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Development of Monitoring Protocols to Detect Change in Rocky Intertidal Communities of Glacier Bay National Park and Preserve

Open-File Report 2010–1283

U.S. Department of the Interior
U.S. Geological Survey

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Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
hectare (ha)	2.471	acre
square meter (m^2)	0.0002471	acre
square meter (m^2)	10.76	square foot (ft^2)

List of Acronyms

3D	Three dimensional
BACI	Before-After-Control-Impact (design)
BACIP	Before-After-Control-Impact-Paired (design)
CG	Coarse-grained sampling
FG	Fine-grained sampling
GRTS	Generalized random-tesselation stratified (survey design)
MARINe	Multi-Agency Rocky Intertidal Network
MHHW	Mean higher high water
MLLW	Mean lower low water
NHP	National Historical Park
NP	National Park
NP&P	National Park and Preserve
NPS	National Park Service
PISCO	Partnership for Interdisciplinary Study of Coastal Oceans
USGS	U.S. Geological Survey
WEST, Inc.	Western EcoSystems Technology, Inc.

List of Symbols

α – alpha	Type I error level (probability of rejecting the null hypothesis when it is true), acceptable error level
β – beta	1- β = power of a statistical test (the probability of rejecting the null hypothesis when it is false and should be rejected)
°	degrees
<	less than
≤	less than or equal to
>	greater than
≥	greater than or equal to

Development of Monitoring Protocols to Detect Change in Rocky Intertidal Communities of Glacier Bay National Park and Preserve

By Gail V. Irvine

Abstract

Glacier Bay National Park and Preserve in southeastern Alaska includes extensive coastlines representing a major proportion of all coastlines held by the National Park Service. The marine plants and invertebrates that occupy intertidal shores form highly productive communities that are ecologically important to a number of vertebrate and invertebrate consumers and that are vulnerable to human disturbances. To better understand these communities and their sensitivity, it is important to obtain information on species abundances over space and time. During field studies from 1997 to 2001, I investigated probability-based rocky intertidal monitoring designs that allow inference of results to similar habitat within the bay and that reduce bias. Aerial surveys of a subset of intertidal habitat indicated that the original target habitat of bedrock-dominated sites with slope less than or equal to 30 degrees was rare. This finding illustrated the value of probability-based surveys and led to a shift in the target habitat type to more mixed rocky habitat with steeper slopes. Subsequently, I investigated different sampling methods and strategies for their relative power to detect changes in the abundances of the predominant sessile intertidal taxa: barnacles -Balanomorpha, the mussel *Mytilus trossulus* and the rockweed *Fucus distichus* subsp. *evanescens*. I found that lower-intensity sampling of 25 randomly selected sites (= coarse-grained sampling) provided a greater ability to detect changes in the abundances of these taxa than did more intensive sampling of 6 sites (= fine-grained sampling). Because of its greater power, the coarse-grained sampling scheme was adopted in subsequent years. This report provides detailed analyses of the 4 years of data and evaluates the relative effect of different sampling attributes and management-set parameters on the ability of the sampling to detect changes in the abundances of these taxa. The intent was to provide managers with information to guide design choices for intertidal monitoring. I found that the coarse-grained surveys, as conducted from 1998 to 2001, had power ranging from 0.68 to 1.0 to detect 10 percent annual changes in the abundances of these predominant sessile species. The information gained through intertidal monitoring would be useful in assessing changes due to climate (including ocean acidification), invasive species, trampling effects, and oil spills.

Introduction

For Glacier Bay and many other Alaska national parks, the National Park Service's mission "to protect unimpaired" the lands and resources within its jurisdiction is complicated by two main factors. First is the lack of knowledge of the status of park resources, their dynamics through time, and the relationships among species and processes. This lack of knowledge makes it difficult to separate natural variation from anthropogenic effects, thus hampering the ability of managers to know when and if they can intervene to effect change. The second complicating factor is large spatial scale. The marine coastline of Glacier Bay National Park and Preserve (NP&P; fig. 1) spans about 1,720 km (Irvine and others, 1994) and for Glacier Bay proper—the focus of this study—1,109 km (Irvine, 1998). The Glacier Bay coastline comprises about 40 percent of the estimated 4,210 km coastline held by all national parks in Alaska. Because the Alaskan national parks contain almost 70 percent of the marine coastline of all US national parks (Irvine and others, 1994), Glacier Bay has a disproportionately large share of the marine coastlines managed by the NPS in both Alaska and the USA.

The 1989 *Exxon Valdez* oil spill in south-central Alaska contaminated more than 2,000 km of coastal habitat and associated biota, including areas of Kenai Fjords and Katmai NP&Ps. This spill illustrated the vulnerability of these coastal environments to anthropogenic effects. Following that event, the Alaska region of the NPS created a Coastal Programs Division for the purpose of developing inventory and monitoring programs for the extensive national park coastlines in Alaska. In 1996, I received funding to develop monitoring protocols and studies that address landscape-scale variation in the coastal biological communities of national parks. Based on jurisdictional, budget and logistical considerations, I was asked to concentrate effort at Glacier Bay NP&P.

Monitoring involves determination of the abundance or status of species through time, accomplished by repeated measurements or counts. The ability to detect change or trends depends on the design of the monitoring, sample size, level of certainty selected, and the natural variability in spatial and temporal patterns of species abundances. As the variability in abundance or any other parameter increases, the ability to detect change in that parameter decreases, given equal sampling effort. Therefore, it is more difficult to detect trends in species that are rare or whose abundance is highly variable. Sample variation may be reduced and the power to detect change increased by stratifying the populations and communities along known gradients of variation, or by increasing sampling effort. Increased sampling costs more, while stratified sampling reduces the ability to make inferences beyond the strata sampled, unless all populations are accounted for in the stratification process.

One of the challenges faced by resource managers in designing and implementing a monitoring program is how to balance the need to sample across broad physical scales for greater spatial inference versus the need to sample intensively enough to detect temporal changes in biological communities. Intensive sampling is often conducted over smaller scales, and inference may be limited to selected habitat types, sites, plots, and species.

The major objective of this study was to develop a probability-based approach to monitoring intertidal assemblages inhabiting protected rocky substrates, so that the results of the sampling could be extended to similar habitat within Glacier Bay proper. Initially, aerial surveys were conducted to classify coastal segments and determine the locations of these rocky substrates. Based on findings from the aerial surveys, the target habitat type was defined as: coastal areas comprised of bedrock (> 1 percent) and/or ≥ 76 percent cobble/boulder substrate, with slopes ≤ 60°. Extensive sampling was conducted at 25 randomly selected sites under the coarse-grained sampling regime. More intensive sampling of 6 sites from the lower half of the bay (a subset of the 25 sites), constituted the fine-grained sampling. These fine-grained sites were all cobble/boulder-dominated sites.

Sampling primarily targeted all macro sessile species and large mobile invertebrates. Analyses to test the power of the sampling to detect changes in abundance of species concentrated on the three most abundant sessile taxa in the sampled habitat type: barnacles, the mussel *Mytilus trossulus*, and the rockweed *Fucus distichus* subsp. *evanescens*. Continued sampling of all sessile species will allow detection of changes in the distribution and abundance of sessile species spatially and temporally within Glacier Bay proper.

The results of the sampling conducted from 1997 to 2001 have inference to the selected habitat type within Glacier Bay proper for the coarse-grained sampling, and to a narrower band of cobble/boulder habitat within Glacier Bay for the fine-grained sampling.

In this final report, I summarize the study, review key findings presented in earlier reports, and describe final results leading to a recommended protocol for detecting change in the abundance of key sessile species of rocky intertidal communities in Glacier Bay.

Methods

Planning and fieldwork for this study were conducted from 1996 to 2001. In 1996, I held meetings with Glacier Bay staff to discuss goals for the project, potential stressors affecting the coastal areas, and approaches to the study. We decided to focus the study in Glacier Bay proper because the park staff rated protected rocky intertidal habitat as their top choice for monitoring, and they were most concerned about potential effects from oil spills and the immigration of sea otters (*Enhydra lutris*), both of which they thought were more likely to affect communities within the bay. Fieldwork was carried out in 1997, 1998, 1999, and 2001.

This study used a probability-based, multilevel design that included:

a. Aerial surveys of a systematically selected subset of coastal segments to characterize their habitat attributes, assess the frequency of different habitat types, and provide a pool of sites of known habitat type for further sampling,

b. Coarse-grained (CG) or lower intensity sampling of a large number of randomly selected sites of a selected habitat type, and

c. Fine-grained (FG) or more intensive sampling of a few sites of cobble/boulder habitat, selected as a subset of the CG sampling sites; the FG sampling also tested the efficacy of additional sampling methods.

I examined the ability of the CG and FG sampling plans to detect trends in the predominant sessile species through power analyses. Power can be defined as the ability to detect a change when one is occurring. Statistically, power is the probability of rejecting the null hypothesis when it is false and should be rejected (Zar, 1984). As part of the power analyses, sampling attributes, such as the number of sites, transects, and intensity of point sampling, were varied to examine their effect on the power of particular sampling plans to detect change. Additionally, I examined the interplay between sampling attributes and management-set parameters (that is; the level of annual change to be detected and error levels) on power (table 1).

The methods used in the three levels of surveys and sampling listed above are described in detail in Irvine (1998) and in appendix A. They are reviewed below, followed by description of the analytical methods.

Field Surveys and Sampling

Aerial Surveys and Description of Habitat Types

The goal of the aerial surveys was to characterize intertidal habitat types and their frequencies in Glacier Bay. The categorical abundances of substrate and spatially dominant sessile biota, as well as slope, were described for each segment surveyed.

The first step in defining a set of sites to survey was the division of a digitized coastline of Glacier Bay NP&P (Geiselman and others, 1997) into 200-m length segments. The 1,109 km coast of Glacier Bay proper yielded 5,545 segments. I estimated that 250 segments could be aerially surveyed during one tide series. Beginning with a random start in Glacier Bay proper, each 23rd segment was selected to be surveyed. Then, from a fixed-wing plane, 241 of the 250 segments were classified categorically for habitat type, slope, and biota (Appendix A: Aerial Survey Standard Operating Procedure). Nine of the segments were found to be inappropriate and were not surveyed; details on the exclusions are in appendix A. Summary data from the aerial surveys were reported in Irvine (1998). These described segments then formed a pool of sites with known habitat types that were available for subsequent stages of the intertidal sampling.

Prior to the aerial surveys, the target habitat type had been defined as predominantly (≥ 76 percent cover) bedrock substrate with slopes ≤ 30º. The results of the aerial surveys led to a change in the targeted habitat type for monitoring, because only one of the 241 segments surveyed had these characteristics. Even increasing the acceptable slope to ≤ 60º added only two more segments to the pool. Thus, in consultation with NPS and Center staff, I decided to define the selected habitat type as segments dominated by cobbles and boulders (≥ 76 percent cover) and/or having a bedrock component (≥ 1 percent); slope was defined as ≤ 60º. This created a pool of 111 segments, which formed the sampling frame of the target habitat type.

Coarse-Grained (CG) Sampling

From the pool of 111 segments with the target habitat type, 30 sites were randomly selected for CG sampling (fig. 2). Five sites were eliminated after the initial draw because they were either too steep, were not true beaches (for example, no land exposed at high tide), or were not accessible because the site was in a wildlife protection area (appendix A).

