Modelling a Network of Marine Protected Areas for the Central Coast of BC

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A Executive Summary

In 1998, Living Oceans Society embarked upon modelling science-based networks of marine protected areas for the Central Coast of British Columbia. The results and methodologies presented in this paper are from three successive refinements of the model. These are the first of their kind in BC, and comparable to only a handful of others in the world. We have made every attempt to use the best available data and apply current reserve design theory and algorithms. This project remains on-going, and details presented here may change. The analysis is current to October 2001, with document edits to July 2002. The next refinement of the analysis is expected in early 2003.

Presently, there are no fully protected areas in BC's Central Coast waters. We define a marine protected area (MPA) as consisting of one or more core no-take areas that should be surrounded by a buffer zone. In this analysis we have focused on identifying the core no-take areas first.

The following findings and methodologies have emerged:

1. **Conservation Hotspots:** Regardless of whether MPA networks are small or large, scattered or clumped, certain areas are identified repeatedly over the course of thousands of solutions. While these areas alone would *not* constitute a fully representative MPA network, it is very likely that without them, such a network would be difficult or impossible to achieve.

2. **Physical Complexity:** Areas of high physical complexity are believed to harbour greater species richness, and as such are distinctive and valuable. We developed a unique methodology to extract a measure of benthic complexity from bathymetric data.

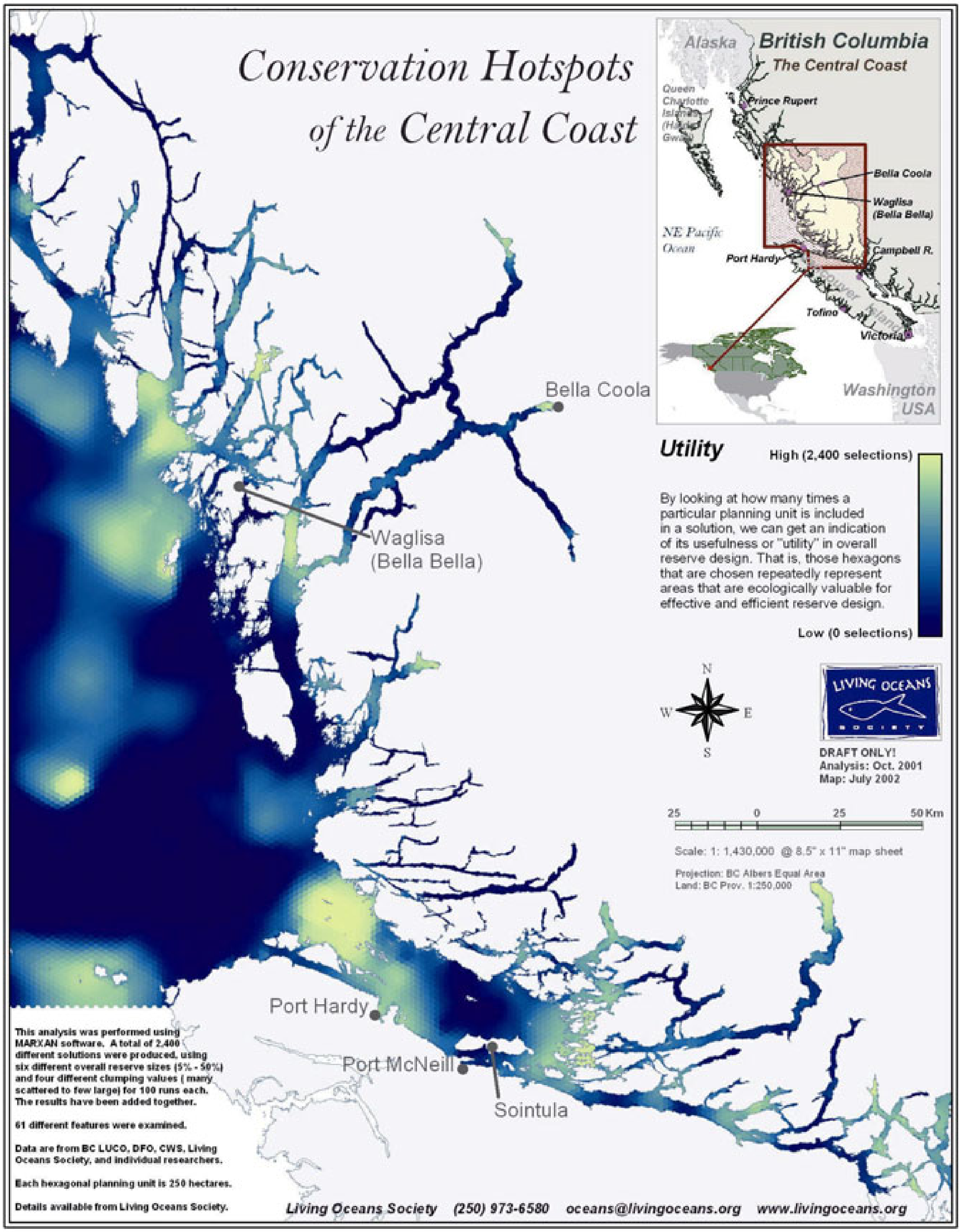
3. **SLOSS:** (Single Large or Several Small?) We have developed a procedure to inform the MPA designer of the ecological vs. pragmatic trade-offs involved between many scattered MPAs and a few large ones.

4. **Scale:** Unique amongst conservation analyses, we have begun to take into account differing scales and spatial variability of processes within different regions in our study area.

5. **Conflict:** Conflicting values, such as biodiversity requirements, declining stocks, and widespread fishing effort, that would appear irresolvable to a human planner, are also irresolvable to a computer model. However, modelling does provide candidate networks of MPAs that can be the basis for discussion in a planning process, where outstanding conflicts and other issues may be resolved.

6. **BC Marine Parks:** BC's marine parks, ecological reserves, and recreation areas, could be effectively incorporated into several possible networks of MPAs. (Note: There are no Migratory Bird Sanctuaries or National Wildlife Areas in the Central Coast.) The exception is Hakai Recreation Area, which owing to its large size and emphasis on recreational use, does not fit in very well; however, portions such as the Goose Islands could be incorporated.

Figure 1: Conservation Hotspots



B Introduction

B.1 Report Overview

This report describes how we constructed a computer model to examine networks of hypothetical marine protected areas in the Central Coast of BC, based on ecological values. This methodology contends with real world conditions such as incomplete and weak datasets, recalcitrant agencies, and a great deal of scientific uncertainty. Using a Geographic Information System (GIS), we have melded several approaches into a hybrid classification that looks at physical and biological features. Using MARXAN (v. 1.2) software, hexagonal planning units (250 ha.) were used as the building blocks for evaluating a wide range of possible MPA networks, offering flexibility of solutions.

We present our modelling and results in the following sections of this report:

C. **Background**: Providing thumbnail sketches of the region and some of the issues involved, as well as introducing marine protected areas and site selection.
D. **Assumptions & Limitations**: Stating what we believe to be the underpinning assumptions of our approach, and to acknowledge that these are limited in scope, and that some may require future verification.
E. **Methods:** By far the largest section of this report, it describes many of the intricacies involved. In here we describe our data layers, aggregation, fitting, classification systems, and how these were entered into the MARXAN model. We also describe our measure of benthic complexity.
F. **Analyses & Results**: We present the results from three "trials" or refinements of the model, representing several thousand network solutions under a wide variety of design conditions. Many of the points listed in the Executive Summary are expanded upon.
G. **Discussion:** Looking back at our results and preliminary feedback from fishermen, locals, and MPA experts, the model appears to be on the right track. We plan to integrate these results with an analysis of fisheries use. We would like to work within government MPA processes, such as Integrated Management.

Concurrent with our ecological modelling, but not discussed in this report, we are conducting a use analysis. This involves interviewing local fishermen and mapping their use of the region's waters. Beginning with the south Central Coast, we plan to perform a *use analysis* with these data, producing "use hotspots." Then we will blend the conservation hotspots with the use hotspots to create conclusions based on both ecological and economic values.

The federal Department of Fisheries and Oceans has selected the Central Coast to be the first area on Canada's west coast to undergo "Integrated Management," as part of its commitment to Canada's Oceans Act (Oceans Act 1996 c.31). The Oceans Act further mandates DFO to create Marine Protected Areas and implement Marine Environmental Quality objectives. The Oceans Act clearly outlines community and Aboriginal involvement as part of the integrated Management process

(Oceans Act 1996 c.31, s 31-33). We expect our work to inform the Integrated Management process by putting candidate MPAs sites on the table.

Thus, this report is *not* attempting to present a completed Conservation Area Design (Jeo 1999) or Conservation Plan (SIWNCP 2000). Rather, we wish to concentrate on creating a scientifically sound model that can then be used to inform such a plan, as would develop out of the Integrated Management process, with full participation of stakeholders and government to government consultations with First Nations governments.

B.2 MARINE CONSERVATION

The ocean is a three dimensional dynamic environment that is strongly influenced by tides and currents, water temperature and salinity, wave action, depth and substrate. Consequently, approaches to conservation that have been developed in terrestrial scenarios cannot be applied directly to the marine environment. It is a challenge to delineate ecosystems based on fluid habitat types, identify fixed migratory corridors for fish and marine mammals, and very difficult to identify sinks and sources. The ranges of large marine carnivores are huge and variable, thus rendering the focal species approach less attractive than on land. In addition, resource use in the ocean is also different. The extraction of trees on land destroys habitat whereas the extraction of fish, with the exception of bottom trawling, can be done without significantly disrupting the habitat but still with significant impacts on the marine ecosystems. Therefore, when applying techniques from the more experienced terrestrial conservation movement, it is imperative to consider the differing needs of the ocean environment as well.

The federal Fisheries and Oceans Canada is currently revising their approach to managing the ocean. Instead of managing fish stocks for commercial exploitation, they are attempting to develop an integrated approach to fisheries and oceans management that addresses the overall health of the ocean while supporting sustainable economic activity. In doing so they have drafted Ecosystem Objectives (DFO 2001c) that we feel adequately constitute the basis for a conservation strategy. They are:

A. Maintain Ecosystem Components
    - Maintain communities within bounds of natural variability
    - Maintain species within bounds of natural variability
    - Maintain populations (genetic diversity) within bounds of natural variability

B. Maintain Ecosystem Component Function
    - Maintain primary production within the bounds of natural variability
    - Maintain trophic structures so that individual species/stages can play their natural role in the food web
    - Maintain mean generation times of populations such that population resiliency is assured

C. Maintain Ecosystem Physical and Chemical properties
    - Conserve critical landscape/bottomscape features and water column properties
    - Conserve water, sediments and biota quality

B.3 PROJECT GOALS & OBJECTIVES

Considering the rich marine environment of the Central Coast and the degree to which it is being impacted by various industries, Living Oceans Society launched a campaign in 1998 to identify promote the establishment of a network of marine protected areas on the Central Coast of BC.

To date, marine protected areas have been selected for recreational purposes, focusing on scenic values and providing access to land for boaters. In most cases, MPAs were simply marine components of terrestrial parks with little attention to the marine biological diversity. Furthermore, these parks rarely have in place fisheries closures or other regulations designed to protect the marine environment.

At Living Oceans Society we felt we needed to take a more scientific approach to MPA site selection and network design. This would ensure that we are selecting sites based on their contribution to conserving biological diversity and developing sustainable fisheries. It is belief that this approach will have credibility with governments, including First Nations governments, and stakeholders.

Therefore we designed this project to meet the following goals and objectives:

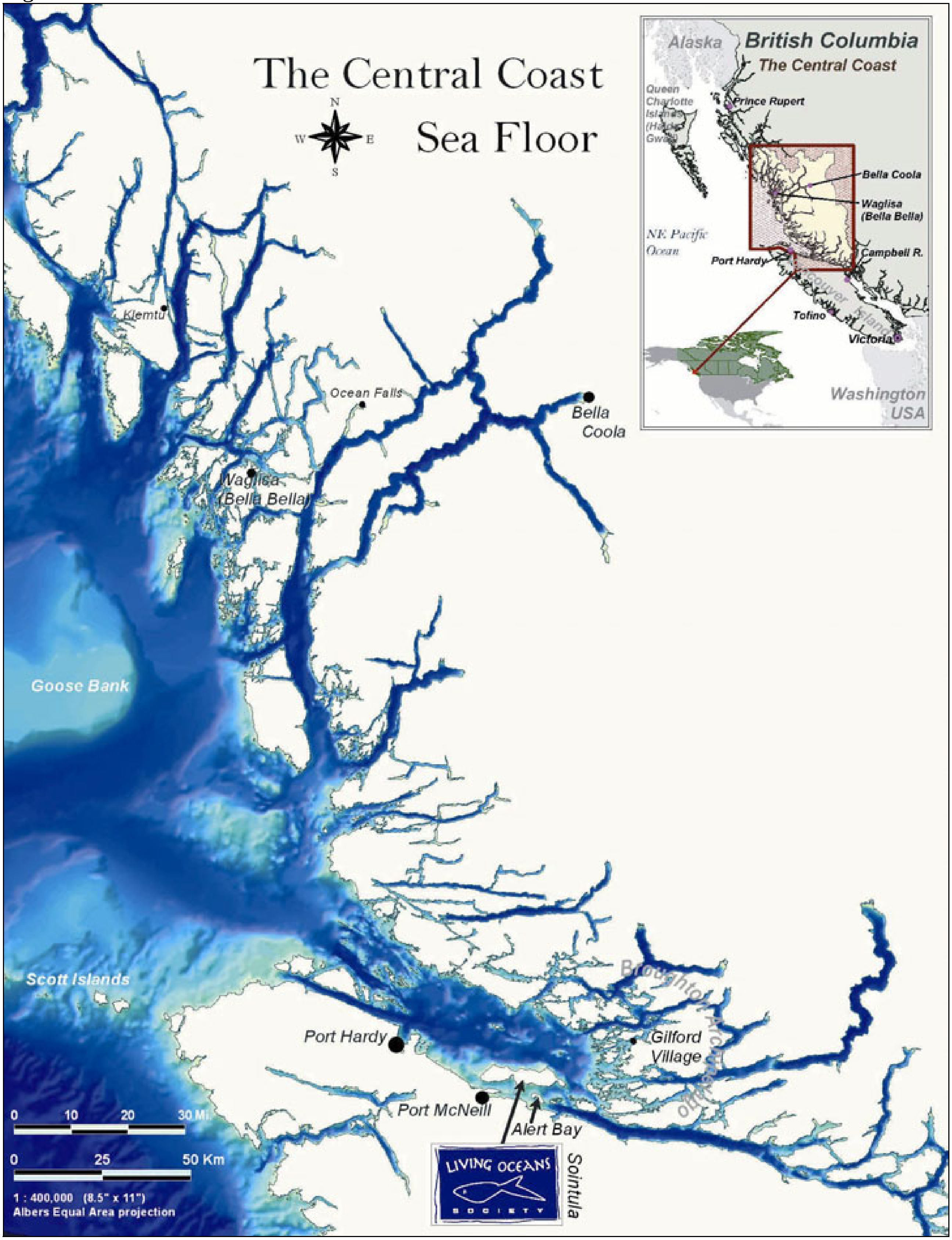
Goal1: Design a network of MPAs based on the latest developments in marine reserve design methodology and other scientific information.

Goal 2: Ensure the proposed network of MPAs is implemented within the context of a government run multi-stakeholder integrated coastal zone management process.

Objectives

- Develop guiding principles for designing a network of marine protected areas
- Develop a clear definition of a marine protected area
- Develop a clear definition of a network of marine protected areas
- Develop a methodology for site selection that incorporates when possible the work being done by other conservation groups, scientists, and government agencies.
- Apply the methodology in the Central Coast Region of BC
- Facilitate an expert review of the methodology
- Present work to federal, provincial, regional, and First Nations governments
- Contribute to the development of a multi-stakeholder planning process to designate the network of MPAs

Figure 2: The Central Coast Sea Floor



C BACKGROUND

C.1 LIVING OCEANS SOCIETY

The Living Oceans Society is a non-profit research and public education organization committed to conserving marine biological diversity to ensure a healthy ocean and healthy coastal communities. Our objectives include:

- Researching the interactions of human activity and the marine environment, ecological systems of the ocean, and advancements in ocean management.
- Educating and increasing public awareness about the ocean and its importance to humans and human health.
- Sharing research results information through presentations, publications, workshops, conferences, and meetings.

C.2 THE CENTRAL COAST MARINE ENVIRONMENT

The Central Coast of British Columbia is identified as a management region by both the federal and provincial governments. With slight variations, the management region for each government extends from Butte Inlet north to Princess Royal Island and inland to include the many fjords. Living Oceans Society has extended the boundary seaward to include the Scott Islands and a significant portion of Goose Bank. From the upper left NW corner to the bottom right SW, which approximates the orientation of the coastline, is about 450 kilometres (280 mi.). The marine component is 2,230,330 hectares (5,511,243 acres), or 22,303 square kilometres (8612 sq. mi.). The extent of the sea reaches 165 km. inland up Dean Channel.

This region contains a wide range of coastal configurations including archipelagos, fjords, passages, estuaries, sandy beaches, rocky shorelines, and open exposed coasts. For the outside waters, temperatures range from 5-14 C (Crawford 2000), with less range in the winter. Inlets and passages may contain localized warm spots exceeding these numbers in the summer, and likewise colder spots in the winter, especially on the surface (Ricker 1989). Salinity ranges from brackish at the heads of inlets, to moderate (e.g. 29-30 0/00 –parts per thousand) in passages, to fully saline in offshore waters (Ricker 1989, Crawford 2000). Water movement is dominated by tidal currents, with wave mixing and seasonal upwellings that bring nutrients from ocean depths to the surface, assuring an abundance of food for a wide variety of species.

While this region is perhaps best known as the home for the northern resident killer whales (*Orcinus orca*), the marine life is diverse. There are over 6500 known species of invertebrates, approximately 400 hundred species of fishes, 161 species of birds, and at least 29 species of marine mammals living in British Columbia. (Governments of Canada and British Columbia, 1998). Although there are no comprehensive surveys in the Central Coast, the wide range of habitat types indicates that most, if not all, of these species can be found in this region.

Shorelines in the Central Coast are predominantly steep rock cliffs, with relatively few mudflats, sand or gravel beaches. Subtidal substrate is classified as mud, hard rock, or sand/gravel. Hard substrates tend to be found near the shore while muddy bottoms dominate the deeper water. Levings *et al* (2002) describe the fish and invertebrates communities associated with these three habitats:

Rocky habitats are characterized by rocky reef fishes, such as rockfish, greenlings, sculpins, and wolfeel as well as numerous epilithic invertebrates. Fifteen species of rockfish (*Sebastes* spp) have been reported from the hook and line fishery in the Central Coast. Lingcod (*Ophiodon elongatus*) are another important commercially caught species from rocky habitats. Lingcod, as well as many other fish species use rocky habitats and crevices for egg incubation. Rockfish, such as copper and quillbacks, are known to feed on small demersal and pelagic fishes and crustaceans. Some dominant epilithic invertebrates documented from Tribune Channel in the Broughton Archipelago include serpulid polychaete wormes, brachiopods, cup corals, sponges and stylasterine coral (*Allopora verrilli*). Rocky habitats in the Central Coast also support prawns (*Pandalus platyceros*) which are caught in a commercial trap fishery.

Sand and gravel habitats are important habitats for many commercial species such as Dungeness crab (*Cancer magister*) and adult groundfish such as English sole (*Pleauronectes vetulus*), rock sole (*Pleuronectes bilineata*), and Pacific cod (*Gadus macrocephalus*). Nearshore sandy and gravel habitats are particularly important nursery habitats for juvenile fishes such as English sole. Infauna sampling and stomach content analysis of fishes and crabs from sand and gravel reveal some components of the food web. Important prey items include sandlance (*Ammodytes hexapterus*) herring (*Clupea harengus pallasi*), demersal fishes (cottids, gobies, pricklebacks and gunnels) and various types of shrimp, crabs, amphipods, polychaete worms and mollusks. Sand and gravel bottoms are particularly important for sandlance, a major prey item of fishes and seabirds.

Muddy sediments in the Central Coast are known to be important rearing and adult habitats for several species of pandalid shrimps (humpback shrimp, spiny pink shrimp, pink shrimp, sidestripe shrimp). Bottom fish from muddy bottoms include flathead sole (*Hippoglossoides elassodon*), pollock (*Theragra chalcogramma*) Pacific tomcod (*Microgadus proximus*) and the dwarf wrymouth (*Lyconectes aleutensis*). These species feed on invertebrates, including pandalid shrimp. Heart urchin (Brisaster latifrons) is a dominant infauna species in muddy fjord habitats such as Kingcome Inlet (Levings et. al 2002).

C.3 CULTURE

Nineteen First Nations bands, each with a rich and unique culture, have resided on the Central Coast of BC for thousands of years. Communities such as Waglisa (Bella Bella), Klemtu, Oweekeno, Hopetown, Kingcome, and Gilford Village remain almost exclusively Native communities supporting many traditional values. Today the First Nations are reasserting their role in the management of the ocean and its resources in order to ensure food and employment for their communities.

The non-Native communities along this coast include the Finnish settlement of Sointula and the Norwegian settlement of Hagensborg, both which retain their ethnic roots. Towns such as Port McNeill started out as small logging camps a few decades ago and now support over 5,000 residents and provide many of the services required on this coast.

Scattered along the coast are also the struggling remnants of once thriving communities such as Namu and Ocean Falls. Canneries in small coastal settlements supported hundreds of people during the heyday of the commercial salmon fishery. Decline in fish stocks and the centralization of processing facilities in Vancouver has left ghost towns, scattered amongst the tall trees and rocky shores.

The commercial fishing industry employs 15,000 people province wide and has a landed value of $400 and $500 million annually (DFO 2002b). The communities of the Central Coat region are dependant for jobs on the boats, in processing facilities, and in the service industries such as marinas.

Recreational fishing in BC contributes 281 million dollars to the GDP (DFO 2002b). In the Central Coast, the sports fishing industry is becoming increasingly important to the communities.

C.4 HUMAN IMPACTS

The ecology of the Central Coast is a delicately balanced system that supports recreational and commercial fisheries, a growing tourism industry, and a coastal way of life. Activities that can have the most consequences for the marine environment include fishing (both commercial and recreational), open net cage fish farming, marine traffic, offshore oil and gas, offshore mining, and ocean dumping. These can impact the marine environment in several ways: loss of biomass, loss of habitat, poor water quality, introduced species, and disease transfer.

C.4.1 OVER-EXPLOITATION

Loss of Biomass from extractive activities is a significant contributor to the decline of the fish stocks. Often, the habitat can remain in place while spawning stock is removed, population age structure is altered, or a sedentary community is extirpated. Halibut, herring, rockfish, shrimp, prawns, crabs, geoduck clams, and the five species of salmon are just some of the better known species that are commercially harvested. Gear types include hook and line, long line, seine, gillnets, traps, bottom and mid-water trawling, and diving. Despite governments attempt to manage the fisheries, DFO stock status reports indicate that 27 of the 56 species harvested are rated as low and another 20 are below average (DFO 1999).

The commercial and recreational abalone fishery has been closed for the entire coast of BC since 1990 due to conservation concerns. However the black market price remains high and poaching is occurring. Surveys by Fisheries and Oceans Canada from 1979 – 1997 indicated a continued decline of abalone densities on the central coast of B.C. (DFO 2002a)

In 2002 the allocation for inshore rockfish in the southern portion of the Central Coast region were reduced by 50% in response to decreased stocks. The inshore rockfish fishery has been in existence since 1955 and peaked in 1995. Now, after almost 50 years of a commercial fishery, DFO is recognizing that traditional stocks assessment and management methods are not appropriate for inshore rockfish because of their longevity, sedentary habit, lack of information on stock structure, and inconsistent data collection (DFO 2000, Kronlund et al 1999).

All five species of salmon migrate out from numerous rivers on the central coast to the open ocean and migrate back to spawn. There are 537 known salmon spawning streams in the Central Coast, predominantly in the north. While there is a great deal of variability over runs and years, with many rivers remaining healthy, current stocks are generally lower than historical levels (CCLRMP 2000). Some major runs such as the Nimpkish River and Rivers Inlet have collapsed dramatically. Within the central Coast, there are at least 9 chinook stocks, 60 coho stocks, 18 sockeye, 35 pink, and 40 chum stocks identified as having high risk of extinction (Buchannan et al cited in CCLRMP 2000).

It is not just the commercially harvested fish that are struggling. Eulachon is an anadromous fish that is known to spawn in only a handful of the rivers in BC. While the Central Coast supports thirteen eulachon runs, only one is of significant size (Knight Inlet). These fish are harvested predominately by the First Nations people and rendered into grease, a staple of coastal First Nations' diets. In recent years the stocks have declined severely for unknown reasons (McCarter & Hay 1999).

Despite the challenges in managing fisheries, new and emerging fisheries are being developed. The sardine fishery, which started in 1917, collapsed in 1947 due to low recruitment rates and overfishing. Sardines were not seen in any great numbers on the coast again until 1992 when they began to appear in large schools. By 1996, government was issuing licenses for experimental fishing along the coast with 2 fishing areas identified in the Central Coast region. Evidence suggests the BC sardines are part of the California stock that is constrained by the 12C isotherm (Ware 2001 cited in DFO 2002). Now, with the stocks returning, efforts to fish them again could result in the same overfishing.

In recent years, the growing cruise ship industry has resulted in increase whale strikes although it is unknown how many whales are injured or killed per year from this industry.

C.4.2 HABITAT LOSS

Habitat loss**,** while not as substantial as in terrestrial environments, is a contributing factor to marine environmental degradation. Oil and gas extraction, potentially one of the most significant disruptions, is currently prohibited in BC but there is a push within the provincial government to lift the moratorium within the next few years. A portion of the Central Coast region falls within the lease area and the impacts would be felt region-wide.

Mining is minimal although aggregate has been removed from the eastern shoreline of Vancouver Island. Aggregate mining destroys the immediate benthic communities, creating a plume of silts that can potentially smother an area significantly larger than the immediate site.

Perhaps the greatest potential habitat disruption is from bottom trawling. Groundfish trawling occurs in deep offshore areas for rockfish, sole, skate, and other species. There is offshore bottom trawling on Goose Bank and around the Scott Islands but the actual size of the area impacted is unknown.

In the shallower inlets and bays, smaller boats trawl for shrimp using beam trawls or otter doors in mud and silt bottom types. This fishery has grown in recent years as more fishermen are trawling to make up for declines in the salmon fishery. There is currently a research project underway on the Central Coast to look at the impacts of this fishery on the habitat although the results are available at this time. Preliminary data show that the otter trawl leaves trenches in the substrate; however, the impacts on the animals is unknown at this time (Levings 2002).

The geoduck is a giant clam that can live up to one meter deep in mud and sand substrate (DFO 2002a). Divers use an air gun to sweep away the mud or sand substrate in order to extract the clams alive and send them to market. The impacts of this type of fishing remain unclear.

There is widespread belief that the waste from fish farms is causing damage to the seabed. Impacts such as changes in relief from sediment build-up, alterations to meiofauna and macrofauna communities, changes in diversity from hypoxia, and loss of spawning habitat for certain species are all issues of concern related to fish farms and habitat loss. No studies have been completed to quantify these effects (Levings 2002).

C.4.3 WATER QUALITY

The waste water from Central Coast communities has generally undergone secondary treatment or enhanced primary treatment, though this is not true of the smallest settlements. There are no large factories such as pulp mills in the study area and virtually no agricultural activity that would lead to pesticide runoff or nitrogen enrichment.

Marine based pollution is more evident. Open net cage fish farms permit the release of antibiotics into the water. Antibiotic resistant bacteria identified in other marine species are believed to be a result of this practice. Pesticides used to treat sea lice on farmed salmon are possibly contributing to the mortality of other *euphasiids* that live near the farms and in the water column (pers comm. Morton 2002). Excess fish food and waste are released into the water column, eventually settling on the seabed. There are 65 open net cage fish farms in the Central Coast region, with over 50 of them located in the Broughton Archipelago and the Narrows.

The inland waters between the mainland and Vancouver Island are a major highway for coastal traffic. The increased cruise ship traffic in recent years has dramatically increased the amount of pollution from ships (Oceans Blue 2002). Furthermore, the cruise ship industry recently came under suspicion for dumping diesel bunker fuel into the ocean although this has not been proven and may not take place on the Central Coast region (Parfitt 2002).

C.4.4 INTRODUCED SPECIES

Introduced species are not predominate in the Central Coast marine environment at this time; however, the potential is very high. Every year Atlantic salmon (*Salmo salar*) escape from the fish farms and some eventually make their way up the rivers. Atlantic salmon have been found to be successfully reproducing in streams on Vancouver Island (Volpe et al 2000), all of which feed into the Central Coast region (Volpe 2002). It is feared that these introduced Atlantics may displace already impacted indigenous populations. Very little research has occurred in this area (but see Volpe et al 2001).

The Green Crab (*Carcinus maenas*) is an invasive species that began appearing in BC in 1999. Originally form Europe, these small crabs are renown for consuming juvenile clams, oysters, and possibly other crabs such as red rock and Dungeness (DFO 2002a). Green crab can also tolerate less saline conditions than domestic species and may lead to them inhabiting river mouths and estuaries. Green crabs have not yet been found as far north as the Central Coast.

C.4.5 DISEASE TRANSFER

Aquaculture activities can act as bio-magnifiers of otherwise background levels of parasites and diseases.

In the spring of 2001, pink salmon smolts (*Oncohynchus gorbuscha*) emigrating from the Broughton Archipelago in the Central Coast were found to be heavily infested with sea lice (*Lepeophtheirus salmonis*) (Morton 2001). The Broughton Archipelago supports a heavy concentration of salmon aquaculture. DFO surveys elsewhere in the Central Coast, where there were few or no fish farms, did not find evidence of sea lice infestation (DFO 2001). Salmon farms elsewhere in the world have been strongly implicated in sea lice outbreaks (Tully et al 1999).

C.5 MARINE PROTECTED AREAS

C.5.1 EXISTING MARINE PROTECTION

There are no fully protected (no-take) marine protected areas in the Central Coast of BC.

(However, Michael Biggs –Robson Bight– Ecological Reserve is effectively closed for the summer half of the year when Orca whales use the famous rubbing beaches there.)

Current and pending legislation allows for the following classification of MPAs:

- Marine Parks, *Ministry of Sustainable Resource Management, provincial government*
- Marine Ecological Reserves, *Water, Land and Air Protection*
- Recreation Areas, *Ministry of Sustainable Resource Management, provincial government*
- Wildlife Management Areas, *Canadian Wildlife Service, federal government*
- Migratory Bird Sanctuaries, *Canadian Wildlife Service, federal government*
- National Marine Conservation Areas (legislation pending), *Parks Canada, federal government*
- Marine Protected Areas, *Department of Fisheries and Oceans, federal government*

Minimum protection standards for each type of MPA vary and they are almost exclusively focused on habitat protection. Most MPAs prohibit, either through policy or legislation, the extraction and exploration of offshore oil and gas, dumping and dredging, and finfish aquaculture. The provincial Ecological Reserves are designed to prohibit the extraction of all natural resources; however, it is the federal government's jurisdiction to implement fisheries closures and in most cases they have failed to do so. Consequently, the Ecological Reserves are failing to meet their objective. At present there are 17 marine protected areas in the Central Coast region covering approximately 102,861hectares (254,175 acres). Thirteen of these seventeen MPAs, covering approximately 84,200 hectares (87%), remain open to recreational and commercial fishing making them, effectively, "paper parks." The remaining four have only limited fisheries closures.

