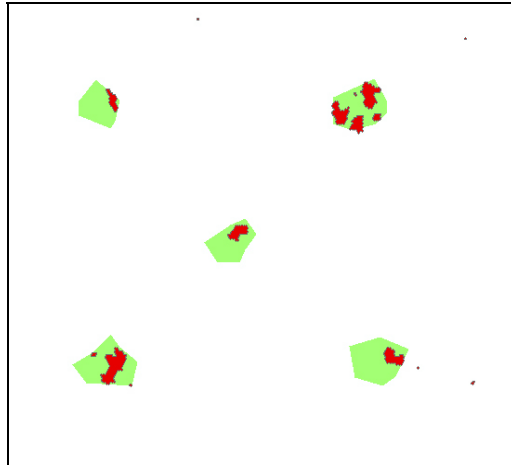


APPENDIX XVI: SPECIES PENALTY FACTOR TESTING RESULTS

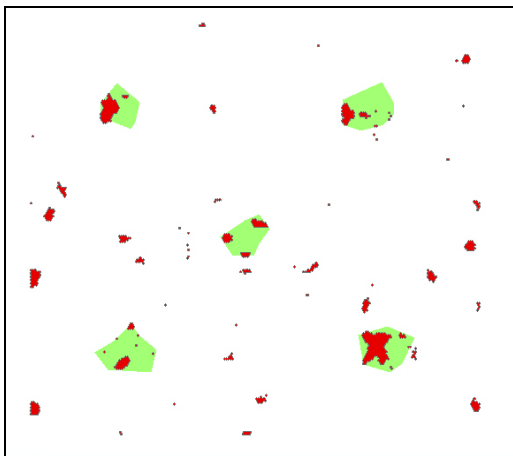
SPF 0.1



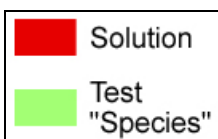
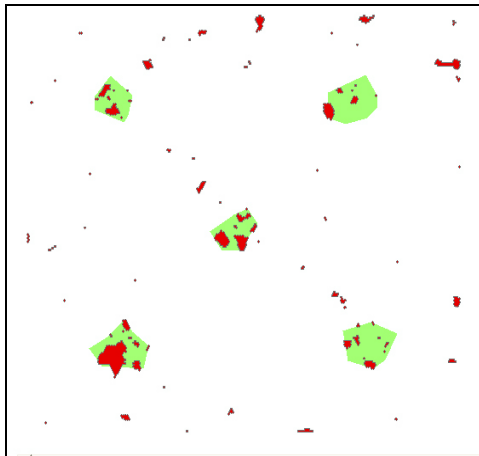
SPF 1