CG sampling was conducted in 1997, 1998, 1999, and 2001. Each 200-m-long site was located in the field using global positioning system coordinates determined from the original segmentation of the digitized coastline. The area sampled was the area between mean higher high water (MHHW), defined by biological characteristics, and the 0-m tide level (mean lower low water, MLLW), set with information from the tide program Tides & Currents for Windows, version 2.5a (Nautical Software, Inc., 1997). A horizontal segment line delimiting the upper bound of the site was laid along the MHHW contour. Six vertical-line transects running parallel to the elevational gradient and perpendicular to the shoreline were laid from MHHW to the 0-m tide level. The start of the first vertical transect was determined randomly within the first 33 m of the horizontal segment line; the succeeding transect lines were laid out systematically, at 33-m intervals with respect to the first. If a vertical transect fell on a section of the segment that was unsampleable due to steep slope or freshwater input, then that transect and the remaining transects were shifted the horizontal distance of the unsampleable area to the right, facing shore. The locations of the transects were randomized again each year.

Two types of sampling, each targeting different types of species, were conducted along the vertical transects. Sessile species were targeted by 3-dimensional (3D), point-intercept sampling along the vertical transects. All species (sessile and mobile), including multiple layers of the same species under the point were recorded, from top to bottom, until the first substrate was found. The substrate also was recorded. Large mobile invertebrate species (starfish, sea urchins, and large chitons) were targeted in band surveys that extended 1 m to each side of the vertical transect line. Species identifications were made to the lowest taxonomic level possible in the field during all surveys (appendix A).

In 1997, the CG sampling used a base sampling intensity of 1 point/m along each vertical transect. Although my original plan was to sample at 5 points/m, I reset the sampling intensity to 1 point/m based on the time it took to do the 3D sampling in an initial field test and the objective of sampling one site per day. As field crews became more experienced and most sites were found to have shorter transects than those in the field test, I increased the sampling intensity to 2 points/m (x.0-m and x.6-m marks). The x.6-m mark was selected as I anticipated that point-intercept sampling at the FG sites would be conducted at 5 points/m, each 20 cm, and that future sampling of CG sites likely would be conducted at 20-cm intervals. At a few sites, sampling was conducted at > 2 points/m. Thus, in 1997, 17 of the 25 sites were sampled at ≥ 2 points/m and 8 sites (sites 62, 63, 69, 216, 217, 218, 223, and 224) were sampled at 1 point/m. Beginning in 1998, I increased the sampling intensity to 5 points/m at all 25 sites to increase the probability of detecting less-common species and to increase the precision of the estimates.

Fine-Grained (FG) Sampling

Fine-grained sampling was conducted in 1997 at 6 of the 25 CG sites (fig. 2; appendix A). I narrowed the focus of the FG site selection in two ways. First, I narrowed the geographical focus to allow easier access to the sites by skiff from park headquarters at Bartlett Cove (located slightly to the east of site 59; fig. 2), because the more intensive FG sampling necessitated multiple days of effort at each site. Second, I decided, in consultation with Center and Park staff, to concentrate efforts on predominantly cobble/boulder sites; only those sites with ≥ 76 percent cobble/boulder substrate were considered for inclusion.

Six sites were selected from the CG suite of sites that fit these habitat and geographic parameters. Below the juncture of the two arms in Glacier Bay there were eight CG sites that had been defined as predominately cobble/boulder habitat during the aerial surveys. One of those, site 88, the most distant from Bartlett Cove in this band, was discarded because the CG surveys had revealed that little cobble/boulder was present. The most southerly geographic site also was discarded. This resulted in the selection of six sites that ranged from just south of the two arms to slightly south of Bartlett Cove (fig. 2).

In 1997, these sites were sampled using both the FG and CG methodologies. The FG data from these sites have inference to the range of cobble/boulder habitat within the band or region that the sites occupy, as these sites also were part of the CG set of sites, which had been randomly selected from the pool of the selected habitat type. Thus, the FG sites are an approximately random sample of predominantly cobble/boulder habitat within the exact band they occupy.

The FG sampling consisted of multiple types of sampling (fig. 3), which are detailed in appendix A. I briefly describe four of the sampling types here: (1) vertical transect by point intercept; (2) horizontal transect by point intercept, (3) quadrat, by point intercept and counts; and (4) band survey by counts. All point-intercept methods targeted sessile species, but counted all species, sessile and mobile, under points. The first sampling type was point-intercept sampling along 10 vertical transects sampled at 5 points/m. The 3D point-intercept sampling methods were the same as those used in the CG sampling. The vertical transects were laid out in a similar manner as those in the CG sampling, except that the sampling of 10 transects led to a smaller (20-m) systematic distance between transects.

In the second sampling type, 30 horizontal transects were sampled per site. Each measured 10 m in length and they were arrayed three per vertical transect, with the location and elevation determined by random-systematic methods. The length of a vertical transect was divided into thirds and a random number identified the location within one of the zones where the horizontal transect origin would be laid. The other two horizontal transects were set at systematic intervals from the first within the two other vertical zones of the beach. Horizontal transects were sampled by point-intercept sampling (targeting sessile species) that used the same intensity (5 points/m) and sampling methodology as employed for vertical transects.

In the third sampling method, a quadrat was sampled at each juncture of the vertical and horizontal transects, with 3 arrayed per vertical transect. This led to a total of 30 quadrats sampled per site. Quadrats were 1/9 m^2 in area and contained a grid of 36 intersections at which points were sampled (fig. 4). Quadrat point-intercept sampling targeting sessile species used the same 3D methodology as used for vertical and horizontal transects. Additional sampling within quadrats included counts of small mobile invertebrates and subsampling counts of littorine snails and barnacle spat/recruits (fig. 4).

The fourth FG sampling method, band surveys, targeted large mobile invertebrates by sampling 1-m-wide bands on each side of the vertical and horizontal transect lines (fig. 3). Methods used were the same as described earlier in the CG sampling.

Analytical Methods

The analytical methods used to estimate the abundance of species/taxa, analyze trends for the predominant taxa, and estimate the power of different sampling schemes to detect changes in abundance for the these major taxa are described below.

Estimating Abundance

A general bay-wide measure of the abundance of species can be given by the total number of hits (counts) of a species across all sites sampled by the CG sampling. Within-year and 3-year (1998–2001) comparisons of the abundance of different species can be made because the total number of points sampled in any one year and for all years (the total) would be the same for all species.

Percent cover was the metric of abundance for sessile species at the transect and site levels. Percent cover can be calculated for all species sampled by point-intercept sampling. However, for the power analyses, which comprise the majority of the analyses presented, specific percent cover measures for each transect at each site were calculated for the predominant sessile species or species groups (also referred to as taxa):

1. The mussel, *Mytilus trossulus*,
2. The brown alga or rockweed, *Fucus distichus* subsp. *evanescens* (note: formerly known as *Fucus gardneri*), and
3. All barnacles (*Balanus glandula*, *Semibalanus balanoides*, *Semibalanus cariosus*, *Chthamalus dalli*, Balanomorpha, and barnacle spat/recruits). Note: all species were recorded to the lowest taxonomic level possible in the field, but for the purposes of analysis, all barnacle taxa and categories (for example, spat/recruits) were combined.

For each site, the percent cover was calculated by dividing the number of hits of the selected species on each transect, by the number of points counted along the transect. Because the counts were done in 3D and multiple layers of a species could be encountered at each point, the percent cover had the potential to exceed 100 percent.

Due to differences in the intensity of point sampling between 1997 and all subsequent years, data analyses were performed on two different CG datasets: a 4-year (1997–2001) dataset and a 3-year (1998–2001) dataset. In 1997, vertical transects at all sites were sampled consistently at a minimum of 1 point/m, whereas in 1998–2001, sampling was conducted at 5 points/m. To maximize the temporal comparison of data from the 1997 to 2001 period, data from 1998 to 2001 were reduced such that only 1 point/m data were included in the 4-year (1997–2001) dataset. When the 1998–2001 datasets were reduced, the single point selected to be included was always that at the meter mark (for example, 1.0 m, 2.0 m, etc.), which matched the sampling conducted in 1997. The 3-year (1998–2001) dataset, which used the full intensity (5 points/m) data, was used in a number of analyses, including those where the effect of variation in the intensity of point sampling on power was being examined.

Trend Analyses

Trend analyses for the predominant sessile taxa (barnacles, *Mytilus* and *Fucus*) were conducted by TerraStat Consulting Group (hereafter referred to as TerraStat; see appendix B for contact information). The 1998–2001 data for each species from each of the 25 sites were tested for exponential trends by fitting a linear regression to log-transformed abundance (percent cover) data. Site and regional trends were evaluated; regional is defined as Glacier Bay proper.

Power Analyses

MONITOR software (James P. Gibbs, 1995) was used to estimate the power (1-β) of CG and FG sampling, as well as the influence of a number of parameters on power. For multiple-site, multiple-year analyses, MONITOR uses a route regression approach to test for trends. For greater detail, see appendix B or Gibbs and Ramirez de Arellano (2007). I used a version of MONITOR with a corrected exponential model (modified MONITOR, *sensu* Hatch, 2003) in my analyses of the 1997–2001 data.

After I completed the analyses using the corrected exponential version of MONITOR, a general concern arose regarding assumptions used by the MONITOR program. To address this concern, I contracted with TerraStat to review and reanalyze a small, but key subset of CG 1998–2001 data. These included power analyses for the three major sessile taxa at 25 and 15 sites.

Described below are the methods I used to analyze the CG data, the FG data, and comparisons between the CG and FG data. These are followed by the methods used by TerraStat.

In my use of MONITOR for multiyear CG data analyses, each site represented a ‘plot’ as defined in MONITOR guidance documents and all plots were weighted equally. I selected the exponential trend option, a constant coefficient of variation, and specified use of two-tailed t-tests. The significance level (alpha, or α) was set at 0.05, except for those specific cases where alpha was varied to examine its effect on power. My runs of the program consisted of 500 iterations. The biological data used for the analyses were a mean (“plot count”) and variance (“plot variance”) measure for a species at a site for the time period under analysis, either the 3-year (1998, 1999, 2001) or 4-year (1997, 1998, 1999, 2001) periods. As described earlier, 3-year data were sampled at 5 points/m intensity, and 4-year data were reduced, for consistency, to 1 point/m intensity. Details on why I split the data into different time periods were presented above and related to the reduced intensity of point sampling in 1997. The percent cover for each taxon was determined as described, prior to calculating the individual site means and variances needed for computing power in MONITOR.

Statistical analyses to calculate the “plot count” and “plot variance” required to run MONITOR were conducted using the software program StatView for Windows (version 4.57; Abacus Concepts, Inc., 1996). The percent cover along each transect for each of the predominant taxa at each site was imported from Microsoft© Excel into StatView. The mean percent cover for a taxon at each site was an average of the percent cover calculated for the six transects over all 3 or 4 years, depending on the dataset used. This mean for a taxon at each site was the plot count used in MONITOR.

In my analyses, plot variance, the second variable required by MONITOR, was the residual mean-square-error of a linear regression on untransformed data (percent cover of a taxon for each transect at a site over time).

I examined the relative importance of different parameters on the power to detect changes in the abundance of the three major sessile taxa (table 1). The largest number of analyses used the CG data with $\alpha = 0.05$. MONITOR results are presented graphically.

