BC Coast Information Team

Marine Ecosystem Spatial Analysis

[Excerpted and revised text from full report.]

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Version 1.2; November, 2003

To facilitate reading through the full CIT report of 184 pages, I have compiled this excerpt based on my own work in the marine environment. If desired, the full report is also available on the Living Oceans Society web site: www.livingoceans.org/library.htm

Citation of this report:

Ardron, J. 2003. BC Coast Information Team Marine Ecosystem Spatial Analysis, v. 1.2. Excerpted and revised from: Rumsey, C., Ardron, J., Ciruna, K., Curtis, T., Doyle, F., Ferdana, Z., Hamilton, T., Heinemyer, K., Iachetti, P., Jeo, R., Kaiser, G., Narver, D., Noss, R., Sizemore, D., Tautz, A., Tingey, R., Vance-Borland, K. An ecosystem analysis for Haida Gwaii, Central Coast, and North Coast British Columbia. DRAFT, Sept. 22, 2003. (184 pages.) www.livingoceans.org/library.htm 44 pages.

1 Table of Contents

2 Executive Summary

The results presented in this paper are the outcomes of modelling hypothetical marine protected areas (MPAs) based on 93 data layers −physical and biological− for the Central Coast, North Coast, and Queen Charlotte Islands.

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. While not necessarily meeting all goals, these areas of high overlap give clear direction as to where initial conservation efforts should be focussed (Figure 1).

The examination of 24 combinations of modelling parameters indicates that regardless of whether reserves are many and small, or few and large, certain areas recur over and over again.[1] For example, within the Central Coast, the following *larger* areas of high conservation utility emerge:

- Hexactinellid Sponge Reefs
- Goose Islands, Bardswell Islands, and vicinity
- Rivers Inlet
- Scott Islands
- Entrance to Queen Charlotte Strait
- Broughton Archipelago
- Head of Knight Inlet
- Cordero Channel

While these areas alone would not constitute a fully representative Central Coast conservation portfolio, it is very likely that were they not included, such a portfolio 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 conservation planning.

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[1] We ran the model 2,400 times, examining 24 combinations of parameters. For each of the 2,400 solutions, the computer went through 15,000,000 iterations, examining possible combinations.

Larger areas of high conservation utility within the North Coast include:

- Hexactinellid Sponge Reefs
- West Aristazabal Island (& NW Price I.)
- Kitimat Arm
- Anger Island & vicinity
- SW & N Porcher Island, and Kitkatla Inlet
- S. Chatham Sound
- Mouth of Nass R.

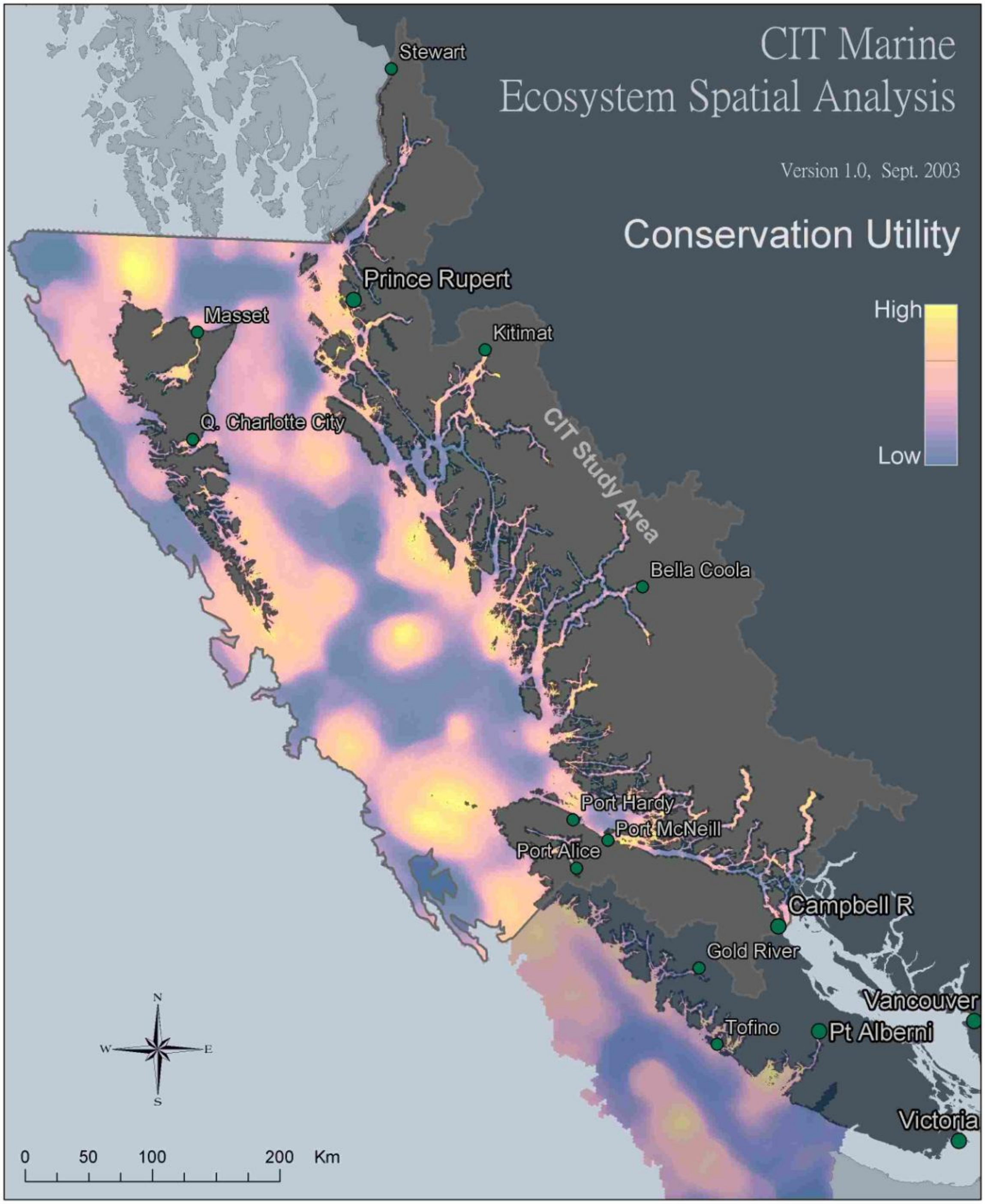
Larger areas of high conservation utility within the Haida Gwaii waters include:

- W. Dixon Entrance
- Naden Hr.
- Masset Inlet
- Skidegate Inlet (Kagan Bay)
- South Moresby Island

Larger areas of high conservation utility off N west coast Vancouver Island include:

- Scott Islands
- Mid-Quatsino Sound
- Brooks Peninsula (Cape Cook) westward to the base of the continental slope