C.5.2 MPA DESIGN PRINCIPLES

In September 1999, Living Oceans Society hosted a workshop to discuss prevailing theories of MPA design from which Living Oceans Society could build the principles of design that worked best for the coast of BC. Nine scientists from Vancouver, England, California, Seattle, and Connecticut met in Sointula, a fishing community on the Central Coast of BC, to discuss the principles of design for marine protected areas. Below are the decision points that were drawn from the workshop and have been incorporated into this project.

THE GOAL OF MARINE PROTECTED AREAS

There is a long-standing debate on whether MPAs are designed for the conservation of biological diversity or the development of sustainable fisheries but is it really an either/or scenario? Sustainable fisheries rely on the continual production of fish. This, in turn, relies on maintaining ecosystem function. However, defining ecosystem functioning is tough, and beyond our much of our abilities at present. Therefore, until our knowledge of the sea increases, the best we can do in most cases is protect biological diversity.

MARINE PLANNING

MPAs, while necessary, cannot alone conserve biological diversity and develop sustainable fisheries. MPAs should be established with the context of Integrated Management (IM) to ensure that the management of marine resources outside of MPAs complement the goals of the MPAs. However, IM is a huge undertaking and the development of the process must not delay the identification and establishment of marine protected areas. Indeed, MPAs should provide the ecological backbone for effective IM planning.

FOCAL SPECIES:

The use of one or two large mega fauna as the main focus for designing a network of MPAs could fail to identify many habitat types. Instead, select a suite of focal species that are linked to a variety of habitats through their life cycle.

SOURCES AND SINKS

Identifying sinks and sources requires a massive amount of information that is not available at present and therefore is not a criteria in the design of MPAs. However it can be assumed that any no-take area will be a source for some species.

SIZE AREA, AND DISTRIBUTION

There is no definitive answer on how many MPAs we need nor how large they should be. We need to start establishing them in order to learn more about size, area, and distribution. However a general rule of thumb is to design no-take areas to be as large as possible and still be supported by communities and user groups.

ENFORCEMENT

An MPA without the support of user groups will not be enforced (especially in remote areas) and therefore building approval of each site amongst fishermen and other user groups is paramount.

C.5.3 DEFINITION OF A MARINE PROTECTED AREA

A marine protected area consists of one or more core no-take areas and should be surrounded by a buffer zone. This means the following levels of protection would apply:

- **Core no-take** areas that prohibit all fishing, exploration and extraction of oil, gas, and minerals, open net cage aquaculture, bottom trawling, dumping and dredging.
- **Buffer zones** that, at a minimum, prohibit exploration and extraction of oil, gas, and minerals, open net cage aquaculture, bottom trawling, dumping, and dredging.
- **Additional activities** such as sewage outfalls, log booming and dumping, recreational artificial reefs, and whale watching could be prohibited on a case-by-case basis.

In this report, we use the word “reserve” interchangeably with core no-take MPA.

The goal of a network of marine protected areas is the conservation of biological diversity and the development of sustainable fisheries. A Network of MPAs should be better than the sum of its parts and should:

- Include core no-take zones
- Represent all habitat types
- Include replication of all habitat types
- Include distinctive features
- Protect rare and endangered species
- Locate no-take zones close enough to anticipate larval transfer and "connectivity"
- Locate no-take zones far enough apart overall to avoid localized disasters such as oil spills.

(See Assumptions and Limitations, below.)

C.5.4 GUIDING PRINCIPLES

Applying MPA design theory in the real world brings out conditions that are not always considered in academic exercises. These include incomplete datasets, pre-existing fisheries management conditions, conservation initiatives, and time limits set by government processes. Living Oceans Society has had to work within these limitations, while remaining flexible as new data and opportunities developed. Above all, we have strived to realize our Guiding Principles in a scientifically defensible manner. They are:

1. Use best available information including physical and biological data, local and traditional knowledge.
2. Develop classification systems that realistically represent the known physical and biological structures and processes.
3. Faithfully reflect the accuracy and scale of the data.
4. Build in flexibility to accommodate additional information at a later date.
5. Consider existing parks, *areas of interest*, and year-round fishery closures.
6. Acknowledge the various human uses of the sea while still meeting conservation objectives.
7. Ensure the methodology is repeatable.
8. Allow for a variety of solutions.

C.6 SITE SELECTION

C.6.1 OVERVIEW

Conservation biologists have been developing practice and theory that began from little or no methodology in early park design to our current, albeit imperfect practices. Roff and Evans (2001) quote Hackman (1993) who pointed out that early attempts to construct parks were often "…more by opportunity than design, scenery rather than science." Likewise, Possingham et al. (2000) cite Pressey et al. (1993) who demonstrated that early parks were based on recreation values rather than biological ones. Most parks were, and still are, considered in isolation. Using a holistic network approach in park design is still in its infancy, with few real world examples.

While it should be clear that more is to be gained by looking at biology than scenery, and networks of protected areas than reserves in isolation, designing such reserves is also much more difficult. The selection of any planning unit over another involves evaluating it with regard to its role within a context of many thousand such units. One planning unit with several valuable features on its own may or may not be the best choice overall, depending on distribution and replication of those features in the study area. Furthermore, as demands on the environment increase, the need to choose a network of reserves that will capture the "most" for the least "cost" becomes imperative. Good guesses are not good enough to user groups, particularly those whose livelihood depend on harvesting the resources.

Creating large tally sheets, or inventories (e.g. Booth et al 1998) can go far in helping identify what is distinctive, natural, or representative of a particular region. These tallies can also aid in determining the relative importance or influence that various features ought to have (see E.8.1) and they can be used in GAP analyses. Still, the question as to *where* the new reserves ought to be placed remains unanswered. Choosing an area with the highest tally, for example, and then the next highest, and so forth, does not guarantee a representative sample of features.

Some computer selection algorithms have been put forward. Most attempt to mimic the human selection process, and as such are called "heuristics." For example, choosing the areas with the most abundance and / or diversity of species has been labelled the "richness," or "greedy" heuristic (Ball & Possingham 2000). While this can produce a good initial reserve, it does not look at rarity or representivity and consequently it is not well suited for network design. These shortcomings led to other heuristics that looked at rarity, and later, irreplaceability as guiding principles. Irreplaceability considers both richness and rarity in a unique approach that considers all remaining feature cells in the analysis and what they can add to that feature's representation (Ball & Possingham 2000).

Unfortunately, these algorithms do not necessarily produce the best answer, and can be up to 20% from the ideal (Possingham et al. 2000). One reason for this is that they are linear, approaching the problem in a predictable and repeatable fashion, choosing the highest value first (as per whatever system of valuation), the next highest second, and so forth until the reserve is built. As such they can get trapped in situations where the reserve built on these attractive units cannot effectively make up the remaining goals with what is left; whereas, a few less "optimal" choices earlier on may free up the choices later.

C.6.2 MARXAN SOFTWARE

MARXAN, a software developed by Dr Hugh Possingham, University of Queensland, and Dr Ian Ball, now at Australian Antarctic Division in Tasmania, attempts to address the problems identified above. In order to design an optimal reserve network, MARXAN examines each individual planning unit for the values it contains. It then selects a collection of these units to meet the conservation targets that have been assigned. The algorithm will then add and remove planning units in an attempt to improve the efficiency of the reserves. What makes this algorithm different from other iterative approaches is that there is a random element programmed into it such that early on in the process the algorithm is quite irrational in what it chooses to keep or discard, often breaking the rules of what makes a good selection. This random factor allows the algorithm to choose less than optimal planning units earlier that may allow for better choices later. As the program progresses, the computer behaves more predictably –but not entirely. The process continues, with the criteria for a good selection getting progressively stricter, until finally the reserve network is built.

Given a sufficiently diverse set of features, it follows that because of the random element, no two runs are likely to produce exactly the same results. Some may be much less desirable than others. Still, if enough runs are undertaken, a subset of superior solutions can be created. Furthermore, the results from all runs may be added together to discern general trends in the selection process. Planning units that are consistently chosen can be said to have higher utility than those that are not. Often these can represent important features, but not necessarily so. They may be useful in their ability to round off a MPA network's design; i.e., fill in the gaps, even if they are not particularly attractive on their own.

In addition to simulated annealing, MARXAN offers the user several other selection methods ("heuristics"), either alone or in concert with annealing. For the series used in these analyses, we have chosen simulated annealing to select the initial reserve network, followed by the "Summed Irreplaceability" heuristic and then "Iterative Improvement" to finish it off. (See E.8.4 for more information.)

MARXAN comes from a lineage of successful selection algorithms, beginning with SIMAN, then SPEXAN (as used in the SITES package by The Nature Conservancy). SPEXAN has been used to look at the Florida Keys Reserve (Leslie et al in press). MARXAN was developed from SPEXAN in part to aid in work on the Great Barrier Reef Marine Park Authority's re-evaluation of their park designations. MARXAN brings with it several features that make it easier to experiment with different conservation targets and costs of various features. This can be valuable in sorting out what values lead to certain reserve shapes. It still requires, however, that the user be technically fluent. There are several parameters that can be adjusted (see E.8 below).

D Assumptions and Limitations

D.1 MPAs as One of Several Useful Tools

While setting aside parts of the ocean free from human extraction and damaging activities may seem obvious to some, it is actually a relatively recent development in our thinking, gaining scientific credibility in only the past ten years or so (Ballantine 1991, Kelleher & Kenchington 1992). We are, after all, terrestrial creatures, and terrestrial notions of wilderness value are still less than a century old (Leopold 1921, cited in SIWNC 2000). Marine notions of wilderness are still nascent. For MPAs, the focus has been on conservation and/or sustainable resource use (Roberts et al In press).

It was not until 1998, that the governments of BC and Canada issued a discussion paper on the topic (Canada & BC 1998). Since that document, no fully protected MPAs have been created, though Race Rocks, a pilot project in southern BC, is apparently close to being designated.

As noted above, there are no fully protected marine reserves in the Central Coast. In all of BC, there is one municipal park (Whytecliffe, 19 ha.), one provincial park (Porteau Cove, 42 ha.), one research site (Pt. Atkinson, 0.85 ha.), and possibly one federal site (Race Rocks / XwaYeN, 251 ha.) (Jamieson & Levings 2001). All told these account for a drop in the ocean, about 313 hectares. Considering that the Pacific Marine Ecozone is conservatively calculated to be 45,764,600 ha. (WHC 2001), **all BC no-take reserves account for approximately 0.0007%** of the total. Even if all these no-take zones miraculously occurred in the Central Coast, they would be only somewhat larger than one of our 11,725 hexagon planning units (250 ha.), or about 0.014% of the total study area.

There have been few studies to examine the efficacy of no-take reserves in BC (but see Wallace 1999a,b). Thus, while fully protected marine reserves have been gaining credibility worldwide, they have not been seriously applied in BC waters, and consequently their usefulness remains unclear to many managers and scientists who have grown accustomed to single-species management. Nonetheless, there are hopeful signs that this attitude may be changing (Jamieson & Levings 2001, Wallace 1999a,b). Just south of the boarder, in Puget Sound, it has been found that ling cod and some species of rockfish have benefited from full protection in areas that are fairly modest in size (Palsson & Pacunski 1995, Palsson 1997).

D.1.1 Assumptions

- That MPAs would be useful as conservation tools in these waters. The small body of literature on MPAs in the northeast Pacific does not guarantee the success of MPAs. However, the weight of evidence worldwide, including a few small studies in BC, would indicate this is very likely so (Roberts & Hawkins 2000
- Measuring MPA efficacy will depend on good monitoring programs with proper experimental design, and an adaptive management approach (Syms & Carr 2001).

D.1.2 LIMITATIONS

- That MPAs alone will not ensure sustainable use of marine resources and that they must be established in conjunction with traditional fisheries and oceans management.

D.2 BEST AVAILABLE DATA

We have always attempted to use the best available data. However, the "best" data are often still not very good. Many datasets came with no or very basic metadata. We outline data gaps below (section E.6). When data have been suspected or known to be weak, we have either not included them (e.g., provincial salinity ecounits), or have given them a low target and penalty in the model (e.g., herring holding areas). Some data we have aggregated together and given only the broadest of classifications (e.g., clams).

D.2.1 ASSUMPTIONS

- That currently available data as used in this model are of sufficient accuracy to yield meaningful results at nominal working scale of 1:250,000.
- That considered altogether, the 61 data layers represent sufficiently diverse taxa, physical features, and spatial coverage to yield results that can be interpreted generally throughout the Central Coast as a preliminary tool.
- That it would cause more ecological harm to wait for better data than it would to make preliminary decisions based on what we do know.
- Data will continue to be added to the model in an on-going basis.

D.2.2 LIMITATIONS

- Many taxa, particularly non-commercial species, are not presently represented (see E.6 data gaps).
- Areas that have not been fully surveyed, or whose characteristic species have not been surveyed, will not appear as particularly valuable in our model.
- All results should be groundtruthed.
- There is a great need for more primary data collection.
- We have incorporated some of Local Ecological Knowledge (2 datasets), and this should be expanded.
- These results have not yet been presented to First Nation governments who could fill many data gaps with traditional knowledge.
- The north Central Coast is particularly thin in data.
- Collaboration with other agencies has proven extremely difficult and yet is necessary to gain access to confidential data (e.g., log book data).

D.3 HABITAT REPRESENTIVITY

Capturing a representative selection of various habitats (as well as species, and processes as they occur in a region) has become a commonly stated objective towards achieving and monitoring biodiversity goals in terrestrial conservation (Noss 1991) and has been applied to marine conservation with an emphasis on physical and enduring features (Day & Roff 2000, Zacharias & Roff 2000).

D.3.1 ASSUMPTIONS

- That using the mix of physical parameters in this model (sections E.2 through E.3 below) as they occur throughout the study area will give a good preliminary indication of habitat representivity and therefore associated biological communities; i.e. biodiversity.
- That different biological communities as captured using physical and enduring features will likely perform differing ecosystem functions; i.e. functional diversity.

D.3.2 LIMITATIONS

- Our physical model would benefit from the addition of better salinity, temperature, and dissolved oxygen parameters.
- Highly mobile and migratory species cannot be easily characterized by a representative habitat approach.
- Some critical species have confounded researchers as to what unknown variable(s) allows them to thrive. For example, the habitat requirements for eelgrass (*Zostera spp)* are believed to be well understood (Durance, C. 2002). Yet, eelgrass species do not respond well to transplanting and restoration efforts (Davison & Hughes 1998).
- Thus, whenever biological distributions are known, these should be given preference over habitat models (e.g., kelp, see E.4.6, below)

D.4 FOCAL SPECIES

Focal species have received a lot of attention in terrestrial conservation (e.g., Noss 1991, Lambeck 1997), but have received less attention in marine conservation (e.g., Day & Roff 2000, Zacharias and Roff, 2001, Roberts et al In press). Different categories of focal species exist, such as indicators, keystone, umbrella, and flagship species (for a complete discussion, see Zacharias and Roff 2001). While some focal species concepts, such as indicator species, are applicable to the marine environment, others are not as transferable. For instance, a popular concept in terrestrial conservation is that of the umbrella species, whose conservation is believed to also protect other species. Unfortunately, umbrella species have few counterparts in the marine world (Zacharias and Roff 2001). One problem with the applicability of this concept to marine systems is that many candidate umbrella species, such as whales, exhibit massive migrations and utilise areas too large to be useful as umbrella species.

Darling *et al.* (1998) studied the summer habitat use of Gray whales (*Eschrichtius robustus*) along the west coast of Vancouver Island. The whales utilized particular pockets of habitat depending on the year, season and food availability, but over extended periods, they used the entire coastline as feeding habitat. Likewise, Gregr (2000) constructed a model of whale habitat in British Columbia from historical whaling records. He found that over the course of a summer fin, sei and male sperm whales were found along the entire shelf break off the north and west coasts of Vancouver Island and humpbacks were found along the entire shelf area, including inlets and enclosed straits.

On the other hand, some marine focal species can be identified and may be useful in conservation. Zacharias and Roff (2001) note that composition indicators, or species who's presence indicates other species or is used to characterize a particular habitat or community are particularly useful. They feel that sea birds, sea grasses, macroalgae, and benthic invertebrates are good candidates for indicators. We feel that sea birds may be also seen as umbrella species since protecting their foraging habitats will afford protection to their prey species. We also used kelp beds as important indicators of the many species associated with them, and hope to include eelgrass beds as the data become available. We use clams as an indicator of sandy shores. Other focal species we included are the sea otter, that have been demonstrated as keystone species on exposed rocky coasts as well as on sandy bottoms, and herring spawning areas that indicate biological hotspots since so many species are attracted to them to feed on the eggs (Hay and McCarter 2000).

D.4.1 ASSUMPTIONS

- All species used in this model are focal species to some extent.
- Focal species may also create habitat for other species and provide their spatial "umbrella" in this fashion (e.g. kelp, E.4.6, below), similar to but not as extensive as terrestrial forests.
- None of the species used in this model, or for which there are data, offer the same utility as popular terrestrial focal species.
- Therefore, the focal species in this model could be said to have much "smaller umbrellas" in terms of associated species protections or as indicators of ecosystem health.
- Biological distributions can be assumed to represent themselves.
- Biological distributions thus have no need to be placed in a spatial habitat hierarchy unless it is known that distributions of a particular species in one area represent a different sort of community than in another area. There are no such species known in the Central Coast. This is assumed to be due to the largely uniform oceanic conditions within our designated regions.

D.4.2 LIMITATIONS

- The applicability of focal species in the marine environment as umbrellas species is much more limited than on land, and much more poorly understood.
- Because connectivity is very different in the marine environment (see D.8 below), the concept of a particular species indicating a certain size of intact habitat is not so readily applicable in the sea.

D.5 REPLICATION

Replication of habitats and focal species occurrences can be a good insurance policy against disasters (Allison et al In press) and misclassification or borderline classifications (Ballantine 1997).

D.5.1 ASSUMPTIONS

- At least three separated occurrences of each conservation feature are required.

D.5.2 LIMITATIONS

- Separations are measured as the crow flies, not as the fish swims, and therefore only approximate measures of marine separation.

D.6 DISTINCTIVENESS

One shortcoming of a representative areas approach is that it requires examining and usually setting aside very large areas. Pragmatically, there may not be the political will or management capability to fully realize this approach. Furthermore, smaller but ecologically valuable areas may be passed over. Roff & Evans (unpublished as of 2001) argue that such "distinct" areas are by definition different from their representative surroundings and may harbour higher (or lower) species diversity, richness, and abundance. These, they suggest, must also be considered in reserve design.

D.6.1 ASSUMPTIONS

- Areas of unusually high physical complexity are distinctive.
- Benthic complexity can be modelled using bathymetric (topological) complexity –see *section E.3.1 and D.10*
- High current areas are distinctive –*E.3.3*.

D.6.2 LIMITATIONS

- The distinctiveness approach shows much promise. Living Oceans Society is suggesting that all data could be analysed for spatial variance, and those that are particularly narrow (i.e., large or many changes within small areas) could be overlaid to identify additional distinct areas. Unfortunately, most data in this present model lack the spatial acuity to perform such an analysis.
- Unavailable data likely would produce many more distinct areas and thus we must consider distinctiveness in the present model to be incomplete.

D.7 RARITY

(See also below, E.5)

Rare, threatened and endangered species are generally given a lot of conservation attention. However, the inaccessible nature of the sea makes it much harder to survey and therefore know most of what is rare. Declining populations may go unnoticed through to their extirpation (Thorne-Miller 1999).

Some rare species, though extremely popular with the media and public, may have ranges too large to be addressed with a network of MPAs on the Central Coast. Orca, Grey, and Humpback whales are examples (see above, D.4). It may still possible to help these species indirectly by protecting their food (prey). We argue that a network of MPAs could do this. Also, there may be spatial "bottlenecks;" i.e., places where these species frequent, that could be protected. For example, Orca rubbing beaches ought to be considered for protection; though, because they are used seasonally, this protection need not necessarily be year-round. The Michael Biggs (Robson Bight) Ecological Reserve is the only such example in BC (Central Coast) that presently enjoys protection. This area is effectively a no-take zone for about half of the year, though it is not officially designated as such.

D.7.1 ASSUMPTIONS

- Protecting rare, threatened, and endangered species in MPAs offers ecological benefits.
- That the species we have included in our model have sufficiently defined ranges as to be useful in modelling MPA networks. (See below, E.5)
- Many inlets may harbour as yet unknown and possibly rare species and sub-species (Austin 1997, Austin pers comm 2000)
- That by sub-classifying inlets into three sub-regions (of which the model seeks at least three sites each) we have to a certain extent captured these unknown species by proxy.

D.7.2 LIMITATIONS

- Most rare, threatened and endangered marine species remain poorly surveyed, if at all.
- Many of the "charismatic megafauna" have untenably large ranges that cannot be captured in a network of MPAs. Thus, for species with larger ranges, MPAs ought to be used to protect the "bottlenecks" in concert with other fisheries management tools.

D.8 CONNECTIVITY

Maintaining corridors between reserves is of less concern in the marine environment than on land where human activities can create barriers much more readily. Nonetheless, the marine environment offers its own unique set of problems. For example, while the current may be flowing north on the surface, it could easily be flowing south on the bottom.

The concept of sinks and sources of larval dispersal has garnered some attention, since it is assumed to be more efficacious to protect the sources rather than the sinks (Casselle 1996, Roberts 1997). And yet, leading MPA practitioners admit that what is a source for one species may be a sink for another: "Seeking the nirvana of a perfect reserve network is misguided." (Roberts 1998a citing Roberts 1998b)

D.8.1 ASSUMPTIONS

- That restricted passages such as marine narrows are critical to connecting the waters on either side.
- That such narrows are characterized by swift currents –which we have employed in this model (section E.3.3).
- That all reserve locations are likely both sources and sinks for different species (Roberts 1998b).
- That by creating a *network* of reserves, the chances and opportunities of larval connectivity increase (Roberts 1998b, 1998a).

D.8.2 LIMITATIONS

- Currents have not been comprehensively modelled for the Central Coast.
- In the absence of good current data (throughout the water column!), we are relying on physical proximity of sites to suggest connectivity.

D.9 FRAGMENTATION

(See also F.2, below)

For some of the same reasons discussed above regarding connectivity, fragmentation of reserves in the marine environment is not quite the same issue as it is on land. Nonetheless, it is true that depending upon which species one is attempting to protect, there would be a minimum effective size, as well as possible edge effects for fished species. As with the issue of connectivity, almost any reserve of any size will afford something helpful protection. When determining the size and distribution of reserves, it is important to also consider management capabilities.

D.9.1 ASSUMPTIONS

- That a variety of reserve sizes will protect a variety of different species.
- That larger reserves will protect more species than smaller ones.
- That larger networks will offer more protection than smaller ones.
- That a few larger reserves are easier to manage than several smaller ones.
- That some features will remain isolated and so must be considered in smaller reserves (e.g., eulachon estuaries).
- That spatially separated reserves offer greater disaster insurance than one larger one (see replication, D.5 above).
- Therefore a network of MPAs should consist of a variety of reserve sizes, spread throughout the study area.
- That by modelling a variety of overall network sizes as well as individual reserve fragmentation, we can identify areas that appear important regardless of exact sizes (see Figure 1: Conservation Hotspots)

D.9.2 LIMITATIONS

- Life history spatial ranges for most species in the Central Coast are unknown.

D.10 BENTHIC COMPLEXITY

(See also E.3.1)

Areas of high taxonomic richness are often associated with areas of varying habitat. The more kinds of niches available in which organisms can live will usually lead to a wider variety of organisms taking up residence. Furthermore, the complexity of habitat can interrupt predator-prey relationships that in a simpler habitat might lead to the clear dominance or near extirpation of certain species (e.g., Eklov 1997). Thus, in complex habitats species may co-exist in greater diversity where elsewhere they might not. Likewise, a greater variety of life stages may also be supported. Thus, complex habitats may exhibit greater ecosystem resilience (e.g., Peterson et al 1998, Risser 1995). Furthermore, if complex habitats do encourage biodiversity, as is being suggested, then it follows that they likely also offer greater resistance to invasive species (Kennedy et al 2002).

Our Benthic Complexity analysis (E.3.1, Ardron In press) has yielded results that make sense when compared to known features. For example, with regard to capturing rocky reefs in the passages, we have shown our results to various fishermen and a fisheries officer with local knowledge of the waters and they have affirmed its apparent accuracy. This is in contrast to other existing measures such as slope or relief. In the future, we would like to pursue this analysis with stratified random analysis experiment, to better affirm its accuracy in predicting various habitat types. Such an experiment could be utilized as part of modelling inshore rockfish (*Sebastes* spp) habitat. These species have recently come under a great deal of scrutiny after stock status estimates of poor health. Furthermore, due to poor data collection, there is a great deal of uncertainty surrounding these fishes (DFO 2000, Kronlund et al 1999). Modelling methods such as complexity may help direct decision-making regarding possible rockfish refugia.

We have examined complex benthic habitats in the inlets, passages, and outside waters of the Central Coast, accounting for three of the 61 features used in this model.

D.10.1 ASSUMPTIONS

- That benthic topological complexity is a good surrogate for benthic habitat complexity.
- That benthic habitat complexity is a good surrogate for benthic species diversity.
- That areas of greater benthic species diversity may also support areas of greater pelagic diversity, due to trophic links.
- That areas of benthic complexity may harbour greater ecosystem resilience.
- That areas of benthic complexity may harbour greater ecosystem resistance to stressors such as invasive species.

D.10.2 LIMITATIONS

- Our benthic complexity was developed by Living Oceans Society for this MPA model. It is therefore a new concept and has not had the opportunity to stand the test of time.
- Our benthic complexity analysis, while anecdotally showing much promise, has not been rigorously groundtruthed or experimentally validated.

D.11 SCALE

Spatial scale and ecology are inextricably linked. How closely one examines an area determines, in part, what one will see, and what is explained. Different problems in ecology demand different scales and sometimes several scales (Levin 1992). For example, for looking at global processes, it is necessary to aggregate fine scale data into coarser scale simplifications, taking care to minimize error (Rastetter et al 1992). For the evaluation of habitat – species ecology, it is generally accepted that finer scales are necessary for effective evaluation and management (e.g., Karl et al 2000, Orrock et al 2000, Caselle & Warner 1996), though coarser scale data are sometimes necessary as well in which to place the finer scale details (Caselle & Warner 1996, Levin 1992). Theory indicates that processes in deeper, offshore waters (our Outside Waters Region) are likely to take place over much greater scales than processes in nearshore waters (Roff 2001 In press).

D.11.1 ASSUMPTIONS

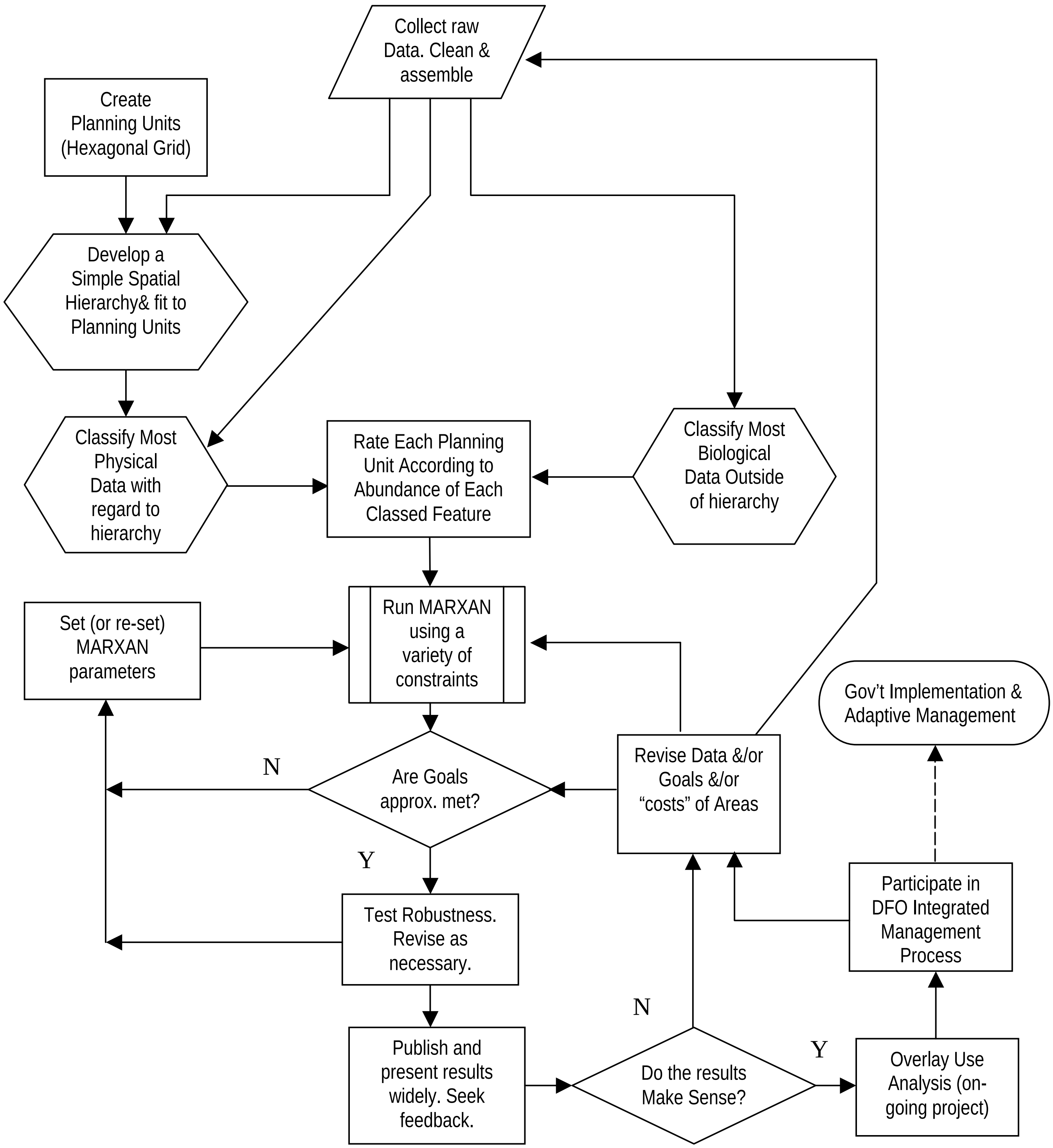
- The planning process (CCLCRMP) that precipitated this Central Coast study worked at a scale of 1:250,000, which is assumed to be a good scale with which to begin a seascape analysis.
- That different places within the Central Coast will reflect processes of varying scales. For example, offshore MPAs will need to be much larger than nearshore shore MPAs.
- We refined our analyses to incorporate some of the issues of scale, without compromising the efficient capture of features:
    1. Adjusting the costs of planning unit perimeters (see *Planning Unit Cost*, *Boundary Cost*, *& Boundary Length Modifiers E.8.3*). We encouraged the relative clumping of reserves in Outside Waters to reflect the larger spatial processes, than Passages, and Inlets.
    2. Accounting for proximity of land. All planning unit borders with land were given no perimeter cost (see *Planning Unit Cost, Boundary Cost, & Boundary Length Modifiers E.8.3*). Thus, reserves constrained by land boundaries such as long narrow inlets are not unduly penalized for their less than efficient shape.
    3. Using buffers to reflect the different scales. When considering Benthic Complexity (see E.3.1), we buffered the Outside Waters by 1500m, Passages by 500m, but did not buffer the Inlets, again to reflect the different spatial processes being captured by this one measure. These buffers were given 2 – 3 times less weighting than the core Benthic Complexity features. The underlying assumption is that the same analysis can apply to spatially varying extents dependant upon the spatial context. That is, confined waters generally have smaller features than the open ocean.

