CHAPTER 8

# Nearshore Marine Conservation Planning in the Pacific Northwest:

## Exploring the Utility of a Siting Algorithm for Representing Marine Biodiversity

*Zach Ferdaña*

## Abstract

Terrestrial conservation planning is well developed. In comparison, there are only a handful of published marine conservation plans and few of them are quantitative. The Nature Conservancy's strategic planning approach, called "Conservation by Design," employs an ecoregional planning methodology to construct conservation portfolios, or high-priority conservation areas. This chapter reports on the development of a regional nearshore marine analysis in the inland seas of Puget Sound, Washington, in the U.S., and the Strait of Georgia, British Columbia, in Canada. The purpose of marine planning within the Willamette Valley-Puget Trough-Georgia Basin ecoregion was to identify a set of conservation areas that capture the full array of representative shoreline ecosystems and a subset of the existing nearshore biodiversity. This chapter outlines the basic steps of the ecoregional planning process, including the identification of conservation targets, assigning conservation goals, assessing population viability and ecological integrity, and selecting conservation areas. A marine planning team identified 37 shoreline ecosystems, one for rocky reef habitat, and 72 marine species as conservation targets. In order to achieve our conservation goals in the most efficient manner possible, we concluded that at least 30% of the total shoreline (excluding humanmade shore units) in the ecoregion warrants an evaluation of ecosystem integrity in order to place these sites in some form of protected status or conservation management. Four terms were adopted to describe and examine representation: overrepresentation ($p > 1.3$), adequately captured ($p => 1.03$ and $< 1.3$), efficiency of representation ($p = 1.0 +/- .03$),



**Zach Ferdaña**
Global Marine Initiative, The Nature Conservancy, 217 Pine Street Suite 1100
Seattle WA 98101
zferdana@tnc.org

and missing values ($p = < .97$). SITES, a reserve site selection algorithm, was used to examine site selection. Marine analyses were developed both in combination with terrestrial information and as a separate, yet parallel, process. The first approach used a seamless 750-hectare hexagon assessment unit across both environments. Although integrative in nature, the seamless unit tended to over-represent shoreline targets (57%), thereby exceeding set conservation goals. However this analysis met most goals, with the missing values category containing only 4% of targets. The second approach used a linear shoreline and nearshore hexagon unit. A 4-tiered nearshore analytical framework was designed to analyze information according to our confidence in the spatial data, and systematically incorporate expert input. It was found that overrepresentation was not as much of a factor as when using the seamless hexagon approach, with only 18% of targets considered over-represented. The missing values category contained 31%, thereby not performing as efficiently as the seamless hexagon in meeting conservation goals. Where the uniformity of the seamless hexagon provided the means to include information across environments in the land/sea interface, the nearshore and shoreline units tended to be more spatially explicit and follow ecological boundaries. In total, there were 186 shoreline/nearshore sites comprising 2,910 km of shoreline in the final conservation portfolio.

## Introduction

Coastal regions across the globe are under particular stress today as human populations concentrate along shoreline environments. Estuarine and marine environments bear the cumulative, negative impacts of land-use and resource-management decisions carried out in adjacent terrestrial and freshwater areas. At the same time, humans are exploiting marine fisheries with an efficiency that threatens to undermine trophic relationships and biodiversity. In response to these threats and challenges, more effort has focused on marine conservation planning in the last few years.

Setting priority areas for conservation often involves a strategic planning approach. The Nature Conservancy's approach is called "Conservation by Design." This is directing the organization to systematically identify the array of places around the globe that embrace the full spectrum of the Earth's natural diversity. It is also a framework for developing the most effective strategies to achieve tangible, lasting results, and to work collaboratively to catalyze action on a scale great enough to ensure the survival of entire ecosystems (The Nature Conservancy, 2001).

In order to protect diversity in a cost-effective manner, the field of conservation has developed general planning principles (Pressey et al., 1993; Margules et al., 2000; Groves et al., 2002). These widely applied planning approaches originated in terrestrial settings and have only recently been applied to marine environments. For example, the World Wildlife Fund recently completed plans for the Sula-Sulawesi Seas, the Meso-American Reef, and Nova Scotian Shelf (Day and Roff, 2000). The Nature Conservancy has completed ecoregional assessments for the central Caribbean (Sullivan-Sealey and Bustamante, 1999) and the northern Gulf of Mexico (Beck and Odaya, 2001), Chesapeake Bay, southern California, and Cook Inlet in Alaska. In addition, The Nature Conservancy and World Wildlife Fund have collaborated in a plan for the Bering Sea (Banks, 1999). Other examples exist outside the non-profit community (i.e., Ward et al., 1999; Airamé et al., 2003; Leslie et al., 2003). In response to the present human impacts and threats facing coastal ecosystems in the Pacific Northwest, methods have been developed for constructing a conservation portfolio across terrestrial and nearshore environments in the Willamette Valley-Puget Trough-Georgia Basin ecoregion (Fig. 8.1; see page XXX). Reported here is a regional planning exercise to test methods of capturing representative nearshore marine biodiversity in a conservation portfolio for the waters of Puget Sound and Strait of Georgia.

## Conceptual Framework for Marine Ecoregional Planning

Marine planning at the ecoregional scale provides a larger context for selecting high-priority conservation areas in estuarine, nearshore, and offshore environments. Ecoregions, not political boundaries, provide a framework for capturing ecological and genetic variation in biodiversity across a full range of environmental gradients. There are three key components to consider during the ecoregional planning process: conservation targets, conservation goals, and population viability and ecological integrity. They are briefly outlined in the following text. For a more in-depth treatment, see Beck (2003).

### *Conservation Targets*

The first step in the Conservancy's regional planning approach is to select conservation targets. These are ecosystems, habitats, and species that represent a diversity of the biotic assemblages in a region. In marine environments, the most effective planning approach is to focus on marine ecosystems and the ecological processes that sustain them (Beck, 2003). This presumes that the conservation of a representation of all the ecosystems will also conserve a representation of the diversity of species found in these ecosystems. Examples include rock platforms that support tide pools, kelp forests, and seagrass meadows.

A robust classification scheme to identify the different types of ecosystems is critical for selecting conservation targets. The choice of a particular classification scheme can significantly influence siting algorithms and decision support tools that identify potential conservation areas. Where possible, classification schemes should be based on biological data, but in the marine environment, surrogate data are usually required. While coastal classifications generally rely on physical factors such as landform, slope, and wave energy, a combination of abiotic and biotic-based targets will likely be most effective in conserving the full array of biodiversity in any given planning region.