Figure 1: Summation of 2,400 Modelling Solutions



3 Introduction

This excerpted report presents the Coast Information Team (CIT) marine ecosystem spatial analysis. This report does not include the nearshore analysis done by The Nature Conservancy & Nature Conservancy Canada, nor does it include any of the CIT terrestrial analyses. For these, we refer the reader to the main report, which is posted on our web site: www.livingoceans.org/library.htm

The CIT study area includes Haida Gwaii, Central Coast, and North Coast regions of British Columbia. This region has a land area of 11 million hectares; its sea area is another 11 million hectares. Important ecological elements in the region include unregulated rivers supporting large populations of spawning salmon and grizzly bears, estuaries, kelp beds, seabird colonies, archipelago/fjord terrain, deep fjord and cryptodepression lakes, and intertidal flats with abundant invertebrates and resident and migratory waterbirds. Haida Gwaii is an especially significant part of the region, containing an insular biota with distinctive, disjunct, and endemic taxa. The diversity of species within the CIT region is far greater than previously thought, but still incompletely known.

The purpose of the CIT ecosystem spatial analyses is to identify priority areas for biodiversity conservation and, ultimately, to serve four well-accepted goals of conservation: 1) represent ecosystems across their natural range of variation; 2) maintain viable populations of native species; 3) sustain ecological and evolutionary processes within an acceptable range of variability; and 4) build a conservation network that is resilient to environmental change. In pursuit of these goals, the ESA integrates three basic approaches to conservation planning:

- Representation of a broad spectrum of environmental variation (e.g., vegetation, terrestrial abiotic, and freshwater and marine habitat classes).
- Protection of special elements: concentrations of ecological communities; rare or at-risk ecological communities; rare physical habitats; concentrations of species; locations of at-risk species; locations of highly valued species or their critical habitats; locations of major genetic variants.
- Conservation of critical habitats of focal species, whose needs help planners address issues of habitat area, configuration, and quality. These are species that (a) need large areas or several well connected areas, or (b) are sensitive to human disturbance, and (c) for which sound habitat-suitability models are available or can be constructed.

Marine protected areas (MPAs) are increasingly accepted as a tool in conserving marine biological diversity and enhancing exploited fisheries (Lubchenco et al 2003). MPA design theory includes criteria such as representation of habitat types, replication, rarity, focal species, and connectivity (Roberts et al 2003). However, the application of design theory remains largely untested, especially in the Northeast Pacific. While marine classification systems designed to delineate habitat types already exist, they do not prioritize candidate areas for protection (Zacharias et al 1998).

How one chooses an efficient collection of marine reserves amongst innumerable combinations of many differing features has become the focus of several algorithms, with *simulated annealing* emerging as one very promising approach (Possingham et al 2000, Sala et al 2002, Ardron et al 2002, Airame et al 2003). It is this approach, using the software MARXAN, that has been applied in the CIT marine ecosystem spatial analysis.

4 Conservation Features

4.1 Overview

The CIT marine ecosystem spatial analysis (ESA) consists of 93 features, both biological and physical, considering representivity, distinctiveness, focal species, and rare or threatened species. Data were compiled from Fisheries and Oceans Canada (DFO), BC Ministry of Sustainable Resource Management (MSRM), Canadian Wildlife Service (CWS), Natural Resources Canada (NRCan), private researchers, and local knowledge.

Table 1, below, summarizes the breakdown of these layers by type:

Table 1

Feature Category	Feature Sub-Category	No. of Layers
Regional Representation	Data Regions	6
Ecosystem Representation	Ecosections	8
Ecosystem Representation	Ecosystem Regions	3 regions + 3 sub-regions
Ecosystem Representation	Enduring Features & Processes	7 exposure + 21 substrate/depth
Focal Species	Flora	13
Focal Species	Seabirds	15
Focal Species	Anadromous Spp. Richness x Stream Magnitudes	1
Focal Species	Mammals	1
Focal Species	Fish	1
Special Elements	Rarity	6
Special Elements	Distinctive Features	4 complexity + 4 current
48 Coarse Filter +	**45 Fine Filter**	**93**

In the following sections, each of these feature categories is discussed. For a more detailed table of the features, please refer to Appendix 1: Marine Layers

4.2 Representation (Coarse Filter)

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). In the CIT marine ESA, we considered a wide range of enduring features and processes, coupled with regional representation to account for variations in survey efforts and methodologies.

4.2.1 Regional Representation

The CIT marine study area comprises 10.6 million hectares of sea, spanning several regional planning initiatives and data collection efforts. Some regions such as Haida Gwaii have been reasonably well studied (though more work is still required), while others, such as the north Central Coast, have hardly been surveyed at all. As such, there is a real danger that areas with more data could *appear* to harbour greater biological richness and diversity, when in actual fact, this may not be the case. In order to account for regional biases in data collection and planning, the marine CIT study area was divided into five Data Regions: North Coast, Haida Gwaii, N. Central Coast, S. Central Coast, and N. West Coast Vancouver Island. Each one of these Data Regions was included as a target feature in the marine analysis to ensure broad scale geographic representivity, and to ameliorate possible regional biases in data collection effort.

4.2.2 Ecosystem Representation

Ecosections

As discussed in *Study Area Ecoregions and Ecosections* [see full report] the CIT ESAs have sought to gain a representative sample of each provincial ecosection within the study area. These include eight marine ecosections: Dixon, Hecate, Queen Charlotte Sound, Vancouver Island Shelf, Queen Charlotte Strait, Johnstone Strait, North Coast Fjords, and Continental Slope. Each one of these ecosections was included as a target feature in the marine analysis to ensure broad scale ecosystem and geographic representivity.

Ecological Regions

In addition to the BC ecosections, the marine ESA considered broad marine ecosystems based on the following four classifications: Inlets, Passages, Continental Shelf, and Continental Slope. The transition from Inlets to Passages to Shelf to Slope 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 westward to the deep sea. These are widely recognized categories and are described briefly below.

Inlets

> "Fjords [inlets] 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." –Dale 1997

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.

Because the Inlet class encompassed a wide variety of features, ranging from large inlets such as Knight Inlet, to small semi-enclosed water bodies, it was further subdivided into three size classes. To arrive at this classification, area of each inlet was log-transformed. Then, the data were broken into four classes based on Jenks natural breaks algorithm. Because the largest two classes had much fewer numbers than the others they were merged together. The resulting three classes are based on actual inlets and therefore there are gaps in the ranges where there were no inlets of that size:

- Very Small Inlets: 5 – 260 ha.
- Small Inlets: 292 – 3167 ha
- Medium to Large Inlets: 3483 – 122,089 ha.