D.11.2 LIMITATIONS

- Water column processes are likely of a broader scale than those of the benthos (Roff 2001 In press). However, we have not separated the two in this model. Instead we have treated offshore waters as more generally pelagic, whereas inshore waters as more closely reflecting benthic scales.
- In capturing a representative array of taxa, we are also capturing a wide array of habitat scales. We have not examined any of these individually, and for most species the data do not exist.

E METHODS

Figure 3: Flowchart of MPA Design Process



As indicated in the above flowchart, we view MPA modelling as only a few pieces to a puzzle that will also include feedback from First Nations, stakeholders, and expert review; use analysis; and Integrated Management. Throughout, the MPA model will be refined as necessary.

Our MPA modelling methodology can be broken down into five sequential steps. The first four we explain in this section, and the fifth is explained in the next section, F.

1. **Data Assembly:** The collection, cleaning, and harmonization of existent datasets.
2. **Data Classifications:** The delineation of data into meaningful categories and sub-categories around which our conservation targets will eventually get built. These may nest hierarchically, but not necessarily so. (Indeed, most of our datasets do not.) We would also like to draw the reader's attention to section E.3.1 where we introduce our unique analysis of Topological Complexity, and apply it as a surrogate measure for Benthic Complexity, an indicator of taxonomic richness.
3. **Representing Data in Planning Units:** Fitting our data into a hexagonal grid of planning units in such a fashion that those features that happen to fall into units with only a small proportion of water (i.e., mostly land) are not unfairly excluded.
4. **Setting Up MARXAN:** targets, penalties, and other parameters.
5. **Analyses & Results.**

E.1 DATA ASSEMBLY

E.1.1 COLLECTION

In order to incorporate all available information in our analysis, we gathered as much biological and physical data about the Central Coast as possible. However, marine data in British Columbia are limited and not often readily available. Being remote, the Central Coast, and especially the north Central Coast, is poorly represented with regard to available data.

Of the datasets that do exist, many are incomplete, out of date, geographically imprecise, or poorly documented. While there are sometimes excellent data for some areas, other areas are completely overlooked. This bias in data quality and coverage can misdirect decision-making if not properly addressed. We have used data from a variety of agencies and researchers, and melded them into aggregate layers for our analysis (Table 1: Data used in the Model). While far from being a comprehensive inventory, it is nonetheless the most thorough to date. Collection of scientific data and local / traditional knowledge remains on-going.

E.1.2 CHOOSING COMMON STANDARDS

Different agencies often use different base data. The most common problem was harmonizing the various datasets' shorelines. Whenever possible, data were analyzed with regard to their native shorelines. In some cases the base data were not available. In these cases, we picked a "best match" shoreline, buffered the feature and then re-cut it to fit the best match. Generally speaking, more of our data were already fitted to the BC Government 1:250,000 shoreline than anything else, and so that became the standard for our maps.

Datasets often use different weightings or measures which have to be normalized if they are to be merged together. Some layers required fairly extensive fitting. The clam species layer was pieced together using four different Dept. of Fisheries & Oceans datasets, none of which cover the entire study area on their own, and some of which are incomplete. We explain the steps taken to aggregate this layer *E.4.5*. This should serve as one example of the sorts of GIS edits necessary in this sort of process. Table 1 provides an overview of the constituent datasets for each layer produced. Sections *E.2 to E.5* discuss the rationale behind aggregated layers and the application of various weightings to the features.

Different agencies often use different geographic projections to map their data. We converted all projections to the BC Government standard: Albers Equal Area. Although this projection can distort straight-line distances and compass directions, it does maintain equality of area. Because we were using various grids in our analysis, equal area was a desirable quality; otherwise, if some grid cells held more area (i.e. features) than others, they could be improperly preferred in selection algorithms.

Table 1: Data used in the Model

Enduring Physical Features and Processes

Raw Data	Resultant Analysis Features (Number of feature classes noted in parentheses)
Exposure (MEC) + Parks Canada Regimes	Regions (3) and Sub-Regions (7)
Depth (CHS) + land (LUCO)	Benthic Complexity (3 regions, weighted)
Depth (CHS) + Substrate (MEC)	Depth-Substrate (3 classes x 3 classes x 3 regions = 27)
High Current (MEC + Parks Canada) + CHS charts + Local Knowledge	High Current (3 regions)

Biological Features

Raw Data	Resultant Analysis Features
Salmon escapement + LUCO streams + BC watershed atlas	Salmon streams –mouths (1, weighted by number of species and abundance)
Salmon holding areas (LUCO/DFO) + local knowledge	Salmon Holding areas (1)
Herring spawn distributions (LUCO) + Habitat Spawn Index (DFO)	Herring spawn (1, weighted by density)
Herring Holding Areas (LUCO/DFO)	Herring holding areas (1)
Birds: Pelagic, alcids, shorebirds, waterfowl (LUCO + CWS)	Pelagic (1, weighted by RI) + alcids (2) + shorebirds (2) + waterfowl (2)
Clam Atlas (DFO) + Shellfish fishery (north, south, DFO) + Geoduck fishery (DFO)	Clam species shorelines (3 regions, weighted by RI)
Macro algae (LUCO, 2 sets + DFO)	Macroalgae (1, weighted by RA & RI)

Rare and Endangered Features

Raw Data	Resultant Analysis Features
Marbled murrelet (LUCO + CWS)	Marbled murrelet (1, weighted by RI)
Eulachon (DFO)	Eulachon estuaries (1)
Sea otter (LUCO)	Sea otter (1)
Hexactinellid sponge reefs (NRC)	Hexactinellid sponge reefs (1, weighted)

Abbreviation Notes:
CHS = Canadian Hydrographic Service
CWS = Canadian Wildlife Service, Environment Canada
NRC = Natural Resources Canada, Geological Survey
DFO = Department of Fisheries and Oceans (Fisheries and Oceans Canada)
LUCO = the former Land Use Coordination Office, Ministry of the Environment, Lands and Parks, Province of BC
MEC= Marine Ecological Classification, BC
LOS = Living Oceans Society

E.2 DATA CLASSIFICATIONS

As explained in the previous section, the data layers used in our analyses usually are an aggregation of several datasets from various agencies (Table 1: Data used in the Model). The feature layers we have collected, aggregated, or created for our analyses can be divided into four basic categories:

1. **Geographic & Oceanographic Spatial Hierarchy**
   - Regions and Sub-regions
     - Inlets
       - High freshwater input
       - Moderate freshwater input
       - Low freshwater input
     - Passages
       - High mixing
       - Moderate mixing
     - Outside Waters
       - Nearshore
       - Offshore
2. **Physical Features and Enduring Processes**
   - Benthic Complexity (1-3 weighting, evaluated by Region)
   - Depth / Substrate (9 classes, evaluated by region)
   - High Tidal Current Areas (1 class, evaluated by Region)
3. **Biological Features**
   - Salmon Streams (1-7 weighting based on species richness and abundance)
   - Salmon Holding Areas (1 class, low emphasis)
   - Herring Spawn (1 class, weighted by a function of Habitat Spawn Index)
   - Herring Holding Areas (1 class, low emphasis)
   - Clam Species (1 class, weighted 1-3 evaluated by region)
   - Kelp (1 class, weighted 1-3)
   - Birds
     - Pelagic (1 class, weighted 1 or 3)
     - Alcids (2 classes)
     - Waterfowl (2 classes)
     - Shorebirds (2 classes)
4. **Rare and Endangered Features**
   - Eulachon (estuaries, 1 class)
   - Marbled Murrelet (1 class, weighted 1-3)
   - Sea Otter (1 class)
   - Hexactinellid Sponge Reefs (1 class, weighted 2 or 3)

Maps of all the above features have been placed in Appendix 4: Maps of Data Layers. [Note to readers of an electronic version of this document: To save file space, that appendix is a separate file from this document.]

E.2.1 GEOGRAPHIC & OCEANOGRAPHIC SPATIAL HIERARCHY

Living Oceans Society has created a hybrid classification, whereby some physical data are used to create a simple spatial hierarchy, remaining physical and some biological data are examined within the context of this hierarchy, and most biological data are assessed independently.

Spatial hierarchical classification systems have been popularized as a way of organizing spatial data to identify areas with similar characteristics (e.g., Noss 1990, Day & Roff 2000). However, it is entirely possible to classify spatial data without it being a hierarchical classification. It becomes a hierarchy only when it is decided that there is an order of classification. Thus, in *spatial* hierarchies, subsequent classifications become physically smaller and smaller.

Spatial hierarchical classifications can help clarify distinct regions and groupings of features. These groupings may also capture other features for which there are no available data. Most often, physical features are used as a surrogate for biological assemblages. If too many features are used, however, there would be so many units created, the hierarchy would result in a multitude of subclasses that obscure more than clarify.

One of the key weaknesses with a spatial hierarchy is that it tries to make the data fit together. For example, in classifying depth, substrate and water movement, the boundaries of these three features will almost never coincide. Often, there will be various small areas, known as “slivers,” which are considered too small to stand on their own. When, for simplicity’s sake, the features’ boundaries are adjusted to fit together, without slivers, important detail can be lost, thereby weakening the effectiveness of the tool. The more layers used in the spatial classification, the greater will be the clutter of slivers produced, thus the number of boundaries adjusted will increase, and consequently the loss of accuracy grows. It does not take many classes and layers before the spatial errors produced can eclipse the original intent of the classification units. Nonetheless, this approach is often promoted because it produces clean disparate shapes with no overlaps. This can make for easier to understand management units. Unfortunately, the spatial error of such systems is rarely discussed. Managers assume, often incorrectly, that the accuracy of the original data is conserved. We discuss introduced error in detail in Appendix 2: Classifications & Hierarchies. Because of the inherent variability of marine features in their fluid environment, these issues of error and variance come to the fore.

There have been several attempts to develop spatial marine classification systems. Some have been applied to the Central Coast of BC; others have been applied elsewhere but offer valuable insight. When Living Oceans began the job of selecting the best ideas from previous classifications, we decided our classification system had to based upon data that are already available or can be readily obtained. Some other approaches required nonexistent data to proceed. As such, our methodology became to a certain extent *data-driven.* Living Oceans really did not want to (re)invent yet another classification scheme; however, in reviewing the existing systems we found issues that that needed to be addressed.

In *Appendix 2: Classifications & Hierarchies* we review previous classifications systems and discuss the problem of spatial error in hierarchical approaches. Below, we introduce the simple hierarchy we developed and how this applies to the Central Coast.

E.2.2 REGIONS & SUB-REGIONS

Living Oceans Society has created a simple two layer spatial hierarchy, and named them r*egion*s and s*ub-regions*. The purpose of the regions and sub-regions is to delineate our study area into biologically meaningful spatial zones. Within the Central Coast Study Area, we believe there are three broad regional categories: **Inlets, Passages,** and **Outside Waters.** While the MPA network is to span these regions, it must also take into account their differing ecosystem processes and characteristics. The transition from Inlets to Passages to Outside Waters broadly reflects the transition from sheltered to exposed areas; as well as mixing regimes: from the fresh water stratified estuarine system of the inlets, to tidally mixed passages, to continental shelf circulation of the outer coastlines where freshwater stratification is minimal. Likewise, salinity increases from Inlets to Passages to Outside Waters.

Because these represent a spatial hierarchy, the regions and sub-regions are fitted to our hexagonal grid of 250 ha planning units; that is, they are either in or out. No single hexagon can contain more than one region or sub-region. This is in contrast to other analysis features that can co-exist within a single hexagon.

To view a map of these features, please refer to *Appendix 4*. We discuss the regions and sub-regions in more detail below.

INLETS

Inlets (fjords) are well explained by Dale (1997):

> Fjords are often seen (as with archipelagos) as definitive of the BC coastline. Indeed, the entire BC coast has been placed within the category "West Coast Fjords Province," Dietrich's (1963) biogeographic classification scheme. Few areas of the world (Norway, Chile and New Zealand) have such an abundance of fjords. Many of BC's fjords are large, exceeding 100 km in length. These generally comprise many habitats, including several which are of special importance to a variety of well-valued species.

To delineate inlets, we examined areas of low exposure (LUCO 1997) and estuarine circulation (Booth et al 1998, Parks Canada 1999). Fine-tuning the boarder between an Inlet and Passage involved visually choosing the hexagons where the inlet fed into a larger water body –usually quite obvious.

At the time of the analysis, little GIS data exist for Central Coast estuaries (often at the heads of inlets), however this situation may be changing. If so, we will incorporate these new datasets into subsequent analyses. Although estuaries are not treated as a feature layer in the model to date, they are indirectly captured due to other feature distributions: waterfowl, shore bird, and salmon streams. Conservation of the land-sea interface, including estuaries, is indeed important and will require coordination between terrestrial and marine conservation efforts. We have recently embarked on just such a process, collaborating with terrestrial conservation organizations to produce a unified land-sea product for the Central Coast and North Coast of BC.

INLETS: FRESHWATER INPUT

Rivers feeding into the inlets provide most of the freshwater in the Central Coast. It is the varying freshwater input to these inlets that accounts for the estuarine circulation within them. The inlets in turn feed into the passages which then connect to the outside waters, accounting for the varying salinities and stratifications throughout the regions and sub-regions.

Ideally, we would be able to incorporate measures of salinity and/or stratification to group together similar inlets. Unfortunately, such data for many Central Coast inlets do not exist. Of those that do, few have been digitized. The Province of BC contracted a revision of the Marine Ecological Classification (MEC) to include these parameters province-wide (Axys 2001). However, the source data for the revised ecounits were not released. At the time this revision was underway, Living Oceans Society did send back extensive comments on the "final" document (Ardron 2001) arguing that amongst other issues, the scale of the analysis was far coarser than the 1:250,000 required and stated. Until the source data are released for quality assurance testing, we feel this issue of scale will remain unresolved. Local knowledge has indicated there are some very questionable designations. Therefore, we have not incorporated these BC MEC salinity or stratification polygons at this time.

In lieu of these data, we have incorporated Parks Canada's freshwater input ratings (Booth et al 1998). These were based on known stream volumes, and estimates for those unknown, summed per inlet. They were broken into three classes: Low, Medium, High. (No quantitative measures were given.) It should be noted that freshwater can come from either snow pack melt or rain, causing a spring and fall/winter freshet respectively. Broadly speaking, the smaller inlets have less freshwater input, with little from snow melt sources. A greater volume of freshwater input generally corresponds to greater stratification and lower surface salinity. It also corresponds to a greater movement of surface water leaving the inlet, through freshwater flow and associated saltwater entrainment. Bottom saline currents are generally inward flowing and in proportion to the outward flowing surface water.

Bottom (benthic) dissolved oxygen (DO) can vary depending on bottom currents and topology. While some archival DO data exist, there has been no comprehensive digitization to date (Dario Stucchi, Institute of Ocean Sciences, pers comm 2000). We view this as an unfortunate data gap, since the survival of benthic organisms is largely limited by an inlet's DO, of which several are known to be quite low (Ricker 1989, Thomson 1981).

PASSAGES

Passages are characterized by generally moderate wave exposures, with certain low exposure areas included. The Parks Canada description of *Straits and Channels* follows (Booth et al 1998):

> This feature is characterized by elongate channels where the maximum fetch direction is often parallel to shore. Fetches are usually restricted to less than 50 km and often less than 10 km so shorelines along straits and channels are often current-dominated rather than wave dominated. The open-ended nature of the channels tends to make water properties more marine than that found in fjords (e.g., Broughton Strait).

Parks Canada was split in classifying the predominant currents as either estuarine or shelf, with small areas defined as tidal. This variety of classes suggests a mixture of influences, rather than one or the other; thus, Passages are best viewed as transition zones, generally connecting the inlets with the outside waters.

PASSAGES: MIXING

Passages are characterized by predominantly tidal currents interacting with brackish water leaving the inlets. They are places of mixing. Ideally, mixing and/or stratification data could help classify these regions.

The discussion in the previous inlets section regarding data availability and the BC Marine Ecological Classification (MEC) is applicable here as well. (That is, few good data exist, fewer still have been digitized, and existing attempts to generalize these data have serious problems…)

Johnston Strait was given a class of its own by Parks Canada (Booth et al 1998) due to its several unique features: nearly fully mixed waters (i.e. homogeneous water column), cool surface temperatures, somewhat low dissolved oxygen, and unique circulation regime. It is also a stand-alone BC MEC ecounit. It is generally considered to be a unique feature of BC's waterways, supports a large volume of marine traffic, and is a key migration route for many other species, such as salmon and orcas.

Once again, in lieu of detailed quantitative data, we have turned to more general qualitative measures. Some measure of mixing would seem in order. At this stage, the available data can only support a two-choice class: highly or moderately mixed. High is taken to mean no readily discernable stratification, such as in Johnstone Strait. Indeed, only Johnstone Strait has been classed as High, with all other Passages presently classed as Moderate. Hopefully, this measure can be further refined as better data become publicly available.

OUTSIDE WATERS

Outside Waters are readily identifiable. These are areas with broad fetch and high wave exposure. While the shorelines and euphotic benthos are exposed to strong wave energy, there is generally weak tidal action except at headlands. Offshore circulation is characterized by continental shelf currents with a surface component of wind driven currents. Certain areas may be exposed to upwellings or downwellings.

This layer is mostly a one to one mapping of the BC Marine Ecological Classification's High Wave Exposure class (>500km fetch). It also includes most of Parks Canada's Open Ocean Transitional regime and most of Parks Canada's *Open Coast* class.

OUTSIDE WATERS: OFFSHORE & INSHORE

Unlike the Inlets and Passages regions, which are limited by the narrow confines of their coastlines, we suggest that Outside Waters mark the beginning of the open ocean or what is sometimes referred to as the "pelagic" environment.

(Actually, all marine waters, no matter how confined, are by virtue of their water column, "pelagic." When people call offshore waters pelagic, what they mean is that these processes come to the fore. That is, given the fluidity and variability of the measures involved, coupled with the poor existent water column data, it would appear that the delineation of the pelagic is really only practical once there is “room to move.” Offshore, these processes occur at spatial scales appropriate to their measurement and classification. Inshore, pelagic processes are often masked or confounded by geographic constraints.)

We have classed Outside Waters as either Offshore or Inshore. We have not explicitly separated out the benthic from the pelagic in either class, though it is understood that the Offshore emphasizes what is commonly considered the open ocean “pelagic” environment, while the Inshore is characterized by a “coastal” nearshore environment. Not surprisingly, we are not the first to have considered this sort of simple offshore / inshore delineation.

Burger et al (1997), following a modified version of Kessel’s (1979) Alaskan system, defined BC’s inshore waters as within 10 km of shore and less than 100 m deep. While this system was used to separate coastal birds from pelagic species, it also indirectly speaks to other biological distributions, such as plankton and certain forage fish, which are important food sources for these pelagic birds.

From surveys in the Strait of Juan de Fuca, Washington coast, and Puget Sound, the majority of Harbour Porpoise sightings (a coastal species) occurred within 11 km of shore and between 10 m and 125 m depth (Calambokidis et al, 1992; cited in Nicolson & Booth 1997). This rule for what might constitute inshore habitat dovetails fairly well with the above Burger classification. (Admittedly, this does assume the same sort of behaviour for porpoises in the Central Coast.)

Mapping the above Burger et al (1997) definition onto the Central Coast, it quickly becomes apparent that with its many troughs, most waters are deeper than 100m long before 10 km offshore. Therefore, we have added a minimum distance of 5 km regardless of depth. Much of the inshore class in fact follows this 5 km boundary. Admittedly, 5 km is an arbitrary minimum, open to revision should there be compelling biological evidence to do so. Informal discussion with experts familiar with the BC coast have brought forth no serious objection to this number other than the lack of data available to rigorously support any number at all… When calculating our offshore distance, we disregarded small offshore islands, such as the Scott Islands, which offer little or no protection or other conditions generally representative of the coastline.

Thus, our definition of inshore waters is: **Those waters extending 5 km (2.7 nautical miles) from shore and up to 10 km (5.4 nautical miles) when under 100m in depth.** The resulting lines have been smoothed and fitted to our hexagonal grid. Offshore waters constitute all others in the Outside Waters class.

E.3 PHYSICAL FEATURES AND ENDURING PROCESSES

E.3.1 BENTHIC COMPLEXITY

(1-3 weighting, evaluated by Region)

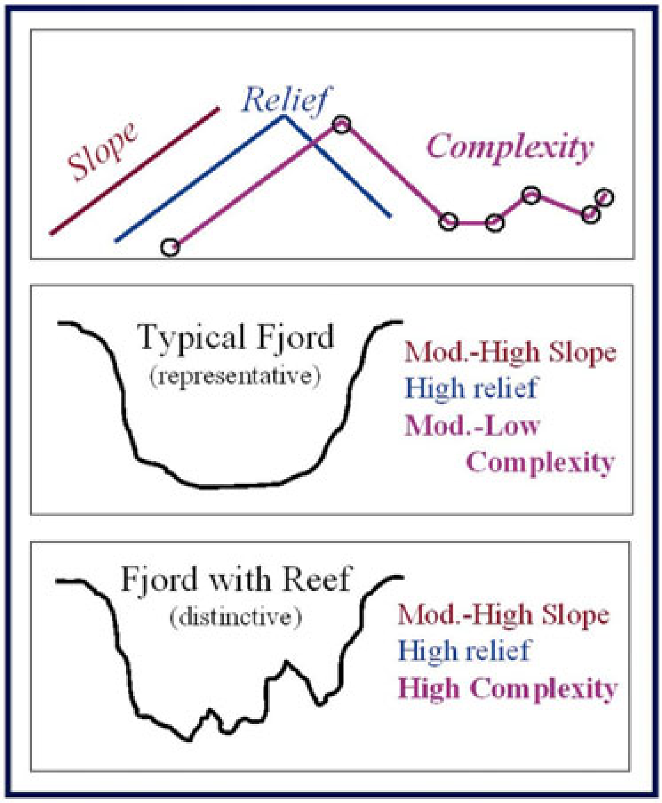
Areas of high taxonomic richness are often associated with areas of varying habitat. The more kinds of niches available in which organisms can live will usually lead to a wider variety of organisms taking up residence. Furthermore, the complexity of habitat can interrupt predator-prey relationships that in a simpler habitat might lead to the clear dominance or near extirpation of certain species (e.g., Eklov 1997). Thus, in complex habitats species may co-exist in greater diversity where elsewhere they might not. Likewise, a greater variety of life stages may also be supported. Thus, complex habitats may exhibit greater ecosystem resilience (e.g., Peterson et al 1998, Risser 1995). Furthermore, if complex habitats do encourage biodiversity, as is being suggested, then it follows that they likely also offer greater resistance to invasive species (Kennedy et al 2002).

As touched upon in our discussion of inshore-offshore, habitat in the 3-D ocean can be broadly delineated into two categories: 1. Pelagic (water column) including physical processes and parameters such as currents, temperature, salinity, dissolved oxygen, and so forth; 2. Benthic (bottom) including depth, substrate, as well as the pelagic parameters as they occur on the sea floor. Most of the pelagic variables are changeable over space and time, which makes them difficult to map, except in the most general of terms. Furthermore, the data are not always available. In our Central Coast analysis, we therefore looked at a subset of physical complexity, benthic (sea bottom) complexity. Specifically, we considered the morphological shape of the sea floor, the "lay of the land," so to speak. We fully acknowledge that this is a particular subset, and is not a panacea for modelling all forms of species richness, but it wasn't such a bad place to begin. The benthos has a much greater variety of species than the pelagic (Lalli & Parsons 1997). Also, it was our belief that areas of benthic complexity might have trophic "spin-offs" benefiting pelagic (water column) species.

We defined benthic complexity as indicated by how often the slope of the sea bottom changed in a given area; that is, the density of the slope of slope of the (exaggerated) depth. Note that this is not the same as relief, which looks at the maximum change in depth (Figure 4). With benthic complexity, we are interested in looking at how convoluted the bottom is, not how steep or how rough, though these both play a role. Complexity is similar but not the same as "rugosity" as is sometimes used in underwater transect surveys, whereby a chain is laid down over the terrain and its length is divided by the straight-line distance. Rugosity can be strongly influenced by a single large change in depth, however, whereas complexity is less so, since all changes are treated more equally.

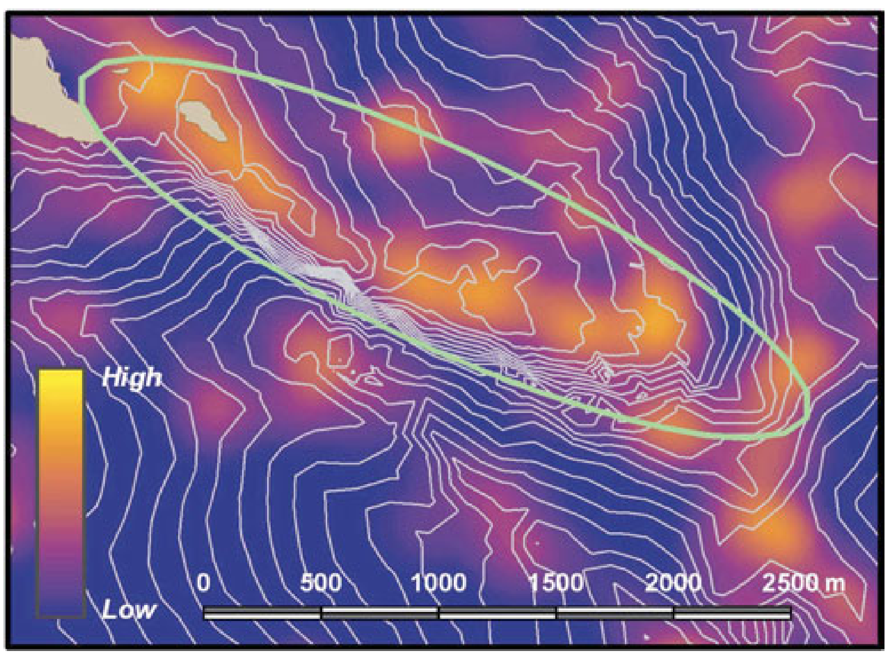
We created this analysis because we felt it captured biologically and physically meaningful features that the other measures missed. For example, archipelagos and rocky reefs are invariably picked out as areas of higher benthic complexity (Figure 5). Both are associated with several marine values. While "obvious" to the casual observer, they had hitherto no simple quantitative definition that could be used to identify them using a GIS. Benthic complexity will often also identify physical features such as sills, ledges, and other distinctive habitats that are associated as biological "hotspots" providing upwellings, mixing, and refugia.

Figure 4: Benthic Complexity



Slope is steepness; relief is roughness; complexity is intricacy. Complexity considers changes in slope (small circles). Complexity can distinguish typical steep-sided features such as fjords from distinctive ones, whereas measures of slope or relief generally cannot.

Figure 5: Example of Benthic Complexity Analysis



Example of benthic complexity analysis that captures a rocky reef (green oval). Bathymetric lines (grey) are in 10m intervals. Notice how well the convoluted lines are identified, whereas regular ones, even if they are tightly packed, are not.

The benthic complexity layer was classed from 1-3, representing areas of moderate, moderate-high, and high complexity, respectively. The top two scores came directly from the analysis, whereas the third score (1) represented a buffer that was applied regionally. In Outside Waters, where the scale of the pelagic processes is considered most widespread and related to benthic complexity, all complex areas (generally large rocky reef complexes and archipelagos) were buffered 1500m. In Passages, complex areas were buffered 500m, reflecting the more limited spatial scale of those regions (generally rocky reefs). Complexity within Inlets (shelves, sills, outcroppings) was not buffered at all, again reflecting the further confined nature of these features. While we could have undergone three separate complexity analyses for the regions, each one tailored to the scale of that region, we felt that using one measure with explicit buffers allowed for standardized scores across the study area, with the buffers being easily adjusted as deemed necessary. Note that because the buffers have only ½ or 1/3 the value of a "core" complex area, they have a relatively low influence on the overall complexity scores for a given hexagon planning unit.

The GIS details of how we performed the Benthic Complexity analysis are given in Appendix 3: Benthic Complexity. This analysis is also discussed in a chapter in the forthcoming publication, Marine Geography (Ardron In press).

To view a map of this feature, please refer to Appendix 4: Maps of Data Layers.

E.3.2 DEPTH / SUBSTRATE

(9 composite classes, evaluated by Region)

Substrate and depth are also two of the most important variables affecting the distribution of biota in the ocean. The substrate type has major consequences for the morphology, behaviour and biomechanics of biota (Levinton 1995). Species must also adapt to the light levels, temperature and pressure that change with depth. As such, many species' habitat preferences appear to be a combination of the two. For instance, a 100 metre deep mud bottom is considerably different than a 10 metre mud bottom with a seagrass bed.

We have divided substrate and depth each into three classes, which when applied together produce nine unique classes (3x3). Each of these is assessed separately with regard to its membership in a region.

SUBSTRATE

- Hard (Bedrock, boulders, cobble, and some sand / gravel)
- Sand (Sand, sand / gravel, and some muddy areas)
- Mud (Mud and sandy mud)

These three-substrate classes are taken directly from the BC Marine Ecological Classification (LUCO 1997, version1). They are similar to the three WWF classes (Day & Roff 2000), though differ from the five WWF classes actually used in an earlier east coast analysis (Day & Lavoie 1998). While we would prefer more than just three classes, it is presently beyond our means to do this independent analysis of the Central Coast (raw data are unavailable), and so we have had to rely on the existent Marine Ecological Classification. Nonetheless, these three classes do still delineate many of the benthic species in the Central Coast region (Levings et al 2002).

Central Coast substrate generally follows a progression from rocky shallower waters, to sandy slopes of moderately deeper waters, to muddy deepest bottoms. One exception is that deep areas of current, such as Johnstone Strait, do not gather much fine sediment, and are thus not classed as muddy. Note that almost all of the inlets are classed as muddy, and therefore this classification does little to differentiate amongst them.

DEPTH

- Euphotic: 0-50m
- Dysphotic / Aphotic: 50-200m
- Bathyal: 200-2000m

These depth classes are taken directly from World Wildlife Fund's benthic depth classes (Day & Roff, 2000). (As there is no water deeper than 2000m in the Central Coast, we did not need their last category: Abyssal / Hadal.)

Prior to adopting the WWF depth classes, Living Oceans analyzed the Central Coast's (CCLCRMP) depth by area, exploring whether there were any naturally occurring breaks in the data. The curve for 0-100m proved to be virtually linear, which would appear to indicate no overall tendency towards particular depths or shelving (Figure 6). At approximately 200m, however, the curve does begin to bend, which would indicate a change in the distribution of deeper depths, and a good location for a class break, as recommended by both WWF and the province, and as is generally accepted (e.g. Thomson 1981) –Figure 6. Note that the little notches or steps in the figures represent clustering around depths of known bathymetry lines (e.g., 100m or 150m) from which the other depths were interpolated. As such, they are an artefact of the data interpolations used, and not actually a feature. These graphs examine depths within the BC Central Coast Land and Coastal Resources Management Plan (CCLCRMP) study area, which does not include most of the offshore component of our own study area. For the purposes of seeking an euphotic (shallow) "break" in the data, however, trends would be more likely to appear when focussing upon the nearshore, which is why we chose to use this subset.