Marine species targets that are least likely to be represented by ecosystem level information are endangered, imperiled, or species considered keystone (see Power, 1996). Many of these species require individual attention because management of their habitats alone is necessary but insufficient for their conservation needs. In addition, aggregation sites usually associated with the physical convergence of water and land or of different water masses, are also used as a marine target type. Examples include the spawning aggregations of reef fish, or breeding congregations of seals and sea lions on haulout sites.

## *Conservation Goals*

A conservation goal is characterized by the amount of the target that should be represented in conservation areas across the planning region. The objective is to assess how much representation is required to maintain its persistence over time. This should ideally be based on historical estimates of the abundance and distribution of the targets. Unfortunately, goals often have to be based on current distributions (Beck and Odaya, 2001). This being the case, different approaches have been adopted to test the representation question in marine environments (Leslie et al., 2003). One such approach is to conduct sensitivity analyses. This involves systematically varying the conservation goals to determine how they affect the overall size of the area selected.

## *Population Viability and Ecological Integrity*

As data are gathered on the distribution of the targets and their locations, attempts are made to ensure that only populations of species and examples of ecosystems that are likely to persist into the future are included (Beck, 2003). However, formal analyses of viability are rare for marine species and similar analyses of integrity are virtually non-existent for ecosystems. While one may not have these sources of information, there are often factors that can be used to "screen" or filter out areas that are not likely to have the best or most viable examples of species and ecosystems. These factors are often built into a "suitability index." Examples include shoreline impacts such as bulkheading (seawalls, jetties) and coastal development (boat ramps, docks, marinas), adjacent impacts such as land-use designation (urban, agriculture), and freshwater impacts such as water quality. These factors generally guide site selection algorithms away from these impacts.

## *Selecting High Priority Conservation Areas*

One of the primary tools being used by The Nature Conservancy in selecting areas that deserve conservation attention is the use of site selection algorithms. For this ecoregion, SITES was used, an optimal reserve selection algorithm (Andelman et al., 1999; Possingham et al., 2000). SITES, previously known as SPEXAN, and subsequently known as MARXAN, is becoming well established in conservation planning circles. SITES is best suited (but not restricted) to the situation where an ecoregion has been divided into a set of candidate sites, or planning units that completely fill the region. Examples include abstract units such as equally sized grids, and natural units of analysis, such as watersheds. These are the basic building blocks for assembling a conservation portfolio.

At the core of reserve selection problems is the overall objective of minimizing the area encompassed with the network of reserves (Pressey et al., 1993). SITES uses a simulated annealing algorithm to evaluate alternative site selection scenarios, comparing a very large number of alternatives to identify a good solution. The procedure begins with a random set of planning units, and then at each iteration, swaps planning units in and out of that set and measures the change in "cost." Cost here does not mean dollars for land purchase, but the amount of area selected in the alternative. The algorithm's objective function is to minimize total area while meeting the desired amount of target representation. This function is a nonlinear combination of the total area and the boundary length of perimeter of the site selection output (Leslie et al., 2003). A boundary length modifier setting in the algorithm's parameters determines the relative importance placed on minimizing the perimeter relative to minimizing area. When this modifier is set very small, the solution algorithm will concentrate on minimizing area, whereas when the modifier is set relatively larger, the solution method will put the highest priority on minimizing the boundary length of the feasible reserve system. In its iterative nature, if the change in cost tends to improve the selected set, the new set is carried forward to the next iteration until the maximum number of iterations is reached.

There are many methods for solving this nonlinear integer programming problem. Do we want fewer, larger sites, or smaller, more dispersed sites of nearshore marine ecosystems and habitats across the seascape? There is never just one "optimal" solution (i.e., the definitive set of conservation areas) in regional planning, but it is possible to identify those areas that are both essential and representative as part of a plan. Siting algorithms provide a context for objective representation that is both measurable and spatially explicit. This chapter explores these parameters in order to test methods for efficient representation of nearshore biodiversity.

## Methods

The purpose of our efforts at The Nature Conservancy was to develop a conservation portfolio that, if conserved and properly managed, will in part protect a representative subset of the existing nearshore marine biodiversity in the Puget Sound and Strait of Georgia. Protecting this representative subset will help ensure the long-term survival of the region's marine resources. Our goal was to illustrate the efficiencies and overrepresentation issues between including terrestrial and nearshore information into a single planning unit, and optimizing for minimum area and target representation using separate planning units. The nearshore data and available information used was limited in several ways when compared with terrestrial inputs. To truly match terrestrial datasets and information would require (1) historic information on marine habitats and species; and (2) viability or population assessments for marine species in setting ecological conservation goals. Unlike terrestrial environments, where extensive surveys report on the condition of individual species, and in some cases, entire habitats, there is no nearshore marine analogue. Therefore, this analysis had to rely on available data that report on quantities of marine ecosystems, habitats, and species, but not on their condition or quality. This translates to the most striking difference between terrestrial and marine analyses, where one is based on landscape condition, the other on representation. This representation was largely based on current classification schemes and surveys along the shoreline. Given these limitations, our intent is to show how different planning approaches can be conducted to best represent the present arrangement of nearshore marine ecosystems, habitats, and species using available data.

## The Planning Unit

The design and selection of the appropriate planning unit is heavily debated within and among conservation planning teams. Choosing the spatial configuration and size are the two main debatable components. Planning units can be categorized into two realms: abstract and natural units. Abstract units are generally equally sized areas that arbitrarily fall across the land and/or seascape. Examples are grids or hexagons. Natural units are generally of variable size that fit within ecological boundaries. Examples are watersheds determined by drainage area, and shoreline segments or reaches determined by the length of a dominant beach substrate. There are advantages and disadvantages with choosing either abstract or natural units for analysis.

Abstract units have the advantage of incorporating information across ecosystems, in this case, the terrestrial and nearshore environments. In addition, equally sized units equally weight the amount of boundary or perimeter per unit in the selection process. From a modeling standpoint, this may be the preferred option. However, abstract units arbitrarily cut across ecosystem lines and randomly bin information.

Along the coast, for example, hexagons may encompass shoreline reaches from both shores of narrow water bodies like inlets or fjords. This aggregation of shoreline units associated with different landmasses may be problematic in that one side of the water body may be more ecologically significant than the other. This may lead to an overrepresentation of ecosystems and habitats in the selection output. Often a unit is chosen for a specific target in order to fulfill its representation goal, but may also select less desirable types that are aggregated along with it. This leads to a less optimized solution. An objective of the selection process is to not only meet each conservation target goal, but also to minimize the amount of that target's representation above the stated goal. In addition, abstract unit size usually lacks ecological justification. If units are too large they may over-generalize the more spatially explicit target data. Likewise, if the units are too small, they may be misrepresenting the level of spatial detail of the data.