Inlets include such major features as Dean and Burke Channels (north Central Coast); Belize and Seymour Inlets (south Central Coast); Gardner Channel and Kitimat Arm (north Coast), as well as smaller inlets such as Sewell Inlet (QCI) and Klaskino Inlet (WCVI).

Passages

> "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." –Booth et al 1998.

Passages are characterized by generally moderate wave exposures, with moderate to strong tidal currents mixing with the less saline waters exiting the inlets. They include such places as Grenville Channel (N. Coast), Fitz Hugh Sound (N. Central Coast), and Johnstone Strait (S. Central Coast).

Continental Shelf

These waters comprised all outside waters out to the 200 metre isobath, which is the conventional delineation of BC's continental shelf (Thomson 1981). 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.

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. Biologically, it embraces much of BC's flatfish communities, particularly in Hecate Strait. The shelf includes much of Queen Charlotte Sound, and the shelf extending from the Scott Islands southeastward to Brooks Peninsula.

Continental Slope

This includes all outside waters between the 200m and 2000m –the westernmost edge of the CIT Study Area. The waters are all highly exposed on the surface, but plunge to depths where the effects of storms are not felt, though some gullies may be swept by deep tidal currents (Thomson 1981). Steeply crenulated canyons, gullies, and troughs characterize the region. These offer habitat and refuge to a wide variety of rockfish (*Sebastes sp*) and are markedly different in species assemblages than neighbouring shelf regions (Fargo & Tyler 1991, Perry et al 1994). The continental slope includes areas of localized seasonal upwellings, such as the Scott Islands, which can provide nutrients and prey for a variety of surface and near-surface species including seabirds and plankton communities (Crawford & Thomson 1991). This region includes deep incursions into queen Charlotte Sound, notably Moresby Gully.

4.2.3 Enduring Features and Processes

Substrate and Depth

Substrate and depth are 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 examined depth and substrate according to region (inlets; passages; shelf and slope together) applying appropriate class breaks for each region. For example, for Hecate Strait (shelf and slope), we looked at depth intervals as defined in the literature thought to best delineate flatfish assemblages: 0-50m, 50-135m, 135-240m, 240m-2000m (Fargo & Tyler 1991, Fargo & Tyler 1992, Perry et al 1994). For passages and inlets, however, which are generally characterized by steep-sided deep U-shaped channels, we looked at only photic (0-50m) and non-photic (>50m) depths, as that intermediate depths are unusual and fragmented. In this case, defining depth according to the penetration of sunlight (photic), as suggested by other practitioners (Day & Roff 2000; Alidina in review) is the only meaningful class break.

We used the three substrate classes from the BC Marine Ecological Classification (LUCO 1997, version 1). They are similar to the three WWF classes (Day & Roff 2000) though differ from the five WWF classes 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). The classes are as follows:

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

Within the CIT study area, substrate generally follows a progression from rocky shallower waters, to sandy slopes of moderately deeper waters, to muddy deepest bottoms. One notable exception is Johnstone Strait, a deep passage with significant bottom currents, which therefore does not gather much fine sediment and thus is not muddy (LUCO 1997, Thomson 1981). Sections of Moresby Gully are also swept by significant bottom currents, which are believed to account in part for the extremely rare Hexactinellid sponge communities there (Conway et al 2001).

Within the analysis some classes were aggregated to avoid the possibility of overly sub-dividing the regions into classes too small or fragmented for consideration at the CIT planning scale, and to compensate for weaker data layers. In all, there are 21 classifications of depth and/or substrate by region, for example, *Passages Hard Substrate Photic Depth* (for a full listing, see Appendix 1: Marine Layers). For areas where data were not available, these were noted as *Unknown Depth* and/or *Unknown Substrate*. By representing these areas as separate feature targets with associated goals, we are ensuring that these areas are not ignored simply because they are data-poor.

Shoreline Exposure

We included the seven shoreline exposure categories of the BC shorezone classification (very protected to very exposed) as well as an "unknown exposure" category to account for areas where the shorezone surveys had not been completed. Wave energy, a function of exposure, has been found to be a key indicator of shoreline communities (Connolly & Roughgarden 1997).

4.3 Focal Species & Special Elements (Fine Filter)

4.3.1 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 & Roff 2001, Roberts et al 2003). Different categories of focal species exist, such as indicators, keystone, umbrella, and flagship species (for a complete discussion, see Zacharias and Roff 2001). A common concept in terrestrial conservation is that of the umbrella species, whose conservation is believed to also spatially protect other species' habitat. Unfortunately, umbrella species are not as widely applicable in the marine environment, though they can prove valuable at more local scales (Zacharias and Roff 2001). One problem with the applicability of this concept to marine systems is that many candidate umbrella species, fitting the typical (terrestrial) apex predator profile, such as killer whales (*Orcinus orca*), exhibit massive migrations and utilise areas too large to be useful as marine umbrella species at most planning scales.

On the other hand, marine focal species can still be identified that are useful in conservation. Zacharias and Roff (2001) note that composition indicators, or species who's presence indicates other species or are 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 focal species. We feel that sea birds may be also be seen at least partially as umbrella species, since protecting their foraging habitats will afford some protection to their prey species. Likewise, kelp beds (*Nereocystis luetkeana* and *Macrocystis intergrifolia*) were treated as local-scale umbrellas for the many species associated with them, as were eelgrass beds (*Zostera* sp). Herring (*Clupea pallasii*) spawn were treated as a keystone species, since so many other species are attracted to, and rely upon, these areas to feed on the eggs (Hay and McCarter 2000).

Flora

For the CIT marine ESA, we considered the following focal vegetation species: Eelgrass, kelp, marsh grasses (*Salicornia* sp.), surf grasses (*Phyllospadix* sp), and a general shoreline vegetation class, aggregated from the BC Shorezone classification that includes *Fucus, Ulva,* halosaccion layers, "reds," "soft browns," and "chocolate browns." (For a more detailed shoreline vegetation analysis, we deferred to the nearshore ESA team –see full CIT report.)

Seabirds

All major BC breeding seabird populations and colonies were considered: Ancient Murrelet, Black Oystercatcher, Cassin's Auklet, Cormorant sp., Glaucous-winged Gull, Pigeon Guillemot, Puffin sp., Rhinoceros Auklet, and Storm Petrel sp. (data provided by Canadian Wildlife Service). In addition, very small islets, far from shore were also considered as surrogates for unsurveyed colonies (Gary Kaiser pers. comm.).

Seabirds are known to prefer certain marine waters. These we treated as "habitat capability" layers. We considered pelagic seabirds (shearwaters, fulmars, albatross, some gulls, and terns); waterfowl (ducks, swans, geese, grebes, and loons); and shorebirds (oystercatchers, sandpipers, plovers, and turnstones). Data were provided by Decision Support Services, Sustainable Resource Management, based on known distributions and expert opinion.