For some analyses, fitting a trend line to the calculated points enabled extrapolation of data to determine how increased sampling of the number of points per meter, number of transects, number of sites, etc. would increase the power of the monitoring protocol. In general, these extrapolations were more useful when calculated power was low. Data reductions also were made. For example, the 1998–2001 CG data allowed the effect of the number of sites, number of transects within a site, and intensity of point sampling to be assessed through reductions of the data, whereas the 1997–2001 CG data allowed the number of sites and transects to be reduced. Site and transect data reductions were made using the mean and standard error of the regression calculated from either the 1 point/m data (1997–2001) or the 5 points/m data (1998–2001). When the number of sites was reduced, I used one random subset of sites to estimate power.

Most CG analyses were conducted on similar parameter sets for all three predominant sessile taxa. However, in a few cases only *Mytilus* data were used, because prior analyses indicated that power results for *Mytilus* were intermediate between those for barnacles (higher) and *Fucus* (lower) (Irvine, 1998). Thus, the results for *Mytilus* should indicate general trends in how different parameters affect the estimation of statistical power. I chose to use only *Mytilus* data to examine effects of more complex combinations of variables (for example, number of sites, level of population change, and number of points sampled per meter).

The MONITOR program also was used to analyze the 1997 FG sampling data. Although the program was designed primarily for looking at the variance of counts made through time (Thomas and Krebs, 1997; Hatch, 2003), when only 1 year of data is available for computing power analyses, then replicate sampling within a site acts as a proxy for temporal sampling (that is, each transect represents a count). Then the mean and variance used in the MONITOR program are computed using the within-site, within-year results of sampling. In my analyses of the 1997 FG sampling data, subsets of the samples were selected (systematically and/or randomly); means and variances for those data subsets were computed and then used in MONITOR. Parameters examined for the FG MONITOR runs were similar to those used in the 3- or 4-year CG sampling analyses (table 1). Many runs based on the 1997 data are reported in Irvine (1998).

Additionally, I compared the power of CG and FG sampling to detect changes in the abundance of species, based on vertical transect data, because this method was common to both sampling regimes. As the FG sampling was conducted only in 1997, I wanted to include the 1997 CG data in the comparisons. Therefore, FG data were compared to CG 1997 data or CG 1997–2001 data, all taken at 1 point/m sampling intensity. Analyses were conducted for the three main sessile taxa across various sampling schemes that involved data from either the 6 FG/CG sites or the full set of 25 CG sites.

Effort was not standardized between the FG and CG sampling regimes. The closest comparison, with respect to effort, would be that for the FG and CG 1997 sampling conducted at the same six sites.

TerraStat performed power analyses on a subset of the 1998–2001 CG data using a more recent version of MONITOR (version 10.0; Gibbs and Ramirez de Arellano, 2007), as well as some different parameters (appendix B). The intent of the reanalyses was to determine if changes to the MONITOR program or changes to parameters used in the analyses caused large differences in estimated statistical power.

TerraStat compared three different analyses: (1) use of TerraStat parameters (see below) in MONITOR version 10.0; (2) use of my original parameters in MONITOR version 10.0; and (3) my original results, which had used my parameters in the corrected exponential version of MONITOR. Additionally, TerraStat examined the effect of the number of sites, by contrasting the power obtained by sampling 25 sites versus 15 sites.

The parameters used by TerraStat in its power analyses included: (a) plot means—the initial year's plot means; (b) plot variance—the standard error of the residuals from an exponential-regression fit to untransformed densities; (c) site reductions—power averaged over 10 random subsets of the 25 sites; and (d) number of iterations—1,000 (appendix B).

Results

Obtaining 4 years of data has allowed: (a) assessment of the abundance of different taxa, (b) analysis of trends in the abundance of the predominant sessile taxa at a site and regionally, and (c) power analyses. Collectively, these analyses support the goals of detecting long-term trends in the abundance of taxa and determining the most appropriate methods for doing so.

Abundance of Taxa

Fucus, barnacles and *Mytilus* were much more abundant than the 78 other taxa encountered in the CG point-intercept sampling along vertical transects (table 2). In the sampling conducted in 1998–2001, of the 61,736 species hits (counts), *Fucus* was counted 19,773 times (32 percent), *Mytilus* 17,903 times (29 percent), and all barnacles 16,047 times (26 percent). These three taxa accounted for 82 percent of all species hits. The next most abundant grouping of taxa, all green algae, comprised 3,603 hits (5.8 percent). This disparity in relative abundance led to the focus on the three most abundant sessile taxa for subsequent analyses.

Trend Analyses

There was considerable variability in the abundance of the predominant sessile taxa, both spatially and temporally (1998–2001), which affected the ability to detect site and regional trends (tables 3–5; appendix B). No significant regional trends were determined for *Mytilus* or *Fucus.* Only barnacles had a significant regional trend (mean trend = +22.5 percent; 2-tailed t-test, p-value = 0.0095; appendix B). For barnacles, all significant trends at individual sites were positive (seven sites), whereas significant trends at sites were more mixed in sign for *Mytilus* (three positive, five negative) and *Fucus* (four positive, one negative) (tables 3–5). The largest range in magnitude of trends among sites occurred for *Fucus* (–70 percent per year to +220 percent per year, appendix B). Further results and details of trend analyses are presented in appendix B.

Power Analyses

I present my power analyses results for: FG sampling, CG sampling, and comparisons of the CG and FG sampling. All these analyses were conducted with $\alpha = 0.05$, except for those specified CG analyses where alpha level was varied. These are followed by results of the TerraStat reanalyses, which include comparisons to some of my results.

Fine-Grained Sampling

The FG data were used to evaluate the power of different point-intercept sampling methods (vertical transects, horizontal transects, and quadrats) to detect change in the abundance of sessile species. Across species, vertical transect sampling provided the greatest power to detect change, generally followed by horizontal transect sampling, then quadrat sampling (fig. 5).

The power to detect change varied consistently among the three main sessile taxa, with the greatest power for barnacles, somewhat less power for *Mytilus*, and least for *Fucus* (fig. 5). The only species group for which the FG sampling of six sites provided sufficient power (> 0.8) was barnacles; for this group, the vertical transect sampling produced the highest power (> 0.9) (fig. 5*C*). The number of vertical transects needed to detect 10 percent decreases in *Mytilus* and *Fucus* at 0.8 power, when only six sites are sampled, was estimated to be 20 and 35 transects, respectively (fig. 6); these numbers are 2–3.5 times higher than the 10 vertical transects sampled under the FG regimen.

Additional analyses of the 1997 FG data that examined the combined influence on power of varying the number of vertical transects and number of points per meter sampled, indicated that increasing both the number of transects and the number of points sampled per meter generally increases power. Only for *Fucus*, where power was low and variable, were some of the extrapolated relationships not as consistent as for *Mytilus* and barnacles (appendix C, figs. C1–C7).

Coarse-Grained Sampling, Alpha = 0.05

Analyses of the 3- and 4-year CG datasets allowed comparison of the effect of the number of years versus the intensity of point sampling on power. The power of the CG sampling of 25 sites, conducted over 4 years (1997–2001) at 1 point/m intensity (fig. 7), was very similar to that found for analyses of the 3-year (1998–2001) CG data taken at 5 points/m intensity (fig. 8). This indicates that increased temporal sampling can compensate for decreased intensity of point sampling.

I found that attempting to increase power by increasing the number of points sampled per meter is not very efficient. The ability to detect 10 percent decreases changes little as CG sampling is increased from 1 to 5 points/m, and remains high for all three taxa (figs. 9–11). In most of the 5 percent and 3 percent annual change graphs (figs. 9–11), the power lines are fairly flat or gently sloping, except for *Mytilus*. At any given sampling intensity, the power is greater for barnacles and *Mytilus,* and lesser for *Fucus*. If the minimum goal is to have a power of at least 0.8 to detect a 10 percent annual change in abundance, then a sampling intensity of 1 point/m in the CG sampling is sufficient for barnacles and *Mytilus*. For barnacles and *Mytilus*, there is very high power (> 0.98) to detect 10 percent annual changes, even at a sampling intensity of 1 point/m.

Increasing the number of transects increases power, as was demonstrated by analyses of the CG (1998–2001) data for *Mytilus* (fig. 12). Only one transect/site is needed to achieve a power of 0.8 to detect a 10 percent decrease in *Mytilus*. At two transects/site the power to detect a 10 percent annual change is > 0.9 (fig. *12A*). With six transects/site, the power to detect a 5 percent annual change is 0.8 (fig. 12*B*).

Increasing the number of sites sampled increases the power to detect changes in *Mytilus* abundance, as illustrated by analysis of CG 1997–2001 data (fig. 13). Sampling 25 sites provides a 1.0 probability of detecting a decrease of 10 percent per year. In fact, sampling 10 or more sites per year produced a power of ≥ 0.9 to detect 10 percent decreases in *Mytilus* (fig. 13*A*). A 5 percent decrease at 0.8 power can be detected by the CG sampling of 25 sites (fig. 13*B*).

When both the number of sites and the number of points per meter sampled are increased, the power to detect trends in *Mytilus* abundance generally increases (fig. 14). Analyses of the 1998–2001 CG data indicated that a > 90 percent probability (0.9 power) to detect a 10 percent decrease in *Mytilus* was readily accomplished by sampling ≥ 15 sites at 1 or more points per meter (fig. 14*A*). Detecting a 5 percent decrease with 0.9 power would necessitate sampling more points per meter: for 25 sites, about 6 points/m; for 20 sites, about 8 points/m (fig. 14*B*). Detecting a 5 percent decrease at a power of 0.8 can be accomplished by sampling 25 sites at about 3 points/m, 20 sites at about 6 points/m, or 15 sites at about 9 points/m.

Coarse-Grained Sampling, Varying Alpha

When the accepted error level (alpha) is increased, the power to detect changes in the abundance of the predominant taxa increases (fig. 15). Analysis of the 1997–2001 CG data indicated that power was high (≥ 0.9) to detect 10 percent changes in the abundance of *Mytilus* and barnacles at a range of alphas (0.05–0.20). The power to detect changes in abundance of *Fucus* generally was lower than for the other taxa. A 0.8 probability of detecting a 10 percent change in *Fucus* generally required $\alpha \geq 0.10$, except for a negative 10 percent change where $\alpha = 0.05$ sufficed (fig. 15). Detecting 5 percent decreases in all three taxa at a power of 0.8 or greater requires $\alpha \geq 0.20$ (fig. 15).

Additional analyses of the effects on power of varying alpha in combination with other parameters support the increase in power when alpha is increased along with increases in number of transects; lesser effects on power occur when alpha and the number of points sampled per meter are increased (appendix C, figs. C8–C26).

Comparison of Coarse-Grained and Fine-Grained Sampling

The power of the CG and FG sampling plans varies for the different species, but the CG sampling of 25 sites is more powerful than the FG sampling of 6 sites (fig. 16). There was less difference between these two sampling schemes for barnacles, which was the only taxon that was adequately sampled (power > 0.8) by the FG sampling. For mussels and *Fucus*, however, the CG sampling at 25 sites was distinctly more powerful (fig. 16).

Comparisons of various sampling plans using only 1997 data indicate that CG sampling of 25 sites has more power than the FG sampling of 6 sites, which in turn has more power than the CG sampling of 6 sites. These results for 1997 data support the positive influence on power of increasing the number of sites or the intensity of sampling. In particular, note that the 1-year CG sampling of 25 sites has more power than the 1-year FG sampling of 6 sites (fig. 16).