Natural units have the advantage in that they fall within ecological boundaries, and in the case of shoreline reaches, are more spatially explicit than generalizing them within abstract units. In addition, using the output from natural unit selection is more intuitive in delineating sites for a conservation portfolio. However, natural units are of variable size, with the algorithm often choosing larger units over smaller ones. This, too, can also lead to overrepresentation problems. Furthermore, using a linear planning unit like shorelines may be inappropriate in that the selection of segments are often randomly scattered and shorter segments may be insignificant at a regional scale. It is appropriate here to come back to the original set of questions being asked of the data and the selection process. Given the level of spatial detail required over a large study area. it may be adequate to generalize the more spatially explicit input data and retain its detail for more site-specific conservation planning. Therefore, several approaches to planning unit configuration were tested.

The first approach was to combine terrestrial and marine target information into a seamless, 750-ha hexagon. The second approach was to use two spatial planning units for the nearshore and shoreline environments; 750-ha hexagons and linear units respectively. This approach separated terrestrial and nearshore site selection. The linear shoreline reaches (determined by the length of the dominant beach substrate) were adopted as analysis units in their original form. Since linear planning units are not the native spatial configuration for SITES, the boundary length modifier had to be customized. SITES uses this modifier to aggregate planning units based on the real extent of shared boundary between planning units. In order to use this parameter, a linear boundary to calculate the adjacency of shoreline units was developed. For every shoreline reach, the adjacent units were identified and the boundary modifier could therefore be set higher to select more contiguous lengths of shoreline, or lower to disperse shoreline units into shorter sections. For this ecoregional assessment, the outputs of these different spatial configurations were compared in terms of the efficiency of target representation.

### *Nearshore Conservation Targets: Shoreline Ecosystems and Intertidal Habitats*

Representative ecosystem types were derived from shoreline classifications and inventories first developed in British Columbia, and then modified in Washington State. The Province of British Columbia developed its physical and biological ShoreZone mapping system based on shore types after Howes et al. (1994) and Searing and Frith (1995). These shore types are biophysical types that describe the substrate, exposure, and vegetation across the tidal elevation, as well as the anthropogenic features and supratidal types. In Washington State, the ShoreZone mapping system was adopted and attributed to both the British Columbia classification scheme as well as the Dethier (1990) method that more precisely segregated intertidal communities. These shoreline inventories were assessed by helicopter over the entire region, then interpreted, classified, and digitized into a geographic information system, or GIS.

Eight thousand and seventy kilometers have been flown and interpreted over the ecoregion, or nearly fifteen thousand linear reaches of shoreline classified according to their landform, substrate, and slope (see Howes et al., 1993; Berry et al., 2001). These data, and the underlying British Columbia summary classification (34 coastal classes and 18 representative shore types), served as the basis for constructing shoreline ecosystem conservation targets.

Eighteen representative shore types were examined within the original classification and aggregated further into 8 shoreline substrate types. This process generalized shoreline ecosystems into discernable coastal communities for planning purposes, distributed evenly across the ecoregion. We then augmented the representative or physical component of the classification with a biological one. To do this, biological information was extracted from the dataset to identify chosen intertidal vegetation types. Saltmarshes (high and low tidal marshes, sedges), seagrasses (eelgrass, surfgrass), and kelps (giant and bull kelps) were chosen as the three vegetation categories to capture the major biological communities of the nearshore zone from the supratidal to shallow subtidal. Although these categories alone do not represent the entire range of intertidal habitats or the most diverse habitat types, they are biologically productive and the most sensitive to man-made alteration. These categories are protected by policy, recognized to be ecologically important, and thus served as the best surrogates to represent a wide range of nearshore habitats.

Eight vegetation combinations were derived from the three categories listed above. These combinations were assembled for each of the eight shoreline substrate types, creating 64 potential physical and biological combinations. These unique types were distilled down to a more manageable list of 37 shoreline ecosystem and intertidal habitat targets (Table 8.1). These distillations were based on expert opinion, with each shoreline substrate type considered separately. When there were not clear dominant vegetation types based on percentages available per substrate category, all vegetation was lumped into a "vegetated" class. In addition, the "saltmarsh and subtidal vegetation" class indicated that all types were present across the intertidal zone.

## Additional Nearshore Datasets

Habitat and species information were collected in the nearshore to augment the data captured within ShoreZone. We calculated 469,461 ha of nearshore marine waters, defined in this study as the area extending from the supratidal zone above the ordinary or mean high water line (i.e., the top of a bluff or the extent of a saltmarsh in the upper intertidal) to the 40-m depth below mean lower low water. This represents 31% of all marine waters in the ecoregion, covering 1,509,733 ha. In addition, we divided the waters of the ecoregion into two distinct sections based on freshwater and oceanographic characteristics (Fig. 8.2; see page XXX). This was done to ensure the selection of occurrences across the natural range of the target.

Fishery-independent video surveys were conducted in Puget Sound by the Washington Department of Fish & Wildlife between 1993 and 1997. These surveys collected data on rocky reef habitat and marine fishes. The rocky reef data contained important attributes including

**Table 8.1. Shoreline conservation targets: Intertidal habitats**

| *Shoreline ecosystems* | *Kelp* | *Kelp and seagrass* | *Saltmarsh* | *Saltmarsh and subtidal vegetation* |
|---|---|---|---|---|
| Mud Flat | 0 | 0 | 618,206 | 136,656 |
| Rock cliff | 0 | 0 | 0 | 0 |
| Rock platform | 0 | 0 | 0 | 0 |
| Rock with sand and/or gravel beach | 254,981 | 109,765 | 0 | 18,365 |
| Sand and gravel beach | 182,046 | 179,744 | 37,128 | 36,695 |
| Sand and gravel flat | 74,565 | 121,036 | 41,104 | 56,599 |
| Sand beach | 135,651 | 63,885 | 66,841 | 57,266 |
| Sand flat | 33,337 | 60,181 | 67,378 | 113,689 |
| Totals | 680,580 | 534,611 | 830,656 | 419,270 |
| Goals | 30% | 40% | 30% | 40% |
| Goals in meters | 204,174 | 213,845 | 249,197 | 167,708 |

relief (elevation) and complexity (roughness of rock structures, crevices). Transformation of these data into conservation targets are discussed in Ferdaña (2002). This information was used to analyze areas deeper than the intertidal zone and associate species data on nearshore marine fishes with a subtidal benthic habitat. No comparable data were available to develop a portfolio of any subtidal habitats deeper than 40 m. Because habitat categorizations were lacking beyond this depth, planning efforts were not extended to deeper waters except in a few shoal areas away from the coast. In addition, rocky reef data were not available for the Strait of Georgia and therefore, only the ShoreZone data could be relied upon to interpret down to the shallow subtidal in British Columbia.