Without natural breaks in the depth distribution, the euphotic depth class had to be determined by other means. Using the WWF work in Canada's Scotian Shelf as an example, Living Oceans chose to map the 50m depth and compare it to known areas of presumed photic biological activity. All such areas were captured. While 50m is sometimes considered too deep to be truly "euphotic," we hypothesize that this euphotic activity within the water column produces spin-offs for those benthic areas in close proximity to them, and vice versa. 50m appears to capture this. Perhaps 40m, say, would work as well; however, the available bathymetry data below 50m is not comprehensive. 50m is an almost ubiquitous isobath (depth contour). Therefore, for reasons of consistency with the east coast model, and strength of the available data (avoiding unnecessary interpolation), we adopted the depth of 50m as put forward by WWF (Day & Roff 2000).

Day & Roff also suggest separating pelagic depths from the benthic depths, and considering these realms separately. In their classification, the pelagic has no euphotic class. In the Central Coast of

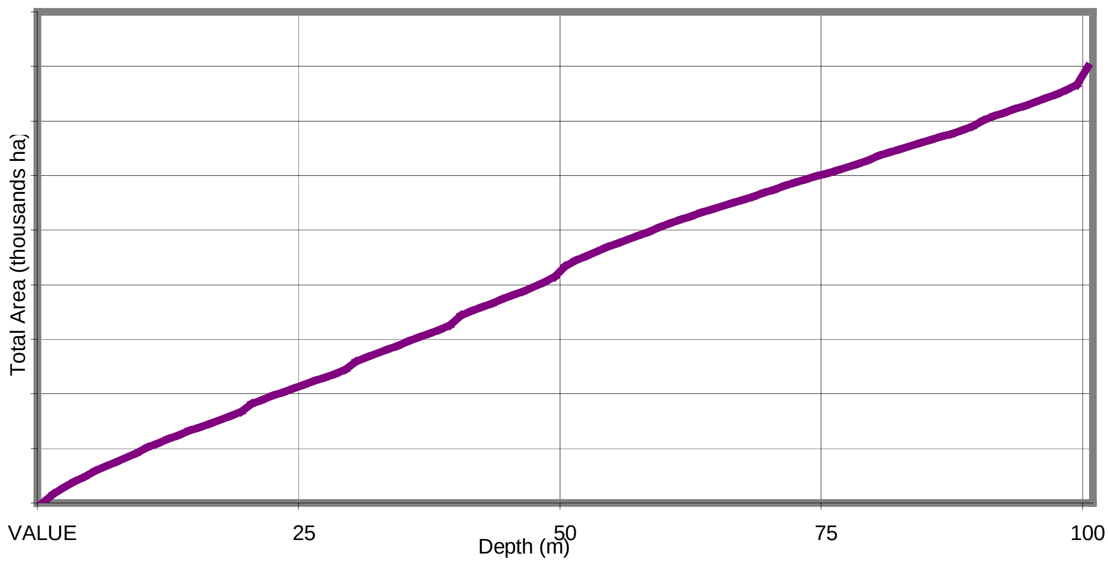
BC, however, euphotic features, such as reefs, sills, banks, and seamounts, impart what we believe to be a strong influence on the associated pelagic communities. For this reason, and because of limited data that accurately reflect pelagic processes, we have left the two grouped together.

The BC Marine Ecological Classification (LUCO 1997) differed from the above by defining their “Photic” (synonym for euphotic) class as 0-20m. However, this shallower class did not capture many known biologically active areas within the Central Coast, such as Sea Otter Shoals or Goose Bank. Furthermore, because areas of bottom depth 0-20m are generally fairly small, they were “swallowed up” by larger adjacent ecounits, and thus effectively disappeared. Figure 7 visually depicts this issue. In 2000, following correspondence with Living Oceans Society, the province decided to re-evaluate their depth classifications. They subsequently decided to create a separate class from 20-50m (Axys 2001). It remains to be seen if this additional class helps or hinders the issue. It is quite likely that these areas might also be too small to stand on their own at the stated scale of the ecounits (1:250,000), whereas one cohesive class of 0-50m could fare much better.

To view a map of this feature, please refer to Appendix 4: Maps of Data Layers.

Figure 6: Plotting Depth vs Area

a) CCLCRMP 1st 100m Depth by Area



b) CCLCRMP Sea Floor by Depth

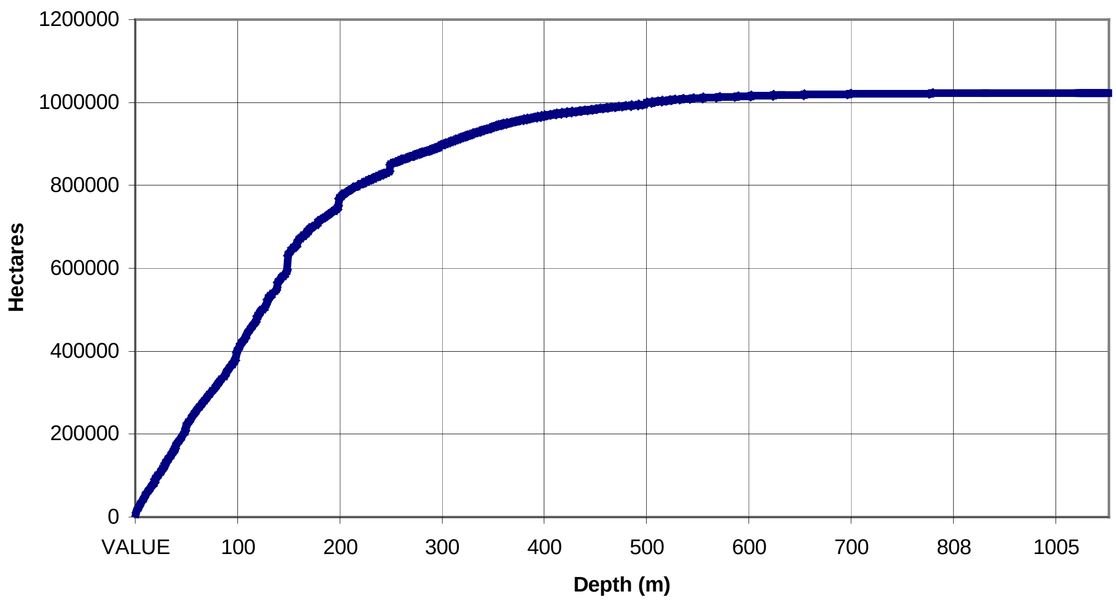
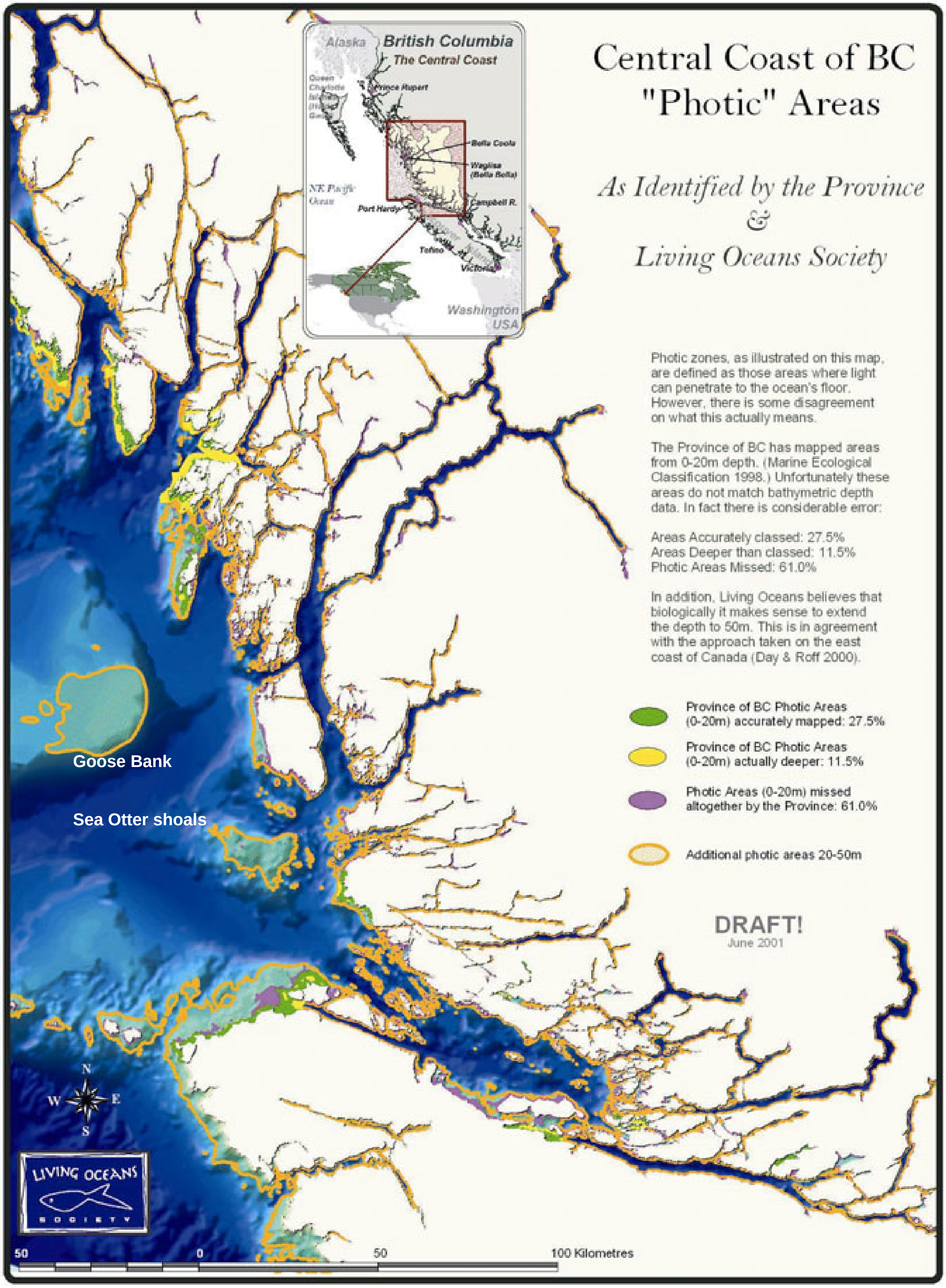


Figure 7: Discrepancies within the Provincial Photic Classification



E.3.3 HIGH CURRENT

(1 class, evaluated by Region)

This layer was taken from the BC provincial classification (LUCO 1997), incorporating additional local knowledge. High Current is defined as waters that regularly contain surface currents (tidal flow) greater than 3 knots (5.5 km/hr or 1.5 m/s). These are areas of known mixing and distinctive species assemblages. In addition, high current areas often represent physical “bottlenecks” to water movement and as such are important to larval transfer and nutrient exchange.

The strong currents of the southern half of the Central Coast, particularly in Johnstone Strait and Discovery Passage, are probably the most influential oceanographic variable of the area (Thompson 1981). They mix the water column so that nutrients, oxygen, temperature and salinity levels are almost uniform throughout (Thomson 1981). The constant re-suspension of nutrients in particular is most likely responsible for the rich biota of the region. Mann and Lazier (1996) explain that tidally-induced mixing in relatively shallow coastal waters prevents stratification of the water column, but the potentially adverse effects on phytoplankton are more than compensated for by the increased nutrient flux to the water column from the sediments. Annual primary productivity in tidally mixed areas tends to be above average for coastal waters (Mann and Lazier 1996). Highly productive and biologically diverse areas, such as the world-renowned dive site, Browning Passage (Queen Charlotte Strait), result from these nutrient-rich, mixed waters.

Unfortunately, the currents in many of the above-mentioned nutrient rich areas are still less than 3 knots, arguing for the addition of a second classification, say 0.5 – 3.0 knots. Data to delineate such a class do not presently exist.

Because high current areas are always well mixed subsets of whatever larger mixing regime may exist, examining them at a sub-regional level (i.e. mixing and salinity regimes) would not make sense. However, species assemblages and associated exposure levels do vary according to region. Thus, high current areas are examined regionally.

To view a map of this feature, please refer to Appendix 4: Maps of Data Layers.

E.4 BIOLOGICAL FEATURES

E.4.1 SALMON STREAMS

(1 class, weighted 1-7 based on species richness and abundance)

The ability for marine protected areas to protect salmon throughout their life cycle is limited due to their migratory nature. However, there are life stages where salmonid habitat is predictable; namely, salmon streams and their associated estuaries. Estuaries and nearshore coastal waters are important rearing habitats for juvenile salmon, particularly from spring to fall (Groot and Margolis 1991). Coastal areas near the mouths of salmon spawning streams can also be important holding areas for adult salmon prior to spawning. Salmon that migrate to sea and then return to streams to spawn and die are an important conduit of nutrients between oceans, streams, and riparian areas. We can emphasize this important tie to land by protecting salmon streams and estuaries as well as associated terrestrial components.

We have used the BC MSRM (LUCO) salmon stream data, which was based on DFO escapement (Williams *et al.* 1994; McDougall 1987). We have crosschecked it with the provincial Watershed Atlas (moving streams when necessary) and fitted that data to the present provincial 1:250,000 coastline. Each stream point was buffered 1000m to reflect an area of influence, estuary, etc. The reasoning behind this buffer is based on that of the BC Salmon Aquaculture Review (SAR 1997) that specified that salmon farm operations should be sited al least a kilometre from any anadromous streams.

A Relative Importance measure was created using existing provincial Relative Abundance (RA) ratings (Table 2). These RA classes were based on criteria presented by Bell-Irving (1978 –cited by Nicolson & Booth 1997).

Table 2: Provincial Salmon Escapement Classes

RA	Maximum escapement (1985 - 1994) by species		
	Sockeye	Chinook/Coho	Chum/Pink
0: none	0	0	0
1: low	< 500	< 100	< 200
2: medium	500 to 5,000	100 to 5,000	2,000 to 25,000
3: high	> 5,000	> 5,000	> 25,000

Our overall Relative Importance (RI) measure was then calculated as follows:

$RI = (RA_{max}) + (RA_{mean}) + 1$

Where, RA_{max} is the maximum abundance score of any of the 5 salmon species;
RA_{mean} is the mean abundance score of all 5 species; and,
each score is rounded to integer values.

Adding 1 to the score makes 0 scores worth 1. The zero score indicates a stream that may have salmon runs (future or past) but for which there have been no observed salmon. Thus, they still may have some importance.

The RI range is therefore 1 –7.

Table 3: Examples of Living Oceans' RI

	Sockeye	Chinook	Coho	Chum	Pink		RAmax	RAmean	**RI**
StreamA	0	0	0	0	0		0	0	**1**
StreamB	1	1	0	0	0		1	0	**2**
StreamC	1	1	1	1	1		1	1	**3**
StreamD	2	1	0	0	0		2	1	**4**
StreamE	3	0	0	0	0		3	1	**5**
StreamF	3	3	2	2	2		3	2	**6**
StreamG	3	3	3	2	2		3	3	**7**

To get a better feel for how our RI measure works, consider the examples presented in Table 3.

Stream A represents the special case of a stream with 0 scores, where salmon are suspected to be present but have not been observed or counted. (RI = 0 + 0 + 1)

Stream B is a typical low abundance stream. Note that the RA_{mean} is 0, and that RI score is only created from RA_{max} , plus the obligatory 1.

Stream C is also a low abundance stream, but species richness gives it a non-zero RA_{mean} and therefore a higher score than B.

Notice the difference between streams C & E. C can be thought of representing species richness (variety of species present), but low abundance; whereas E can be thought of representing low species richness but high abundance. Had we simply summed the RA scores across species, stream C would have scored higher than E (5 vs. 3), even though E had an important sockeye run, and many more fish than C (at least 5001 vs. 796 (i.e. 99+99+199+199)). Our combined RI score accounts for salmonid species richness *and* abundance. Single species abundance is, however, given more weighting than richness with low abundance. That is, a river with one strong run (E) is given a higher ranking than one with several weak runs (C).

Commonly used diversity indices are based on the same principle as our RI as they also combine abundance with species richness. It is suggested that these information indices, such as the Shannon-Weaver Index, contain more information than species richness or the abundance of any particular species alone. Unlike these other measures, which are calculated on presence numbers, ours is based on a pre-determined abundance ranking per species. This ranking is justified based on the biology of the species (different species have differing ranges of abundance). Unlike diversity measures that generally favour evenly distributed species, we were also seeking to identify streams with large runs.

The Province's RA score was based on the *maximum* year, 1985-1994. Using the maximum implicitly allows for the restoration of runs / streams that may have recently collapsed. However, this is not the same as explicitly rating each stream or run with regard to its level of present degradation and/or threat. This is an important analysis that so far as we can determine has not been completed for the Central Coast (several emails to DFO scientists, 1999-2000). We view this as a significant gap in knowledge.

To view a map of this feature, please refer to Appendix 4: Maps of Data Layers.

E.4.2 SALMON HOLDING AREAS

(1 class)

Holding areas are those places where fish, usually adults, are known to congregate. Often they fall within a bay or behind a point of land that will provide a back-eddy from opposing tidal flow. Also, these are often favourite fishing spots. In terms of marine protection, they represent one kind of "bottleneck" whereby a species can be strategically protected.

The salmon holding areas layer covers only the South Central Coast and consequently was given very low weighting in our analysis. We included it so that we could track how many holding areas were captured in various solutions, without this feature driving the analysis.

The salmon holding areas layer is an aggregation of provincial point data (buffered 1000m) and local knowledge (polygons).

To view a map of this feature, please refer to Appendix 4: Maps of Data Layers.

E.4.3 HERRING (*CLUPEA PALLASII*) SPAWN

(1 class, weighted on a function of Habitat Spawn Index –shorelines)

Because of its importance as a commercial fishery, herring catch and herring spawn distribution have been well tracked since 1928. The north Central Coast herring stock is one of five major BC herring stocks. It is expected to remain healthy for the next few years, though may decline in the longer term (DFO 2001). The commercial herring roe fishery takes place in only a few concentrated areas of the Central Coast, yet it is the second largest in BC.

Because of their wide range, herring are not easy to protect through MPAs except when they aggregate to spawn. In British Columbia, reproduction occurs in the spring; generally March and April, eggs are deposited on intertidal and shallow subtidal vegetation and substrate. Although some spawning habitat characteristics are apparent, we do not fully understand why some areas are consistently chosen over other, seemingly similar areas (Hay and McCarter 2000). There are documented cases, however, where herring no longer spawn along shorelines that have been altered (SoE 1998). Re-establishment and enhancement of spawning habitat has not, to date, been successful (Hay and McCarter 2000).

In the fall the juvenile herring begin an offshore migration joining the schools of immature and maturing adult stocks (DFO 2001b). There are several, inter-related factors that affect the survival of juvenile and herring, or *recruitment*. Temperature, climate, current patterns, food availability, predation, and the amount and distribution of spawning are thought to be important factors controlling herring recruitment (SoE 1998; Mann and Lazier 1996; Campbell and Graham 1991). Spatial protection of spawning areas distributed throughout the Central Coast may help to ensure new recruits are available to the population.

At all stages of their lives, herring are an important link in marine food webs. Consequently, there are important ecosystem effects to the protection of spawning sites and the maintenance of healthy herring stocks. Annual herring spawn events also contribute greatly to the overall productivity of the local area (Hay and McCarter 2000). Invertebrates, fish and seabirds, and particularly ducks and gulls, are all predators of herring eggs (Hart 1973; Hay and McCarter 2000). Herring eggs and larvae are also important prey of Gray whales (Darling *et al.* 1998). Once herring have hatched, they become vulnerable to predators in the zooplankton such as jellyfish, chaetognaths, ctenophores and pilchards and other filter-feeding fish (Hart 1973; Purcell 1990; Purcell and Grover 1990). Adult herring are also main prey item that have been described as a major fodder animal of the sea (Hart 1973). They are fed upon by fish, sharks, whales, seals, sea lions, and marine birds (Hart 1973; SoE 1998). Herring are a considerable proportion of the diet of many commercially important fish species: lingcod (71%), chinook salmon (62%), coho salmon (58%), halibut (53%), Pacific cod (42%), Pacific hake (32%), sablefish (18%), and dogfish (12%) (SoE 1998).

Incorporating recurring herring spawning areas into a network of marine protected areas (MPAs) is critical to protect prime spawning habitat from destruction and alteration, supply sources of new recruits to the herring population to support marine food webs and commercial fisheries, and protect areas of high productivity and biological activity that result from the deposition of millions of fish eggs.

This has been a well-studied species with a fairly strong confidence level in the data. We assembled a layer of herring spawn distribution from previous datasets taking our shorelines from the provincial data (LUCO 1996) and updating the numbers with DFO data (2000). Certain shoreline segments required revision. These were examined by DFO (B.McCarter, various emails, Jan. 2001).

For more information on our hexagon fitting formula for herring, please refer to E.7.4.

To view a map of this feature, please refer to Appendix 4: Maps of Data Layers.

E.4.4 HERRING HOLDING AREAS

(1 class)

Holding areas are those places where fish, usually adults, are known to congregate. Often they fall behind a rocky reef or a ledge that will provide a back-eddy from opposing tidal flow. In terms of marine protection, they represent one kind of "bottleneck" whereby a species can be strategically protected.

The herring holding areas layer, like the salmon holding areas (E.4.2), covers only the South Central Coast and consequently was given very low weighting in our analysis. We included it so that we could track how many holding areas were captured in various solutions, without this feature driving the analysis.

The Herring holding areas layer uses provincial point data, buffered 1000m. These data are a result of interviews with DFO fisheries officers.

Mackinson (1999) studied herring shoals in the Central Coast as well as the Strait of Georgia. He found that Central Coast herring do not display the same tendency for holding as they do in Strait of Georgia. Shoals were denser, yet formed more temporarily as they would split into smaller schools and would sometimes regroup into large schools in different locations. A high proportion of the shoals in the Central Coast, however, were strongly associated with rises/drop-offs of rock outcroppings.

To view a map of this feature, please refer to Appendix 4: Maps of Data Layers.

E.4.5 CLAMS (SHORELINES)

(1 class, weighted 1-3)

Using a combination of survey and fishing data, we used these data not just to represent these commercial species' distributions, but also as a surrogate to indicate possible loose sandy / mud shorelines and related species assemblages –depending on exposure. Because different exposure regimes will harbour different biotic communities, clam shorelines were evaluated by region.

[Since the last analysis (Oct. 2000: trials3), we received data on shoreline types. These will likely be included in Trials 4, with the clams no longer acting as a shoreline surrogate.]

The clam data were aggregated from four DFO datasets: South Central Coast clam fisheries, North Central Coast clam fisheries (likely incomplete), the Clam Atlas (South Central Coast), and North Central Coast Geoduck Fisheries (incomplete). They required more than the usual number of GIS manipulations, which we explain below:

- The South Central Coast clam fisheries data were originally given a Relative Importance (RI) rating from 0-5. We re-classed these down to three RI classes: 1 (0,1); 2 (2,3); 3 (4,5). All other layers did not have any relative measures. They were assigned a Relative Importance value of 2.
- All layers were merged together.
- Layers were sorted such that in the case of overlapping layers, higher RI values superseded lower ones.
- The merged layer was converted to a grid. (Cell area = 0.2 hectares.)
- This grid was compared with our previously created "photic depth" grid. Clam areas deeper than 50m were considered inaccurate, and were removed.
- Because several different shorelines were used in the constituent data, they had to be fitted to a common standard. To accommodate most of the spatial variability, the grid was expanded by 2 cells (approx 100m). Then, it was clipped to the BC standard 1:250,000 shoreline.
- A grid of just the shoreline was created, with a Relative Importance value assigned to each cell.

Thus, the aggregate clam layer is a one-dimensional shoreline, though the original data were two-dimensional areal polygons of various sizes and scales. The conversion from the area to line measure was felt to more accurately represent the way in which the data were actually collected (i.e. intertidal surveys and use interviews). With the exception of the few (incomplete) geoduck polygons, we doubted the ability of the data to say much about areas below low tide, though we did clean up the merged polygons (up to 50m depth) for future application, if found to be appropriate.

While most layers in our analyses are ranked in our hexagonal grid on a scale of 1-36, the clams are ranked only 1-5. While this smaller range reduces the possible descriptiveness of the data, it also safeguards against false distinctions, reflecting our lower confidence in the datasets (see also p 62).

To view a map of this feature, please refer to *Appendix 4*.

E.4.6 KELP (*NEREOCYSTIS LUETKEANA* AND *MACROCYSTIS INTERGRIFOLIA*)

(1 class, weighted 1-3)

The kelp layer is a combination of the two main canopy-forming kelp species in British Columbia: *Nereocystis luetkeana* and *Macrocystis intergrifolia*. *Nereocystis*, or bull kelp, is an annual species that recruits opportunistically to disturbed areas (Watson unpublished). It grows rapidly and achieves its entire size in one growing season (O'Clair and Lindstrom 2000). Autumn storms eventually remove individual plants and eventually the entire bed, resulting in pronounced seasonal changes in bed density and biomass. *Macrocystis*, giant kelp, on the other hand, is a perennial species. It grows all year around and can live several years. Fall and winter storms do thin giant kelp beds but not as severely as bull kelp. Bull kelp tolerates a wider range of temperatures and salinity than giant kelp; however, both species require water that is relatively nutrient rich. As can be seen from the map in *Appendix 4,* they flourish in exposed waters and areas of good current and flushing, but are generally not found further up inlets where nutrient turnover is lower. It is not uncommon to have a mixture of kelp species in a given bed. In fringing kelp beds, bull kelp is often found on the outer edge of giant kelp beds since it grows in more exposed areas. Giant kelp forms a denser canopy than bull kelp, thereby inhibiting the growth of understory species of algae (Watson unpublished). In contrast, bull kelp's life cycle allows understory kelps to grow. Although kelp beds change seasonally in area and biomass, the composition and abundance of kelp beds is fairly constant from year to year (Watson unpublished). Kelp beds are an important habitat for numerous species of fish, invertebrates, birds and marine mammals, including rockfish, salmon, herring, lingcod, sculpins, sea urchins, abalone, crabs, pigeon guillemots, pelagic cormorants, great blue herons, seals, sea otters, and gray whales.

Macroalgae is easily visible and can be surveyed from air. 1993 aerial surveys were digitized for LUCO. Unfortunately, these were not easily fitted to existing land files, and were difficult to accurately register (Nicolson & Booth 1997). Furthermore, it is incomplete for the south Queen Charlotte Strait / Johnstone Strait region. To augment this layer, we added the Canadian Hydrographic Service "kelp" as taken from charts, digitized for the BC government. This layer does not distinguish between species.

In the process of digitization, these coverages were given relative importance ratings (RI 1-5) based on area, and relative abundance (RA 2-4), based on density noted from source documents. If not known, RA was set to 3 (Nicolson & Booth 1997). We merged all the layers, and summed the RI + RA. Any overlaps were ceded in favour of the higher score. We then reclassed the sum (3-9) into 3 classes only. It is felt that 3 classes is all the data can support. While some of the data separated out species, much was classed as “mixed” or “kelp,” and those that were separated out were almost invariably part of larger mixed patches. Therefore, we have grouped them together. All polygons were expanded approximately 150m, to allow for seasonal and data variability.

With the two layers combined and buffered, local knowledge still indicates areas missed, perhaps for reasons of scale, or seasonal variability. We have not attempted to add to this layer, however, but present it in light of these possible gaps.

To view a map of this feature, please refer to Appendix 4: Maps of Data Layers.

E.4.7 BIRDS

Bird data came from two sources: BC government and Canadian Wildlife Service. On closer examination, much of the LUCO source data originated from CWS personnel and interviews. However, the LUCO data appeared to be of a finer scale and were treated as the base layer, augmented with additional information from Canadian Wildlife Service, when they differed. [Note: We have recently received further seabird data –colonies and critical habitat– from CWS which will be incorporated in subsequent models.]

SEABIRDS: PELAGIC AND ALCIDS

The seabirds are divided into two groups: Pelagics, including porcellariformes and phalaropes; and Alcids: auklets, murres, puffins, and murrelets. Seabird habitat can be divided into two functional categories: nesting and feeding habitat. Important nesting sites are identified as High relative importance. These nesting sites, such as Triangle Island, are critical nesting habitat for several seabird species. For instance 70% of the worlds population of Cassin’s Auklets nest on Triangle Island (Cannings et al. 1999). Feeding habitat is also critical. Seabirds feed on plankton, such as euphausiids, and fish such as sandlance, herring, sauries, and juvenile rockfish (Cannings et al. 1999). Important seabird feeding areas can therefore also indicate areas of plankton and fish abundance.

For alcids, nesting sites were separated out as a separate class from feeding grounds. A high conservation target and penalty were applied to the nesting class, while a low target and moderate-low penalty were applied to feeding habitat. (For an explanation of conservation targets and penalties, refer to E.8.1.)

For pelagic species, however, because the nesting and adjacent foraging grounds tend to blur together, they were given two weightings: RI = 3 for Scott Islands and 5km to sea; RI = 1 for other feeding grounds. An overall moderate-high target and penalty were applied.

Marbled murrelets are the only alcid that nests in old growth trees (Cannings & Cannings 1996). They also endangered, and are discussed as a rare and endangered feature E.5.2.

To view maps of these features, please refer to Appendix 4: Maps of Data Layers.

WATERFOWL AND SHOREBIRDS

The waterfowl category includes all dabbling ducks, diving ducks, swans, geese, grebes and loons. Although species in this group breed inland; they use coastal areas during spring and fall migrations, or throughout the entire non-breeding season which can be between late summer (July-August) to mid May, depending on the species. Therefore, unlike the seabirds, we are just considering feeding habitat since they utilize coastal areas rich in food abundance and estuaries. Herring spawn is important food resource for some species of waterfowl, particularly Western grebe, oldsquaw, harlequin ducks, surf and white-winged scoter, great scaup, and common goldeneye (Nicholson and Booth 1997). Herring spawn areas are given high importance to reflect the use by waterfowl and other species (see E.4.3). Likewise, estuaries, which are rated for salmon (E.4.1) and eulachon (E.5.1), may also be important for water birds.

LUCO data (Nicholson and Booth 1997) for bird groupings was given relative importance (RI) ratings High, Medium, Low, based on abundance, modelled range, and observations. Low and medium are generally considered to represent habitat use, with the medium category suggesting more actual observations, while the low is based on modeling. The high category, on the other hand, can represent known critical feeding areas (Jacqueline Booth, pers comm). Because the high category is different from the other two, we have decided to map it as one feature, and the low/medium as another.

To view maps of these features, please refer to *Appendix 4*.

E.5 RARE AND ENDANGERED FEATURES (SEE ALSO D.7, ABOVE)

E.5.1 EULACHON *(THALEICHTHYS PACIFICUS)* –ESTUARIES

(1 class)

Eulachon are an ecologically and culturally important fish species (Hart 1973). Eulachon spawning areas in the Central Coast are limited (McCarter and Hay 1999). Although larval eulachon spend very little time (hours) in their natal streams, the associated estuary or inlet is important juvenile habitat. Eulachon streams and estuaries should therefore be considered for protection.

Eulachon are heavily preyed upon during spawning migrations by spiny dogfish, sturgeon, Pacific halibut, whales, sea lions, and birds. In the ocean, it is also preyed on by salmon and other large predatory fishes (Fishbase 2001, Pacific States Marine Fisheries Commission 1996).

Estuaries were identified from McCarter and Hay 1999, and digitized using a 2000m circular buffer from the centre point in the shoreline.

To view a map of this feature, please refer to Appendix 4: Maps of Data Layers.