The most equivalent comparison of FG and CG effort and power is comparison of the 1997 data for the 6-site analyses (fig. 16). These analyses are for data from the same set of sites. Effort is somewhat greater for the FG sampling (10 transects/site sampled at 5 points/m) versus the CG sampling (6 transects/site sampled at 1 point/m), and the difference in power reflects that increased effort. There is no equivalent comparison of effort and power for the 25-site CG sampling versus the 6-site FG sampling; effort is much greater for the 25-site CG sampling.

The multispecies results, condensed in figure 17, compare the relative power of the CG (1997–2001) sampling and the FG (1997) sampling to detect changes in abundance. For all taxa, the multiyear CG sampling of 25 sites has more power to detect change. These results reflect the positive effects on power of increasing the number of sites sampled or temporal sampling.

TerraStat Power Reanalyses

The TerraStat results for barnacles and *Mytilus* were quite similar to those I obtained in previous analyses (figs. 18, 19, 21), including analyses for *Mytilus* that examined the effect of number of sites on power (figs. 18 and 19). However, TerraStat results for *Fucus* indicated a decrease of 5–10 percent in power to detect changes in its abundance (fig. 20 and appendix B). This decrease in power for *Fucus* appeared to be due primarily to the differences in starting parameters used rather than to changes to the MONITOR program, because the starting mean for *Fucus* in the new analysis was an average of 4 percent lower than the values I used (appendix B). Note that the results of my original analyses shown in figure 20 are aligned with reanalyses that used my original parameters in the newer MONITOR 10.0. This also indicates that it is a change in the parameters used for the TerraStat *Fucus* analyses, rather than the changes in the MONITOR program that caused the differences in power results for *Fucus*. The similarity in power results for barnacles and mussels when both MONITOR 10.0 and its earlier version are used, and when both TerraStat and my parameters are used, provide support for being able to directly interpret prior analytical results for those species groups. The TerraStat findings of somewhat reduced power to detect change in *Fucus* abundance should be taken into account when interpreting my earlier analyses. Implications of this finding for long-term monitoring design are examined in section, “Discussion.”

TerraStat analyses that manipulated the number of sites found that decreasing the number of sites sampled from 25 to 15 decreases the power to detect trends for the three predominant sessile taxa (figs. 18–21). For *Mytilus* and barnacles, this change is minimal at the 10 percent trend detection level, but becomes more important for detection of smaller annual trends (figs. 18, 19, 21). However, for *Fucus,* the TerraStat analyses indicated lesser ability to detect trends: even with 25 sites sampled, the ability to detect 10 percent trends was below the 0.8 power level specified as the minimum desired level, although the ability to detect negative 10 percent decreases almost reached the 0.8 level (fig. 20). When only 15 sites are sampled, the power to detect 10 percent annual trends for *Fucus* significantly decreased (fig. 20).

Discussion

During the *Exxon Valdez* oil spill in 1989, extensive intertidal habitats and their resident biological communities were affected directly by oil. In the injury assessment following the spill, great emphasis was placed on statistically sound sampling designs that allowed results to be more broadly generalized, and on the need to sample intensively enough to detect effects. As a result, probability-based designs were used in some studies (for example, McDonald and others, 1995; Peterson and others, 2001). This setting, coupled with the recognition that the NPS lacked baseline data for the biological resources on its coasts, stimulated the interest of the NPS in developing probability-based designs for long-term monitoring of intertidal communities along national-park coasts.

Study Design

One objective of monitoring is to detect change in populations or communities through time. However, the ability to detect change is related to the extent of the variation that exists, and the design and intensity of sampling. Managers of expansive national parks, such as Glacier Bay NP&P, are faced with what seem to be daunting challenges imposed by the tremendous physical scale and remoteness of the environments that they manage.

An approach to reconciling these different issues is through use of probability-based designs. Such designs allow the results of surveys to be extrapolated to the universe of sites from which the sampled sites were selected (the sampling frame). Deviations from the design cause some reduction in the extent or scope of inference.

A central purpose of this project was to provide managers with an analysis of several probability-based monitoring designs conducted at different scales of inference and effort. The three levels of survey and sampling included aerial surveys, CG sampling of many sites, and FG sampling of a few sites. An adaptive-sampling approach was used, where results of the first stage of surveys informed the decision making that led to the next sampling stage, etc.

The first stage, the aerial surveys, characterized the frequency of different intertidal substrate types within Glacier Bay. Of the 250 segments identified, 9 could not be surveyed, thus slightly reducing the extent of inference to the universe of coastal segments delineated within Glacier Bay proper. The systematically selected set of characterized segments also is available for other studies, thus facilitating further establishment of probability-based studies in Glacier Bay. This pool of sites has since been used by researchers examining the effects of sea otters on intertidal clams (Bodkin and others, 2007).

The results of the aerial surveys led to a revision in the characteristics of habitat types selected for the monitoring program. The finding that bedrock-dominated habitat with slope ≤ 60° was rare was unanticipated, even by resident NPS staff. The abundance of cobble/boulder habitat, and its location in the more protected waters of Glacier Bay where it is likely to be stable, led to its inclusion along with bedrock as the habitats of focus (Irvine, 1998). The unexpected results of the aerial surveys illustrate one of the values of probability-based surveys for avoiding bias.

At the CG sampling level, 5 of the 30 randomly selected sites could not be sampled, for reasons given in section, “Methods.” The elimination of these five sites somewhat reduces the extent of inference of the sampled CG sites to what was defined as target habitat within Glacier Bay. Except for the site eliminated because it was in a wildlife protection area, these eliminations may provide an estimate of the error of the segmentation process and the aerial surveys in correctly describing intertidal habitat within Glacier Bay.

The error rates can be estimated for both the aerial surveys and the selection of CG sites. During the aerial surveys, 9 (or 3.6 percent) of the 250 segments selected were flown but not surveyed. The reasons for not surveying a segment included: (a) segments actually were stream banks and not intertidal habitat (n=4), which likely is an error arising from the digitization of the coastline; (b) segments were snow covered at the time of the survey (n=3), therefore could not be surveyed; and (c) segments apparently had changed since the charts used for the digitized coastline were created. Segments in this latter case occurred in areas of rapid sedimentation and, despite their coordinate matches, did not resemble the ArcInfo segment maps. The snow-covered segments also might have had a slightly higher elevation, because the tides had not removed the snow.

During the selection of CG sites, 5 of 30 randomly selected segments were eliminated because they were in a wildlife protection area, too steep, or not a true beach (had no land exposed at high tide). After subtracting the one site that was in a wildlife protection area, these four eliminated segments constituted 13.33 percent of those selected. These represented errors in the classification process, but because all were surveyed at low tide, it would have been difficult during the surveys to determine those that were not true beaches.

The CG and FG sampling plans were designed to examine the ability to effectively sample the variation expressed in intertidal communities across different scales. The scales reflected geographic variation and within-site (local) variation. These variations were addressed, respectively, by increasing the number of sites sampled and their geographic scope, and by increasing the intensity of sampling. Geographic inference differed for the CG and FG sampling plans, due to the selection of FG sites from a narrower band of Glacier Bay (approximately the lower half of the bay). The decision to sample cobble/boulder-dominated sites during the FG sampling reduced the inference to that habitat within the narrower geographic band. Although I found some decrease in power to detect change in *Mytilus* geographically, based on analyses of 1-year data (Irvine, 1998), I have not conducted similar analyses for other intertidal species nor on multiyear data. Further analyses might indicate if a geographical bias exists.

A major question posed in this study was whether sampling many sites less intensively (CG sampling of 25 sites) had higher power to detect trends than did more intensive sampling of fewer sites (FG sampling of 6 sites). I found that the CG sampling had greater power to detect changes in the abundance of the three predominant sessile taxa.

For within-site sampling that targeted sessile taxa, vertical transects were selected as a sampling technique for several reasons. First, they sample across the elevational zonation of species, which is one of the major sources of variation in intertidal communities. Second, if climate change occurs, then the vertical distribution of species could be affected. For example, zones could shift vertically without the relative abundance of a species changing across a beach. If fixed quadrats or horizontal transects initially are established within zones, then changes noted in the abundance of a species or an assemblage might reflect changes for that position, but might not reflect changes occurring across the beach. Vertical transects also provide a good approach for sampling cobble/boulder habitat, as the draped transect lines sample topographically diverse substrates better than quadrats, due to the complication of variation in surface area sampled within quadrats. In addition to these rationales for using vertical transects, I found that sampling of vertical transects has greater power to detect changes in abundance of the major sessile taxa compared to the other point-intercept methods tested (quadrats and horizontal transects; fig. 5). Further support for the usefulness of vertical transects comes from a study on bedrock substrates in southern California that found that sampling of randomly placed vertical transects more precisely estimated the percent cover of species than did fixed plots (Miller and Ambrose, 2000).

The effort and cost associated with the CG and FG sampling regimes is not equivalent, as could be expected from the large difference in the number of sites sampled. This is discussed in section, “Design Issues for Glacier Bay Intertidal Monitoring.”

Comparison with Other Intertidal Monitoring Designs

For this study, a probability-based monitoring design was planned to test whether the variation that exists in rocky-intertidal assemblages in Glacier Bay could be sampled sufficiently to allow trend detection of the predominant sessile species, while providing inference to the universe of the selected habitat type within the bay. The goal was to provide managers with the ability to broadly generalize changes in abundance. Most sampling of rocky intertidal environments has not followed a probability-based monitoring approach, but has relied on selected sites (Channel Islands National Park (NP) — Richards and Davis, 1988; Olympic NP; Kinnetic Laboratories, Inc., 1992; Partnership for Interdisciplinary Study of Coastal Oceans [PISCO]; and Multi-Agency Rocky Intertidal Network [MARINe] — Ambrose and others, 1995; Raimondi and others, 1999) and often fixed plots or transects.

The population approach taken by Channel Islands NP staff led to target species being followed in fixed plots at selected sites (Richard and Davis, 1988). The intent was that the results would provide trend information for those species, as well as for early detection of abnormal conditions. The MARINe program primarily has sites throughout California, but in connection with PISCO has stretched geographically to include some sites in Mexico, the Pacific Northwest (including British Columbia) and Alaska. Sites are selected and intentionally spaced, and the core protocol targets specific algal and invertebrate assemblages. However, the use of vertical transects and some randomization in their placement allows sampling to be extrapolated to the site. Biodiversity sampling at the site provides data with great taxonomic definition. Band surveys and quadrat sampling also are conducted at sites. The creation of a broader network of sites allows the detection of regional and latitudinal biogeographical changes that may result from broader-scale effects due to oceanographic or climate change. Changes to sites from oil spills or other effectors can then be understood within a broader context (P.T. Raimondi, University of California, Santa Cruz, pers. comm., 2008).

Selecting sites, quadrats or transect locations without a random component to the choice limits the ability to make broader inference from the results. When sites, or other sampling units, are selected to be similar, then it is likely that variation would be reduced. If so, then the power to detect change should be increased. The growth in development of sampling designs for impact and monitoring studies is discussed in Schmitt and Osenberg (1996) and Murray and others (2006).

Two additional probability-based designs for intertidal monitoring are in progress in Alaska. One is an offshoot of the Glacier Bay design, which I adapted for Sitka National Historical Park in southeast Alaska. Sitka has a short coastline (approximately 1 km), so the whole beach is defined as the sampling frame. Sessile species are being sampled by vertical transects set systematically with a random start; large mobile invertebrates currently are sampled by band surveys along the vertical transects; and small mobile invertebrates are sampled in quadrats placed systematically along the transects. Power analyses were conducted to test whether the design can detect desired levels of change in target species (Irvine and Madison, 2008).