Moulting seaducks (Scoter sp. and Harlequin Ducks) inhabit certain nearshore BC waters during summer months. Because they are unable to fly, they are particularly susceptible to stressors such as oil spills (Savard 1988). These areas were also considered separately for each species grouping (data from CWS Coastal Waterbird Inventory; and from Savard 1988, digitized by J. Booth).

Anadromous Streams

BC's anadromous streams were captured using a species richness x stream magnitude ranking. Eight of BC's nine anadromous spp were considered (eulachon, the ninth, was treated separately). These include all *Oncorhynchus* spp and Dolly Varden (*Salvelinus malma*). About 1 out of 10 BC stream systems were considered *likely* to support significant numbers of anadromous species. Of those, about half were assigned a low score (1-4 out of a possible 24), meaning that they are small streams supporting only a few species. Only the Fraser River (outside the CIT study area) received a top score (24), with the Nass and Skeena rivers tied in second place (20). For a full description of this layer, please refer to Appendix 2: Stream Richness x Magnitude.

Seller Sea Lion

Seller Sea Lion (*Eumetopias jubatus*) haul-outs and rookeries were ranked on a scale of 1-4 based on population density.

Herring spawn

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 2001). Invertebrates, fish and seabirds, and particularly ducks and gulls, are all predators of herring eggs (Hart 1973; Hay and McCarter 2001). 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).

Herring spawn (Clupea pallasii) shorelines were ranked on a density measure based on DFO's Spawn Habitat Index (Hay & McCarter, 2001), using the latest available times series data (DFO 2002). Data were cube root transformed and standardized to shoreline length per hexagonal planning unit.

4.3.2 Rare and Threatened Species

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). In the marine ESA, we consider five Special Elements, on account of their rare or threatened status: Hexactinellid sponge reefs, Eulachon estuaries, Sea otter (not WCVI), estuaries containing red or blue listed species, and Marbled Murrelet marine habitat.

Hexactinellid Sponge Reefs

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 et al 2001, Conway 1999). 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 2002). We strongly support the recommendations of Conway (1999), Krautter et al (2001), and Jamieson & Chew (2002), all who suggest that these sponge reefs be permanently protected from trawling. Since the summer of 2002 they have been given some protection in the form of a fishing closure, however closures can be lifted at any time at the discretion of fisheries managers. There are only four such reefs known to exist in the world, all of which are in the CIT study area.

Eulachon Estuaries

Eulachon (*Thaleichthys pacificus*) 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).

Data were downloaded from DFO Habitat and Enhancement Branch's public web site (DFO 2003), and were compared to FISS data, and published literature (McCarter and Hay 1999). Points were snapped to the BC Watershed Atlas when appropriate.

Sea Otter

Sea otters (*Enhydra lutris)* 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). 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).

While the WCVI population appears to be increasing, the only known established colony in the CIT study area is in the Goose Islands.

Red-Blue Estuaries

Estuaries in the North Coast and QCI harbouring provincially red (rare) or blue (threatened) listed species, mainly birds, were identified by Remington (1993), and digitized by Living Oceans Society for the CIT.

Marbled Murrelet Marine Habitat Capability

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 and high current areas have also been considered in the marine ESA.

Marbled Murrelets are known to prefer certain marine waters. These we treated as a "habitat capability" layer. Data were provided by Decision Support Services, Sustainable Resource Management, based on known distributions and expert opinion.

Habitat-Forming Corals

We considered areas known to harbour large habitat-forming corals, which may well be threatened or endangered, but due to a lack of surveys their status largely remains unknown. Coral outcrops and "forests" are important habitat for adult fishes, crustaceans, sea stars, sea anemones and sponges because they provide protection from these currents and from predators. Some commercially important fish species are found in association with these reefs, such as Atka mackerel, *Pleurogrammus monopterygius,* and shortspine thornyhead, *Sebastolobus alascanus,* in Alaska. Rockfish are associated with *Primnoa* corals in the Gulf of Alaska (Etnoyer & Morgan 2003).

4.3.3 Distinctive Features

One shortcoming of a representative areas approach is that it requires examining and possibly 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 (2002 unpublished) argue that such smaller "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. Distinctive areas may also be thought of as representative of a certain type of habitat, but at a finer scale than the nominal scale of the study (John Roff, pers. Comm.). In the marine CIT ESA, we included two separate indicators of distinctive habitats: Benthic topographical complexity, and high current.

Benthic Complexity

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).

Benthic topographical complexity is indicated by how often the slope of the sea bottom changes in a given area; that is, the density of the slope of slope of the depth. Note that this is not the same as relief, which looks at the maximum change in depth. Benthic complexity considers 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 (Ardron 2002).

We used 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. 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 (Ardron 2002).

In the marine ESA, benthic complexity was examined separately within each of the four Ecological Regions (inlets, passages, shelf, slope).

High Current

This layer was extracted from the BC Marine Ecological Classification, version 2 (LUCO 1997, Axys 2001), as well as 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 that region. 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 south Central Coast passages. 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.

Because high current areas are always well mixed subsets of whatever larger mixing regime may exist, we have classified them as distinctive areas. They were considered separately for each of the four Ecological Regions (inlets, passages, shelf, slope).

5 Conservation Goals (Targets)

Halpern (2003) reviewed 89 studies of no-take marine reserves and found that regardless of size, marine reserves lead to increases in density, biomass, individual size, and diversity in all functional groups. However, larger reserves did produce larger increases. Halpern goes on to caution "…that to supply fisheries adequately and to sustain viable populations of diverse groups of organisms, it is likely that at least some large reserves will be needed." (ibid pp129-130)

A variety of Marine reserve sizes ranging from 10% to 50% 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. Furthermore, it has been found that larger reserves often have beneficial effects disproportionate to their size (Halpern 2003). In the marine CIT ecosystem spatial analysis, we explored a variety of conservation goals (also know as "targets" in the literature) that produced overall areas ranging from 5% – 50% of the study area. Specifically, we looked at Marxan solutions that comprised 5, 10, 20, 30, 40, and 50 percent of the study area. However, this does not imply that equal amounts of each of our 93 feature elements were represented. Rather, as explained below, each feature was assigned a goal based on a range of six relative rankings.

Before choosing actual percentages per feature as a goal, we examined each dataset and assigned to it a relative term, where "moderate" was taken as the common baseline or average value. The five terms used were: *low, moderate-low, moderate, moderate-high, high,* and *very-high*. In general, we assigned lower rankings such as *low* or *moderate-low* to features that were common (i.e. plentiful), and higher rankings features that were more unusual or rare. Umbrella and keystone species were generally assigned a *moderate-high* ranking. By using these six simple qualitative rankings, we were able to class the features relative to each other. Once that was completed, we could 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 to compare scenarios. Table 2 displays the actual percentages attached to each qualitative ranking. Columns display each conservation scenario, while the rows display the rankings.