E.5.2 MARBLED MURRELET *(BRACHYRAMPHUS MARMORATUS)*

(1 class, weighted 1-3)

Marbled murrelets, in the auk family, are on the provincial “Blue” list of vulnerable species. They may be moved to the “Red” list of endangered species in the near future since the marbled murrelet population has suffered an estimated 40% drop in the past decade alone (Cannings and Cannings 1996). Both natural and human-related factors may be contributing to the species' decline; potential causes include the loss of suitable nesting habitat, accidental death in gill-nets, oil pollution, increases in predator populations, and declines in food supplies due to recent El Nino events (SEI 1999).

Marbled murrelets lay a single egg on wide, mossy branch of old growth conifer trees (Cannings and Cannings 1996). Therefore, during breeding season, murrelets can be found foraging just offshore of old growth forests. Concentrations of foraging murrelets are sometimes found associated with tidal rips, high current areas, or river plumes. Researchers have identified a marbled murrelet juvenile nursery area in a semi-protected Nereocystis bed in Alaska (Kuletz and Piatt 1999). Although no similar areas have been identified in the Central Coast of BC, kelp beds in general are given a moderate-high target and penalty in the analyses.

Marbled murrelet data came from two sources: BC government and Canadian Wildlife Service. Most of the LUCO source data originated from CWS personnel and interviews. While there was considerable agreement on areas of high and moderate importance, the datasets differed significantly on suspected areas of use (low importance). To address this issue, we summed the two layers together, taking only areas of overlap for low importance areas, but keeping BC government areas of moderate and high importance regardless of overlap. The GIS details are as follows:

The BC government data were given values 1-3 based on their relative importance scores. The CWS data had not been given explicit importance rankings (though the comments elicited some sense of these), and were all given a value of 1. The 2 layers were summed together. The results therefore ranged from 0-4. The first two classes, 0 and 1, were discarded. The remaining 3 were re-classed as RI = 1,2,3.

To view a map of this feature, please refer to Appendix 4: Maps of Data Layers.

E.5.3 SEA OTTER *(ENHYDRA LUTRIS)*

(1 class)

Sea otters were once abundant throughout the Northeast Pacific but were hunted to near extinction from the mid-1700's to early 1900's. Apocryphally, the last known sea otter in British Columbia was accidentally shot in 1929. Between 1969 and 1972 eighty-nine sea otters were reintroduced to Checleset Bay off northwest Vancouver Island and the population has been increasing at a rate of 17 percent per year (Estes 1990; Watson unpublished). The sea otter's range has also been steadily increasing. They can now be found between Barklay Sound and the North end of the Island, and in the Goose Group islands and Hakai Recreational area, near Bella Bella (Nicholson and Booth 1997; Watson unpublished). Their current range in the Central Coast is unknown; however, they may extend north of the Stryker Group (J. Watson, personal communication). Presently, the only known established colony in the Central Coast is in the Goose Islands.

Sea otters are important predators of invertebrates such as sea urchins and have been shown to play an important ecological roll as a keystone predator (Estes 1990).

Unlike other marine mammals, sea otters do not have a blubber layer. They rely on their fur to keep warm and are therefore particularly vulnerable to oil spills, even minor ones. Several thousand (approx. 5000) sea otters died in the 1989 Exxon oil spill in Valdez, Alaska (Marine Mammal Center 2000).

E.5.4 HEXACTINELLID SPONGE REEFS

(1 class, weighted 2 or 3)

Hexactinellid sponge reefs are unique to the BC coast and are important in terms of their ecology and their similarity to extinct Mesozoic sponge reefs. There is already evidence that they have been damaged by bottom trawling (Krautter et al 2001, Conway 1999). We strongly support the recommendations of both Conway and Krautter, who suggest that these sponge reefs be permanently protected from trawling. There is one known sponge reef complex in the Central Coast, of only four in the world, all of which are in BC waters.

Data were received from Natural Resources Canada. Polygons were cleaned. Upon consultation (K. Conway, pers comm 2001), we determined the following weighting: Areas found to have complete coverage of sponges were given a weighting of RI = 3, and those of incomplete coverage were weighted RI = 2.

In the spring of 2002, while setting a mooring to monitor one of the last undisturbed mounds, researchers discovered that it had been trawled since the previous visit (K. Conway pers comm. July 02). There followed an outcry that led to these areas being closed to groundfish trawling. However, they have not yet been given any permanent protection, such as MPA status.

To view a map of this feature, please refer to Appendix 4: Maps of Data Layers.

E.6 DATA GAPS

Our model has been designed to easily accept data as they become available. Ideally, we would like information on many more species and processes. While the “wish list” is virtually endless, priority datasets that are also somewhat within the realm of possibility include: Groundfish (esp. *Sebastes* spp.), eelgrass (*Zostera spp*), geoduck (*Panopea generosa*), better substrate, better current, dissolved oxygen (esp. benthic). Invertebrates as a whole are poorly represented, as are key trophic species such as sandlance (*Ammodytes hexapertus*).

While we feel that MPA design cannot afford to wait for better data, it could only benefit by any additions. We will incorporate new data or improved data as they become available.

These data gaps are explained below:

GROUNDFISH DISTRIBUTIONS

Few scientific surveys exist for the Central Coast groundfish. Therefore, distribution is generally inferred from fisheries use. While we have some observer data, it is of a short time period (1996 – 2000), and is spatially coarse (DFO statistical sub-areas). Furthermore, it mixes halibut landings with those of rockfish, even though the habitat requirements are fairly distinct. A much longer time series GIS layer could be assembled from logbook data. No one at DFO has apparently done this, though it is apparently being considered. The logbook data is considered confidential, and therefore out of our reach. Provincial coverages of the fishery are incomplete for the Central Coast.

Rockfish stocks are declining. MPAs are indicated by DFO as one likely tool to assist rockfish recovery (DFO 2000, Kronlund et al 1999). Presently, we are relying on our benthic complexity measure to identify rocky reef habitat, and our kelp data to indicate juvenile refugia.

EELGRASS

Eelgrass beds are considered by the Department of Fisheries and Oceans to be critical salmonid habitat, as well as being important to a variety of other organisms. The province has aerial video taped the shorelines, from which some biological “banding” data were produced. These were recently given to Living Oceans Society, and will likely be incorporated in our next analysis. DFO is planning to do some pilot surveys using underwater video in 2002, though it is unclear at this stage whether comprehensive surveys will proceed (B. Mason pers comm Dec. 01). A BC eelgrass mapping initiative has begun, composed of governmental and non-governmental organizations including Living Oceans Society, but it is mostly focussed on the Strait of Georgia at this time.

GEODUCKS

The Geoduck Harvesters Association in collaboration with DFO has done extensive dive surveys identifying geoduck habitat. Unfortunately, these are considered confidential.

Better Substrate Data

The substrate data used in this analysis are really too coarse in scale and in classification (3 classes only), to effectively define habitat at 1:250,000. We recommend data of better resolution and more classes.

Better Current Data

The present provincial "High Current" designation (as used in this analysis) is insufficient to identify several current related features. Improved comprehensive current modelling could yield an intermediate classification (0.5-3 knots, say) that would help separate well-flushed areas that could be expected to have good nutrient transfer and oxygenation from stagnant oxygen-poor areas.

Benthic (bottom) currents would be valuable to better understand the benthos, and help delineate these habitats, though this gap will probably never be filled.

Dissolved Oxygen (DO)

Recognized universally as an important measure of pelagic and benthic marine habitat, DO readings have been taken in several BC waters over the past decades. However, to the best of our knowledge, these have neither been comprehensively collated by the agencies involved (e.g., DFO, University of British Columbia, BC Museum), nor have they been digitized. Geo-referenced DO readings for the benthos in our inlets would serve as a valuable measure to better classify them.

Key Trophic and Forage Species Distribution Data

For example:

- Sandlance (key to many inshore species and pelagic birds)
- Capelin (possibly linked to the local migration patterns of whales and dolphins)
- Phytoplankton (distribution is poorly covered, with most studies outside the Central Coast e.g., West Coast Vancouver Island).

Invertebrate Distributions

Invertebrate data are almost non-existent for the vast majority of species. Shellfish data are limited to shorelines, though we know their distribution goes beyond this. The inlets are known by divers and scientists to harbour a wide variety of rare and endangered invertebrates (Austin 1999), and yet few efforts have been made to survey them, and none at a wide-ranging scale.

Pinniped Locations (Seals and sea lions)

Previously, we noted these as a data gap. However, we are pleased to report that after about two years of requests to DFO, we have recently received some spatial datasets on seals and sea lions. While too late for the present analysis, we are considering their inclusion in a future version. There appears to be some discrepancies with local knowledge, which we are reviewing.

E.7 REPRESENTING DATA IN PLANNING UNITS

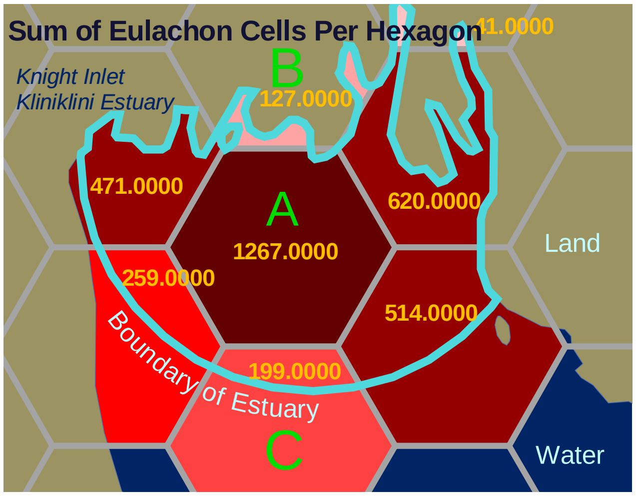
To get an accurate picture of how abundant a feature is within a planning unit (hexagon) we considered two factors:

1. How much of it is there
2. How much of it could there be there (i.e., its possible maximum). In our analysis this often equals the amount of seawater contained in the hexagon, but for shoreline features would be a total measure of shoreline per hexagon.

Considering just the summation of a feature's presence (point #1) would unfairly penalize hexagons that had full 100% presence of the feature, but not 100% water. This situation might prove to be important when, for example, the nearshore component plays a critical role, such as in estuaries. In this situation, a planning unit is very unlikely to contain but a fraction of its area as water, and yet may play a far more important functional role than an offshore planning unit with the same amount of the feature, but surrounded by water (See Figure 8).

In our model we make allowances for how much water is available per planning unit, accounting for feature density, as well as occurrence.

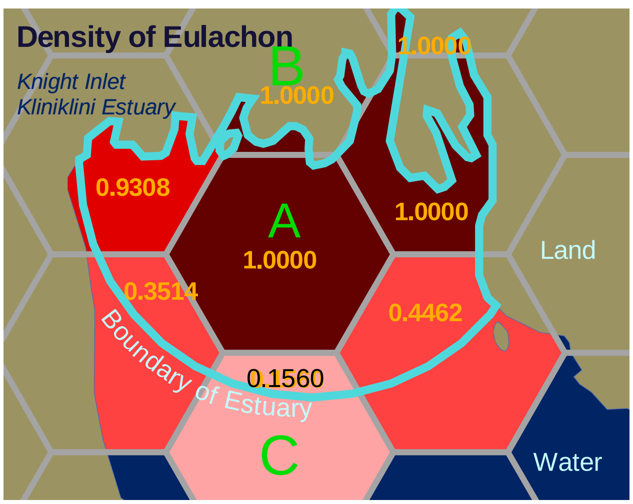
Figure 8: Fitting Data within Hexagons



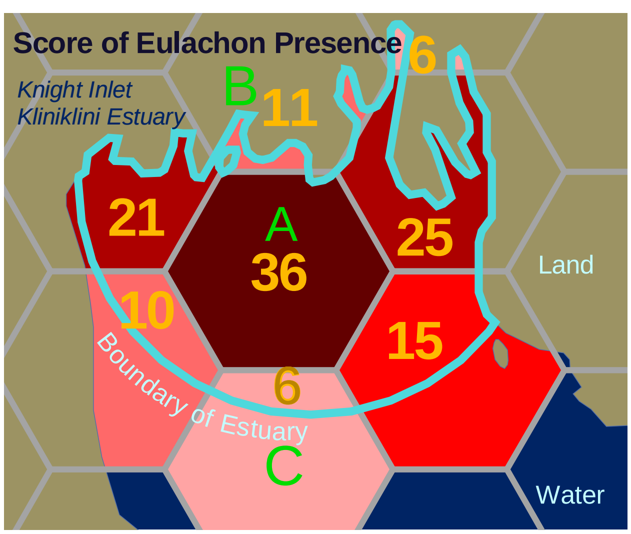
To the left is a view of a well known eulachon estuary. Eulachon runs, including this one, have recently collapsed...

Consider the three hexagons, A, B, C. (They are 250 ha. each.)

If one were just to sum the number of feature grid cells that fall into each, B & C are markedly less "valuable" than A. But, is this their true value? B does, after all, contain those valuable nearshore bays...



In this second map, notice that hexagons A and B include the eulachon estuary for all of their available cells; i.e., for all water. C, on the other hand has only 16%. So, on a basis of density, A & B are more valuable than C, which answers the above concern regarding nearshore habitat. But is this a fair reflection of their values? C, after all, has 57% more feature cells than B, and yet has a score over six times lower... Consider as well that the boundary that divides C in two is, of course, somewhat arbitrary...



Multipying the above two examples produces hexagons with the relative shades of red in the third map. It gives scores whose values represent a component from each of the above two maps. We take the square root which compresses that score to more represent a single dimensional relative measure. This also absorbs some data variability, including the somewhat arbitrary nature of boundaries. Thus, the resulting score places value both on density and numbers, with due regard for variability.

C has half the value of B, which seems "right," since C is on the outside and B is at the mouth of the estuary. A, dead centre, is most valuable of all.

E.7.1 PRESENCE / ABSENCE AREAL DATA

For presence / absence data, the formula we generally used is:

$$\text{HexScore}_{f(presence)} = \sqrt{((\Sigma f)^2 / N_f)} \qquad \ldots\ldots 1$$

Where f is the feature occurrence (presence = 1, absence = 0); thus $\sum f$ is the sum of all feature cells;

And N_f is the total number of possible feature cells –which is usually the same as the total number of water cells.

Another way to state this is:

$$\text{HexScore}_{f(presence)} = \sqrt{(\Sigma f * f_{mean})} \qquad \ldots\ldots 2$$

Where f_{mean} is the mean value of that feature, wherever there is water. For presence data, this is the same as density as discussed above.

In English, this translates to: "The sum of the feature multiplied by the density of that feature in the planning unit."

The square root is used to compress the scores, to avoid data variability inappropriately influencing the selection process. (It can also be thought of as reducing a two dimensional score down to one.)

For presence / absence features, the scores can range from 0 to 36 per hexagon.

For weighted ("Relative Importance" –RI–) features, the above formula is multiplied by the mean of the feature cell weightings:

$$\text{HexScore}_{f(RI)} = \text{HexScore}_{f(presence)} * RI_{mean} \quad \ldots\ldots 3$$

Where, $RI_{mean} = \sum f_{(RI)} / N_{f(presence)}$;

And $\sum f_{(RI)}$ is the sum of all the RI feature cells

And $N_{f(presence)}$ is the total number of presence feature cells.

E.7.2 LINE AND POINT FEATURES

The above formulae were used for most of our two-dimensional areal features (GIS "polygons"). For line features, we used the same formulae, except that N_f represents the total number of possible shoreline cells, instead of water.

Point features were all given buffers to convert them into appropriate areas, and then were treated as above.

E.7.3 EXAMPLES

To illustrate all of the above, consider the following simple example: There are two hexagons, both with 400 feature cells (0.2 ha. grid squares) that note presence of a species. The first one is half water (total available cells = 638), while the second is all water (total available cells = 1275). Thus, in the first hexagon the feature is twice as dense as the second. Using the above presence / absence formula (1), we would find that a hexagon with the same number of feature presence cells but half the water would get a score $\sqrt{2}$ or 1.4 times higher than the second hexagon. The rounded scores would be: 16 and 11, respectively.

Consider instead that both hexagons were 100% water, but the features of the first were weighted twice as much as the second (RI=2 vs. RI=1). In this case, the first hex would be scored twice as high as the second, since weightings are considered outside of the square root. Their rounded scores would be: 22 and 11, respectively.

E.7.4 EXCEPTIONS

For certain datasets, the above formulae were not appropriate. These included herring spawn and clam beaches.

HERRING SPAWN SHORELINES

To analyse herring spawn shores, we used the Department of Fisheries and Oceans (DFO) Spawn Index (SHI). The cumulative Spawn Habitat Index is calculated by the sum of the product of each measured spawn length and the median of the product of spawn width and egg layers (spawn thickness) pooled geographically. This makes it essentially a three-dimensional score, though the spawn length has been given greater weighting due to a greater confidence in this dimension (Hay & McCarter 2001). The scores for the Central Coast ranged from less than 10^1 to over 10^6. The formula we used to fit the data to hexagons is:

$$\text{Score (per hexagon)} = \sqrt[3]{((\sqrt{\text{SHI}} * N_{spawn}) / N_{shore})}$$

Where, SHI = Spawn Habitat Index (2000)
N_{spawn} = Number of grid cells with herring spawn shoreline in the hexagon
N_{shore} = Number of grid cells that are shoreline in the hexagon

Thus, like our regular shoreline formula, we examined the Spawn Habitat Index by its shoreline density per hexagon. However, unlike our regular approach, we took a square root of the SHI to transform the scores a more normal distribution, and a cube root of the result to reduce data variability, effectively reducing it from a three dimensional score to one dimension. The range of scores produced was 1 – 42 per hexagon, which is similar to the 1 – 36 range produced by our regular presence / absence formula. Considering the long time frame of the herring data (1928 to present, with some changes in methodology however – Hay & McCarter 2001) we felt this layer could support the six additional classifications. Indeed, we view herring spawn as one of our most reliable datasets.

CLAM BEACHES

Unlike the herring spawn data, our clam data were weak (north Central Coast only). After applying our regular shoreline formula, we re-classed the results into six classes, 0-5. (Raw scores ranged from 0-34.) Hexagon re-classed scores of 0 (raw scores <3) were considered insignificant, and were dropped. Thus, the final range was 1 – 5. We feel this data layer is not strong enough to justify any greater precision. (See also E.4.5)

E.8 SETTING UP MARXAN

MARXAN has several parameters to look at when determining whether a particular planning unit (and its associated features) is or is not included in the final reserve network:

1. **Conservation Targets**: How much of a feature is aimed for in the MPA network.
2. **Penalty Values**: How much cost is accrued for not attaining the conservation target.
3. **Minimum Separation Distance**: The minimum distance that distinct groupings of a feature should be from one another.
4. **Separation Number**: The number of distinct groupings of a feature required (i.e. replication).
5. **Minimum Clump Size**: The minimum number of planning units (hexagons) needed to count as a valid grouping of the feature.
6. **Planning Unit Cost**: A relative value applied to planning units such that some may be more difficult or “expensive” to set aside than others.
7. **Boundary Cost**: The relative cost of the planning units’ shared boarders.
8. **Boundary Length Modifier**: The relative cost of a reserve’s perimeter.

In addition, one must set the parameters that control the stochastic “annealing” curve during the selection process, how many iterations will make up a single run, and whether other selection algorithms will be appended to finish off selections begun using simulated annealing.

We discuss these parameters below.

E.8.1 CONSERVATION TARGETS & PENALTIES

Fitting the features onto the hexagons brings us one step closer to choosing hexagons for possible MPA networks. However, before this can be accomplished, one must still decide:

1. How much of a feature is “enough;” and,
2. How much it matters if this much is *not* collected.

Setting “Conservation Targets” addresses the first concern. Setting “Penalties” addresses the second. With regard to site selection algorithms: *Penalties direct the relative search effort for a feature, whereas targets set the end-point of that search.* Although generally targets and penalties match each other, this is not always so (see Table 5).

In our trial analysis we expressed all conservation targets as percentages of the total feature. We examined targets that produced overall reserves from 5% – 50% of the study area. These equated to having “moderate” targets that ranged from 6% – 60% (see Table 4). Once a target is met, the algorithm will not try to collect any more of it, though in some cases more may be acquired while collecting other features. We did not assign any penalties to features that were over-represented.

Penalty values determine how much cost is accrued for not attaining the conservation target. This is a factor that diminishes as the target is approached, based on an estimation of the cost required to fully meet the feature’s conservation target. As such, the actual penalty applied tends to be higher than optimum. Generally, we used the penalty value as a relative factor to reflect the relative importance of a feature, and sometimes to also reflect the relative confidence in that dataset or its spatial completeness, as compared to others.

Before choosing actual percentages, we examined each dataset and assigned to it a conservation target and penalty, using relative terms, where “moderate” was taken as the common baseline or average value. The five terms used were: *low, moderate-low, moderate, moderate-high, high*. By using these five simple qualitative rankings, we were able to class the features relative to each other, then implement a range of actual numerical targets and observe the effects. Such a strategy (though not in the context of MARXAN) has been suggested by Levings and Jamieson (1999) as “dimensionless scores,” to be used to meet various criteria such as distinctiveness, and naturalness. The addition of the computer software allows for quick feedback between the dimensionless measure and the actual target numbers as percentages of the whole (Table 4).

In general, we assigned lower penalties to those datasets in which we had lower confidence. We did not want these datasets driving the analysis. We assigned higher penalties to rare, threatened, & endangered species, as well as to features that had high importance conservation values (such as bird nesting sites). We chose our targets to reflect both the scarcity of the feature (higher target) and whether it represented just itself, or acted as a surrogate for several species assemblages (e.g., kelp or complexity). For a widespread regional feature such as depth-substrate, we examined the distribution of classes per region and then determined appropriate targets for them (see Figure 9 below).

Table 4 outlines how these qualitative measures translated into quantitative conservation targets and penalties for our most recent runs (Trials3). Notice that we treat rare features separately from other ones. Also, note that while most features are assigned a “moderate” target, the overall reserve network size is consistently smaller (83%) than that target. This is because the conservation targets reflect not just spatial area, but may also reflect the weighting of “Relative Importance” scores for that feature in different areas. These may include non-spatial use values such as nesting, breeding, foraging, and so forth.

Table 5 lists the features analyzed in Trials3, and their respective relative targets and penalties.

Table 4: Targets & Penalties per Network Size

Total Reserve Size	5%	10%	20%	30%	40%	50%	
Conservation Targets							*Penalties*
Low	2%	4%	8%	12%	16%	20%	*0.25*
Moderate-Low	4%	8%	16%	24%	32%	40%	*0.50*
Moderate	**6%**	**12%**	**24%**	**36%**	**48%**	**60%**	***1.00***
Moderate-High	8%	16%	32%	48%	64%	80%	*1.50*
High	10%	20%	40%	60%	80%	100%	*2.00*
Rare Low	*Not Used*						
Rare Moderate-Low	15%	20%	30%	40%	50%	60%	*1.50*
Rare Moderate	30%	35%	45%	55%	65%	75%	*2.00*
Rare Moderate-High	45%	50%	60%	70%	80%	90%	*2.50*
Rare High	60%	65%	75%	85%	95%	100%	*3.00*

Table 5: Feature Targets & Penalties

Feature Name	Target	Penalty
herring spawn	moderate	moderate
herring holding	moderate-low	low
herring fishery roe	none	none
salmon streams	moderate	moderate
salmon holding	moderate-low	low
salmon fishery net	none	none
macroalgae (kelp)	moderate-high	moderate-high
bird: pelagic	moderate-high	moderate-high
bird: alcid high	high	high
bird: alcid low	low	moderate-low
bird: waterfowl high	high	high
bird: waterfowl low	low	moderate-low
bird: shore high	high	high
bird: shore low	low	moderate-low
sponge rare	rare: moderate-high	rare: moderate-high
mamu rare	rare: moderate	rare: moderate
eulachon rare	rare: moderate-high	rare: moderate-high
sea otter rare	rare: moderate-high	rare: moderate-high
clam outside	moderate	moderate
clam passage	moderate	moderate
clam inlet	moderate	moderate
complex outside	moderate-high	moderate

complex passage	moderate-high	moderate
complex inlet	moderate-high	moderate
current outside	moderate-high	moderate
current passage	moderate-high	moderate
current inlet	moderate-high	moderate
outside hard photic	moderate	moderate
outside hard dysphotic	moderate	moderate
outside hard bathyal	moderate	moderate
outside sand photic	moderate	moderate
outside sand dysphotic	low	moderate
outside sand bathyal	moderate	moderate
outside mud photic	moderate	moderate
outside mud dysphotic	moderate	moderate
outside mud bathyal	moderate	moderate
outside offshore	moderate-low	moderate
outside inshore	moderate	moderate
passage hard photic	moderate	moderate
passage hard dysphotic	moderate	moderate
passage hard bathyal	moderate	moderate
passage sand photic	moderate	moderate
passage sand dysphotic	moderate	moderate
passage sand bathyal	moderate	moderate
passage mud photic	moderate	moderate
passage mud dysphotic	moderate	moderate
passage mud bathyal	moderate	moderate
passage high mixing	moderate	moderate
passage mod. Mixing	moderate	moderate
inlet hard photic	high	moderate
inlet hard dysphotic	high	moderate
inlet hard bathyal	high	moderate
inlet sand photic	high	moderate
inlet sand dysphotic	high	moderate
inlet sand bathyal	high	moderate
inlet mud photic	low	moderate
inlet mud dysphotic	low	moderate
inlet mud bathyal	low	moderate
inlet low freshwater	moderate	moderate
inlet mod. freshwater	moderate	moderate
inlet high freshwater	moderate	moderate

SETTING THE DEPTH-SUBSTRATE TARGETS

Most data distributions in our analyses are restricted to a small proportion of the study area. Depth-substrate, however, cover it completely. Placing them into the three regions creates 27 (3 classes depth x 3 classes substrate x 3 regions) unique features. Considering there are a total of 61 features in the Trials3 analysis, this gives substrate-depth features considerable influence. This influence can be used positively to help ensure that a widespread and even spatial distribution of the study area is achieved. However, the depth-substrate distributions are not at all similarly distributed. Thus, we felt some care should be taken in choosing their target values.

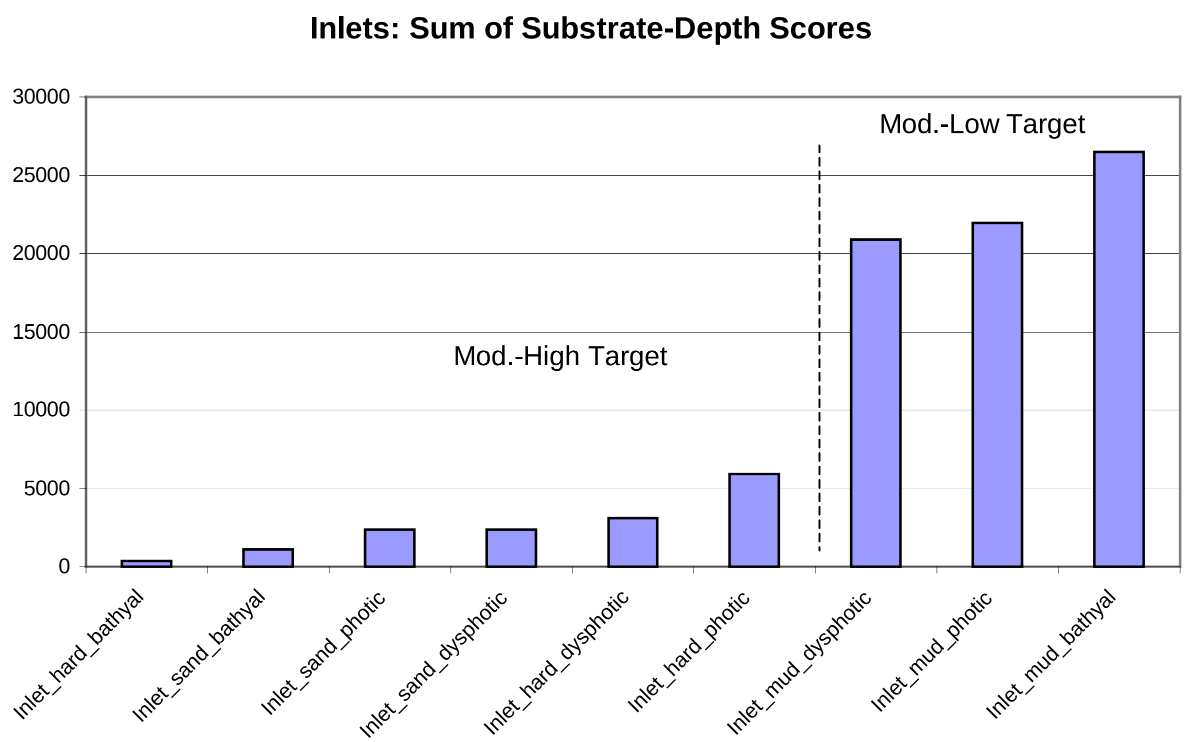
While we recognize the importance of representing all features "evenly," there must also be consideration given to less common and perhaps especially valuable (because of that uncommonness) features. Furthermore, those features with broad distribution can, by their sheer volume, eclipse other smaller ones in the selection procedure. If we don't correct this bias, we could end up with a marine equivalent of the "rock and ice" problem in some terrestrial protected areas where ecologically less productive areas such as mountain tops are set aside, while the smaller more valuable verdant valley bottoms remain open to exploitation.

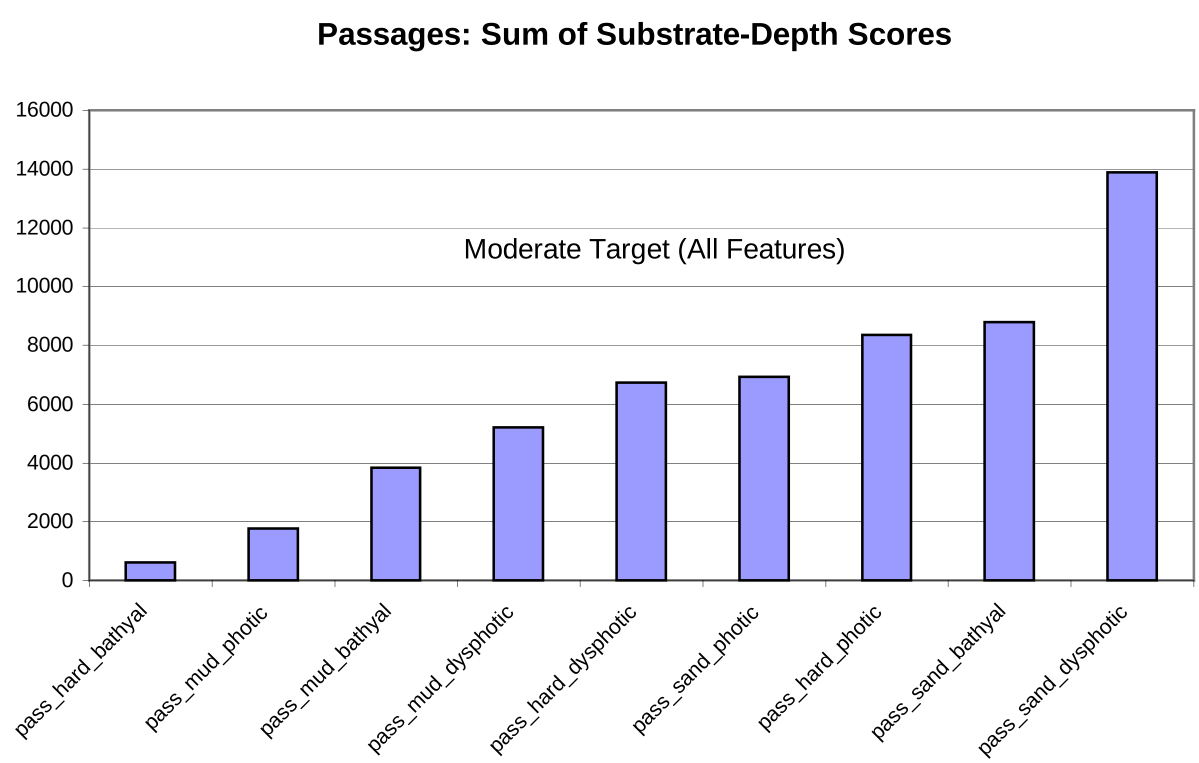
We examined substrate-depth features by region, looking for break points in the data. As can be seen from Figure 9, the distributions vary dramatically. This is encouraging, as it suggests that the three regions are markedly different, and that they are therefore justifiably separated. The data themselves may or may not have obvious breaks. Inlets obviously do; Passages apparently do not; Outside Waters has a preponderance of one feature (sand-dysphotic).