Since the Glacier Bay and Sitka intertidal monitoring projects were initiated, another probability-based approach has been developed, the generalized random-tessellation stratified (GRTS) survey design (McDonald, 2004; Stevens and Olsen, 2004). This approach creates a spatially balanced sample and has flexibility for adding sampling units while maintaining the spatial balance. Thus, it improves upon both systematic and simple random designs. The only intertidal monitoring project I am aware of that is using this approach is that of the Southwest Alaska Network of the National Park Service (Bodkin and others, 2008). This project is currently in the design and testing phase.

Power, Trend Detection, and Impact Analysis

Power is the ability to detect a trend if one is, in fact, occurring (or as stated earlier, the probability of rejecting the null hypothesis when it is false and should be rejected). A priori power analyses are used during the monitoring design phase to estimate how effective the monitoring plan is likely to be. Because these analyses often used limited temporal data, they should not be viewed as being predictive, just the best estimate of how various designs will perform.

The levels that are set for power and other aspects of the monitoring design vary amongst programs. Channel Islands NP has set, as their goal for monitoring, a power of 0.8 to detect a 40 percent change in species abundance through time, with an alpha of 0.05. It is not clear over what time frame this 40 percent change is computed. The North American Amphibian Monitoring Program (http://www.pwrc.usgs.gov/naamp/) previously stated on their website that monitoring programs should be able to detect population trends with a power of 0.9, but an alpha of 0.20. Their rationale for setting a relatively high alpha value is that it is more important, from a conservation standpoint, to detect declines than to be correct about whether they are occurring (Sam Droege, U.S. Geological Survey, written comm., 2009). The signaling of a decline could initiate further sampling or research to clarify the trend or investigate causes. For threatened or declining species, however, failing to detect a trend could be detrimental to the species and to management, therefore setting a smaller error rate (for example, $\alpha = 0.01$) may be an important aspect of the monitoring design (Gibbs and Ramirez de Arellano, 2007).

Setting the levels of change to be detected is a management decision, but it should be made with cognizance of how short-term changes compound over time. Even small annual changes of 5 percent quickly accelerate over time to appreciable levels of change (table 6).

Various types of power analyses can be performed. I have focused on comparing the ability of different sampling strategies to detect trends in the predominant sessile species through use of the MONITOR program. Trend detection is the goal of most monitoring programs so the power to detect trends in counts or abundance is assessed frequently. Another type of power analysis has focused on the ability to assess impacts, and uses power analysis to compare one site before and after impact (Before-After sampling design) or comparisons of two or more sites (Before-After Control Impact [BACI], or Before-After-Control-Impact Paired [BACIP] designs) (for example, Schroeter and others, 1993; Osenberg and others, 1996; Minchinton and Raimondi, 2001). Additional permutations of this impact type of sampling design have been suggested (for example, Stewart-Oaten and others, 1986; Underwood, 1994). These types of analyses could be performed on Glacier Bay data if there were suspected or known effects to one or a group of sites. Having a number of sites which could act as controls for an affected site, with both categories followed for multiple sampling intervals both before and after an event (an asymmetrical BACI design, Underwood, 1994) might provide the best option for assessing the degree of impact to that one site. Thus, the data gathered through time from the network of sites provides a backdrop against which impacts can be assessed.

Variation in the Ability to Detect Change among Taxa

Power to detect change varied consistently among the three predominant sessile taxa. Highest power to detect change occurred for barnacles, followed by lower power for the mussel *Mytilus trossulus*, then the rockweed *Fucus distichus* subsp. *evanescens*. Power will be related inversely to variability and/or abundance.

Power analyses of Channel Islands (California) rocky intertidal data also indicate differences among taxa, with greatest power to detect changes for rockweeds, lower power for the California mussel *Mytilus californianus*, then barnacles, and lowest power for *Endocladia muricata*, a red alga (Minchinton and Raimondi, 2001). Because the species comprising these taxonomic groups, as well as their abundances and ecology, differ from those in Glacier Bay, it is not surprising that the power relationships among taxa are not the same. For example, the rockweeds are comprised of entirely different taxa: *Silvetia compressa* (formerly *Pelvetia fastigiata*) and *Hesperophycus californicus* (formerly *H. harveyanus*) (see MARINe website: http://www.marine.gov/Research/CoreSurveys/SeaweedOfCalifornia.html). The Glacier Bay sites also are protected, while the Channel Island sites are exposed rocky (bedrock) habitat. The study design also influences the power results; because many of the plots at Channel Islands were selected to be within zones dominated by these target taxa (Richards and Davis, 1988), the abundances of the target taxa generally are fairly high. The geographical variation in power for similar taxa (for example, rockweeds) indicates that we should use caution when borrowing information from other areas to guide power analyses.

There is some indication from Glacier Bay data that greater variation in the abundance of a species (only *Mytilus* data for 1997 were examined) led to decreased power. The trend in power was related to geographical distribution of sites, with decreased power to detect change in *Mytilus* for sites lower in the bay (Irvine, 1998). This decreased power may be related to the increased species diversity found in the lower part of the bay (Sharman, 1990).

The geographical trend in the power to detect change in *Mytilus* abundance calls to the fore another issue, which is that the abundances of the major space-holding species in the intertidal are not independent. Competition for space occurs, and can be mediated by predation and disturbance (for example, Connell, 1961; Paine, 1966; Dayton, 1971; Sousa, 1979). Thus, variation in one species can affect variation in other species. If additional species become more common in Glacier Bay as glaciers recede or as climate warms, then the relative abundances, and hence power to detect change in barnacles, *Mytilus*, and *Fucus* may change. Because this sampling program is not targeting specific species, but is assessing the biotic composition of a site, differences in the occurrence and relative abundance of species through time will be assessed. The species that are dominant now may not be dominant at some time in the future. Sampling at the CG level may make it difficult to detect species with low abundances, however, and could be combined periodically with more intensive sampling, site surveys, or timed surveys to increase detection of less-common species.

Design Issues for Glacier Bay Intertidal Monitoring

The power and design of a monitoring program will be influenced by both management-set parameters (for example, the desired power, level of change to be detected, and alpha level), and sampling parameters (for example, number of sites, transects, quadrats, etc.). The biological data provide the basic information needed for assessing how to sample to achieve the management-set parameters. Another factor greatly affecting the ultimate sampling design is cost. I consider first how different designs (for example, CG and FG) and parameters affect power, then discuss effort and cost considerations.

CG sampling provides more power to detect change than the FG sampling, which is due primarily to the increase in the number of sites sampled under the CG regime. Increasing the number of sites, number of transects, or intensity of points sampled per meter all increase the power to detect trends. The effect of increasing sites and transects is pronounced, generally more so than increasing the intensity of point sampling. It may be harder to observe the effect of increasing point sampling, as very low-intensity point sampling has high power to detect change for barnacles and *Mytilus*. However, the power curves associated with increasing point sampling for barnacles and *Fucus* have fairly flat or gentle slopes, indicating that increasing the number of points sampled per meter has little influence on power.

Manipulations of alpha (error level) had relatively straightforward effects on power, which were attenuated when power reached very high levels (for example, 1.0; fig. 15). Increasing alpha increased the ability to detect trends, but, in general, the effect seems to be somewhat less than the effect of increasing the number of sites (fig. 15 versus figs. 18–21).

How do the CG and FG sampling differ in effort and cost? I stated in the "Results" section that the most equivalent comparison of effort and power between the CG and FG sampling is rendered by comparing the power analyses of the same six sites sampled by each method in 1997 (fig. 16). The increased intensity of the FG sampling led to somewhat increased power to detect change for all three of the predominant sessile taxa, with the greatest increase in power for barnacles. If we examine the effect of increasing the number of sites on power by comparing the analyses of CG data (1997, 6-site data versus 1997, 25-site data; fig. 16), we see a solid increase in power for all three sessile taxa. Multiyear sampling of the 25 CG sites leads to further increases in power (fig. 16).

The major difference in cost or effort between the CG and FG sampling is exacted by the logistical cost associated with sampling more sites. Originally I had planned on sampling two CG sites per tide, but the distances between sites meant that only some site pairs could be sampled consistently on one tide (probably five pairs; although the exact number depends on the number of people sampling and their expertise). If we compare the FG and CG vertical transect/band sampling in terms of people-days, the FG sampling costs 18 people-days (3 people × 1 site/day × 6 sites), and the CG sampling costs 40–60 people-days (minimum 2 people × 0.8-1 site/day × 25 sites = 40–50 people-days). Having three people doing the CG sampling increases the likelihood of being able to sample two sites per day, but the overall number of people-days would be 60. Thus, the CG sampling is approximately 2–3 times as expensive, in people-days, as the FG sampling, but samples 4 times as many sites. In the upper reaches of Glacier Bay, it is very helpful to have the support of a larger vessel than a skiff, but that further increases the costs.

I considered setting initial conditions high: power of 0.9 to detect a 10 percent annual change in the abundance of the predominant taxa, with an alpha of 0.05 (Irvine, 1998). However, the reanalysis by TerraStat supports lowering the power level to 0.8, or perhaps even lower for *Fucus*. A power level of 0.8 would encompass annual changes of 5–10 percent in *Mytilus* and barnacles sampled at 25 sites (figs. 18 and 21), 10 percent annual changes in *Mytilus* and barnacles sampled at 15 sites (figs. 19 and 21), and would come close to being able to detect 10 percent decreases in *Fucus* sampled at 25 sites (fig. 20). However, the power to detect 10 percent increases in *Fucus* is less, approximately 0.68 (fig. 20). This decrease in power from previous analyses is attributed primarily to the reduced plot mean estimate used for *Fucus* in the new analyses (average decrease of 4 percent in starting means; appendix B). The new analyses used the starting year mean values at each site as the plot or site mean input to MONITOR, whereas, my previous analyses used an average value for a taxon over all years. Increased temporal sampling is likely to increase the power to detect trends in *Fucus*. This is illustrated by the finding of very similar power for the 4-year (1997–2001, 1 point/m) and 3-year (1998–2001, 5 points/m) datasets (figs. 7 and 8, respectively); in this case increased temporal sampling compensated for lower sampling intensity.

In addition to increasing temporal sampling, there are other options for increasing the power to detect change in *Fucus*. One would be increasing the number of sites, which provides the greatest increase in power (fig. 20). Increasing the number of transects sampled/site or the error level (alpha) also enhance power, but to a lesser degree. Increasing the number of points sampled/m has a yet smaller effect on power. Because the CG sampling, as conducted from1998 through 2001, provides high power to detect 10 percent annual changes in *Mytilus* and barnacles, no adjustments are needed to the CG sampling plan to effectively sample those taxa.

An alternative method for increasing power would be to make the vertical transects at the sites fixed in location, thus reducing the spatial variability over time. The data thus far have been from new (re-randomized) transect locations at a site each year. Because the power to detect trends for the major sessile species is relatively high, the challenges of marking and relocating precise transect locations may not warrant the effort. If quadrat sampling for small mobile invertebrates is coupled with vertical transect sampling in the future, then it probably would be worthwhile to fix the location of transects and quadrats to reduce the spatial component of variation in abundance due to re-randomization of sampling locations within a site each year. The abundance of small mobile invertebrates is likely more sensitive to changes in substrate composition.