Table 2

Relative Ranking	Conservation Goals (Percentages)					
Low	2	4	8	12	16	20
Mod-Low	4	8	16	24	32	40
Moderate	6	12	24	36	48	60
Mod-High	8	16	32	48	64	80
High	10	20	40	60	80	100
V. High	12	24	48	72	96	120*
Overall Size	**5**	**10**	**20**	**30**	**40**	**50**

*Goals greater than 100% cannot be met, but do serve to give these features a higher emphasis.

Appendix 1: Marine Layers lists all 93 features in the marine ESA, and their assigned relative goals.

6 Portfolio Assembly

6.1 Site Selection

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. A systematic approach to reserve design is strongly urged (Margules & Pressey 2000, Possingham et al 2000). Experience from other jurisdictions have shown that an ad hoc approach to marine protection can lead to decisions which do not necessarily ensure efficient or effective reserve design, and may later be regretted (Stewart et al 2003, Gonzales et al 2003).

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 (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 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.

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.

6.1.1 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.

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 2003). 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 6.3below).

6.2 Planning Units

The Marine ESA planning units are a regular grid of 500 hectare hexagons. There are about thirty-two thousand of these hexagons in the analysis which covered the entire CIT marine study area, and down the west coast of Vancouver Island.

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.

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

Presence / Absence Areal Data

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

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

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:

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

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.

For presence / absence features, the scores can range from 0 to 16 per hexagon.

Our sensitivity analyses indicate that this compression of values was found to be robust to random grid shifts and variations in base shorelines used by different datasets.

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

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

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

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.

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.

6.3 Marxan Parameters

Marxan consists of 8 main parameters to direct the optimization algorithm:

1. **Conservation Targets (Goals)**: 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. **Boundary Length Modifier**: The relative cost of a reserve's perimeter
4. **Minimum Separation Distance**: The minimum distance that distinct groupings of a feature should be from one another.
5. **Separation Number**: The number of distinct groupings of a feature required (i.e. replication).
6. **Minimum Clump Size**: The minimum number of planning units (hexagons) needed to count as a valid grouping of the feature.
7. **Planning Unit Cost**: A relative value applied to planning units such that some may be more difficult or "expensive" to set aside than others.
8. **Boundary Cost**: The relative cost of the planning units' shared boarders.

Of these, the first three are the most important. The first parameter, conservation goals, has been discussed above (section 5), and is equivalent to stating how much of a feature is enough to meet one's conservation objectives. In the marine ESA, we explored a wide variety of goals so as to provide planning tables with a range of possibilities, from low to high conservation objectives.

The other Marxan parameters are discussed below.

6.3.1 Penalty Values

Assigning a penalty to a feature is in effect saying how much it matters if this feature's goal (target) is *not* met. That is, for features that do not meet their goals, penalties are assigned (on a sliding scale based on how closely the goal was achieved); and in turn it is these penalties that will "direct" the algorithm in its search for features. Thus, features with higher penalties are generally met first (if they can be met) than similarly distributed features with lower penalties. 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. 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 play important ecological roles (such herring spawn).

As with goals (targets), penalties were first given a relative ranking. From those weightings were assigned as follows:

Relative Penalty	**Marxan Weighting**
Low	0.25
Mod-Low	0.50
Moderate	1.00
Mod-High	2.00
High	4.00
V. High	8.00

Appendix 1: Marine Layers lists all 93 features in the marine ESA, and their assigned relative penalties.

6.3.2 Boundary Length Modifier (Clumping)

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= 0.0625, 0.250, 1.000, 4.000) This is an arbitrary parameter that must be arrived at through experimentation. While we found that solutions 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 data populate the planning units in a consistent fashion and that the planning units themselves are consistent.

6.3.3 Other Parameters

The other Marxan Parameters were handled as follows:

- **Minimum Separation Distance**: Not used. This parameter greatly increases processing requirements. For such a large number of planning units (32,000) and features (93), its use was impractical.
- **Separation Number**: Not used. (As above.)
- **Minimum Clump Size**: Not used. We felt the 500 hectare hexagons were already sufficiently large. In practice, the hexagons naturally clump together.
- **Planning Unit Cost**: All planning units treated the same. Cost set to 1. As that the objective of this exercise was to explore just conservation values, we did not consider whether some planning units might in practice be more difficult to protect than others.
- **Boundary Cost**: This parameter was used to fine-tune the relative clumping of hexagons in the four Ecological Regions (inlets, passages, shelf, slope). To determine this value we looked at the edge to area ratio of each of these regions and then created an appropriate scalar. The non-dimensional measure we used was: $\sqrt{(P^2/A}$ where P = total perimeter of region, and A = total area of the region. By altering the boundary costs per region, we allowed for more fragmented solutions in areas constrained by geography, such as inlets, but encouraged more clumped solutions in open waters, such as over the continental slope. The resulting boundary costs were as follows:

Region	**Boundary Cost**
Continental Slope	1.54
Continental Shelf	1.00
Passages	0.34
Inlets	0.21

7 Results

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. While not necessarily meeting all goals, these areas of high overlap give clear direction as to where initial conservation efforts should be focussed.

7.1.1 24 Scenarios; 2,400 Solutions

We examined 6 reserve network sizes: 5%, 10%, 20%, 30%, 40%, and 50%. In addition, we examined four MARXAN clumping parameters: very scattered, scattered, moderate, and moderately clumped (BLM = 0.0625, 0.250, 1.00, 4.00). For each of these 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 15 million iterations.

7.1.2 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 Ball & Possingham 2000).
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 blue (seldom chosen) to yellow (chosen frequently) in the map, [Figure 1]. 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, within the Central Coast, the following *larger* areas of high conservation utility emerge:

- Hexactinellid Sponge Reefs
- Goose Islands, Bardswell Islands, and vicinity
- Rivers Inlet
- Scott Islands
- Entrance to Queen Charlotte Strait
- Broughton Archipelago
- Head of Knight Inlet
- Cordero Channel

While these areas alone would not constitute a fully representative Central Coast conservation portfolio, it is very likely that were they not included, such a portfolio 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 conservation planning.

Larger areas of high conservation utility within the North Coast include:

- Hexactinellid Sponge Reefs
- West Aristazabal Island (& NW Price I.)
- Kitimat Arm
- Anger Island & vicinity
- SW & N Porcher Island, and Kitkatla Inlet
- S. Chatham Sound
- Mouth of Nass R.