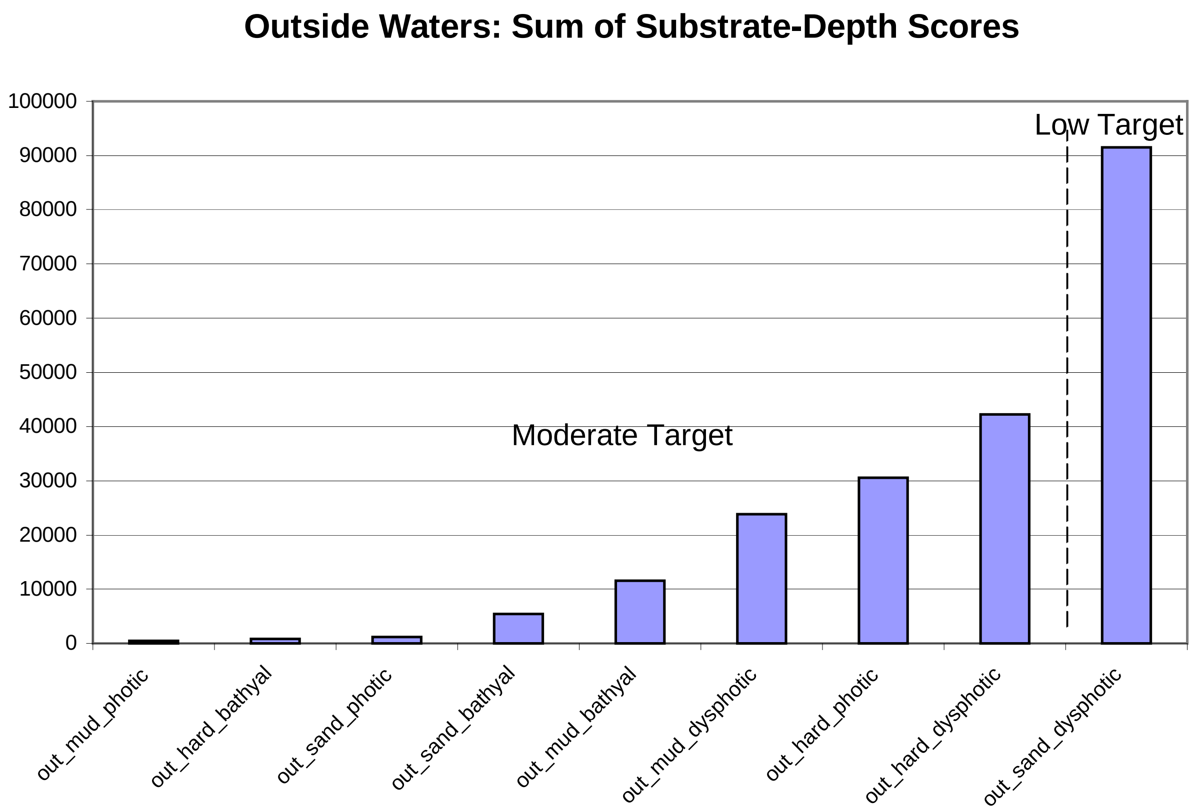
While it might be tempting to raise the targets of the lowest items in all regions, we have chosen to refrain from doing so as we are not convinced that these numbers do not reflect to some degree data error (i.e., misclassification), and the tails of a normal distribution. Furthermore, in absolute terms (x-axis: number of grid cells), even the barely noticeable columns in the Outside Waters chart are represented in comparable numbers in the other two regions. The relative target assigned to each depth-substrate grouping is noted on the figures below.

The penalties for all depth-substrate features were left at "moderate."

Figure 9: Distribution of Depth-Substrate







E.8.2 SEPARATION DISTANCE, NUMBER, & CLUMP SIZE

- Minimum separation distance: The minimum distance that distinct groupings of a feature should be from one another. This allows that the MPAs are spaced far enough apart to provide safety against localized disasters. Physical and rare features were generally assigned 10 km., while biological features were given 15 km. This measure is "as the crow flies," not as the fish swims. As such it was not very relevant to our heavily crenulated coastline (thus the rather arbitrary distances chosen). For most of the Central Coast, ecological separation is determined by geographic boundaries such as headlands, and especially the inlets. While MARXAN does not presently allow for regional separation targets, we partially achieved this goal by sub-classifying the inlets and passages based on physical processes, and then setting conservation targets for those spatial features. This ensured that a variety of geographically distinct sub-regions were selected in each network solution.
- Separation number: The number of distinct groupings of a feature required (i.e. replication). We generally used 3. In principle this target is to provide spatial insurance against localized catastrophes, such as oil spills. However, this factor could not explicitly consider whether the feature occurred within one spatial ecological region (such as an inlet), or several. We relied on our regions and sub-regions to provide this sort of spatial insurance. Without detailed current modelling, we see no to way explicitly test if these assumptions have been met.

- Minimum clump size: The minimum number of planning units (hexagons) needed to count as a valid grouping of the feature. Generally we left this set to 1 (250 ha.), but used 2 for the eulachon estuaries, where 2 hexagons (or more) was thought to more effectively capture this rather solitary feature. Note that most features tend to naturally group anyway, and so clump size has not been an issue in this model. Furthermore, due to its fluid nature, the marine environment is less prone to the effects of island biogeography on species population viability as accepted in terrestrial conservation (MacArthur & Wilson 1967).

E.8.3 PLANNING UNIT COST, BOUNDARY COST, & BOUNDARY LENGTH MODIFIERS

- Planning unit cost. For our analyses all planning units were deemed to have the same cost (=1). However in future runs, we may adjust this number to reflect use-conflict areas. This is a tricky variable to use correctly, however, as that these costs are meant to balance the conservation values gained. Unless all scores are normalized across the board, unsatisfactory results can occur. (Apples and oranges.) We are also investigating other ways to incorporate use levels into the analysis. One way would be to run a completely separate use analysis with MARXAN, and then to apply spatial algebra to the two resultant datasets, conservation and use, to come up with a composite picture. We are leaning towards this approach.
- Boundary cost: The relative cost of the planning units' shared boarders. These were 1.0 for Outside Waters, 0.75 for Passages, 0.5 for inlets, and 0 for land. Keeping land to zero ensured that inefficiently shaped reserves that were constrained by land were not unduly penalized (since no other shape was possible). Since the Central Coast is characterized by many such places, land exerts a considerable influence in reserve shape. While setting the land to zero removes some disincentive to such reserves, it does not remove all, since long narrow shapes still have a higher perimeter to area ratio (*see BLM, below*). That the Outside Waters, Passages, and Inlets have different costs reflects the different scales of the processes that occur in these regions, moving from broad-scale pelagic to finer scale estuarine. This in turn will effect how clumped the reserves are in these regions, with smaller clumping occurring in the Inlets. The relative ratios of 1, ¾, and ½ were arrived at by experimentation, visually judging whether the known resources of each region were being over or under-characterized by the chosen reserve shapes. This is a conservative solution that could be more rigorously applied based on the shoreline to water area ratio, which is much more dramatic than the present ratios chosen. However, we had some concerns that applying some form of this ratio would make the reserves unmanageable; that is, the reserves in the inlets would be too small and many. This is still under investigation for our next trials. Adjusting the boundary costs did not radically change the solutions produced; rather, it was a fine-tuning measure. This is part of our response to the many issues surrounding oceanic variability (both over space and time). We hope to more explicitly address data variance and process scale in subsequent models. This parameter works in concert with BLM, below.

- Boundary Length Modifier (BLM): The relative cost of a reserve's perimeter. Higher costs will force larger (but fewer) reserves, whereas a low cost will allow for several small ones. We have explored a wide range of this parameter (BLM= 0.004, 0.008, 0.016,… 8.000) but have focused on four to cover the range from fragmented to moderately clumped (BLM= 0.111, 0.333, 1.000, 3.000) This is an arbitrary parameter that must be arrived at through experimentation. Through investigating this parameter, we also arrived at a methodology to estimate network efficiency versus reserve size, or "SLOSS" (single small or several large). This we discuss in our *Results* section (F.2). While we found that reserves using a BLM near 1.0 offered good efficiency with realistic manageability, we also discovered that the more fragmented solutions (which more truly represented the densities of conservation values) were valuable when summed together to show trends or "hotspots."

  As solutions progressed from scattered to clumped, they behaved predictably, shedding smaller reserves and aggregating onto the larger ones. This would indicate that the model is robust to this parameter.

E.8.4 ANNEALING AND HEURISTICS

Each MARXAN run consisted of 10,000,000 iterations of the simulated annealing algorithm (C.6.2). The annealing schedule was arrived at by experimentally observing the results as they developed while the program was running ("verbose mode"). This fixed schedule was found to produce better results than the automatic "adaptive" schedule. Generally, it was found that setting the annealing schedule was a delicate operation that required some patience, and that it could easily be set incorrectly. Because of the many iterations, we could both widely explore the global decision space ("hot temperatures") and have time at the critical lower temperatures to fully refine the reserve selections.

We used "summed irreplaceability" to finish off approximately the last 25% of the overall reserve size, and followed that by "iterative improvement" to check each planning unit for its utility in the final design (Ball & Possingham 2000). The irreplaceability heuristic examines how necessary each planning unit is to achieving the conservation targets for each feature: The more planning units that can meet a particular target, the lower that particular feature's irreplaceability within that hexagon. This irreplaceability heuristic improves upon the final reserve network, ensuring that both richness and rarity are accounted for. In combination with simulated annealing, a wide variety of possible solutions can be examined. Unlike "product irreplaceability," whereby the scores are multiplied, summed irreplaceability is more robust to weak or inaccurate data.

The resultant selection for each run was fine-tuned using the iterative improvement algorithm that examines each chosen hexagon individually and considers whether the reserve network's score would suffer more from its exclusion.

[The latest release of MARXAN (1.8, as of Feb. 2002) offers more flexibility in the iterative improvement algorithm than was available in version 1.2 when our trials were run. This will be examined in Trials 4.]

F Analyses & Results

Over the past year, we have run several thousand analyses of the Central Coast (each of 10 million iterations) in three sets of "Trials." Our initial results (Trials1) were completed in January 2001 and presented in a satellite meeting at the American Association for the Advancement for Science AGM, in February. Those results were published in our first white paper on the topic (Ardron et al 2001). A refinement of that analysis (Trials2) was presented at the Second Symposium on Marine Conservation Biology (June 2001), and the Society for Conservation GIS annual conference (July 2001). The results in this present document represent a summary of our work to date including a third series of analyses (Trials3) based on feedback from the previous two, as well as refinements of our own. Trials3 was presented at the MPA PowerTools conference Oct. 21, 2001, hosted by Living Oceans Society in White Rock BC.

We fully intend to continue refining the model's parameters and to add new data as they become available. Thus, Trials3 will be followed by a fourth series, likely in early 2003.

Over the course of the three trials, we have investigated:

1. **Conservation Hotspots:** Regardless of whether MPA networks are small or large, scattered or clumped, certain areas are identified repeatedly over the course of thousands of runs. While these areas alone would *not* constitute a fully representative Central Coast MPA network, it is very likely that without them, such a network would be difficult or impossible to achieve. We have named these areas "conservation hotspots."

2. **SLOSS:** (Single Large or Several Small?) We have developed a procedure to aid in the design of efficient reserve networks. This can produce a quantifiable range of compromises between many small scattered MPAs and a few large ones.

3. **Conflict:** Conflicting values, such as biodiversity requirements, declining stocks, and widespread fishing effort, that would appear irresolvable to a human planner, are also irresolvable to a computer model. However, modeling does provide candidate networks of MPAs that can be the basis for discussion in a planning process, where outstanding conflicts and other issues may be resolved.

4. **BC Marine Parks:** Most of BC's marine parks, ecological reserves, and recreation areas could be effectively incorporated into several possible networks of MPAs. The exception is Hakai Recreation Area, which owing to its large size and scope does not fit in very well; however, portions such as the Goose Islands could do so.

F.1 CONSERVATION HOTSPOTS

Rather than just examining one set of model parameters, we have chosen instead to look at a range of different reserve sizes and a range of reserve fragmentation. From these, we then examined the results for emergent trends. Thus, rather than debating what is the “right” percentage to set aside, or whether larger reserves are better than several smaller ones, we have hopefully avoided these arguments for the time being by focussing on those areas that emerge under a variety of conditions. Those areas that were selected repeatedly we interpret as having a high “utility;” that is, usefulness, to marine reserve network design.

F.1.1 24 SCENARIOS; 2,400 SOLUTIONS

We examined 6 reserve network sizes: 5%, 10%, 20%, 30%, 40%, 50%. Generally, 10% to 50% reflects the range of reserve sizes that have been suggested as being efficacious as a conservation and/or fisheries management tool (MRWG 2001, NRC 2000, Roberts & Hawkins 2000, Ballantine 1997, Carr & Reed 1993), with an emphasis on larger reserves coming from the more recent literature. We added a lower 5% solution as a “worst case scenario,” acknowledging that this would mostly likely *not* offer sufficient protection.

In addition, we examined four MARXAN clumping parameters, ranging from very scattered to fairly clumped (BLM = 0.1111, 0.3333, 1.0, 3.0).

For each of the 24 combinations of variables (6 reserve sizes x 4 clumpings), we ran MARXAN 100 times. Thus, we examined a total of 2,400 MARXAN solutions. For each of those 2,400 solutions, the algorithm performed 10 million iterations.

F.1.2 UTILITY

By looking at how many times a particular planning unit is included in a solution, we can get an indication of its *utility* in overall reserve network design. That is, those hexagons that are repeatedly chosen likely represent areas that are more useful for effective and efficient MPA network design. While it has been suggested that these hexagons may be “irreplaceable,” we have avoided using this terminology for two reasons:

1. This may cause some confusion with the irreplaceability heuristic which is part of the MARXAN software package, and is based on a completely different set of assumptions (Pressey et al 1994, cited in MARXAN v1.8). We used this heuristic in concert with simulated annealing and iterative improvement.
2. We are not actually saying that these areas are irreplaceable. While this may be true for some sites that harbour rare species (such as the hexactinellid sponge reefs), it is not necessarily so for all sites. Rather, these areas of high utility represent places that appear to be the most useful in the development of optimal reserve network solutions that best approach our targets, using a minimum of area. Less optimal solutions could possibly be found using larger areas of lower utility.

We have indicated the sum total of these 2,400 solutions as shades of dark blue (seldom chosen) to yellow (chosen frequently) in Figure 1: Conservation Hotspots. The examination of various clumping values indicates that regardless of whether reserves are many and small, or few and large, certain areas recur over the course of many runs. For example, five “conservation hotspots” that we have identified in the South Central Coast include:

1. Scott Islands
2. Entrance to Queen Charlotte Strait
3. Broughton Archipelago
4. Head of Knight Inlet
5. The Narrows (narrow passages in the extreme south of our study area)

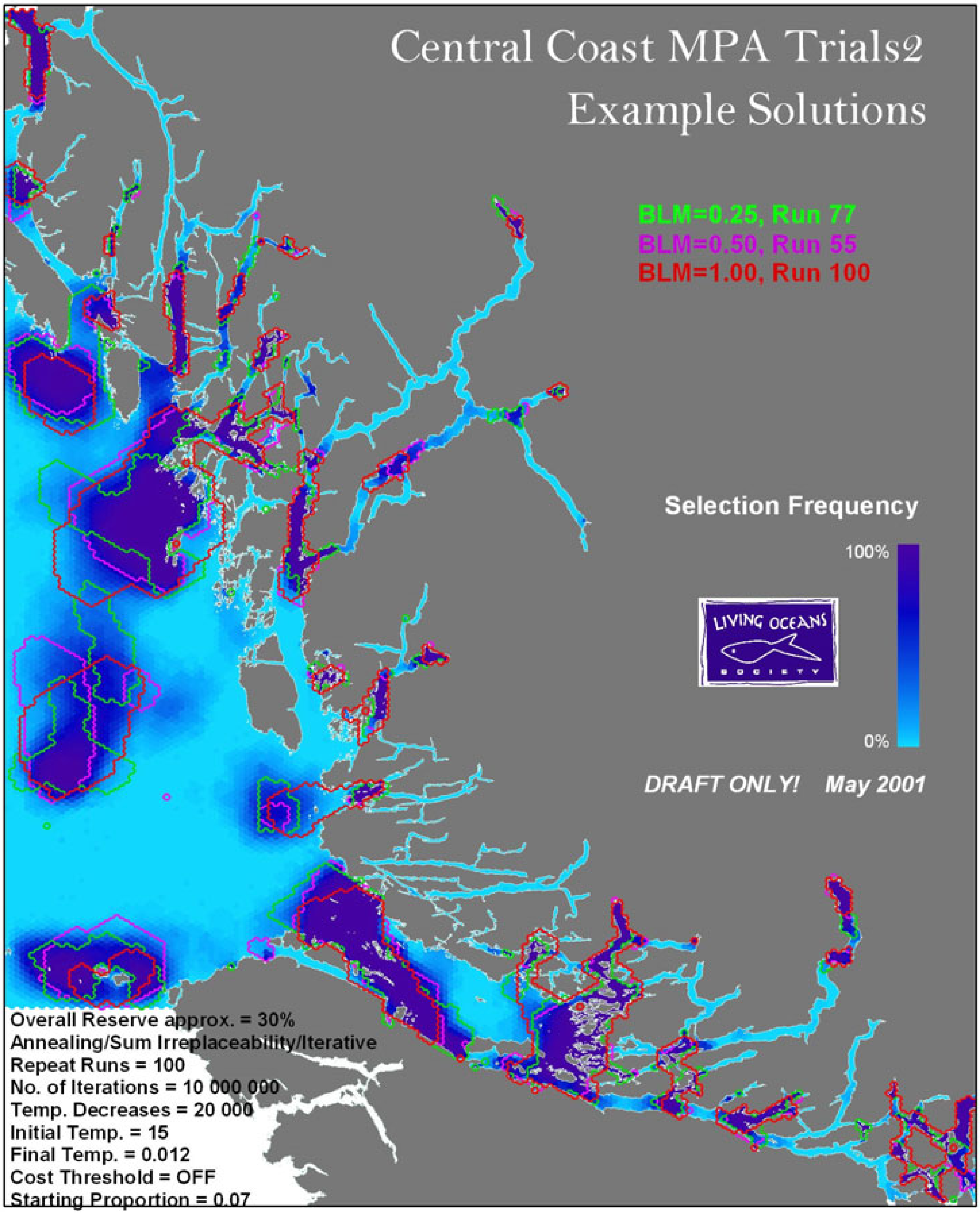
While these areas alone would not constitute a fully representative South Central Coast MPA network, it is very likely that were they not included, such a network would be difficult or impossible to achieve. Thus, regardless of what exact percentages were chosen by whatever planning processes, and the exact shape of the boundaries, we would expect the bright yellow areas to be key components of most MPA networks.

F.1.3 FLEXIBLE SOLUTIONS

Conservation hotspots alone would not constitute a fully representative South Central Coast MPA network. The individual network solutions produced by MARXAN can be diverse. Such diversity allows for greater flexibility when considering external factors, such as user interests, parks, local politics, and access & enforcement.

Figure 10 depicts the three possible solutions circled in Figure 13, below. [Please note: These solutions are depicted as examples only.] Though all three solutions meet the conservation targets efficiently and are therefore good reserve designs, they are still quite different from each other. Clearly the most grouped solution (BLM=1, red) would be more practical than the others in terms of management and enforcement, though its penalty in terms of failing to meet all targets is slightly greater (Figure 13).

Figure 10: Examples of MPA Solutions



F.2 SLOSS

SLOSS, “Single Large Or Several Small,” has been a longstanding debate in terrestrial conservation, with much less attention paid to the marine environment (but see Roberts & Hawkins 2000, Halpern in press, MRWG 2001). The basic question revolves around whether several small reserves are more effective in managing conservation values than a few large ones. In general, for the marine environment there seems to be agreement that most practical solutions will involve a mixture of both small and large reserves. Still, the question remains: what sort of mixture?

F.2.1 PLOTTING RESERVE FRAGMENTATION

As discussed above E.8.3, the Boundary Length Modifier (BLM) in MARXAN is a parameter that determines how disparate or clumped final reserves will be. We can use this parameter to investigate the SLOSS question. As depicted in Figure 11, several small reserves have a great deal of perimeter (edge), but relatively less area than clumped larger reserves. (Each vertical scatter plot shows the results of 100 runs per BLM.) Notice that this is not a linear function, however, and there comes a point when both curves begin to taper off: BLM 0.5 – 1.0.

Combining the two curves of Figure 11 into a dimensionless measure, fragmentation (area / perimeter^2), yields Figure 12. Again, note how this is not a linear curve, and that the slope begins to taper between BLM=0.5 and 1.0. This inflection could be a point of diminishing returns, balancing the two competing parameters (less edge but more area), and representing a possible compromise.

F.2.2 MARXAN PENALTIES VS. FRAGMENTATION

We examined exactly what reserve penalties might be expected at different BLMs (Figure 13), and whether these had any relation to the “S” curves of the previous two plots. By adjusting how much MARXAN clumped planning units together, and comparing those solutions with the normalized penalties incurred, we were able to explore what clumping factor likely represented the ideal compromise between many scattered reserves and a few large ones, given a somewhat flexible overall reserve size. For the figures shown, the solutions ranged from about 27.5% overall reserve network size to about 30.8%. However, the feasible solutions (BLM= 0.5 – 2.0) ranged from 29.5% to 30.5%; i.e., an overall size of 30%, +/-0.5. Experimentation with other reserve sizes yielded similar results (not shown).

Note that the line is plotted through the lower portion of the scatters because these are the lower penalty solutions that interest us. Each vertical scatter represents the results from 100 runs, per BLM.

While the results are at first a little non-intuitive, there are similarities with the previous two figures. Notice the dip, again between BLM=0.5 & 1.0.

A collection of several small reserves does predictably well at including all features (far left of plot, Figure 13); however, they are completely impractical in terms of management. As one increases the clumping factor, initially the penalties incurred increase, even though overall area used is also slightly increasing, indicating that it is harder to include all features as efficiently in larger clumps. But, as clumping and total area continue to increase, at a certain point the penalties dip (centre of curve, Figure 13). This represents the point where the increasing area allows features to be captured reasonably well. After this point the penalties increase once again, indicating that the larger reserves are failing to capture smaller more isolated features. Thus, the dip represents the ideal mix of smaller and larger reserves. Likely, a slightly less ideal, but greater clumping value would be chosen to balance the needs of management with those of efficient reserve network design. In the case of the example below (from Trials #2), this might be best captured by BLM=1.0, even though 0.5 is the theoretical "ideal."

This procedure, as developed by Living Oceans Society, can be used as an effective tool to narrow down the choices of SLOSS, with a better understanding of the trade-offs involved. However, this procedure does not directly speak to issues of connectivity. By setting conservation targets for regional and sub-regional representation, we ensured a broad spatial distribution of reserves. This broad distribution indirectly encourages connectivity, though does not guarantee it.

Figure 11: Effect of the Boundary Length Modifier on perimeter and area of reserves

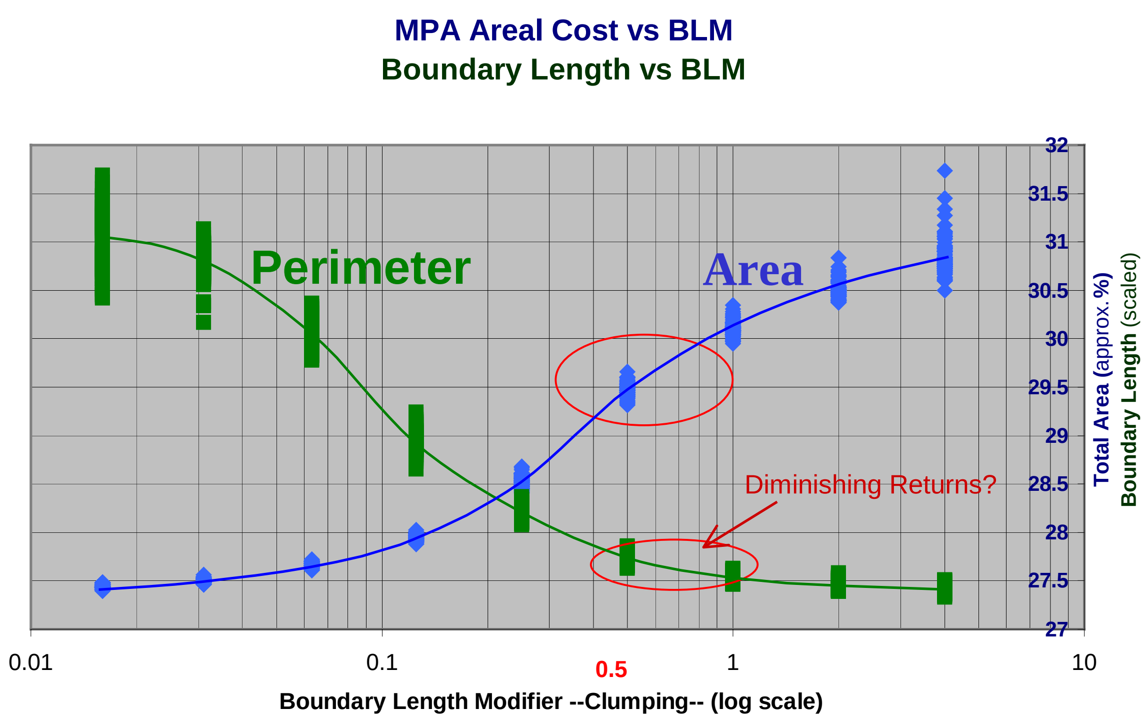


Figure 12: Dimensionless Fragmentation vs. Clumping (BLM)

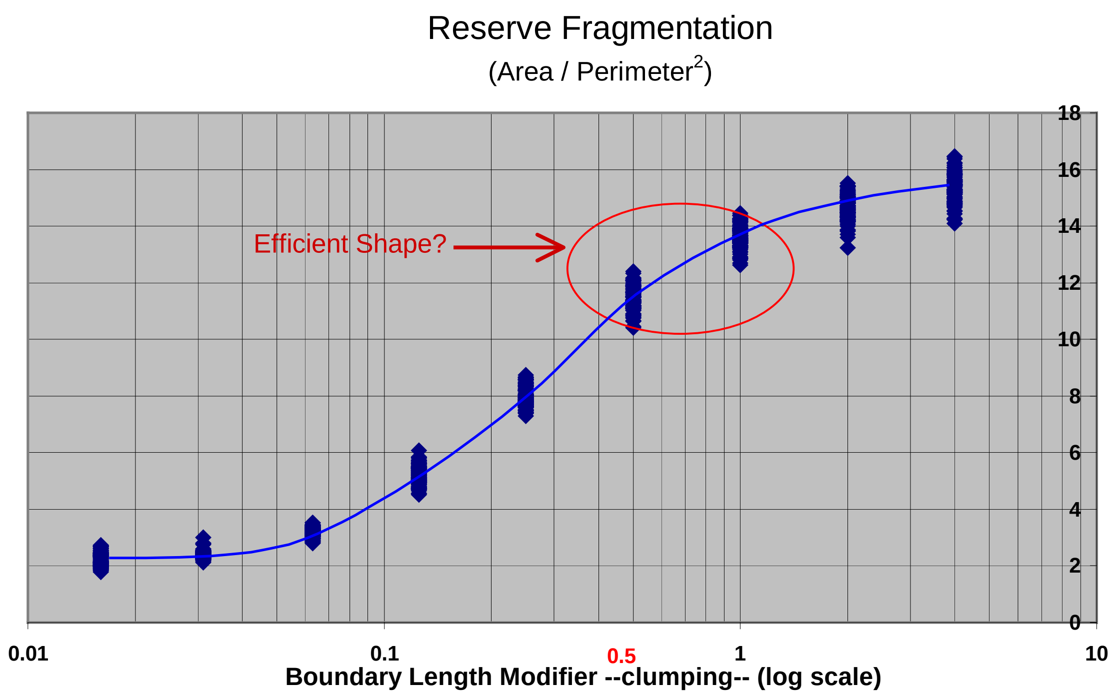
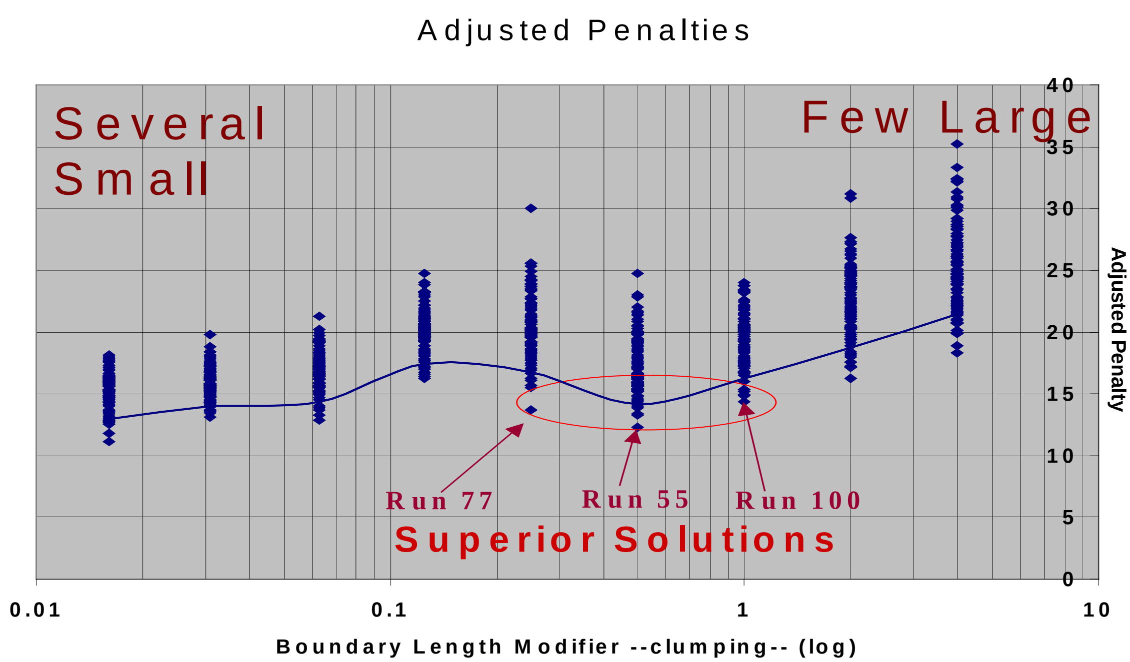


Figure 13: Plotting Penalties (normalized) vs Reserve Clumping



F.3 CONFLICT

In our initial trials (#1), we were curious to see how the selection algorithm would handle what might be real-life scenarios. To do so, we modelled the clash of values that could conceivably be found within an Integrated Management planning process.