If we assume that increased data collection over time would increase the power to detect change for *Fucus*, then the recommended sampling protocol for these sessile intertidal assemblages is to conduct the CG sampling scheme annually at the 5 points/m level. The suggested protocol is detailed in appendix D. Because the newer power analyses indicate somewhat reduced ability to detect change in *Fucus* (fig. 20), I do not recommend reducing the number of sites sampled. Power analyses of the FG data provide an example of the repercussions on sampling intensity that result when only a small number of sites are sampled. In order to achieve the same 0.8 level of power to detect 10 percent decreases in the main sessile taxa, the number of transects per site would need to be increased to approximately 35 for *Fucus* and 20 for *Mytilus* when only 6 sites are sampled; current sampling is sufficient for barnacles (fig. 6).

Although an equivalent level of power might be achieved by sampling fewer sites more intensely, there is additional value to having a larger number and greater spread of sites throughout the bay than was the case for the FG sampling. Note, however, that a random selection of a few sites from the entire bay might have good geographic spread and broad inference, but would not necessarily increase the probability of detecting different events. The logistic costs of visiting a few, quite dispersed sites also could be very high or prohibitive.

Sampling a larger number of sites is likely to increase the capture of particular types of effects, events, and changes, as well as increasing the likelihood that these sites better reflect the overall condition of the bay. If effects do occur that are likely to affect a small subset of the sites (for example, ice scour or trampling effects), having a larger number of sites increases the ability to compare affected versus unaffected sites. For example, site 69 (Berg Bay, fig. 1) was noticeably different from other sites in 1997 in being dominated by barnacles. I hypothesized that the site had been disturbed (probably by ice) prior to the spring set of barnacles in 1997. Later I learned from crab researchers that much of Berg Bay froze in the winter of 1996–97 (Tom Shirley, Texas A&M University, and Jim Taggart, U.S. Geological Survey, oral commun.). The pattern of species abundances since then (fig. 22) is giving us a trajectory of the rate and pattern of secondary succession following a major site disturbance. Additionally, the slow recovery of *Fucus*, as compared to barnacles and mussels, indicates that it might be an important indicator of disturbance or change to intertidal communities.

Results detailed in this report indicate that generally high power exists to detect trends in the major space-dominating sessile taxa. As more temporal data are acquired, it is likely that the power to detect changes in trends of these sessile taxa will increase (for example, CG data, 25 sites, 1997 versus 1997–2001 data, fig. 16). An increase in power with additional data and increased temporal spread of data indicates that, in the future, the park could evaluate whether to sample these 25 sites every other year (or less frequently), or perhaps combine sampling the 25 sites every other year with sampling a subset in the intervening years for some indication of annual changes or major events.

This report has concentrated on analyses of sampling to detect trends in the major sessile taxa. For more complete sampling of intertidal assemblages, protocols are needed for sampling small mobile invertebrates (such as predatory snails, limpets, and littorine snails), and more effective sampling of large mobile invertebrates. Some data exist for both of these groups that could assist in proposing more effective sampling. Small mobile invertebrates were sampled within quadrats during the FG sampling. Large mobile invertebrates were sampled via band surveys along the vertical transects in both CG and FG sampling, but were uncommon. Sampling should be modified to concentrate sampling for this latter group (notably starfish) on the lower areas of the intertidal (Irvine and Madison, 2008).

Small and large mobile-invertebrate species can have dramatic effects on the abundances of the major sessile species under natural conditions (e.g. Irvine, pers. obs.), and following oil spills (Cubit and Connor, 1993; Highsmith, and others, 1996; Irvine, 2000). Therefore, development of protocols to effectively sample these groups would greatly strengthen an intertidal monitoring program and increase understanding of changes occurring to these communities.

The sampling protocol as designed thus far has the power, if implemented and carefully executed, to enable the park to assess changes occurring to the major sessile species in these intertidal communities throughout Glacier Bay over the long term. To achieve and further this goal, I provide the following comments based on this study:

Implementation of the CG monitoring protocol for sessile species, as conducted from 1998–2001 (that is, sampling of 25 sites, 6 vertical transects/site, 5 points/m) will allow the park to detect 10 percent annual changes in the abundance of barnacles and *Mytilus*. Annual sampling will increase the ability to detect events, but sampling could be conducted at greater time intervals (for example, biennially or triennially).

The somewhat reduced ability to detect trends for *Fucus* argues against reducing the number of sites; however, increasing the time series of data is likely to increase the power to detect trends for *Fucus*.

If cost is an issue, the number of sites might be reduced, but this would reduce power to detect change in abundance of *Fucus*. If the number of sites sampled is reduced, the number of transects, points sampled per meter, etc. would need to be increased to maintain or increase power.

There are advantages to maximizing the number of sites sampled, while maintaining a random selection of sites. A GRTS design would allow greater flexibility for altering the number of sites while maintaining spatial balance of the sites. However, shifting to a GRTS design would result in a loss of applicability of many of the results of this study and the ability to extend the timeline of data from sites already established.

To more completely sample the macrobiota of the rocky intertidal communities within Glacier Bay, development of effective monitoring protocols for small mobile invertebrates and large mobile invertebrates should be considered.

Why Monitor the Intertidal?

The data obtained indicate that we can monitor the major sessile intertidal taxa. Why should we? Intertidal communities are very productive and diverse assemblages of species with extensive ties to terrestrial and marine species. The complexity and strength of the links has been illustrated by oil spills and a wealth of observation and investigation. The particular sessile species focused on here are all spatial dominants over broad geographical extents and are significant ecologically. Mussels and rockweed provide structure to the intertidal that can increase the species diversity of the communities. Additionally, mussels are an extremely important prey for many species including other invertebrates, fishes, birds, and mammals (including humans). Immigrating sea otters are expected to have effects on both intertidal and shallow subtidal species, including mussels, as their numbers continue to increase. Benthic-feeding waterfowl (for example, scoters [*Melanitta* spp.], goldeneyes [*Bucephala* spp.], and harlequin ducks [*Histrionicus histrionicus*) currently may be having a more extensive effect than sea otters. Surveys of marine predators in Glacier Bay have estimated that these benthic-feeding waterfowl have a combined population size greater than 30,000 individuals, with seasonal shifts in the abundance of different groups (Drew and others, 2008). Barnacles, another important prey for a number of species, also are included in the diets of black bears (*Ursus americanus*) in Glacier Bay and brown bears (*U. arctos*) in Katmai NP&P. These intertidal communities, located at the juncture of the atmosphere, ocean and land are vulnerable to effects from all three directions.

Monitoring of these rocky intertidal habitats falls under the mantle of long-term ecological monitoring. Although the direct relationship of the findings to management actions may not always be clear (Oakley and Boudreau, 2000), with time and development of understanding of natural patterns in species abundances and distributions, a greater understanding of the Glacier Bay ecosystem will result.

The findings from long-term monitoring may contribute substantially to the ability to assess effects to the intertidal from issues or stressors of concern to the park. Some of these are: oil spills, immigration of sea otters, shifts in species abundances and distributions due to local or global climate change, and invasive species. One potential invasive species that could have large effects on the intertidal communities of Glacier Bay is the green crab, *Carcinus maenas*. The green crab is spreading north up the west coast of North America, and by 1999 had reached British Columbia (U.S. Environmental Protection Agency, 2009).

Linking intertidal monitoring at Glacier Bay with monitoring planned for Sitka National Historical Park (NHP) would allow more robust assessment of biogeographical changes in species abundances and distributions caused by climate change or the advance of invasive species. Expanding the linkage of Sitka NHP and Glacier Bay NP&P studies to monitoring programs being set up in Prince William Sound and the NPS Southwest Area Network parks would expand our ability to understand community dynamics across the Gulf of Alaska, and detect effects from broader-scale environmental drivers, including climate change.

One of the major threats of climate change is acidification of the oceans resulting from increased atmospheric CO_2 (for example, Orr and others, 2005). Sessile invertebrates with calcareous shells (for example, mussels and barnacles) or whose larval forms have such shells will be particularly vulnerable to changes in ocean acidity. Thus, consistent sampling of ocean water as well as intertidal sessile species may indicate important changes in the marine environment that are not detected so readily in pelagic systems. The visibility and accessibility of marine intertidal communities, as well as their complexity, are some of the reasons why these communities have been studied intensively. This knowledge base increases the potential for understanding changes that may occur, even though it does not eliminate the need for focused research.

Thus, having and implementing an effective monitoring protocol for intertidal communities in Glacier Bay may aid detection and interpretation of major changes that are likely to occur. This study provides the first step in that direction by providing an effective protocol for assessing changes occurring to the major sessile taxa in the rocky intertidal communities.

Conclusions

The probability-based survey and sampling approaches used in this study have provided a broad characterization of intertidal habitats within Glacier Bay, as well as statistical comparison of different sampling approaches that varied in their inference, intensity, and techniques. The three levels of surveys included: aerial surveys, CG sampling, and FG sampling. At each level, there were some reductions in inference based on: segments that were classified inappropriately (aerial surveys), segments that could not be sampled (CG sampling), or geographical and habitat restrictions (FG sampling).

Rocky habitat, including cobble/boulder and bedrock substrates, was the focus of on-site surveys. Analyses presented focus on the three predominant sessile taxa: barnacles; the mussel *Mytilus trossulus;* and the rockweed *Fucus distichus* subsp. *evanescens*. The CG sampling, which involved sampling 25 randomly selected sites at relatively low intensity, provided a higher degree of power to detect changes in the predominant sessile taxa than did the more intensive FG sampling of 6 sites. The FG sites, a subset of the CG sites, were cobble/boulder dominated and were located in the lower half of the bay.

I provide data illustrating the effect on power of different sampling methods (quadrats, vertical transects, and horizontal transects), sampling parameters (number of sites, number of transects, intensity of point sampling per meter), and management-set parameters (the level of change to be detected, certainty [alpha]).

Point-intercept sampling of vertical transects had greater power to detect change than did similar sampling of horizontal transects and quadrats. The number of sites sampled had the largest effect on power, followed by the number of transects sampled and alpha levels. The number of points sampled per meter had the least effect on power. There were consistent differences among species in the ability of the sampling to detect changes in their abundances. There was greater power to detect changes in abundance of barnacles, somewhat less power for the mussel *Mytilus*, and least power for the rockweed *Fucus*.

The CG sampling regime carried out from 1998 through 2001 would provide the park a means to assess changes to these intertidal taxa and communities on a broad spatial scale. Under this approach, sampling would occur annually (or at greater time intervals) at the 25 established sites, using 6 vertical transects per site, sampled at 5 points/m. This sampling provides a power of 0.8 or greater, with an alpha of 0.05, to detect annual changes of 10 percent for barnacles and *Mytilus*. The ability to determine change for *Fucus* is somewhat less, particularly for increases in abundance; however, acquiring more data over time should increase the ability to distinguish trends. Further effort is needed to develop effective protocols for small and large mobile invertebrates.

The data from this project provide managers with substantial information that will be useful in designing and implementing a long-term intertidal monitoring program with sufficient power to detect trends for important sessile taxa inhabiting rocky shores within Glacier Bay. Data from this study and future monitoring also may be used to assess impacts to these biological communities from such causes as climate change, invasive species, oil spills, trampling, or the immigration of sea otters.