Larger areas of high conservation utility within the Haida Gwaii waters include:

- W. Dixon Entrance
- Naden Hr.
- Masset Inlet
- Skidegate Inlet (Kagan Bay)
- South Moresby Island

Larger areas of high conservation utility off N west coast Vancouver Island include:

- Scott Islands
- Mid-Quatsino Sound
- Brooks Peninsula (Cape Cook) westward to the base of the continental slope

7.1.3 Flexible Solutions

Areas of high conservation utility alone would not constitute a fully representative conservation portfolio. 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.

Once an initial selection of conservation areas has been chosen, probably based on the areas of high utility, but also taking into account the needs of the communities and stakeholders, the Marxan algorithm can be re-run, locking these areas into the network. Areas required to complete the portfolio (i.e. meeting the agreed-upon conservation goals) can then be explored. These could once again be taken to stakeholders for comment, and then locked in or out of the analysis as the case may be. It is anticipated that three such iterations would be sufficient to create a core network of conservation areas. Finer scale planning could contribute to rounding out the portfolio on a local basis.

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9 Appendix 1: Marine Layers

CIT Marine ESA Feature Layers

Marine Feature Name	Goal	Goal Rationale	Penalty	Penalty Rationale	Weighted?	Range	Mean: Hexes >0	No. of Hexes >0	Total Values
Ecosystem Representation									
Shelf Region	Moderate	Broad Representivity	High	Overarching Region	No	0-16	15.2	13997	212370
Passages Region	Moderate	Broad Representivity	High	Overarching Region	No	0-16	11.7	2740	32032
Inlets Region	None	See Inlet Sub-regions	None	See Inlet Sub-regions	No				0
Medium to Large Inlets	Moderate	Broad Representivity	High	Overarching Region	No	0-16	9.2	3432	31667
Small Inlets	Moderate	Broad Representivity	High	Overarching Region	No	0-15	6.8	391	2660
Very Small Inlets	Moderate	Broad Representivity	High	Overarching Region	No	0-11	4.4	152	671
Slope Region	Moderate	Broad Representivity	High	Overarching Region	No	0-16	15.6	11174	174053
Dixon Ecosection	Moderate	Provincial Classes	Low	Broad Representation	No	0-16	14.9	2471	36935
Hecate Ecosection	Moderate	Provincial Classes	Low	Broad Representation	No	0-16	14.5	2928	42483
QC Sound Ecosection	Moderate	Provincial Classes	Low	Broad Representation	No	0-16	15.3	7546	115762
Van I Shelf Ecosection	Moderate	Provincial Classes	Low	Broad Representation	No	0-16	14.2	4014	57024
QC Strait Ecosection	Moderate	Provincial Classes	Low	Broad Representation	No	0-16	12.6	649	8145
Johnstone Ecosection	Moderate	Provincial Classes	Low	Broad Representation	No	0-16	10	884	8832
N Coast Fjords Ecosection	Moderate	Provincial Classes	Low	Broad Representation	No	0-16	10.3	3808	39272
Cont Slope Ecosection	Moderate	Provincial Classes	Low	Broad Representation	No	0-16	15.2	6504	99048
Regional Representation									
North Coast Data Area	Moderate	Compensate Uneven Sampling	Mod-High	Geographic Representation	No	0-16	13.4	5079	67908
Haida Gwaii Data Area	Moderate	Compensate Uneven Sampling	Mod-High	Geographic Representation	No	0-16	14.9	9652	143946
NWCVI Data Area	Moderate	Compensate Uneven Sampling	Mod-High	Geographic Representation	No	0-16	15.4	6596	101350
N Central Coast Data Area	Moderate	Compensate Uneven Sampling	Mod-High	Geographic Representation	No	0-16	11	2084	22955
S Central Coast Data Area	Moderate	Compensate Uneven Sampling	Mod-High	Geographic Representation	No	0-16	11.2	2097	23389

WCVI Data Area	Moderate	Compensate Uneven Sampling	Mod-High	Geographic Representation	No	0-16	14.9	6333	94261
Enduring Features & Processes					No				
Shelf Sand Photic	Moderate	Common	Mod-Low	Weak Substrate Data	No	0-16	12	2226	26753
Shelf Mud Photic	Mod-High	Unusual	Mod-Low	Weak Substrate Data	No	0-16	3.9	171	672
Shelf and Slope Hard Photic	Moderate	Common	Mod-Low	Weak Substrate Data	No	0-16	8.8	2973	26306
Shelf and Slope Hard not Photic	Low	Very Common	Mod-Low	Weak Substrate Data	No	0-16	11.3	6739	75883
Shelf and Slope Sand not Photic	Low	Very Common	Mod-Low	Weak Substrate Data	No	0-16	13.2	8219	108757
Shelf and Slope Mud not Photic	Moderate	Common	Mod-Low	Weak Substrate Data	No	0-16	12.2	1660	20193
Shelf and Slope Mid-depth a	Mod-Low	Representivity	Moderate	Reliable Bathymetry	No	0-16	11.6	7827	90756
Shelf and Slope Mid-depth b	Mod-Low	Representivity	Moderate	Reliable Bathymetry	No	0-16	11.6	7145	82596
Shelf and Slope Deep	Mod-Low	Representivity	Moderate	Reliable Bathymetry	No	0-16	14.6	10311	150626
Pass Hard Photic	Moderate	Physical Representivity	Mod-Low	Weak Substrate Data	No	0-16	5	643	3222
Pass Sand Photic	Moderate	Physical Representivity	Mod-Low	Weak Substrate Data	No	0-16	4.2	562	2357
Pass Mud Photic	Moderate	Physical Representivity	Mod-Low	Weak Substrate Data	No	0-16	3.2	925	2984
Pass Hard not Photic	Moderate	Physical Representivity	Mod-Low	Weak Substrate Data	No	0-16	4.9	731	3577
Pass Sand not Photic	Mod-Low	Quite Common	Mod-Low	Weak Substrate Data	No	0-16	8.2	830	6809
Pass Mud not Photic	Mod-Low	Quite Common	Mod-Low	Weak Substrate Data	No	0-16	8.7	1275	11080
Inlets Photic	Moderate	Physical Representivity	Mod-Low	Weak Substrate Data	No	0-16	2.9	2626	7671
Inlets Hard not Photic	Moderate	Physical Representivity	Mod-Low	Weak Substrate Data	No	0-15	4	346	1373
Inlets Sand not Photic	Moderate	Physical Representivity	Mod-Low	Weak Substrate Data	No	0-16	5.3	313	1669
Inlets Mud not Photic	Low	Very Common	Mod-Low	Weak Substrate Data	No	0-16	6.9	2709	18769
					No				
Unknown Substrate	Moderate	Account for Knowledge Gaps	Mod-Low	Knowledge Gaps	No	0-16	15	6924	103799
Unknown Depth	Moderate	Account for Knowledge Gaps	Moderate	Knowledge Gaps	No	0-16	3.3	4816	16010
Very Protected Shorezones	Mod-High	Distinctive Habitats	Mod-High	Sensitive to disturbance	No	0-12	3.4	101	339
Protected Shorezones	low	Very Common	Moderate	General Feature	No	0-15	4.7	4417	20831
Semi-Protected Shorezones	low	Very Common	Moderate	General Feature	No	0-14	4.2	3613	15191