Additional marine species were included in the assessment, including various rockfishes and other marine fishes, seabirds, marine mammals, and invertebrates (Table 8.2). The final list included 72 species: 9 fish, 3 marine mammals, 50 seabirds and 10 invertebrates. For seabirds, individual species either served as surrogates for groups of species (i.e., American wigeons were used to represent 4 species of dabbling ducks), or individual targets represented multiple species (i.e., seabird nesting colonies represented 13 different species).

## *Sensitivity Analyses*

There were three critical components of the SITES algorithm to construct before the strengths and weaknesses of a seamless planning unit and multiple, separate units could be tested: a suitability index, setting conservation goals, and a species penalty factor.

The suitability index is an assemblage of different costs or impacts that are scaled relative to each other. This relative cost value is assigned to every planning unit. Cost can be many different things, but here serves as an index of values that either adversely affect the health of an ecosystem (human impacts) or make conserving a particular area less feasible (designation of land use and socioeconomic values). This index tends to reduce representation in places where human uses or modifications restrict conservation options. It is user defined, usually incorporating a variety of impacts to the environment, but may also include land status. These costs are generally seen as either more (i.e., lands already in some protected status) or less (i.e., lands devoted to resource extraction) suitable for conservation action. For our purposes, costs to the nearshore were primarily impacts, making particular places less suitable for conservation. There were also land use designations as factors in the intertidal and shallow subtidal zones.

Direct impacts to the shoreline were defined, as well as offshore factors. Shoreline impacts included the amount of armoring along the shoreline, the presence of railroad beds in the higher intertidal zone, and the number of public and private boat ramps. Offshore factors included ferry and commercial shipping routes. Land use and

**Table 8.2. Marine species conservation targets included in the data analysis**

| *Target Scientific Name* | *Target Common Name* | *Taxa* |
|---|---|---|
| *Branta bernicla* | Black Brant | Bird |
| Various species | Dabbling ducks | Bird |
| Various species | Diving ducks/bay ducks | Bird |
| *Histrionicus histrionicus* | Harlequin duck | Bird |
| *Gavia* spp. | Loons | Bird |
| *Brachyramphus marmoratus* | Marbled murrelet | Bird |
| *Aechmophorus* spp. | Red necked grebes | Bird |
| *Melanitta* spp. | Scoters | Bird |
| Various species | Seabird [nesting colonies] | Bird |
| Various species | Shorebirds-mud/ aggregated | Bird |
| *Aechmophorus occidentalis* | Western grebe | Bird |
| *Sebastes melanops* | Black rockfish | Fish |
| *Sebastes caurinus* | Copper rockfish | Fish |
| *Ophiodon elongatus* | Lingcod | Fish |
| *Clupea pallasi* | Pacific herring [spawning] | Fish |
| *Ammodytes hexapterus* | Pacific sandlance | Fish |
| *Sebastes maliger* | Quillback rockfish | Fish |
| *Hypomesus pretiosus* | Surf smelt [spawning] | Fish |
| *Sebastes nigrocinctus* | Tiger rockfish | Fish |
| *Sebastes ruberrimus* | Yelloweye rockfish | Fish |
| *Gorgonocephalus eucnemis* | Basket star | Invertebrate |
| *Lopholithodes* spp. | Box crabs | Invertebrate |
| *Pollicipes polymerus* | Gooseneck barnacles | Invertebrate |
| *Ptilosarcus gurneyi* | Orange sea pens | Invertebrate |
| *Haliotis kamtschatkana* | Pinto (northern) abalone | Invertebrate |
| *Polyorchis penicillatus* | Polyorchis jellyfish | Invertebrate |
| *Crassedoma giganteum* | Rock scallop | Invertebrate |
| *Tritonia diomedea* | Rosy tritonia | Invertebrate |
| *Virgularia* spp. | Seawhips | Invertebrate |
| Various species | Spiny vermilion star | Invertebrate |
| *Phoca vitulina* | Harbor seal [pupping] | Mammal |
| *Eumetopias jubatus* | Steller sea lion [haul out and rafting] | Mammal |

designation factors included ownership of tidelands (public versus private), fisheries closures, marine reserves, and other protected areas. Using the same nearshore costs within both hexagons and shoreline planning units resulted in similar indices. This provided consistency in running the site-selection analysis using both spatial formats. Since there was no way to assess viability for individual marine targets, the suitability index was built as a means of driving the algorithm towards the least disturbed examples of habitats.

Since good, comprehensive historic records were not available, population viability assessments with which to set goals have not been conducted regionally, and there was a lack of survey work reported on the condition of nearshoreprocesses, conservative (low) goals were set to help the algorithm assemble an efficient portfolio of sites important to multiple targets. Using this approach, we attempted to answer the question, 'Where do we start?' in evaluating places for nearshore biodiversity, as opposed to "How much (area) is enough?" to conserve that biodiversity. ShoreZone data were the most uniform across the ecoregion, providing the best data for describing a portfolio representative of the ecoregion's nearshore. We began by setting a "portfolio goal" for how much of the total shoreline length should be included in the nearshore marine portfolio. We examined a variety of portfolio goal levels from 20% to 40%. Likewise, we examined multiple goals for individual shoreline ecosystem targets ranging from 15% to 50% of the target's current extent.

Goals for individual shoreline ecosystem targets were determined by the relative diversity of habitats across the tidal range. The biologically simplest targets—unvegetated shorelines—received a goal of 25% of current extent. The biologically richest targets—shorelines with saltmarshes, seagrasses, and kelps—received the highest goal of 40%. The other targets received goals within this range,corresponding to their presence across the intertidal zone. In this way, the site selection algorithm chose more occurrences of the biologically richest sites to ensure representation of the wider range of species that occupy them. This approach to goal setting attempted to integrate intertidal habitats. The final goals chosen for the analysis are shown in Table 8.1.

For rocky reef habitats we set a goal of 30% of known existing occurrences, attempting to capture places with the highest levels of relief and complexity. Although data were not comprehensive across the ecoregion, and represented only one subtidal habitat, rocky reefs with and without the confirmed co-occurrence of rockfish species were identified by the algorithm. In setting goals for species targets we considered the relative abundance, distribution, and number of occurrences as well as our confidence in the data. Datasets that were more comprehensive across the ecoregion, recently compiled, represented a specific life stage (i.e., spawning) as opposed to observational or behavioral (i.e., swimming), or represented a series of observations over time, received higher goals. With these factors in mind, goals ranged from 20% to 60% of known occurrences.