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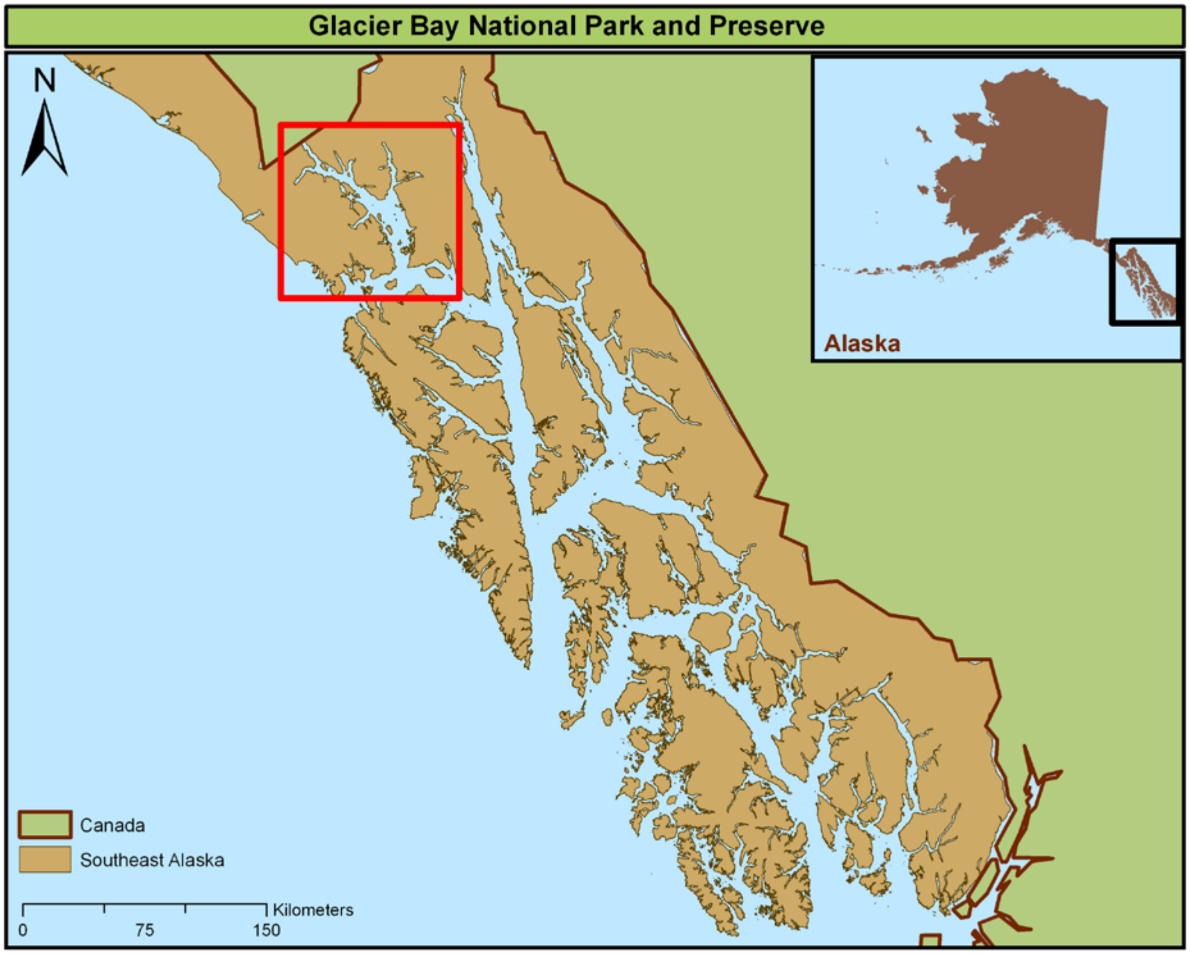


Figure 1. Location of Glacier Bay National Park and Preserve (red box) in southeast Alaska (black box in inset).

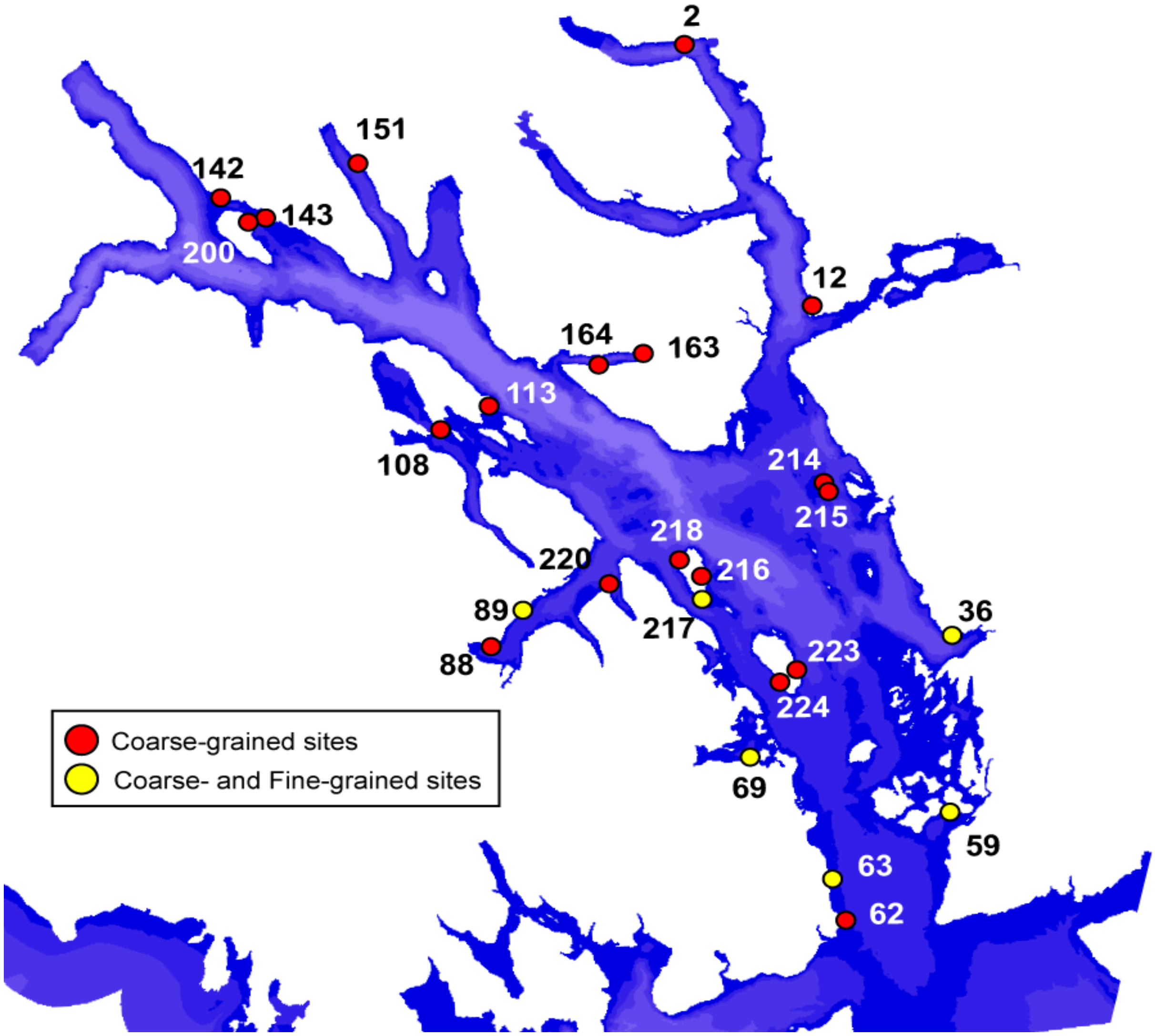


Figure 2. Locations and segment numbers of the coarse-grained and fine-grained sites in Glacier Bay National Park and Preserve. Fine-grained sites are a subset of the coarse-grained sites.

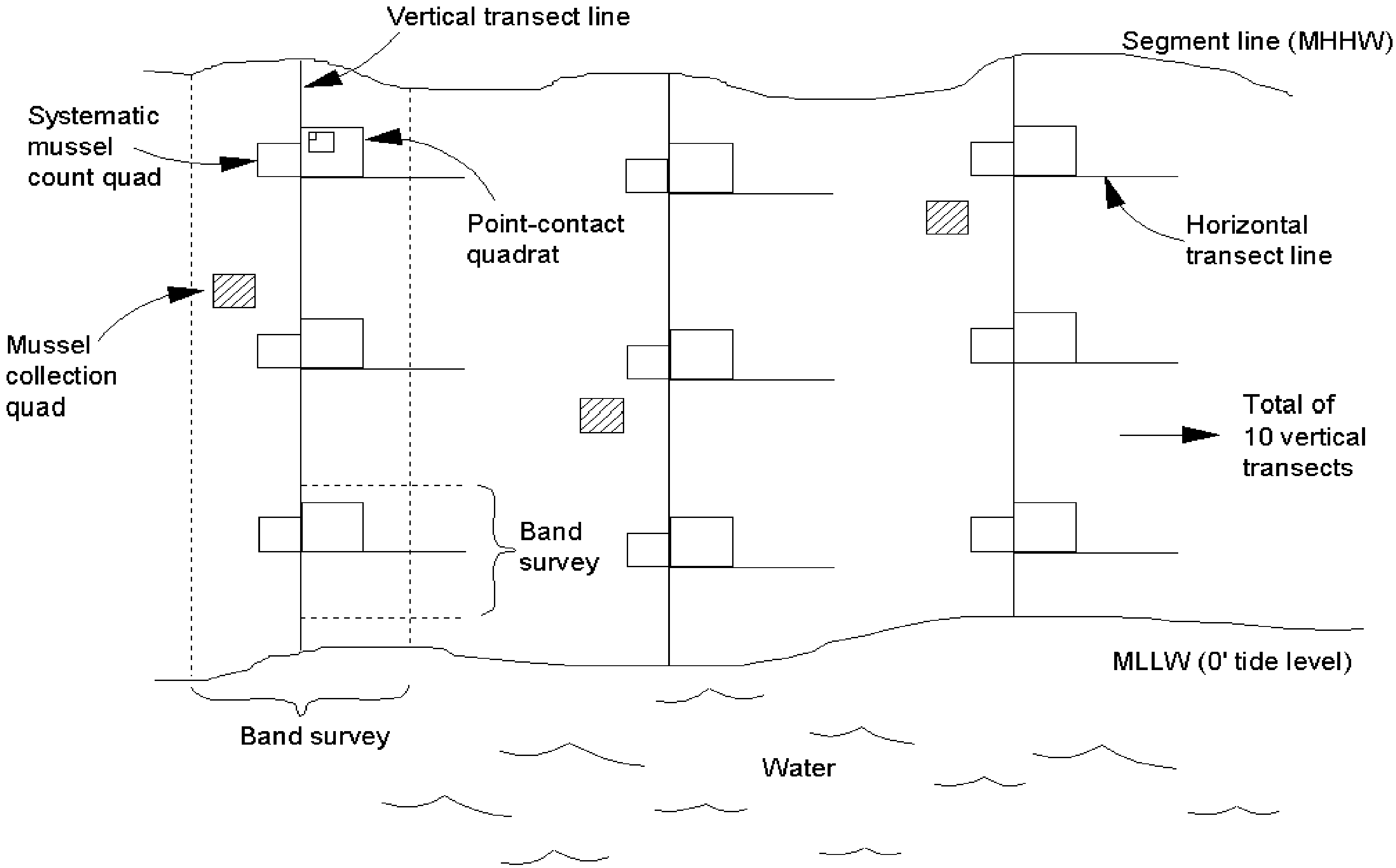


Figure 3. Layout of the various sampling methods used during the fine-grained surveys.