Semi-Exposed Shorezones	Mod-Low	Common	Moderate	General Feature	No	0-12	4.1	1747	7095
Exposed Shorezones	Moderate	Representative Habitat	Moderate	General Feature	No	0-9	3.6	637	2283
Very Exposed Shorezones	Mod-High	Distinctive Habitats	Moderate	General Feature	No	0-10	4.9	86	422
Unknown Exposure	Moderate	Account for Knowledge Gaps	Moderate	Knowledge Gaps	No	0-15	4.8	982	4714
Distinctive Features									
Complexity Shelf	Mod-High	Distinctive Areas	Mod-High	Important to many Spp	Yes 1-7	0-107	29.4	6517	191799
Complexity Passages	Mod-High	Distinctive Areas	Mod-High	Important to many Spp	Yes 1-6	0-82	16.2	2036	32926
Complexity inlets	Mod-High	Distinctive Areas	Mod-High	Important to many Spp	Yes 1-7	0-63	12	2052	24552
Complexity Slope	Mod-High	Distinctive Areas	Mod-High	Important to many Spp	Yes 1-7	0-113	30.7	4530	139188
High Current Areas Shelf	Mod-High	Distinctive Areas	Mod-High	Connectivity	No	0-16	9.7	253	2453
High Current Areas Passages	Mod-High	Distinctive Areas	Mod-High	Connectivity	No	0-16	7.8	234	1832
High Current Areas Inlets	Mod-High	Distinctive Areas	Mod-High	Connectivity	No	0-14	7	145	1018
High Current Areas slope	Mod-High	Distinctive Areas	Mod-Low	Questionable Data		0-16	9.5	160	1518
Special Elements: Rarity									
Hex Sponges	Very High	Rare	Very High	Extremely Rare	Yes 2-3	0-48	24.4	203	4944
Eulachon Estuaries	High	Threatened	High	Threatened	Yes 1-5	0-125	26.4	34	896
Seaotter (not WCVI)	High	Locally Rare	High	Rare	No	0-14	6.9	21	144
Large Corals	High	Likely Threatened and/or Rare	Moderate	Weak data	Yes 1-4	0-64	20.7	3614	74934
Red-Blue Bird Estuaries	Very High	Red-Blue Spp Critical Habitat	Moderate	Incomplete South	Yes	0-100	44.9	73	3275
Marbled Murrelet Capability	Moderate	Habitat	Mod-High	Red Listed Sp	Yes 2-3	0-48	29.7	2540	75382
Focal Species									
Eelgrass Polygons	Mod-High	Umbrella; critical habitat	Mod-High	Biodiversity, Nursery	Yes 1-4	0-38	4.5	304	1358
N Coast Eelgrass Biobanding	Moderate	Few Other Data	Moderate	Unknown Reliability	Yes 1-2	0-21	4.4	483	2132
QCI Eelgrass Biobanding	Mod-Low	Other Data Available	Mod-Low	Unknown Reliability	Yes 1-2	0-20	5.6	326	1815
NWCVI Eelgrass Biobanding	Mod-Low	Other Data Available	Mod-Low	Unknown Reliability	Yes 1-2	0-20	4.1	152	620

NCC Eelgrass Biobanding	Moderate	Few Other Data	Moderate	Unknown Reliability	Yes 1-2	0-15	3.7	645	2417
SCC Eelgrass Biobanding	Moderate	Few Other Data	Moderate	Unknown Reliability	Yes 1-2	0-14	2.8	297	822
WCVI Eelgrass Biobanding	Mod-Low	Other Data Available	Mod-Low	Unknown Reliability	Yes 1-2	0-22	4.2	229	969
Kelp	Mod-High	Umbrella; critical habitat	Mod-High	Biodiversity, Juveniles	Yes 1-4	0-18	2.4	1174	2822
Kelp Biobanding	Mod-Low	Many Occurrences Recorded	Mod-Low	Other Data Available	Yes 1-2	0-25	6.1	3161	19336
Marsh Grasses Biobanding	Moderate	No Other Data	Moderate	Unknown Reliability	Yes 1-2	0-24	4.1	3077	12723
Surfgrass	Moderate	No Other Data	Moderate	Unknown Reliability	Yes 1-2	0-24	4.8	1448	7001
Other Vegetation Biobanding	Moderate	Amalgamation	Moderate	Increased Reliability	Yes 1-5	0-45	7.1	6099	43310
Unknown Biobanding	Moderate	Account for Knowledge Gaps	Moderate	Knowledge Gaps		0-15	5	868	4370
Bird Colony AnMu	Moderate	Bio Representivity	Moderate	Breeding Seabird Sp	Yes 1-5	0-79	24.9	1758	43851
Bird Colony BlOy	Moderate	Bio Representivity	Moderate	Breeding Seabird Sp	Yes 1-5	0-23	3.5	410	1416
Bird Colony CaAu	High	Largest Global Breeding Area	High	Threatened	Yes 1-5	0-80	21.4	5162	110634
Bird Colony Co	Moderate	Bio Representivity	Moderate	Breeding Seabird Sp	Yes 1-5	0-47	13.3	659	8742
Bird Colony GWGu	Mod-Low	Very Common	Mod-Low	Adaptable Sp	Yes 1-5	0-65	15.7	4245	66436
Bird Colony PiGu	Moderate	Bio Representivity	Moderate	Breeding Seabird Sp	Yes 1-5	0-69	13.9	1588	22080
Bird Colony Pu	Moderate	Bio Representivity	Moderate	Breeding Seabird Sp	Yes 1-5	0-79	23.6	397	9379
Bird Colony RhAu	Mod-High	Largest in E Pacific	Mod-High	Breeding Seabird Sp	Yes 1-5	0-79	23.3	2747	63888
Bird Colony SP	Moderate	Bio Representivity	Moderate	Breeding Seabird Sp	Yes 1-5	0-79	20.1	6410	129070
Small Islets	Mod-Low	Very Common	Moderate	Unsurveyed Colonies	Density	0-25	7.7	4624	35692
Pelagic Seabird Capability	Moderate	Habitat	Mod-Low	Coarse Data	Yes 1-3	0-49	28.9	6543	188991
Waterfowl Capability	Moderate	Habitat	Mod-Low	Coarse Data	Yes 1-3	0-48	17.8	7609	135185
Shorebird Capability	Moderate	Habitat	Low	Inconsistent Data	Yes 1-3	0-48	18.2	8566	155612
Moulting HaDu	Moderate	Bio Representivity	Moderate	Vulnerable Sp (moulting)	Yes 1-3	0-46	8.1	445	3587
Moulting Scoters	Moderate	Bio Representivity	Moderate	Vulnerable Sp (moulting)	Yes 1-4	0-47	8.5	837	7109
Anad. Richness x Str. Magnitude	Moderate	Spp Richness & Abundance	Moderate	Several datasets	Yes 1-24	0-198	25.8	742	19124

Steller Sea Lions	Moderate	Habitat	Moderate	Haul outs and Rookeries	Yes 1-4	0-63	21.9	760	16658
Herring Spawn	Mod-High	Keystone	Mod-High	Only data available	Density	0-49	8.2	1942	15906

10 Appendix 2: Stream Richness x Magnitude

This appendix is included to give the reader an idea of the steps involved in creating the data layers that fed into the model. In this particular example, anadromous streams are considered. Explanations of the other layers are available on request.