By setting goal ranges we tested the sensitivity of conservation target representation. The importance of sensitivity analyses is to evaluate the efficiency of representation during the site selection process when goals and other pararmeters are varied. In addition to establishing goal ranges to test sensitivity, we experimented with a range of boundary modifiers for clumping hexagons that represented nearshore species and rocky reef habitat, and connecting adjacent linear units of representative shoreline ecosystem types.

Another key component is the penalty factor assigned to each target. A penalty is weighed against the cost factors and applied to targets for not meeting conservation goals. In other words, the penalty means that the user defines the importance of the target in meeting its goals, and this weighting is factored against cost. Therefore, if a target is assigned a relatively high penalty factor, then the algorithm will try harder to meet its goal, even if it has to select planning units with high cost values. We used our confidence in the data to help set this parameter. Targets represented by data with higher confidence received a higher penalty factor.

## *Multiple Scenarios Explored*

Optimized, efficient, and spatially explicit representation of conservation targets across the ecoregion is an important aspect of defining a marine conservation portfolio. There are challenges in over-representing certain target elements, and not meeting conservation goals for others. Our objective was to explore two site selection scenarios to test these levels of representation for shoreline ecosystems, intertidal habitats, and marine species. We evaluated site selection output using definitions of "overrepresentation" and "efficiency of representation" as defined in Leslie et al. (2003). In addition, we added two categories in examining representation—"missing values" and "adequately captured."

Overrepresentation was defined as a target exceeding its assigned goal by 30% or more ($p > 1.3$). Adequately captured were determined to be targets that exceeded their goals but were not considered over-represented ($p = > 1.03$ and $< 1.3$). Efficiency of representation was defined as a target meeting its goals at or close to 100% ($p = 1.0 +/- .03$). The last category, missing values, were targets that did not meet their goals ($p = < .97$).

Our first approach was to adopt the 750-hectare hexagon as the seamless planning unit across terrestrial and marine environments. All spatial datasets were intersected by the over 8,000 hexagons from the foothills of the Cascade Range to the waters of Puget Sound and the Strait of Georgia. We examined a variety of SITES parameters in configuring planning unit selection as described earlier. Variations of each parameter were tested until an optimal setting was found. With these optimal settings in place, we ran a single scenario and evaluated the amounts of representation across all nearshore target types. We chose the "best" output from SITES, which reflects the least overall cost (minimizing area and perimeter of planning units) across all iterations within the scenario in meeting conservation goals.

We also tested representation levels by conducting a nearshore-only analysis using two spatial planning units (shoreline units and nearshore hexagons). We used an analytical and expert review framework to order targets into "tiers" for portfolio assembly, capturing sites where multiple targets occur, where suitability for conservation is highest, and where our confidence in individual datasets is sufficiently high. Taxon groups (i.e., marine fishes) were analyzed at different stages of portfolio assembly. This was an attempt to build stepwise analyses, control data biases, and minimize overrepresentation of individual targets. The approach for building a nearshore marine portfolio combined spatial analysis and expert review into a tiered system. At each tier we analyzed ecosystem, habitat, and species data, then called upon experts to choose a select number of sites for that stage from the overall representation. These sites then became the "locked-in" areas for subsequent SITES runs. This systematic approach of varying the goals and building expert designation into the framework was used to test each tier against the other while refining the portfolio.

## Results

We concluded that an overarching portfolio goal of 30% of the entire shoreline ecosystem (not including human-made shore units) was appropriate to identify priorities in evaluating the conservation of the diverse coastal environment. Reviewers consistently indicated that a 20% goal omitted some critical sites, especially where extensive dikes have been built but ecological processes were still intact (i.e., adequate freshwater and tidal flow regimes in estuaries for juvenile fish rearing habitat). Further, reviewers indicated that a goal of 40% identified too many sites that were often felt to be low in potential quality. Given that the algorithm attempts to filter a large amount of information into a representative subset, we felt that 30% was the appropriate level to test efficiency and overrepresentation of targets within a selection arrangement.

### *Influence of the Seamless Hexagon*

In an attempt to have a consistent planning unit across the entire planning region, all target information was input into hexagons. SITES parameters were varied until optimal settings were established that best met conservation goals and minimized overrepresentation as much as possible. We have focused our results for this report on the nearshore portion only.

We input 119 data elements representing all of our shoreline ecosystems, habitats, and species targets. We stratified the 37 shoreline ecosystem targets into two sub-regions (Fig. 8.2) to make 74 data elements. For marine species, we generated 44 data elements from 72 targets. Some of these elements served as surrogates for more than one target (i.e., seabird colonies), while others had two data elements for one conservation target (i.e., some seabird targets were represented by two different datasets because of their spatial differences in British Columbia and Washington). We used an additional data element for

**Table 8.3. Results of the seamless hexagon and separate nearshore analyses.**

| *Data elements* | *1A & B* | | *2A & B* | | *3A & B* | | *4A & B* | |
|---|---|---|---|---|---|---|---|---|
| | *SU1* | *SU2* | *SU1* | *SU2* | *SU1* | *SU2* | *SU1* | *SU2* |
| Stratified shoreline | 52 | 12 | 12 | 18 | 5 | 9 | 5 | 35 |
| | 70% | 16% | 24% | 16% | 7% | 12% | 7% | 47% |
| Species/rocky reef | 16 | 10 | 15 | 27 | 14 | 6 | 0 | 2 |
| | 36% | 22% | 33% | 60% | 31% | 13% | 0% | 4% |
| Total | 68 | 22 | 27 | 45 | 19 | 15 | 5 | 37 |
| | 57% | 18% | 23% | 38% | 16% | 13% | 4% | 31% |

Columns 1A & B: Overrepresentation (p> 1.3); Columns 2A & B: Adequately captured (p = > 1.03 and < 1.3); Columns 3 A & B: Efficiency (p = 1.0 +/- .03); Columns 4A & B: Missing values (p = < .97); SU1 = Seamless units; SU2 = Separate units. Numbers outside of parenthesis indicate the number of data elements in each category. The total number of data elements is 119, or 74 stratified shoreline and 45 rocky reef/marine species elements

rocky reef habitat, bringing the total discrete data elements to 45. For this exercise, we analyzed representation by data elements as they were input into SITES, and not by conservation target.