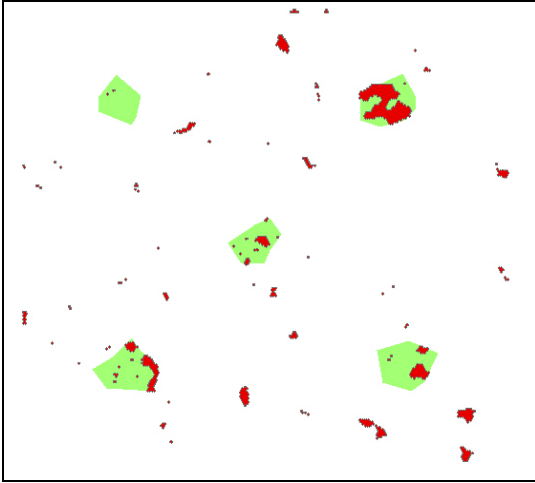
SPF 10



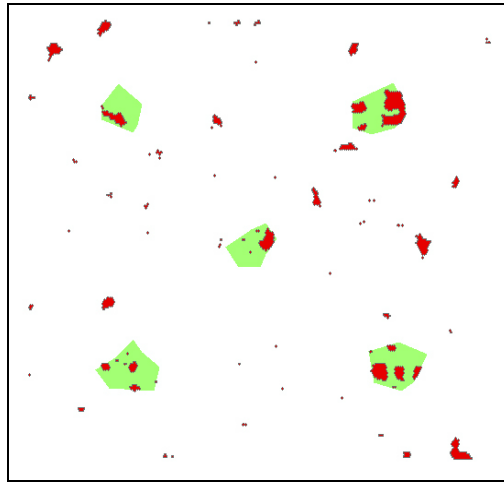
SPF 100



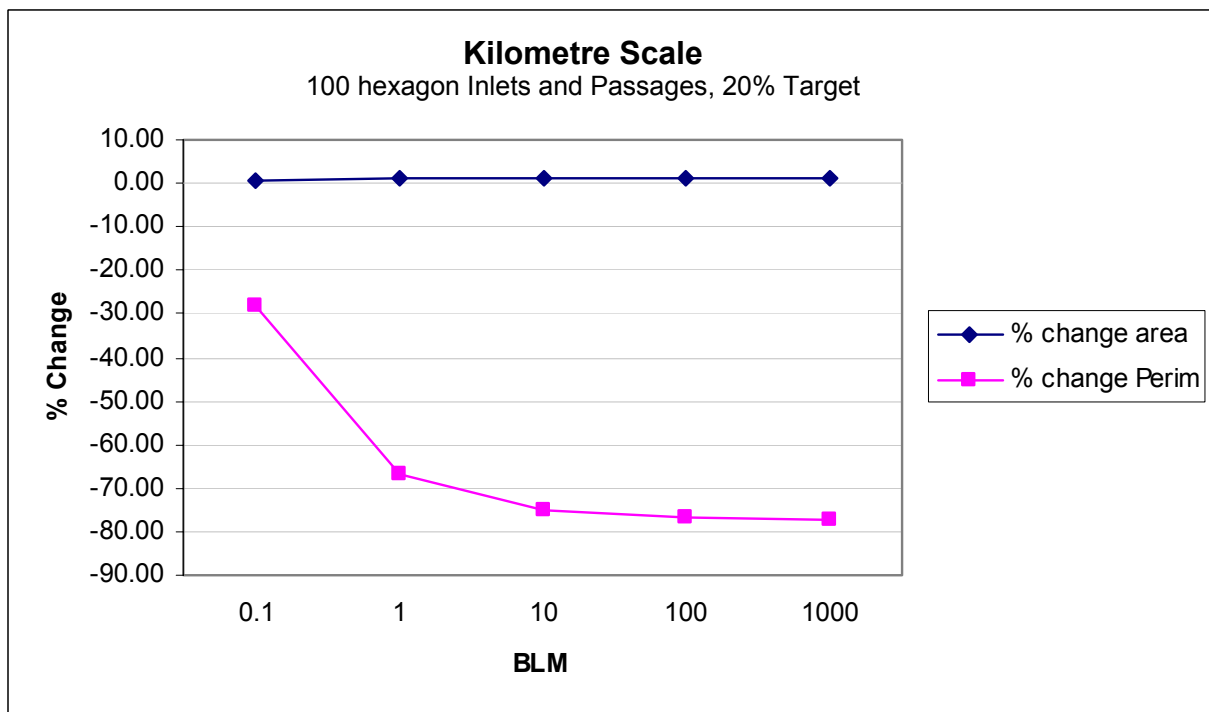
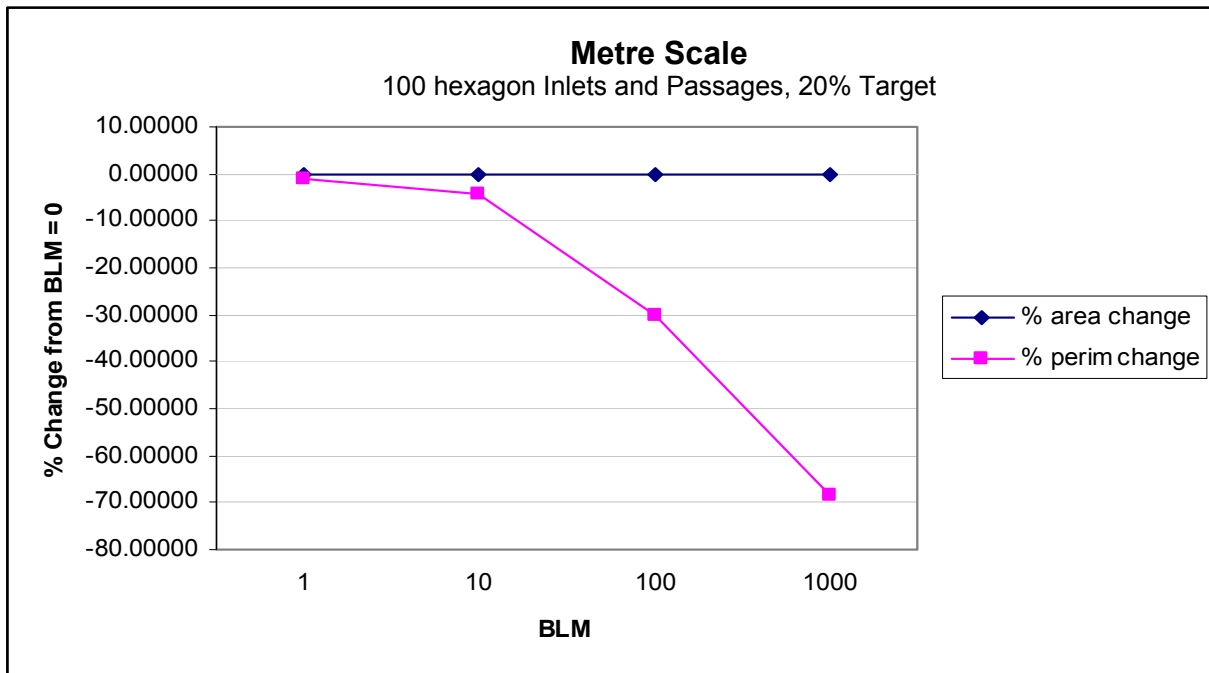
SPF 1,000



SPF 10,000



APPENDIX XVII: RELATIONSHIP BETWEEN BLM AND COST MAGNITUDE



VITA

Surname: Loos (née Maxwell)

Given Names: Sarah Amber

Place of Birth: Vancouver, British Columbia, Canada

Educational Institutions Attended:

University of Victoria 2003 to 2006

University of Victoria 1995 to 2001

Degrees Awarded:

B.Sc. (Honours) University of Victoria 2001