F.3.1 IRRECONCILABLE DIFFERENCES…

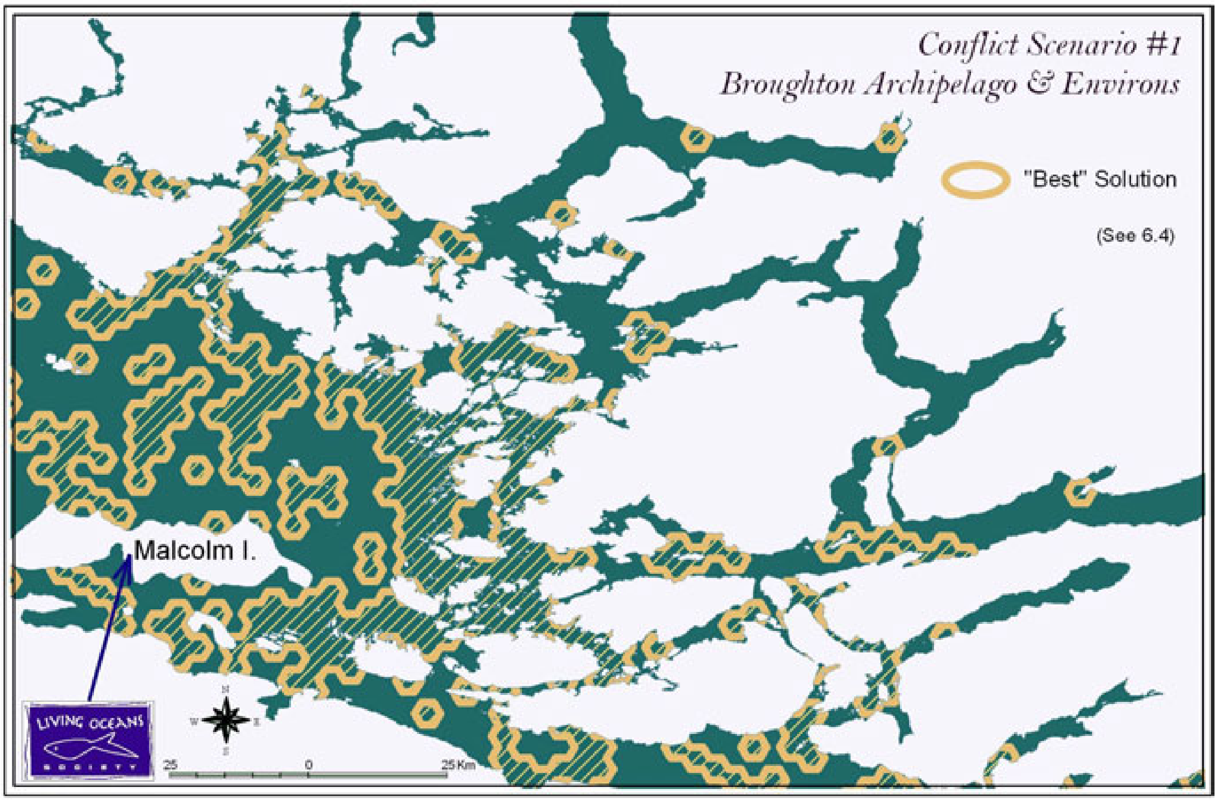
In one such scenario, we assumed for the sake of argument that fisheries require 35% set aside in no-take areas to remain healthy (e.g., Hastings & Botsford 1999), but that only 12% overall is available (the BC Government number used in terrestrial planning). Furthermore, existing marine parks must be incorporated. The results of this scenario are anything but clear. Despite the 12% threshold, the algorithm continued to gather planning units until about 25% of the study area was protected, thus balancing additional costs (area) with conservation values gained. But, there are no clear patterns. There is a widespread smattering of small reserve sites. This we interpret as “desperation” on the part of the algorithm to represent all features equally, with many far from attaining their conservation targets. As it stands, the “best” run is only a partial success, attaining about ½ the targets set, and only so by exceeding the 12% threshold considerably (~25%), producing a myriad of tiny reserves. Such a solution would be impossible to implement (Figure 14a).

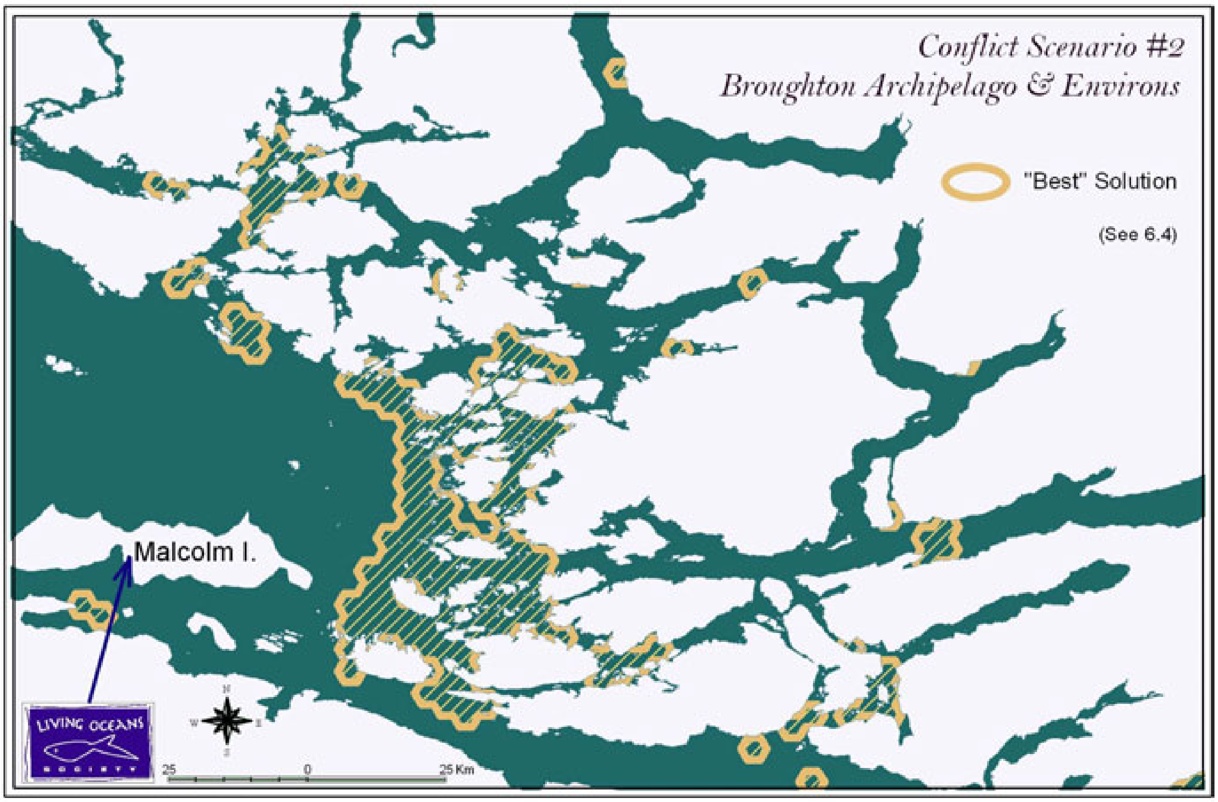
F.3.2 A REASONABLE COMPROMISE?

In another scenario, as a sort of real-life compromise of the above, the 12% threshold is strictly enforced. The 35% conservation targets, however, are reduced to 25%, as might be expected at a planning process table since scientists have a hard time proving without a doubt what is truly necessary for a marine organism’s survival, while user groups seem much more certain about what they need to survive. As a sort of concession, we no longer required that reserves fit to existing parks. But, we also made the boundary costs twice as high, so that those little sites in the above solution are now less acceptable. This scenario proved more successful in providing solutions with less scatter than the first one. But, despite lowering the conservation targets, only about 1/3 of the targets are met this time in the best of 50 runs. Is this an improvement? From the standpoint of management, despite the better clumping, there are still far too many small reserves. From the ecological point of view, the cup is either 1/3 full or 2/3 empty, indicating that biological values would very likely continue to degrade unless a greater concession on the part of user groups is also achieved. Again, this scenario as it stands would be impossible to implement (Figure 14b).

In short, situations of conflicting values that would appear irresolvable to a human planner, probably also appear irresolvable to a computer selection algorithm such as MARXAN. It would be up to the planning participants of an actual process to come to some sort of mutual understanding before it could be expected that more rigorous analysis could provide practical and acceptable MPA networks.

Figure 14 a) & b) Conflicting Planning Values, Scenarios #1 & #2



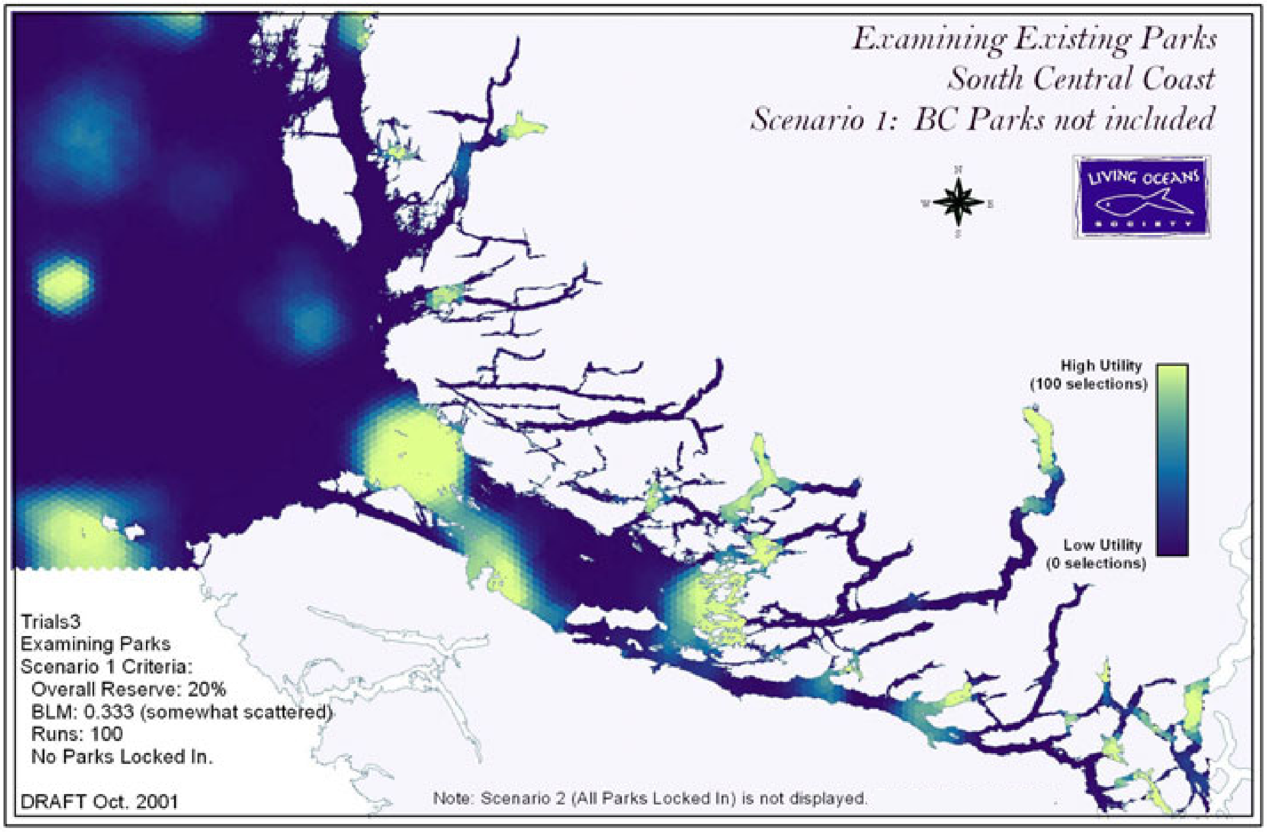


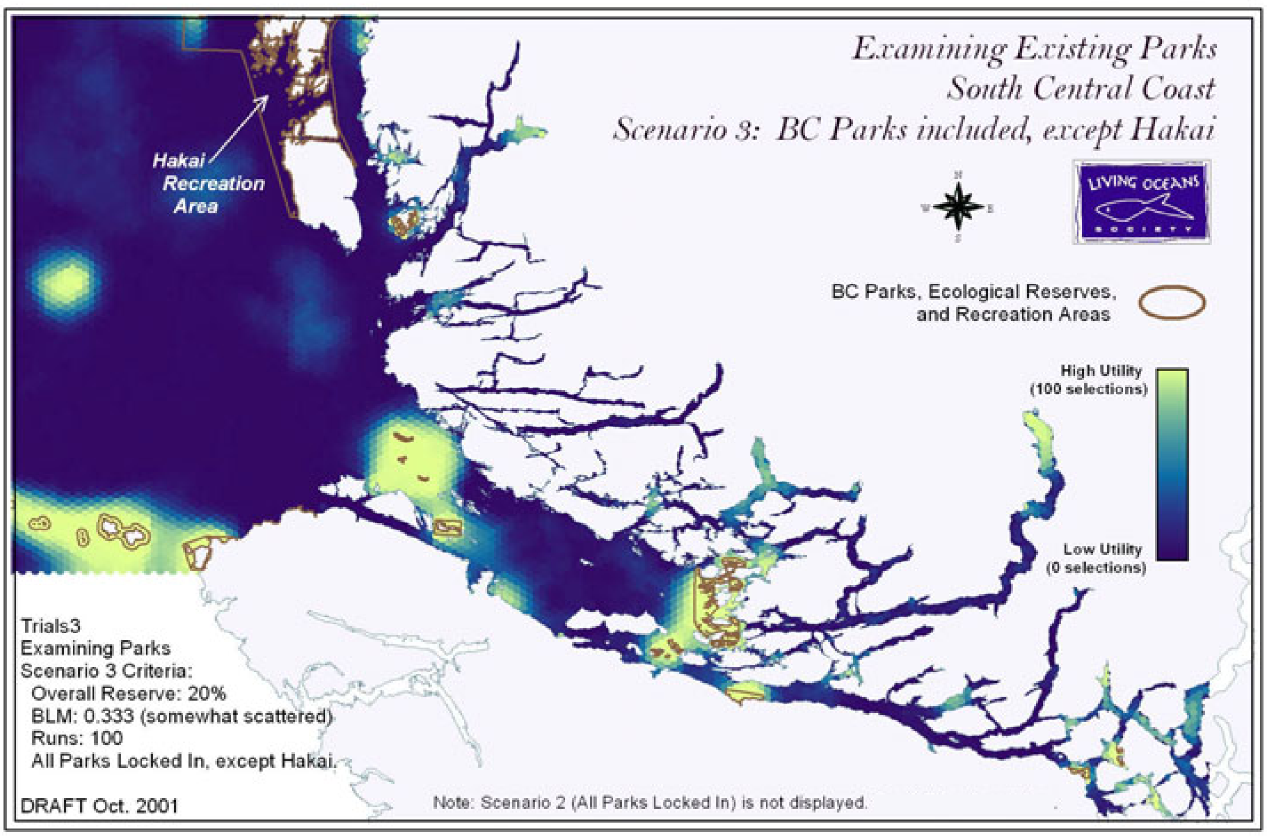
F.4 EXISTING BC MARINE PARKS

Although the previous two "conflict" scenarios clearly point out that there are yet no magic answers to what has been a long-standing conflict of values between the ecology movement and the decision-makers, they really do not help us move forward in effective reserve network design. The next three scenarios consider a happier set of assumptions; namely, that ecological values do actually mesh with MPA design criteria. For example, if scientists suggest that a species needs 35% of existing habitat to survive, then that will be accepted as a reserve network goal. Using these harmonious assumptions, we have examined how existing provincial parks would fit into these MPA networks.

In all three trials, we have looked at how "locking in" BC marine parks, ecological reserves, and recreation areas affected the distribution and shape of the solutions produced. (BC marine parks, reserves, and recreation areas are not currently managed with no-take components. There are no federal Migratory Bird Sanctuaries or National Wildlife Areas in the Central Coast.) We again examined a variety of reserve sizes, 5% – 50%. Figure 15 below depicts the results of 100 runs at 20%. In short, BC parks, ecological reserves, and recreation areas fit in very well, with the one notable exception of Hakai Recreation Area. Hakai Recreation Area is the largest provincial marine use area in BC. Locking it into the analyses forces the algorithm to focus a lot of values in this one area, making for one very large no-take area in this region, while reducing the emphasis on other areas such as Queen Charlotte Strait. With Hakai Recreation Area removed from the analysis, however, all other BC marine parks easily dovetail into the MPA solutions, with only minor alterations in reserve size, shape and distribution (Figure 15). Portions of Hakai Recreation Area, such as the Goose Islands, show up as conservation hotspots, and could be valuable in a network of no-take areas as well.

Figure 15 a) & b) Examining How Parks fit into MPA Networks





G DISCUSSION

G.1 THE MODEL

The main intention of this modelling exercise was to identify marine areas that likely warrant conservation attention. In doing so, we also have begun investigating several reserve design questions: How large should individual MPAs be? How many? How much overall area should be protected? Should existing marine parks be included? As discussed in detail the previous section, MARXAN provided us with a tool to investigate some of these questions. It has also provided us with several solutions to choose from, as well as a great deal of flexibility in how the model is set-up. We have produced a map of conservation hotspots to use as a starting point for discussions with stakeholders and planners. We continue to incorporate the comments of locals and experts. We plan to integrate the results of our on-going fisheries use analysis to provide an indication of possible conflicts with present day fisheries, and solutions that might be found. We hope to be able to work within the DFO Integrated Management process.

VARYING DATA QUALITY

Throughout this entire project, we have been absolutely aware that the quality of any model is only as good as the quality of the data used to create it. We therefore had to carefully choose which data to include in our model. We felt that MPA selection should be based upon as much scientific data for the region as possible in order to build the most complete model possible; however, some datasets were simply not strong enough to be included. We did include other datasets that had known or suspected deficiencies, but that we felt were still workable. We believed that it would be more harmful to wait for more data than it would be to cautiously proceed based on what we do know.

All of the biological datasets are to varying extents “presence” data (not presence/absence), and thus could have significant unacknowledged holes. However, for those that represent commercial species such as herring (spawn) or salmon (streams), surveying has been extensive over a period of decades, and we are confident that all the major areas have been captured. For others, such as Marbled murrelets or clams (north Central Coast), we realize that important areas may have been missed, and that a perspective over time is largely missing. The physical datasets are considered to be presence/absence and do cover the entire study area. As such, the physical features tend to draw the selection away from just those areas with known biological distributions.

We have tried to minimize the effects of variable data quality in three ways: First, in classifying the data, we were careful to not stretch any data beyond their perceived descriptive power or scale. Secondly, since MARXAN allowed us to assign individual penalties for each dataset, we could place more emphasis on datasets in which we had more confidence. Thirdly, since some features were construed more as focal species or surrogates than others, we adjusted their targets and penalties accordingly to account for their varying “umbrellas.”

Consequently, we are confident that the resultant conservation hotspots are not simply artefacts of data-rich areas, and are encouraged by their even spatial distribution. However, we are concerned that there were few pelagic data available for the offshore waters, and thus the areas chosen in the offshore waters are likely incomplete.

MODEL ROBUSTNESS

Not all models are equally robust to a wide variety of datasets of varying qualities. As discussed in *Appendix 2: Classifications & Hierarchies*, spatial hierarchies are prone to increasing error as more levels of data are added to the model. Instead of limiting the number of datasets, we have elected to limit our spatial hierarchy to just two levels.

Likewise, analyses that set out to distil a myriad of variables down to a few principle components become very dependant upon the quality of those key datasets. While principle components analyses are valuable when creating simplified habitat models for endangered species (Bahn & Newson 2002), they may not be helpful in the design of a reserve network where representation of a wide variety of taxa is desired.

Therefore, in our model we have attempted to include as many datasets as possible. The use of MARXAN allowed for this. Over the course of the three trials, we have added and modified data. These changes subtly altered the results, indicating that the model was sensitive to them, but not overly so. Thus, unlike other models that rely on simplifying ecological processes down to a few key datasets, our approach of including whatever data we can reduces the burden upon any particular dataset, and thus increases the model's robustness to individual datum errors.

Ten million MARXAN iterations assured us of solutions that were not cut off prematurely. A million iterations has been suggested as a minimum (Andelman et al 1999). One hundred runs at each combination of variables produced a good distribution of solutions, some better than others (see Figure 13: Plotting Penalties (normalized) vs Reserve Clumping). One hundred solutions of each combination also provided flexibility when choosing solutions to focus on. Considering the scatter of the results, we view 100 solutions as a minimum. In subsequent analyses, when we are fine-tuning results, we may increase this number. Due to the stochastic element in the selection algorithm, it has been our experience that it is misleading to run the model just a few times. In our preliminary set-up runs, we still ran the model at least 50 times. The random factor in the model can occasionally hit on something quite extraordinary, but probability dictates that it may require several hundred runs to do so. Used in such a fashion, we view the subset of superior MARXAN solutions to represent genuinely efficient and attractive solutions. These solutions are very likely to be superior to any simpler iterative "decision-tree" approach (Possingham & Andelman 2000). Furthermore, while a decision tree may appear attractive due to its clearly predictable steps when arriving at a solution, this also limits the approach to one solution only, and is therefore less flexible than simulated annealing.

By running a multitude of MARXAN models using various size targets and clumping, we were able to explore the model's behaviour. In an animated image we constructed from image cells of individual runs, the reserves can be seen to grow and collapse in a predictable and consistent fashion. Had the reserves instead jumped about, this would have indicated possible problems with the algorithm. (Or, such problems can also occur if planning unit boundaries and costs are mismatched with feature targets and penalties.) Thus, we are convinced that our model behaves in a predictable and robust fashion.

ACCURACY OF RESULTS

To field test the results of such a large regional analysis would be daunting and is beyond our capabilities. However, by comparing our results with local knowledge, expert opinion, and other studies, we have gotten reasonable sense that they are indeed relevant.

There is only one other study of the Central Coast that has comprehensively examined possible MPAs. This was conducted by Jacqueline Booth & Associates (1998) for Parks Canada who subsequently published a summary document (1999). This study was constrained by the Parks Canada's mandate to choose only one large MPA, and specified mandatory representivity criteria (see K.1.3). Furthermore, their boundaries were somewhat different than our own. Nonetheless, in areas where our study areas matched, *all the Parks Canada Candidate Areas overlapped with our own Conservation Hotspots.* Due to its restriction of examining only large areas, Parks Canada's results had no counterpart to our smaller hotspots. Nonetheless the large degree of overlap between these two completely different studies gives us reason to be confident in our larger conservation hotspots, and by extrapolation, to our smaller conservation hotspots as well.

BC Parks' coastal ecological reserves overlap very well with our conservation hotspots (see F.4), including some of our smaller ones. While our modelled networks are much more extensive, thereby limiting the power of the spatial correlation, this too would appear to indicate that our model is capturing known and valuable ecological areas.

Many of our conservation hotspots have previously been identified by other agencies and sometimes other environmental organizations. However, until now, the advocacy has been piecemeal. For example, the Scott Islands is a well known area for seabirds, and has been the subject of Canadian Wildlife Service studies (e.g., Rodway 1990, Rodway et al 1990). The three westernmost islets are free from the human-introduced predators (rats and racoons) that occur on the other two. As a consequence they still support significant seabird colonies (CWS 1989). The Scott Islands are being considered as a CWS Marine Wildlife Area. The Scott Islands have also been identified by the BC Canadian Parks and Wilderness Committee (CPAWS undated) and by the World Wildlife Fund (WWF 2000).

To acquire a grassroots response, we have begun to take these preliminary conservation hotspots to fishermen and locals. While much more travelling and presentations are planned, the initial responses have been positive. Questions with some of the results from earlier models have been addressed and corrected by re-examining the MARXAN parameters for certain features.

Likewise, initial results have also been presented to various marine and GIS modelling experts. Presentations include a side meeting at the AAAS (San Francisco CA, Feb. 2001), presentation to DFO and BC Parks (Port Hardy BC, March 2002), Second Symposium of Marine Conservation Biology (San Francisco CA, June 2001), Society for Conservation GIS (Bodega Springs CA, July 2001), MPA PowerTools conference (White Rock BC, Oct. 2001), presentation to Pacific Biological Station (Nanaimo BC, March 2002), presentation to Canadian Wildlife Service (Ladner BC, July 2002). We have refined our model as a result of these interactions.

Preliminary discussion with some First Nations bands indicates a great deal of agreement regarding the ecological values of our identified conservation hotspots. (This should *not* be construed to mean that First Nations necessarily support these as MPAs.) Further discussions are being planned.

We recognize that this model will undergo further refinements as data become available, and as a consequence of local feedback and expert review. Nonetheless, that the present model is correctly identifying many known conservation hotspots of the Central Coast gives us the confidence that it is already a valid model capable of producing meaningful results.

INTEGRATING THE MODEL WITH SOCIO-ECONOMICS

The results of the present model are designed to inform MPA network design as a result of ecological values. However, this model does not consider social or economic implications of these possible networks. Living Oceans Society is committed to working with local communities, stakeholders and all levels of government including First Nations to consider these issues.

Presently underway is a Living Oceans Society project to collect and map the knowledge of commercial fishermen. This is the first such survey of the region. From this we will be able to gain a sense of present day fisheries use. Effective MPA networks that had a lesser impact on fisheries use would be given preference to comparable ones that came with greater impact. Again using MARXAN, these would be selected by integrating the conservation hotspots analysis with this use analysis and seeking optimal solutions.

G.2 IMPLEMENTATION

Modelling networks of MPAs without a way to implement them is an exercise that will not protect biological diversity or develop sustainable fisheries. Living Oceans Society believes that results of such analyses ought to be used to inform a conservation strategy for the region, and that the best way to do this is within a government led multistakeholder process. We believe the people who work, live, and govern in the region need to be involved in the design and implementation of a network of MPAs.

On the water, enforcement is a challenging issue and many MPAs, especially the remote ones, will depend on the sport and commercial fishermen's willingness to comply with the regulations. Any proposed MPA model must remain flexible in order to accommodate the views of process participants. Consequently, our modelling work does not identify one "solution." Rather, MARXAN allows for several solutions. Summing these together into "conservation hotspots" illustrates which areas are selected repeatedly, emphasizing those areas that are more likely to be included in any network solution that is developed. The actual boundaries of each potential protected area remain vague, allowing participants to be involved in determining the actual boundaries of the core no-take areas and buffer areas.

G.2.1 RECOMMENDATIONS

With regard to a planning process for the Central Coast of BC, Living Oceans Society has recommended the following:

INITIATE AN INTEGRATED MANAGEMENT PLANNING PROCESS FOR THE CENTRAL COAST OF BC

With the constant decline of our fisheries and resulting negative impacts on our coastal communities we must act now to improve the way we use our ocean resources. A well designed Integrated Management Planning Process can lead towards ecosystem management of our marine environment, develop sustainable fisheries, and establish a network of marine protected areas while including all stakeholders, First Nations, and governments.

Living Oceans Society has recommended that the federal government:

- Commit adequate financial and human resources to ensure that an Integrated Management Planning Process for the Central Coast region of BC be completed.
- Ensure that the Integrated Management Planning Process is integrated with the Science and Fisheries Management Branches of DFO.
- Develop Memorandums of Understanding with the First Nations Governments outlining how this process will address or be without prejudice to aboriginal rights and title, land claims, and aboriginal fisheries.

DEVELOP CLEAR GOALS AND IDENTIFY PRODUCTS

In order to engage stakeholders in consensus based planning, participants must have a clear idea of why they are at the table and what products will be produced at the outcome of the process. Most marine stakeholders are volunteers and if they are unsure of what they are trying to accomplish then they will not participate.

Living Oceans Society has recommended that the Integrated Management Planning Process for the Central Coast must, at a minimum, address the following:

- Identify and establish a network of marine protected areas, including a core of no-take zones.

DEVELOP A CLEAR DEFINITION OF MARINE PROTECTED AREAS

DFO is committed under the Oceans Act to establish marine protected areas. However the levels of protection in marine protected areas remains unclear, causing confusion and mistrust amongst stakeholders, First Nations, and local governments. On land, where planning process have had success in establishing protected areas, table participants know that a protected area means no logging, no mining, no hydro. These minimum levels of protection protect the area from resource use and provide some idea of how protected area status will contribute to the conservation of biological diversity. However the draft minimum standards for MPAs refer only to habitat issues, not the most prevalent resource use issues. If we are to use MPAs to conserve marine biological diversity and develop sustainable fisheries we must identify restrictions that will be placed on commercial and recreational fishing.

Therefore the Living Oceans Society has recommended that marine protected areas be defined as core no-take areas with buffer zones. The core no-take zones prohibit the extraction of all living and non-living things plus the prohibition of bottom trawling, extraction of non-renewable resources, dumping and dredging, and open netcage fish farms. Buffer zones prohibit bottom trawling, extraction of non-renewable resources, dumping and dredging, and open netcage fish farms but allow fishing activities that do not compromise the objectives of the core areas. Additional activities such as log booming and sewage outfalls will be permitted on a case by case basis.

ENSURE REPRESENTATION OF COMMERCIAL FISHERMEN

The major resource use on land is forestry and it is run by a handful of large companies. These companies have the time and money to send representatives to planning processes to negotiate their interests. Therefore the current model for terrestrial planning can adequately engage the major resource users. Commercial fishermen, on the other hand, remain mostly independent of large companies and are therefore not as organized. There are at least 44 commercial fishing associations run mostly by volunteers. Most groups do not have the time or the funds to send representatives to a time-demanding process and therefore their voices are not heard. These groups often have opposing mandates and goals and they cannot be adequately represented by one seat at the table. Without their representation it is very difficult to effectively discuss marine resource use and marine protected areas.

Living Oceans Society has recommended that Fisheries and Oceans Canada work with all commercial fishing associations to develop an Integrated Management Planning Process that ensures their full participation and can accommodate their work schedules.

IDENTIFY APPROPRIATE SCALE OF PLANNING

The scale of planning on land is very different from that of the ocean. Resource use on land has resulted in large areas being set aside for general management, protected area status, and special management zones. In the ocean, resource use is often done on a finer scale, site-specific basis. Although fishing may be listed as occurring within a DFO Statistical Sub-Area, it may in fact occur in only one or two very localized areas. Since independent fishermen do most fishing, the restrictions on commercial harvesting may affect the total fishing effort very little but could affect one or two fishermen a great deal. Strategic level planning at the 1:250000 scale does not allow one to deal with the specific resource use activities of an area.

The Living Oceans Society has recommended that:

- The Central Coast region be planned in two stages, the South Region (Cape Caution to Bute Inlet) and the North Region (Cape Caution to Princess Royal Island). These two areas must be planned consecutively, not simultaneously, to allow the full participation of the stakeholders.
- All maps be produced at approx. 1:40,000 scale to allow detailed planning of the area.

PROVIDE NECESSARY DATA TO ALL PARTICIPANTS.