The best scenario output tables from SITES were used to evaluate the results of the seamless hexagon planning unit. We examined the stratified shoreline ecosystems and intertidal habitats both combined with and separately from the marine species and rocky reef elements (Table 8.3). The overrepresentation (p > 1.3) of all data elements was 57%, or 68 out of 119. Within the 74 stratified shoreline elements, 52, or 70%, were considered over-represented. For the 45 marine species and rocky reef data elements, only 16, or 36%, were considered over-represented. The adequately captured category (p= > 1.03 and < 1.3) contained 23% of all data elements, or 16% of the stratified shoreline elements and 33% of the marine species and reef elements. The efficiency of representation (p = 1.0 +/- .03) for the seamless hexagon analysis revealed 19 total data elements, or 16% (7% shoreline stratified targets and 31% marine species/reef elements). Finally, the missing values category (p = < .97) contained 4% of all elements, or 7% of shoreline and 0% species/reef designations (Fig. 8.3; see page XXX).

The optimal reserve program attempts to represent target elements at their assigned levels and minimize the total area selected. Since aggregating shoreline reaches within hexagons tended to generalize the spatial data into arbitrary groups, the seamless hexagon analysis over-represented ecosystem and habitat conservation targets. Additionally, terrestrial data was input into the coastal hexagons, further influencing the selection process. On the other hand, this scenario either adequately captured or efficiently represented most of the remaining data elements, leaving only 4% of the elements that did not meet their goals. This is an important component when evaluating overall efficiency of site selection in comparison to elements that either met or exceeded goals (96%).

This result facilitated the need to extract shoreline information from the hexagons and apply a distinct linear planning unit. The nearshore species and rocky reef habitat information, however, could continue to be run within hexagons but was also separated from the influence of terrestrial target data. Going from one to two planning unit configurations meant that we had to construct an analytical framework for tracking the selection process while keeping a close eye on the various categories of representation.

## *Influence of the Shoreline Unit and Nearshore Hexagon*

We designed an analytical framework for constructing shoreline and nearshore site selection separate from the terrestrial environment. This -tiered framework was an attempt to control data biases and overrepresentation that we found in running SITES using the seamless hexagon approach.

Tier 1 involved the experimentation of different goals and expert evaluation to come up with initial seascape sites. A stepwise analysis was performed to identify initial seascapes based on various SITES scenarios applied to hexagons. The objective was to use multiple goals to evaluate which planning units would get chosen most often. This form of an "irreplaceability analysis," or the selection of core sites, included the evaluation of the importance of the conservation target, data confidence and co-occurrence of species. From this we combined taxonomic groups into four categories. First we input data on the forage fish targets (i.e., herring and sand lance) into SITES, with areas chosen over a range of goals for each target (20% to 40%) being locked into the algorithm for subsequent data computations. Next, data for lingcod, rockfish, and the rocky reef habitats were input, and again the most selected areas were locked in. This procedure was repeated for seabird, marine mammal and invertebrate targets. We then evaluated this initial analysis and nominated the first portfolio seascape sites based on regional importance throughout the ecoregion. This identified 9% of the shoreline toward our 30% portfolio goal.

Tier 2 added sites most important to nearshore marine fish targets outside of Tier 1 sites. The marine team selected forage fish, rockfish, and lingcod as primary conservation targets for portfolio assembly based on their regional significance and international recognition as keystone species ecoregion-wide. This time SITES re-evaluated these selected marine fish species and rocky reef habitat data with goals set between 30% and 60%. Tier 2 identified an additional 14% of the shoreline, bringing the total to 23%.

Tier 3 added the rest of the target information, including seabirds, marine mammals and invertebrates, with goals for these targets set between 30% to 60%. In addition, two quality assessment workshops were conducted after the Tier 2 analysis to review the selected sites. We reviewed the portfolio to ensure best quality shorelines were included, especially any unique, diverse, or pristine sites known from field surveys. This tier added 4% of the shoreline, bringing the total to 27%.

Throughout the ecoregional planning process, we assembled coastal ecologists and biologists to fill data gaps by identifying places of known nearshore diversity or individual species significance. The information we learned from experts provided us with a means to compare to the spatial analysis. The purpose of Tier 4 was to evaluate all previously nominated expert sites that were not selected from the analysis up to this point, and incorporate a subset of them into the portfolio. Our primary measure of including an expert-derived site was to verify whether the site was of importance at the scale of the ecoregion and captured the targeted nearshore biodiversity. We determined that many sites originally nominated were not significant for inclusion in the portfolio because they were insufficiently important to warrant removing other sites to make room for them within our 30% portfolio goal. If we were to have added the shoreline associated with all the expert-nominated sites, Tier 4 would have inflated by 11%, or 832.5 km of shoreline, thereby over-representing shoreline types without analytical discrimination. By applying scrutiny to the expert-nominated process, Tier 4 added only 1% of the shoreline, bringing the final draft nearshore marine portfolio to 28%. This represented approximately 2,095 km of shoreline out of the total natural (excluding human-made) shoreline of 7,533 km (Fig. 8.4; see page XXX). We elected not to search for the additional 2% of shoreline to meet our portfolio goal of 30%, anticipating the addition of some shoreline when integrated with a separate terrestrial analysis.

In looking at representation of the marine targets through this 4-tiered process, we found that overrepresentation was not as much of a factor as when using the seamless hexagon approach (Table 3). The final draft nearshore-only analysis over-represented 22, or 18% of the 119 data elements. In analyzing the shoreline planning unit results, only 12 of the 74, or 16% of the stratified shoreline elements were considered over-represented.. For the 45 marine species and rocky reef data elements, only 10, or 22 % were considered over-represented. For the adequately captured category, 38% of all data elements were represented, or 24% of the stratified shoreline and 60% of the marine species and reef elements. The efficiency of representation for the separate analysis units revealed 15 total data elements, or 13% (12% shoreline stratified targets and 13% marine species/reef elements). The missing values category contained 31% of all elements, or 47% of shoreline and 4% species/reef designations.

Utilizing the results from both the seamless hexagon and nearshore-only analysis using two planning units, we then conducted a site delineation process that refined the portfolio into priority conservation areas (Fig. 8.5; see page XXX). The final nearshore marine component of the integrated ecoregional assessment identified 186 shoreline/nearshore sites within the Puget Trough and Georgia Basin. In combining the separate analyses and refining boundaries, all nearshore conservation goals were met.

## Discussion

The nearshore is subject to forces both oceanic and terrestrial, producing ecosystems that are dynamic and "open" in nature. This openness of marine populations, communities, and ecosystems probably has marked influences on their spatial, genetic, and trophic structures and dynamics in ways experienced by only some terrestrial species (Carr 2003). The nearshore is not easily defined and mapped, thus conservation planning is more difficult than on land. Conducting this regional analysis of nearshore biodiversity, however, was a step forward in objective representation and quantitative marine site selection.