Overview

This measure of anadromous species richness x stream magnitude is such that it disregards very small streams, and gives higher scores only to exceptionally rich and large streams.

About 1 out of 7 (14%) of BC's stream systems were judged to be *possibly* anadromous, and 71% of those were assigned a score of greater than zero. That is, about 1 out of 10 BC stream systems were considered *likely* to support significant numbers of anadromous species. Of those, about half were assigned a low score (1-4 out of a possible 24), meaning that they are small streams supporting only a few species. Only the Fraser River received a top score (24), with the Nass and Skeena rivers tied in second place (20).

Data Sources

BC fish presence data were compiled from 3 different FISS point sources: *evp* files – sample sites on streams; *evs* files–"stream mouths" which turned out to include other reach data as well; and FISS wizard enquiries producing spatial point files in csv format. Each data source was merged separately for all of BC. It was found that while there was considerable agreement amongst the three BC datasets, they were *not* identical, and sometimes were inconsistent with each other. Thus, it was decided to use all three, although duplicate points would be generated and would need to be weeded out later. A few other databases from private researchers were also used. However, these were small. FISS line files (evz) were found to add no new species presence information not already covered by the points and were not used.

Eight of BC's nine anadromous spp were considered (eulachon, the ninth, was treated separately). These include all *Oncorhynchus* spp (FISS codes: SK, CO, CM, CH, PK; CT_ACT_CCT; ST_SST_WST) and Dolly Varden, DV_ADV (*Salvelinus malma*).

Stream Network Assignments

A network analysis was performed on the BC watershed atlas to create cohesive stream networks connecting all stream reaches to the coast. Thus, every stream reach was identified with a stream network number that corresponded to a point that intersected the coastline. This required considerable data cleaning.

Most fish presence data were then assigned to a stream network. Watershed codes were used when given. When not given, points were spatially joined to the stream networks they intersected (+/- 2 metres). However, many FISS points did not fall on streams. For these, the following operations were performed:

Use first 14 digits of WSA code if available;

Check for overlap with other points that had a WSA code;

Seek a code match using first 12 digits of WSA code if available;

Seek a code match using first 9 digits of WSA code if available;

Check over the above work based on nearest distance to stream systems, within 100 metres. This caused 10 points to be reassigned, and allowed for 119 additional points to be assigned to a stream system.

Overall, 135 of 31,835 FISS points (0.4%) were not assigned a stream system. That is, they had no WSA code, and did not fall within 100m of a WSA stream. Some of these appear to be incomplete duplicates of other points, while others appear to be complete orphans, perhaps because the WSA is not entirely comprehensive in its coverage of streams and tributaries, or perhaps due to a mistake in coding the UTM locations of these points.

Richness

Due to inconsistencies found in the datasets, we decided that our measure of richness would require more than 1 record to appear in a stream network (per species) before it would be counted. It is believed that this would weed out many spurious points with a minimum effect on good data. Since we merged three FISS datasets together, it is likely that more than one point should appear on a stream network, were it valid. Indeed, most stream networks had several points. The difference between >0 records (conventional approach with perfect data) and >1 records (our criterion based on inconsistent data) is given in the table below:

	Networks >0	**Networks >1**
Chinook	229	129
Chum	1040	577
Coho	1227	787
Pink	826	401
Sockeye	308	184
Cut throat	746	522
Steelhead	371	240
Dolly Varden	496	346

1590 systems of 8175 had >0 anadromous sp records; whereas 1120 had >1 records. Species Richness Relative Importance was assigned a number 1-4 based on steps of every two species, as shown below:

Spp Richness (8175 systems)	**Networks >0**	**Networks >1**	**RI**
1	325	338	1
2	318	267	1
3	363	210	2
4	213	114	2
5	136	67	3
6	95	51	3
7	87	39	4
8	53	34	4

Magnitude

Stream magnitude (attribute of the WSA) was log-transformed (natural logarithm). The resulting range was 0-11. This score was scaled to 1-6. This eliminated all streams of magnitude 2 or less, a subset of second order streams. Only three BC rivers exceeded a score of 4: The Fraser (6), Skeena (5), and Nass (5). Thus, excluding these three exceptional rivers, the measure was designed to have the same weighting, RI=1-4, as richness.

Magnitude x Richness

Richness RI measures and magnitude RI measures were then multiplied together to produce a composite measure of richness and magnitude, with 796 river systems in BC receiving a score of 1 or greater. The only river to get a top score (24) was the Fraser, with the Skeena and Nass both tied in second place at RI=20. About 30% all possibly anadromous streams (>1 spp) were eliminated because they were either too small, or in fewer cases because they had no more than one observation record per species. Of the remaining half, about half of those scored a low score of 1 - 4.

Note: the table below considers all stream systems with >0 anadromous sp, records even though we actually looked at >1 record (see above). This was to allow for comparisons later between the two approaches. Consequently, looking at the table, one can see that about half of these have a score of 0. As noted above, 30% of streams with >1 record scored 0.

RI: Richness x Magnitude	**No. of Stream Systems**
24	1: Fraser
20	2: Skeena, Nass
16	11
12	26
9	22
8	26
6	67
4	96
3	40
2	244
1	261
0	794
Total >0	796

Coast Information Team Marine Analysis

To incorporate this data layer into the CIT marine analysis, stream mouths (points) were expanded one grid cell (100m) in all directions to account for those that fell near the boundary of two hexagons. This created 300m squares (9 grid cells) for each point. They were neither clipped to the shoreline nor rationalized to the hexagons, as that the buffer was used only as a way to distribute the stream's scores across boundaries, and does not correspond to an actual physical feature. This "blurring" of the stream mouths was to account for spatial differences between watershed atlas data and other data used in the CIT, as well to spread the score more evenly across hexagons that by chance happened to bisect or nearly bisect a stream mouth.