Despite the commitment of both the federal and provincial governments to provide data to the participants of other processes, most data have been seriously inadequate or missing entirely. In addition, it has been extremely difficult to obtain any digital data for independent GIS analysis. Instead, participants have been required to accept government analysis of the data.

Living Oceans Society has recommended that:

- All planning data be shared with process participants at the beginning of the process and updated as the government receives more information. These could include base data, catch data, scientific surveys, and gathered local knowledge.
- All process participants be supplied with digital (GIS) and hard-copy versions of these data.

G.2.2 Creating the Opportunity for MPAs and an Integrated Management Process

At present, most BC marine resource users distrust government processes. The DFO Mifflin Plan, BC Central Coast LRMP, BC North Island Straits, and BC Salmon Aquaculture Review left many feeling these processes were biased and inadequate. Therefore, living Oceans Society has invested resources in building awareness of MPAs and the need for a government led process to discuss the designation and management of a network of MPAs. To build this awareness and trust we have completed or will soon complete the following:

Memorandum of Understanding with First Nations

We are currently working with the 16 bands in the south Central Coast region to develop MoUs that permit LOS to implement an MPA Outreach Campaign focusing on the 5 major conservation hotspots identified in the region (see F.1.2). LOS agrees not to advocate directly to government for the protection of any specific site; but rather, we will work with government to develop a process that enables First Nations government to negotiate at a government-to-government level. Initial response to the MoUs has been favourable and we are presenting to various councils in the next month. Once the MoUs have been signed, we will start a series of presentations in schools, community groups, rotary groups, governments, etc.

MPA Information Brochure

We wrote and designed an MPA Information brochure that outlines in common everyday language what is an MPA and why we need them. We also depicted examples of the biological and cultural values of the region. Twenty thousand copies of the brochure have been sent to people who work and live in the Central Coast.

MPA Art Show

We are working with forty artists to create an art show about the ocean and the five Conservation hotspots on the south Central Coast. We have taken over fifteen artists on visits to the sites and worked with ten artists on underwater interpretative works. Other high profile artists have donated work for the project. This art show will be used to strengthen the connection between the people of the coast and the ocean. More specifically, we want to engage people in a discussion of the ocean’s value outside of being a source of food and employment.

This art show will be on display in Sointula, Alert Bay, Port McNeill, Port Hardy, Campbell River, Victoria, and Vancouver. We will prepare a special edition of our newsletter (20-30 pages) to include samples of the artwork, outline the need for MPAs, provide an overview of the science we use to identify MPAs, and introduce some of the people of the coast and their connection to this region.

USE ANALYSIS

As discussed above (Integrating the Model with Socio-Economics), we are conducting a "use analysis" that involves gathering information from commercial fishermen regarding where they fish. This use analysis will be melded with the present conservation model. As a result of working with fishermen to gather this information from them, we have had the opportunity to talk one-on-one about MPAs, listen to their concerns, and build awareness and support amongst the fleet.

G.2.3 IMPLEMENTATION TO DATE

The value of modelling a network of MPAs can only be fully realized if there is a plan for implementation of such a network. This requires the work of many partners. A non-governmental organization such as Living Oceans Society can play a significant role in shaping the planning process, and encourage awareness and participation in the discussion of designating a network of MPAs.

The Central Coast of BC has been identified as the pilot project for Integrated Management on the west coast of Canada. Efforts are currently underway to ensure that the process is adequately resourced. Preliminary review of the process structure indicates that the government is looking at ways to deal with the time-limited planning issues versus the timeless requirements of management. Furthermore, the Central Coast process is being designed for the issues and conditions specific to the region while continuing to meet national standards (Brenda Bauer, DFO, pers comm July 2002).

Living oceans Society will continue to monitor and comment on this process to ensure that it provides the opportunity for us to present our MPA network design, and work with the people who live, work, and govern in this region to conserve ocean health.

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J APPENDIX 1: GLOSSARY OF SPATIAL TERMS

(In order from large to small)

Study Area: The area of our analysis, incorporating the Central Coast of BC. This is a large expanse from approximately the westernmost extent of the Scott Islands (off the northwest tip of Vancouver Island), northward to the top of Gil and Princess Royal Island, west to include the full extent of Burke and Dean Channels, and Knight Inlet, and south to the mouth of Butte inlet (but not including the inlet). From the upper left corner to the bottom right, which approximates the orientation of the coastline, is about 450 kilometres (280 mi.). The marine component is 2,230,330 hectares (5,511,243 acres), or 22,303 square kilometres (8612 sq. mi.). The extent of the sea reaches 165 km. inland up Dean Channel.

CCLCRMP: Central Coast Land and Coastal Resources Management Plan. A BC Government process where stakeholders, government –including the Department of Fisheries and Oceans (DFO), and First Nations– worked toward a vision and use strategy of the Central Coast. The CCLCRMP is the first LRMP in BC to have a marine component. The marine plan area is about half the size of our *Study Area*, keeping much closer to shore. However, the north – south extent is about the same. Living Oceans Society participated in the three year process.

Spatial Hierarchy: A system of classifying space, such that no two areas overlap. Being hierarchical, it places some *features* above others; thus, *features* are nested. Note that this nesting requires that features lower in the hierarchy must conform to the shapes of those above. Living Oceans Society has created a simple two-tier spatial hierarchy of Regions and Sub-Regions:

- **Inlets:** Low, Moderate, High Freshwater Input
- **Passages:** Moderate, High Mixing (i.e. Moderate, Low Stratification)
- **Outside Waters:** Inshore, Offshore

Some of our data are classed with regard to their membership within the spatial hierarchy at the level of Regions. Other data remain independent of it *(see E.2)*.

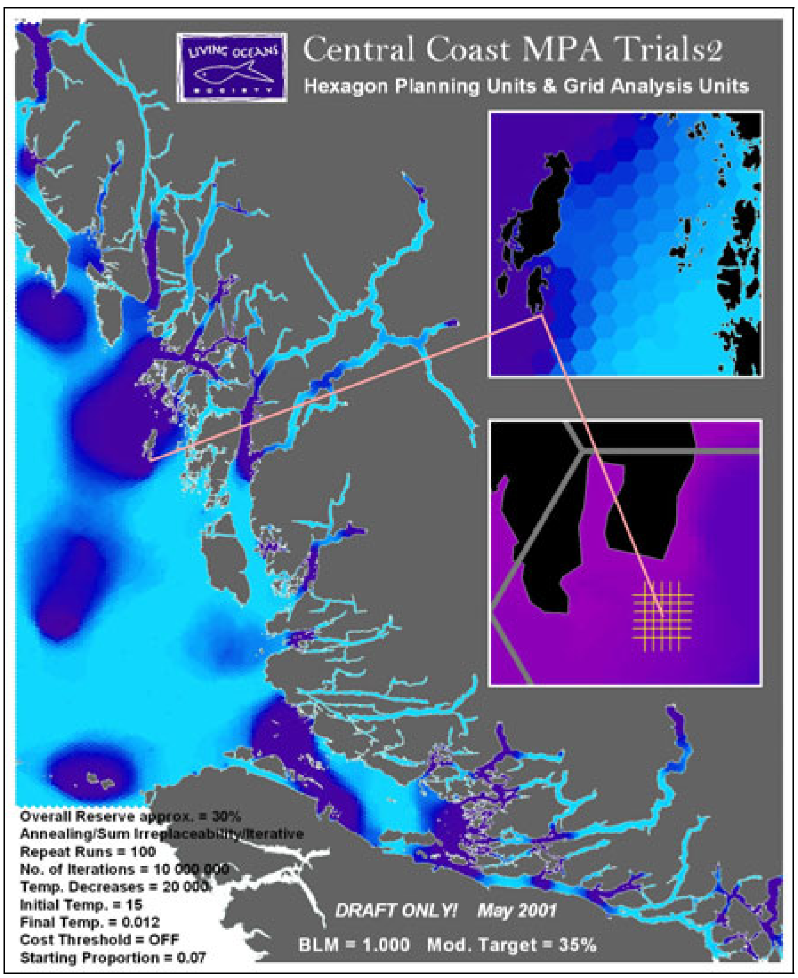
Feature: A physical trait of the environment (e.g., physical complexity) or physical process (e.g. high current), or biological distribution (e.g. herring spawn) that is used in our analysis. Depending on the feature, this may reflect several sources of data merged together. Each hexagonal *planning unit* is scored according to its representation of each feature. Note that those features that are within our *spatial hierarchy* will be defined with regard to their position within the hierarchy. Those features not placed within the hierarchy do not depend on the hierarchy for their definition.

Feature Classes: Those components that make up a *feature*. For instance, three different substrate delineations are classes of the combined Depth-Substrate *feature.*

Planning Unit: The individual hexagonal cell that together with other cells makes up the planning grid that covers our *Study Area.* These are the "building blocks" of our MPA selection. This use of the term *planning unit* is commonly used in reserve design. However, it should not to be confused with the term as sometimes applied by government to designate large subsections of a planning process. Our planning units are hexagons of 250 hectares each (617.74 acres), which is approximately 1,700 metres (5577 feet, 1.06 miles) across, from flat edge to flat edge. They are regularly spaced and sized. There are 40,365 such planning units. However, many are completely surrounded by land, and some others (such as in the SE corner) fall outside our study area, leaving 11,725 in our analysis. Note that the planning units do not span boarders of the *Spatial Hierarchy*; that is, they are either completely inside or outside of each Region and Sub-Region.

Feature Grids: If the *planning units* are building blocks, then the cells of the feature grids are the aggregates that make up each brick. They are the smallest spatial components of our analyses. They are 0.2 hectares (0.5 acres) in area per cell, which is about 44.7 metres (146.7 feet) square. Each feature grid cell contains a value for that feature; it may be presence (=1), relative importance (e.g. RI=1,2,3), or an index (e.g. Herring Spawn Habitat Index). One hexagon *planning unit* can contain approximately 1275 feature grid cells. All feature grid cells within a hexagonal *planning unit* are used to calculate a score for that *feature.* These feature grids do not conform to any planning unit or hierarchical boundaries; they are regularly spaced.

Figure 16 Example of Hexagons and Feature Grid



K Appendix 2: Classifications & Hierarchies

In this appendix, we review previous classifications systems. We discuss the problem of spatial error in hierarchical approaches.

K.1 Existent Classification Systems

K.1.1 BC Marine Ecological Classification (MEC)

The BC Marine Ecological Classification (MEC) is based upon the Marine Ecological Classification System for Canada (Marine Environmental Advisory Group, 1999), and was developed in 1997 as a provincial marine planning standard. It is the intention of the BC government that this system be used in marine planning throughout BC, including the Central Coast. It is designed to be a spatial hierarchy, beginning with broad Ecozones, and working downwards to its Ecounits. It is at the level of these ecounits where the first delineations based upon enduring physical features and processes occur. While The MEC has since been updated to include more attributes, the original BC ecounits as examined for our analysis were comprised of five attributes: Wave Exposure, Depth, Substrate (i.e. sediment), Relief, and Current. The scale of the ecounits is said to be 1:250,000, but no quality assurance tests have been undertaken to support this number. Areas smaller than 15 square kilometres were treated as "slivers," and eliminated by aggregation with neighbouring polygons (LUCO 1997). While clearly designated as a spatial hierarchy, it is unclear how the ecounits (version 1 or 2) were actually created; that is, the ordering of the five attributes, or how boundaries were shifted to absorb slivers. No biological features are included in this classification system.

The BC MEC was groundbreaking in both its scope and objectives. However, over time, certain weaknesses have come to light. For our analysis, we have separated the ecounits out by their five attributes, and evaluated them individually:

- Exposure (high/med./low): Considered the coarsest of the five, we have found it useful for the broad scale delineation of our three Regions. While the MEC defines Johnstone Strait as low wave exposure, data summarized by Ricker (1989) indicates a moderate exposure regime, as does local knowledge.
- Current (>3 knots, 1.5 m/s): Found to be accurate in those areas noted. However, several areas were missed. An additional low current class (< 0.5 knots, 25 cm/s) could conceivably identify nutrient poor waters.
- Substrate (3 classes): This layer is very coarse but there are no available substitutes.
- Depth (3 classes): (See Figure 7: Discrepancies within the Provincial Photic Classification) The shallowest class, "photic," was found wanting for three related reasons: 1. 61% of areas that fit the photic class were not represented; i.e., error of omission. 2. A further 11.5% of the areas were actually deeper than classed; i.e., error of commission. 3. The 0-20m class created many small polygon slivers that were absorbed by neighbours, which aggravated the previous

two problems, making for a combined error of 72.5%. In addition, by only looking at 0-20 metres the photic class missed several known areas of biological activity. Living Oceans Society has urged the expansion of this class to include waters 0-50 m in depth. However, the province has elected to instead add a new depth class from 20-50 m. (Axys 2001).

- Relief (high/low): Despite several inquiries, no one appears prepared to explain exactly how the class was produced, making this the weakest of all the MEC attributes. This layer has undergone recent revision in the revised version, becoming two features: slope and roughness. Living Oceans Society argued for a measure of physical (benthic) complexity (E.3.1).

K.1.2 WORLD WILDLIFE FUND: A NATIONAL FRAMEWORK FOR MARINE CONSERVATION

Like the MEC, the World Wildlife Fund's system is quasi-hierarchical, capturing enduring physical features and processes. Also like the MEC, no biological features are included, though it is acknowledged that they could be used at finer planning scales (Day & Roff, 2000). The eight levels of the hierarchy are clearly stated (Day & Roff, 2000). While some work has been applied, in a somewhat earlier form, to classify the Scotian Shelf in eastern Canada (Day & Lavoie, 1998), it has never been applied in BC. Nowhere has it yet led to MPA design proposals that we are aware of. Work on the Canadian east coast remains on-going.

This classification system was extremely influential in our earlier work. We attempted to emulate its classes, adapting them as necessary to the west coast environment. However, we ran into several troubles regarding spatial accuracy of data representation which eventually led to our re-examining the hierarchical approach altogether (see K.2 below).

K.1.3 PARKS CANADA: STUDY TO IDENTIFY NATIONAL MARINE CONSERVATION AREAS

It is the mandate of Parks Canada to choose one National Marine Conservation Area (NMCA) per region. (The Parks Canada Queen Charlotte Sound Region includes and extends somewhat beyond the Central Coast.) Four "Study Areas" have been chosen, of which three are completely contained by the Central Coast. To assess these areas, they examined representivity and naturalness using a myriad of features. These include 37 physical themes and sub-themes, 27 biological, and 5 cultural. All were given significance and occurrence ratings which were then summed. These were compared with overall regional scores and adjusted if necessary. With regard to representivity, areas were ranked according to four physical subtotals, four biological, and one cultural. The physical and biological totals each account for 45% of the grand total, with cultural filling in the remaining 10%. Naturalness was treated as an index of human activities that have occurred within each planning unit, such as log booming, aquaculture, population, and so forth (Booth 1998, Parks Canada 1999).

We borrowed heavily from many of this system's classes.

Parks Canada mapped their themes onto the BC MEC ecounits (version1), which were used as planning units to build the Areas of Interest.

The Parks Canada approach was the first analysis of the Central Coast looking at MPA designation. However, the mandate of choosing only *one* fairly large multi-zoned location limited the freedom they could exercise, and as a result only four candidate areas were produced. In assessing representivity, no one place can be all things, and so features are inevitably missed. Obviously, no replication of features is possible, except within the boundaries of the one NMCA. Though rare features, when included, were given higher weightings, no rarity or irreplaceability analysis was undertaken. This analysis was performed using a GIS, but no selection algorithms were used, other than the summation as described above. Some of the features used in the analysis, such as upland relief or tectonics, may not benefit from MPA designation, but were included as a result of the Parks Canada policy to examine all features when considering its representivity criterion.

Nonetheless, the Parks Canada report was certainly the most detailed and GIS-sophisticated of any up to then. *Most of their resulting study areas overlap with "conservation hotspots" in our analyses.*

K.1.4 ADDITIONAL CLASSIFICATION SYSTEMS

- *Coastal Tourism Resource Inventory* (ARA Consulting *et al* 1992, for BC Ministry of Tourism)
- The various *Biosuitability* reports for *Salmonid Farming in Net Cages* (Ricker 1989, for BC Ministry of Agriculture Food and Fish (MAFF))
- *An Overview of Key Conservation, Recreation and Cultural Heritage Values in British Columbia's Marine Environment* (Dale 1997, for BC Land Use Coordination Office)

K.2 ERROR IN SPATIAL HIERARCHIES

For purposes of illustration, let us call the planning units of our hypothetical spatial hierarchy "ecounits." When spatially compiling several features, there are two factors that will determine the final resolution of our ecounits:

1. The resolutions of the input layers; in particular, their boundaries.
2. What constitutes a "sliver polygon," how it is removed, and how many there are.

K.2.1 CUMULATIVE ERRORS: BOUNDARIES

The effect of the first factor (input layers) is fairly easy to explain: An ecounit could be made up of any or all the layers, thus the resolution of the collective whole is as weak as the weakest layer. To be fair, many ecounits may not be bounded by the weakest layer at all, and could therefore be of better resolution. To estimate *average boundary resolution* one might do a weighted mean based on perimeter length of each layer. Thus, layers with short perimeters would have less effect then those with a lot. Still, this average is just an average, within a range that is defined by the layers of highest and lowest resolution. What's more, without access to the source data (usually the case), it is impossible to predict if a given ecounit is above or below this average. Thus, we must return to the beginning of this paragraph: **the resolution of the weakest layer sets the resolution of the final lines**, even though some lines may actually be better than this.

Furthermore, if the classification is a true hierarchy, where that "weakest link" is placed in the hierarchy can affect the overall accuracy of the resultant ecounit *(see below).*

K.2.2 CUMULATIVE ERRORS: SLIVERS

Sliver polygons are those areas that are considered too small to stand on their own, and must therefore be absorbed into neighbouring polygon(s). This is the second, and in the authors' opinion, the much more severe source of error in hierarchical and amalgamative approaches such as the BC Marine Ecological Classification (MEC). It is also more difficult to characterize.

Slivers can be produced whenever a feature is split up. This happens in two ways: 1. Through the classification of a feature, and 2. Through the overlay of features. Thus, as classes are increased, or as layers are added, more slivers will likely be produced. Slivers, and their associated loss, represent a loss of overall accuracy. Therefore, the accuracy of the final product is inversely proportional to the number of classes and layers that define it. In this light, hierarchical classification systems that use many classes and datasets, though they may appear rigorous, are also subject to extensive spatial error!

The loss of spatial resolution due to the steady removal of slivers can be significant, and is usually much greater than that of the layers' initial resolutions. For example, in the case of the BC MEC, a sliver is defined as anything less than 1500 ha, which for a hypothetically 1:250,000 product means that the only way it would fall within the bounds of the initial boundary resolution is if it were a very skinny polygon less than 250m wide, that would be 60km or more in length! Otherwise, the sliver is wider than would otherwise be absorbed by "noise," and is therefore "signal." So, by absorbing slivers, one is removing "signal," that is, descriptiveness, from the data. With every sliver removed, the remaining data are a little coarser, or more "generalized." Considered over the course of several iterations of layers, with slivers being removed first at the classification stage, and again at the amalgamation (overlay) stage, the cumulative effects can be very large indeed.

Thus, even if a spatial hierarchy's source data were all of reasonable (e.g. 1:250,000) resolution –which is often not so– the final product would still not be 1:250,000. In fact, the more feature layers added to this sort of classification system, the less its final accuracy.

THE AMALGAMATIVE VERSUS HIERARCHICAL APPROACH

The above discussion assumes that the classification features are all merged together more or less at once –an amalgamation. That is, that no one feature is placed before any other feature. In other words, our ecounits are themselves *not* actually a spatial hierarchy, in that no one layer is placed before another. This is contrary to the approach promoted by World Wildlife Fund (Day & Roff 2000) whereby certain features such as depth are placed higher in the hierarchy than others such as substrate. Each of these is labelled as a "level" within the hierarchy. While the BC MEC is described as "hierarchical," (e.g., LUCO 1997), this refers to the ordering of the Ecozones, Ecoprovinces, Ecoregions, and Ecosections. The BC MEC Ecounits do not conform to this hierarchy (that is, they are not fitted within it), nor are they hierarchical with regard to their constituent feature layers.

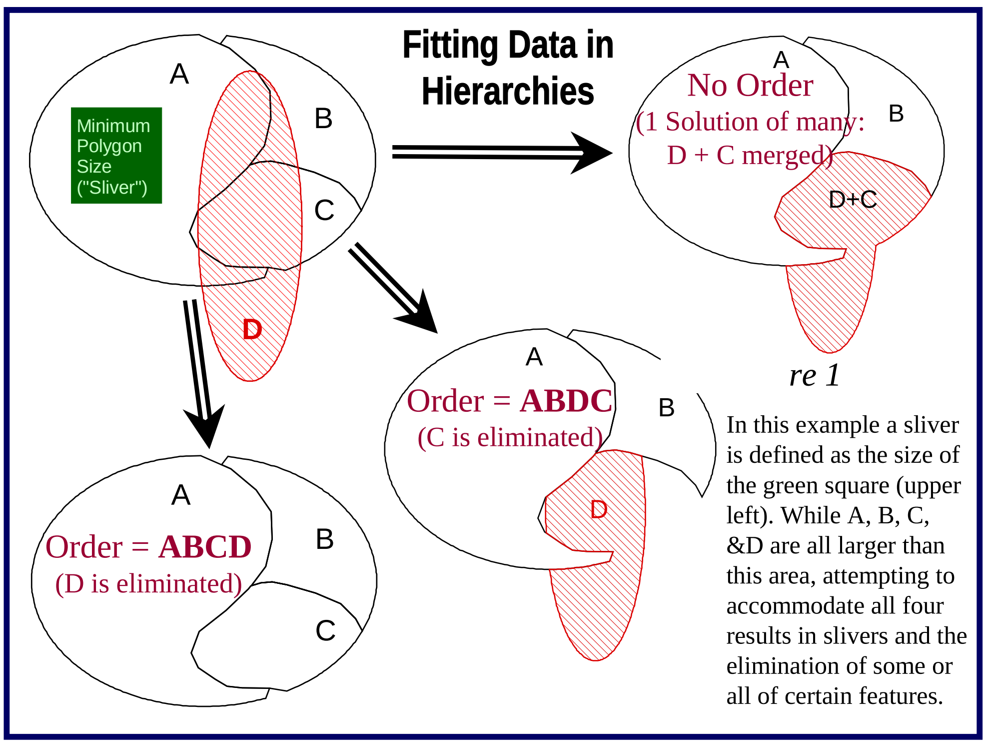
In terms of accuracy it is probably a good thing that the Ecounits do not nest hierarchically, as that the error produced by slivers could well increase. This is because a preceding layer could rigidly divide otherwise large enough polygons into slivers, which would then have to be removed. Consider Figure 17: Hierarchical Polygon Error. A, B, C are non-overlapping polygons. They could be classes of one feature, substrate for example. In a hierarchy, let us assume they are higher than polygon D. In such a case, they slice D up into several polygons, all of which fall below the minimum threshold.

And so, D is eliminated. If the hierarchy were re-arranged, ABDC, say, then D is higher than C, and eliminates C.

As layers are added to a hierarchy, there are fewer and fewer options of how to keep a subsequent layer intact. Thus, *layers near the bottom of a hierarchy suffer disproportionately from loss of accuracy due to loss and absorption of slivers*.

To determine the possible bounds of such error, consider that given enough classes and layers, all the polygons would eventually approach minimum size. In such a situation, any subsequent layer's boundaries would be all but eliminated or absorbed, in what would amount to a very crude re-sampling of the data. The resolution would be thus degraded to that of the sliver threshold, which in BC Terrestrial Ecosystem Mapping (RIC 1997) would be an order of magnitude coarser than the resolution required for a 1:250,000 scale product, or in the case of the BC Marine Ecological Classification, worse still, about 151/2 times ($\sqrt{15}$km^2 minimum square) –in the range of **1:4,000,000**. In other words, any error in higher order levels is not only propagated throughout the hierarchy, but it is used to force the shapes of the lower levels' boundaries with increasing error at a resolution approaching that of the sliver size (assuming a square), or sometimes worse (e.g. Figure 17).

Figure 17: Hierarchical Polygon Error



In an amalgamative approach, such as the BC MEC, where there is no explicit hierarchy, many solutions are possible such that some of each polygon can be represented (see "No Order" in Figure 17). Intuitively, this would appear to be preferable. Unfortunately, unlike a formal hierarchy, the effect is rather unpredictable, as that the generalization error can vary, depending on the size and shape of the slivers, the choices made during sliver removal, and the order that the layers were added (which may even vary from place to place, ecounit to ecounit). The worst case scenario is still the same as that for a hierarchy; i.e., the resolution of the final product equals or exceeds that of the sliver size. However, given some care, it may not occur so often.

Should the polygons be produced one layer at a time, the generalized boundaries will have the unwanted effect of adding error to the subsequent iteration. This is because the generalized boundaries almost always have a greater error than the source data. Thus, *the order in which an amalgamative classification is built will affect the shape of the final product,* even though it is not explicitly hierarchical.

Because some data are considered coarser or "higher" in the hierarchy, it might seem intuitive that they should be added to the ecounits first, followed by finer data. However, considering that the data added towards the bottom of a hierarchy (or amalgamation) suffer most from sliver removal, this ordering is actually backwards. Therefore, ***if a hierarchical or amalgamative approach is being used, finer data should be incorporated first, before coarser data***. In our reading of the literature, however, we have found no discussion of this counter-intuitive strategy.

Another way to minimize the occurrence of sliver error is to construct the polygons all at once. But, in many cases, it may be too complicated to attempt.

Returning to Figure 17, consider the "No Order" solution. D & C are merged to create one composite layer. Notice that only by merging layers could all features be represented. Unfortunately, the good solutions will vary from situation to situation, and thus few rules can be applied. A room full of GIS technicians would produce a room full of different ecounits… When tested against the source data for error, some solutions might be found better than others; but, some solutions might be found to be about the same overall as others, even though they produced ecounits of differing shapes and differing errors in individual classes of features.

Thus, the procedure used to create these ecounits is not likely repeatable, nor is the one solution produced likely to be ideal. Statistically unrepeatable results, such as our hypothetical ecounits, are said to be "unreliable."

For these reasons related to spatial error, we elected not to define our planning units through a spatial hierarchy such as the BC MEC. Instead, we used a regular hexagonal grid. Our "hierarchy" extended no further than defining our simple regions and sub-regions (E.2.2), where the error introduced is minimal and in our opinion, acceptable.

L APPENDIX 3: BENTHIC COMPLEXITY GIS RECIPE

"Reality is but a Convenient Measure of Complexity…"

1. **Get the best bathymetry** available and if lines or points, convert them into a grid with the smallest cell size reasonable. Under-sampling will miss important details and amplify coarse complexities beyond where they exist. This is of particular concern when studying steep-sided but narrow features such as fjords, inlets, and canyons, which can easily get cluttered. Rule of thumb: Cell size in metres = scale (denominator) / 4000. (Central Coast: 0.2 ha.)
2. **Exaggerate the depth.** This will bring out any smaller changes in depth that might get overlooked. Unlike measures of relief, we are looking at all changes in depth, not just the biggest ones. This multiplier also pushes the very steep features (such as the sides of fjords) to a maximum slope ~approaching 90 degrees~ and clumps them together; otherwise, they tend to dominate the results. Rule of thumb: Start with 10x as a multiplier. (Central Coast: 20x.)
3. **Derive the slope of the exaggerated depth**.
4. **Exaggerate the slope, maybe.** This might require some experimentation. For small areas of detailed reliable bathymetry this is probably not necessary. For large grids, however, this exaggeration can keep the next slope (step 5) into the whole numbers, which allows for the use of integer grids, easing memory and computational requirements. Rule of thumb: Do not use a multiplier to begin with. (Central Coast: 20x.)
5. **Derive the slope of the (possibly exaggerated) slope.** Examine the results. Look for a somewhat even spread of values, with many (2/3, say) in the lower half of the legend. If values cluster dramatically near the low end, go back to #4 and apply a multiplier, say, 10x. If they cluster near the top, then your multiplier in #4 is too high. If you used a TIN, you will see some of the TIN "creases." This is normal, since this is where the slope changes. Rule of Thumb: When displayed using a graduated legend, look for an even (log-normal) distribution of colours.
6. **Reclass the results** of #5 into groupings of equal intervals. Toss the first half or so, and keep the last half, more or less. Because we have exaggerated the depth, the lower numbers generally reflect inconsequential changes in slope as well as data variability & inconsistencies. This can be thought of like "pushing" photographic film beyond its normal ASA. The results will pick out dim differences that would otherwise go unnoticed, but will also bring out a lot of "graininess." The exact ratio will depend on the quality of the data, the exaggerations used, and a certain degree of personal judgement. Including too much leaves various unimportant artefacts; excluding too much might miss features. Look at the display: do they reflect areas that might be complex? Rule of thumb: Start out using ½. (Central Coast: top 2 out of 5.)
7. **Reclass the remaining grid cells** into equal intervals and apply a simple weighting. For the Central Coast, we used a two-class system, rating them 1, or 2, depending if they were in the highest class ("2") or the second highest ("1"). I would suggest not going beyond four or five classes. Rule of thumb: Start out using two classes. (Central Coast: 2 classes.)
8. **Calculate the density** of these remaining cells. Calculating density is a good way to extrapolate the results to extend beyond the TIN creases, thus smoothing out the display. In order to calculate density in ArcView 3.x, the grid cells have to be converted to points. I have written a script for this, *grid2pt*, which is posted on ArcScripts. Then, calculate the density of the points. Use the class weightings in #7 as a "population" measure; i.e., a cell with a value of 2 is worth twice that of a cell having a value of 1. The search radius will depend on the scale of your data, and the sorts of questions you are asking. Bigger search radii bring out trends more clearly, but may miss details that you value. Don't be afraid to play around, using different search radii to answer different questions. I prefer using a kernel function. Rule of thumb: Search Radius in metres = scale (denominator) / 100. (Central Coast: 1000m.)
9. **Congratulations!** Now you should have a good index of those areas that have more changes in slope than others; i.e., *benthic complexity*. Look at it. Chances are you'll see areas of known species richness. You may also see areas you previously had not considered. If you want to separate High, from Low, say, reclassify (as in #6), keeping about the top half, and tossing the lower half. You can create a shape file from these, using maybe three classes. To produce pretty colour gradients (e.g. Figure 2), keep everything, but normalize the grid into a meaningful scale, such as 1-100. This will also allow for using an integer grid which takes up less space, and doesn't have the legend bugs that floating grids sometimes have.
10. **Weed out the very smallest clusters** according to scale. (In the Central Coast, we used 30 ha as the cut-off.) If your study area has regional differences, it may be appropriate to buffer the remaining clusters according to the scale of the data and processes being examined. (Central Coast: Inlets no buffer; Passages 500m; Outside Waters 1500m.)
11. (Optional) **Bore all your friends** and associates while praising the virtues of this new analysis. Drink beer alone in pubs wondering why no one talks to you anymore… Get real. (*See title*)

M Appendix 4: Maps of Data Layers

[Note to readers of the electronic version of this document: Appendix 4 has been removed as a separate file, due to its large size. Please download separately.]

The maps in this appendix include:

- Regions & Sub-Regions
- Physical (Benthic) Complexity
- Depth-Substrate
- High Tidal Current Areas
- Salmon Streams & Holding Areas
- Herring Spawn & Holding Areas
- Clam Shorelines
- Kelp
- Pelagic Birds
- Alcids
- Waterfowl
- Shorebirds
- Rare & Endangered Species

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