Comparing the utility of an abstract spatial planning unit (i.e., hexagons) with a natural one (i.e., shoreline reaches) was an important step in evaluating site selection. Although uniform abstract units, such as hexagons, decrease the accuracy of ecological data because of the arbitrary boundaries imposed on the land or seascape (see Fotheringham, 1989; Stoms, 1994), they provide a simple method for mapping data and evaluating effects of selection unit variation on reserve selection (Warman et. al., 2004). This uniformity also provides the means to include information across environments such as the land/sea interface. Alternatively, natural units of analysis tend to be more spatially explicit and follow ecological boundaries. This may reduce additional refinement of site boundaries after the selection process when determining a priority conservation area. However, they are often quite variable in size, and some may be considered too small for effective implementation of conservation areas. In either case, size is an essential component to consider prior to building a conservation portfolio. Typically, the larger the planning unit size, the more generalized and therefore over-represented the conservation targets. Morphology of the study area (i.e., long, straight coastal environments versus highly convoluted coasts with many estuaries or fjords), scales of data input, and spatial unit configuration are all factors to consider. It is essential to examine both the habitat complexity of the region and the scale of the data available for reserve selection before deciding the size and shape of the selection unit (Warman et. al., 2004). We therefore attempted to match the size of the abstract planning unit roughly in relation to the scales of data input, and used both an abstract and natural unit for comparing target representation.

The objective of this planning process was to examine multiple approaches to spatial planning unit configuration in order to achieve the most efficient suite of sites representing nearshore ecosystems, habitats, and species. We established a set of site selection definitions to help us determine what conservation targets contained missing values, which were efficient in their representation, those that were adequately captured, and others that were over-represented. The marine planning team decided that overrepresentation was a key issue to consider because we wanted to be conservative in our approach to selecting shoreline as potential conservation areas. We concluded that the 750-hectare hexagon unit was too large and therefore generalized the shoreline data. This drove the cost of selecting those sites up, decreasing optimization. This decrease in optimization yielded an overrepresentation of shoreline targets. The development of a separate nearshore-only analysis using two spatial planning units therefore gave us the opportunity to increase the overall efficiency of the portfolio. We determined that the shoreline planning units tended to minimize overrepresentation, thereby increasing overall efficiency (i.e., combining efficiency of representation and adequately captured categories). The under-representation of many elements in the nearshore-only analysis was not a big concern for us given that we still had to combine terrestrial analyses along the coast, thereby adding shoreline to the overall portfolio through a site delineation process.

Other planning teams may not consider over-representation as a significant factor, even though it drives up the cost of the reserve system. For instance, if efficiency of representation is considered to be the key issue, then overrepresentation of conservation targets may be viewed as beneficial for the long-term conservation of species (see Warman et. al., 2004). The seamless hexagon analysis reduced the number of missing values. This is essential if there is not any further refinement of the portfolio, either through integration with other analyses (i.e., combining separate terrestrial and freshwater site selection) or a site delineation process that ensures that all conservation targets have met their goals. If this is the emphasis of the planning team, then using the nearshore-only approach may not be preferred. The results of our separate unit analysis illustrated that 31% of all data elements did not meet goals in relation to the 69% that met or exceeded them. This could be seen as a less overall efficient portfolio in comparison to the seamless hexgon analysis that met or exceeded 96% of its goals. Depending on the teams' definition and expectations of the optimal reserve program, there may always be trade-offs to make when examining issues of representation.

Our nearshore analysis framework combined both spatial data and expert opinion in building a conservation portfolio. ShoreZone data provided an excellent baseline on coastal characteristics, painting a regional picture over thousands of kilometers of shoreline. Through this lens, we were able to capture concentrations of multiple nearshore targets within the conservation portfolio. This was a starting point, however, and not a complete picture. As it can only represent the places to begin evaluating the current condition of nearshore marine ecosystems, incorporating expert review into the site selection process provided a critical assessment of quality. However, extensive ground-truthing of the selected areas is necessary to further assess condition and ecological integrity. Varying goals or representation levels did allow us to consider the "irreplaceability" of selected sites. Irreplaceability here means the number of times a single planning unit is chosen over mutiple scenarios. The varying of goals to determine irreplaceable sites is based on where conservation targets are found, and not on the attributes of a single best scenario and the particular rules used to select sites (see Pressey et al. 1994; Hopkinson et al., 2001). The nearshore-only analysis helped identify both representative and high-quality places because it combined irreplaceability, optimization, and expert review. Consequently, the nearshore portfolio captured an array of representative habitats and species in addition to providing an indication of priority conservation areas.

The Puget Sound and Strait of Georgia region is heavily impacted by human development, and this development is expected to only increase. Point and nonpoint source pollution, invasive species distributions, aquaculture, and coastal development continue to threaten the integrity of the region's marine life. "Conservation by Design" sets forth The Nature Conservancy's vision for abating these threats and calls to action the implementation of conservation strategies. It is anticipated that marine ecoregional planning methods will be improved upon as advances in our understanding of marine biodiversity and the threats they face are made, and the datasets that underlie these analyses, improve. Until then, utilizing automated site selection algorithms and expert opinion provide a foundation for initially comparing ecosystem and habitat representation across ecoregional land and seascapes. We therefore put forth these methods and results as the first iteration with the expectation that future iterations will improve our confidence in conservation portfolios intended to preserve nearshore marine biodiversity.

## *Acknowledgements*

The author would like to thank the following individuals, agencies, and organizations for participating on the marine technical teams and providing helpful assistance: Curtis Tanner (U.S. Fish & Wildlife Service), Helen Berry and Betty Bookheim (Washington Department of Natural Resources), Jacques White and Phil Bloch (People for Puget Sound), Megan Dethier (Friday Harbor Laboratories, University of Washington), Pierre Iachetti and Gary Kaiser (Nature Conservancy Canada), Mary Lou Mills, Dave Nysewander, Bob Pacunski, Brian MacDonald, and

Mary Lou Mills (Washington Department of Fish & Wildlife), Paul Dye (The Nature Conservancy), Mark Zacharias and Carol Ogborne (Ministry of Sustainable Resource Management), and Mary Morris (Archipelago Research LTD). Additional thanks goes to Mike Beck, Dan Dorfman and John Floberg of The Nature Conservancy for reviewing this manuscript.

**The Nature Conservancy** is an international non-profit conservation organization that seeks to preserve the plants, animals, and natural communities that represent the diversity of life on Earth by protecting the lands and waters they need to survive.

## References

Andelman, S. A., Ball, I., and Stomms, D., 1999. SITES 1.0: *An Analytical Toolbox for Designing Ecoregional Conservation Portfolios*, Arlington, VA, The Nature Conservancy. 55 pp.

Airamé, S., Dugan, J. E., Lafferty, K. D., Leslie, H., McArdle, D. A., and Warner, R. R., 2003. Applying ecological criteria to marine reserve design: a case study from the California Channel Islands, *Ecological Applications*, 13(1) Supplement: S170-S1854.

Banks, D., Williams, M., Pearce, J., Springer, A., Hagenstein, R., and Olson, D., 1999. *Ecoregion-Based Conservation in the Bering Sea*, Washington, DC, World Wildlife Fund, and Anchorage, AK, The Nature Conservancy. 72 pp.

Beck, M. W., and Odaya, M., 2001. Ecoregional planning in marine environments: identifying priority sites for conservation in the northern Gulf of Mexico, *Aquatic Conservation: Marine and Freshwater Ecosystems*, 11: 235-42.

Beck, M. W., 2003. The Sea Around – Planning in marine regions, in Groves, C. (ed.), *Drafting a Conservation Blueprint*, Washington DC, Covelo and London, Island Press, pp. 319-44.

Berry, H. D., Harper, J. R., Mumford, T. F., Jr., Bookheim, B. E., Sewell, A. T., and Tamayo, L. J., 2001. *The Washington State ShoreZone Inventory User's Manual. Nearshore Habitat Program*, Washington State Department of Natural Resources, Olympia, WA. 29 pp.

Carr, M. H., Neigel, J. E., Estes, J. A., Andelman, S., Warner, R. R., and Largier, J. L., 2003. Comparing marine and terrestrial ecosystems: implications for the design of coastal marine reserves, *Ecological Applications*, 13(1) Supplement: S90-S107.

Day, J., and Roff, J. C., 2000. *Planning for Representative Marine Protected Areas: A Framework for Canada's Oceans.* Report prepared for World Wildlife Fund Canada, Toronto. 147 pp.

Dethier, M. N., 1990. *A Marine and Estuarine Habitat Classification System for Washington State*. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA. 56 pp.

Evenson, J. R., and Buchanan, J. B., 1997. Seasonal abundance of shorebirds at Puget Sound estuaries, *Washington Birds*, 6:34-62.

Ferdaña, Z. A., 2002. Approaches to integrating a marine GIS into The Nature Conservancy's ecoregional planning process, in Breman, J. (ed.*), Marine Geography: GIS for the Oceans and Seas*, Redlands, CA, ESRI Press, pp. 151-58.

Fotheringham, A. S., 1989. Scale-independent spatial analysis, in Goodchild, M., and Gopal, S. (eds.), *The Accuracy of Spatial Databases*, London, Taylor and Francis, pp. 221-28.

Groves, C. R., Jensen, D. B., Valutis, L. L., Redford, K. H., Shaffer, M. L., Scott, J. M., Baumgartner, J. V., Higgins, J. V., Beck, M. W., and Anderson, M. G., 2002. Planning for biodiversity conservation: putting conservation science into practice, *BioScience* 52(6): 499-512.

Hopkinson, P. J., Travis, M. J., Evans, J., Gregory, R. D., Telfer, M. G., and Williams, P. H., 2001. Flexibility and the use of indicator taxa in the selection of sites for nature reserves, *Biodiversity and Conservation*, 10:271-85.

Howes, D. E., Harper, J. R., and Owens, E. H., 1994. *Physical shore-zone mapping system for British Columbia*, Technical Report, Victoria, British Columbia, Canada, Coastal Task Force of the Resource Inventory Committee (RIC), RIC Secretariat. 71 pp.

Howes, D. E., Wainwright, P., Haggarty, J., Harper, J., Owens, E., Reimer, D., Summers, K., Cooper, J., Berg, L., and Baird, R., 1993. *Coastal Resources and Oil Spill Response Atlas for the Southern Strait of Georgia, Victoria, British Columbia*, Canada, BC Ministry of Environment, Lands and Parks, Environmental Emergencies Coordination Office. 317 pp.

Leslie, H., Ruckelshaus, M., Ball, I. R., Andelman, S., and Possingham, H. P., 2003. Using siting algorithms in the design of marine reserves, *Ecological Applications*, 13(1) Supplement: S185-S198.

Margules, C. R., and Pressey, R. L., 2000. Systematic conservation planning, *Nature*, 405: 243–53.

The Nature Conservancy, 2001. *Conservation by Design: A Framework for Mission Success*, Arlington, VA, The Nature Conservancy. 16 pp.

Possingham, H., Ball, I., and Andleman, S., 2000. Mathematical models for identifying representative reserve networks, in Ferson, S., and Burgman, M. (eds.), *Quantitative Methods for conservation Biology*, New York, Springer-Verlag. pp. 291-306.

Power, M. E., Tilman, D., Estes, J. A., Menge, B. A., Bond, W. J., Mills, L. S., Daily, G., Castilla, J. C., Lubchenco, J., and Paine, R. T., 1996. Challenges in the quest for keystones, *BioScience*, 46(8): 609-20.

Pressey, R. L., Humphries, C. J., Margules, C. R., Vane-Wright, R. I., and Williams, P. H., 1993. Beyond opportunism:key principles for systematic reserve selection, *Trends in Ecology and Evolution*, 8: 124–28.

Pressey, R. L., Johnson, I. R., and Wilson, P. D., 1994. Shades of irreplaceability: towards a measure of the contribution of sites to a reservation goal, *Biodiversity and Conservation* 3: 242-62.

Searing, G. F., and Frith, H. R., 1995. *British Columbia Shore-zone Mapping System*, Contract Report by LGL Ltd., Sidney, BC for the Land Use Coordination Office, Victoria, British Columbia, Canada, BC Ministry of Environment. 46 pp.

Stoms, D. M., 1994. Scale dependence on species richness maps, *Professional Geographer* 46: 346-58.

Sullivan-Sealey, K. M., and Bustamante, G., 1999. *Setting Geographic Priorities for Marine Conservation in Latin America and the Caribbean*, Arlington, VA, The Nature Conservancy. 125 pp.

Ward, T. J., Vanderklift, J., Nicholls, M. A., and Kenchington, R. A., 1999. Selecting marine reserves using habitats and species assemblages as surrogates for biological diversity, *Ecological Applications*, 9: 691-98.

Warman, L. D., Sinclair, A. R. E., Scudder, G. G. E., Klinkenberg, B., and Pressey, R. L., 2004. Sensitivity of systematic reserve selection to decisions about scale, biological data, and targets: case study from Southern British Columbia, *Conservation Biology*, 18: 655-66.