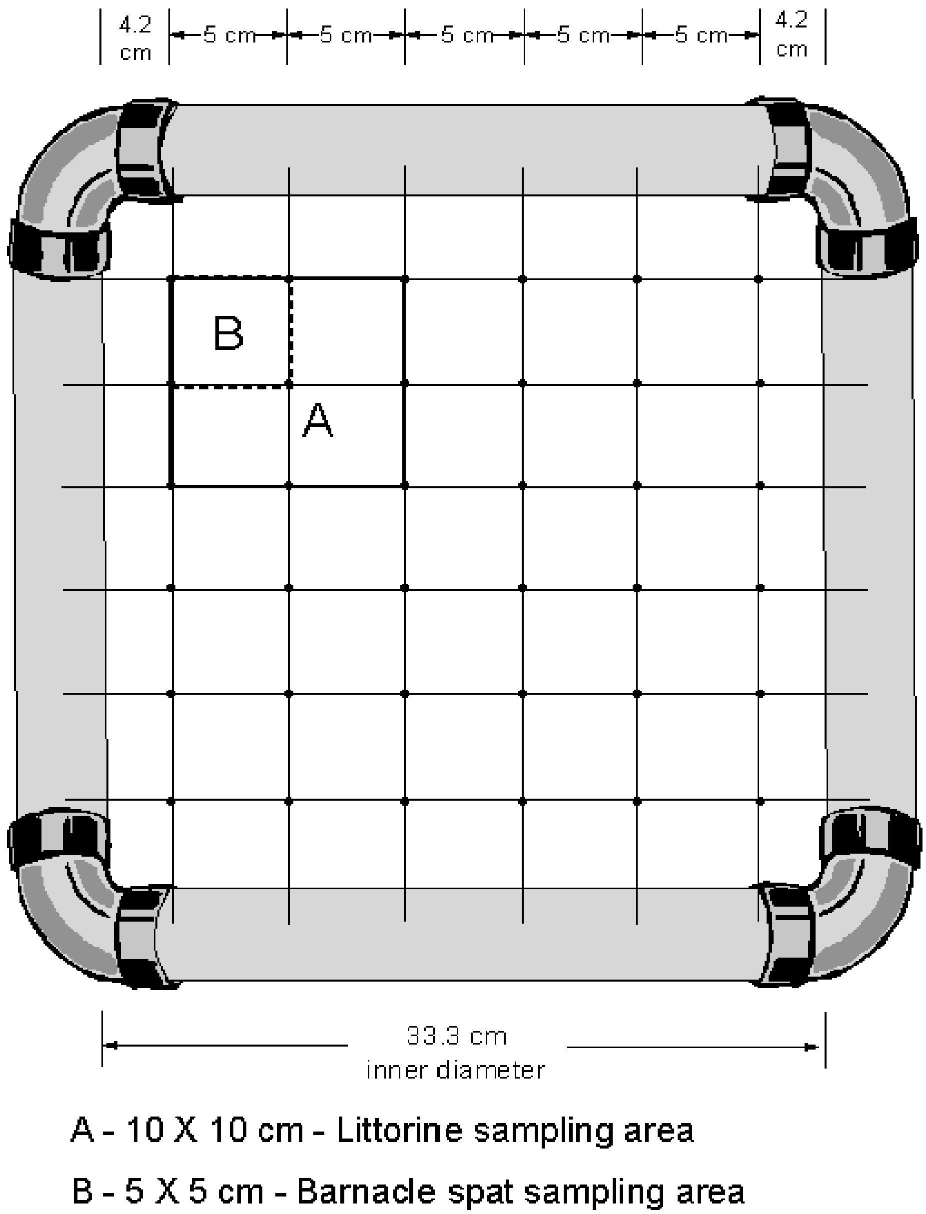


Figure 4. Quadrat used for point-contact sampling at the fine-grained sampling level. Littorine snails and barnacle spat/recruits were subsampled in the indicated areas.

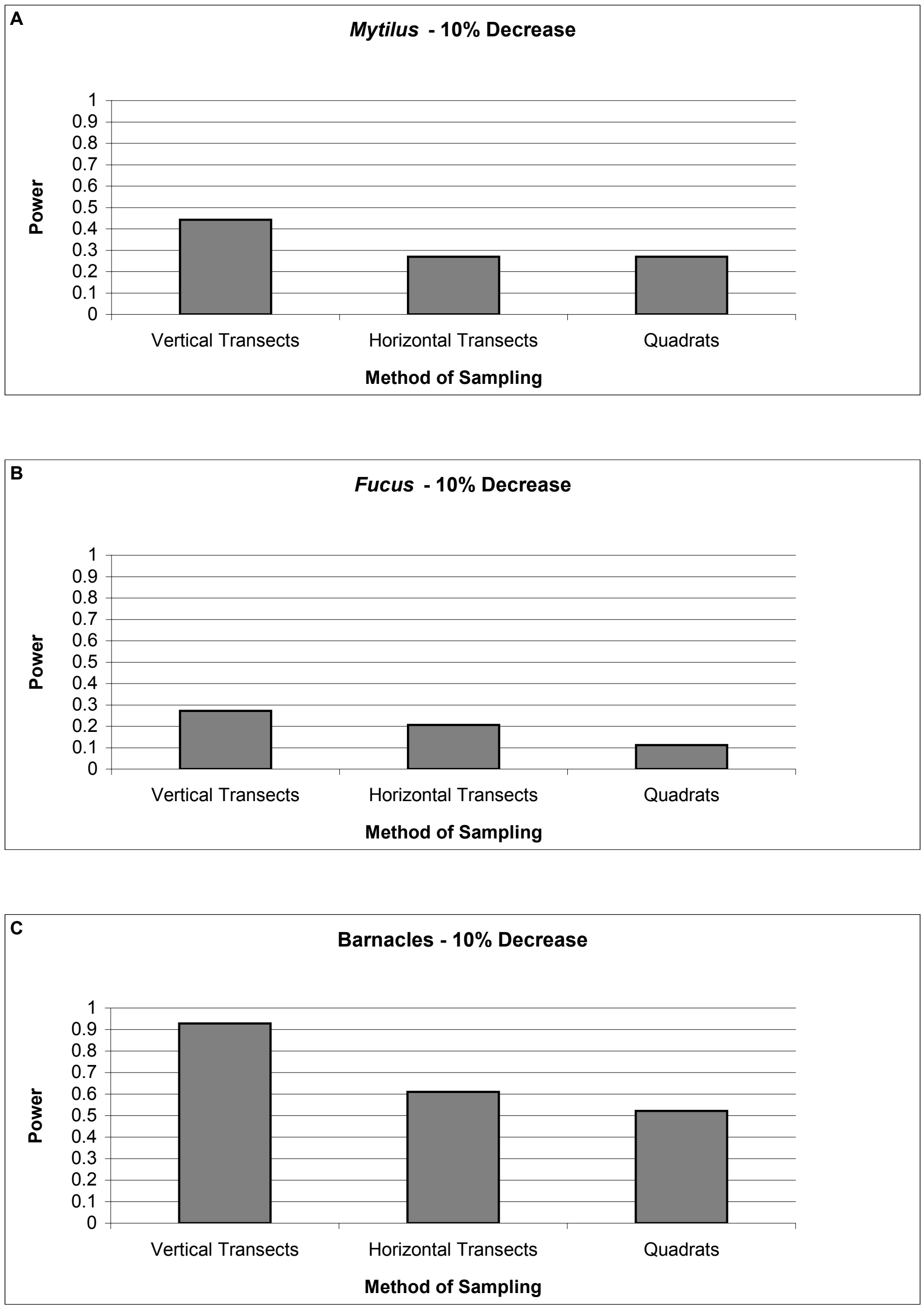


Figure 5. Comparison of the power of three point-intercept sampling methods conducted as part of the fine-grained sampling protocol in 1997. At six sites, 10 vertical transects, 30 horizontal transects, and 30 quadrats were sampled. *A*. Power to detect a 10 percent decrease in *Mytilus*. *B*. Power to detect a 10 percent decrease in *Fucus*. *C*. Power to detect a 10 percent decrease in barnacles. $\alpha = 0.05$.

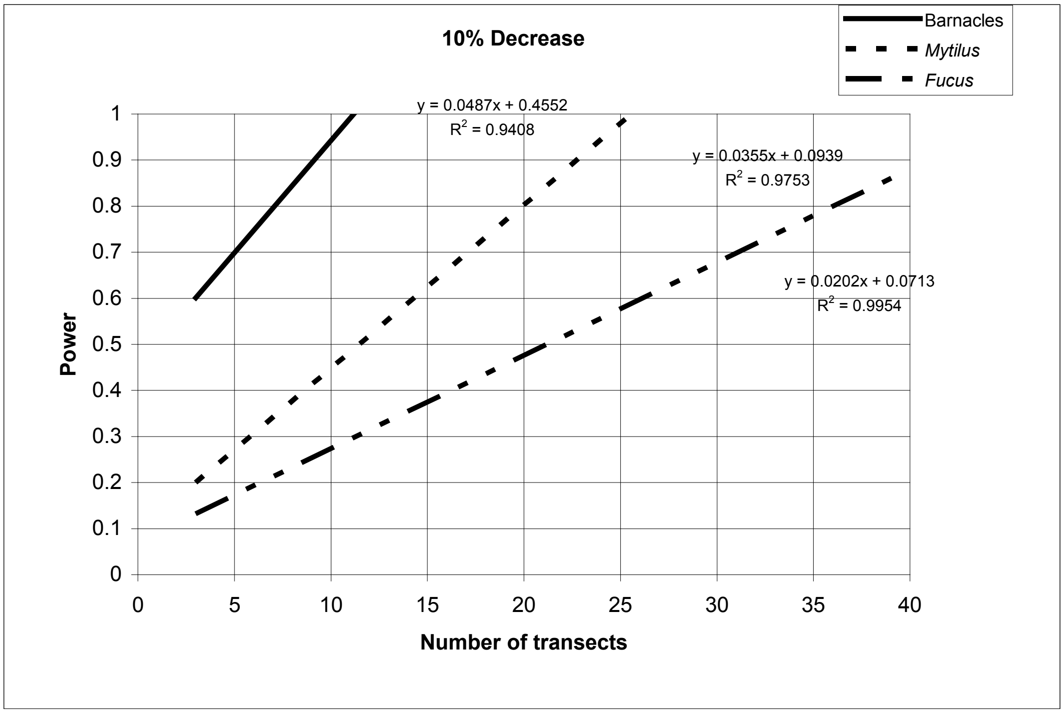
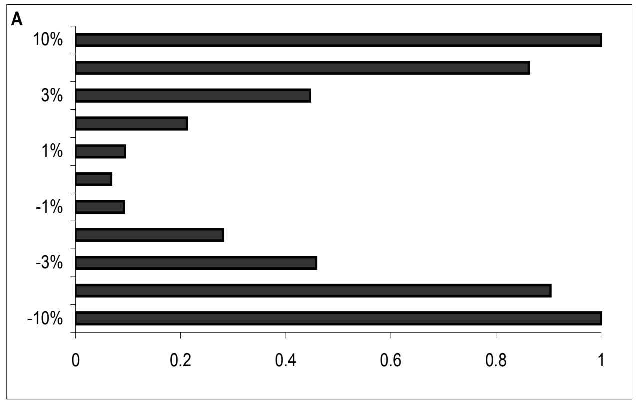


Figure 6. Power to detect a 10 percent decrease in the predominant sessile species as related to the number of transects sampled. A linear trend is projected based on data collected from 1997 fine-grained sampling of six sites. Each transect was sampled at a frequency of 5 points/meter. $\alpha = 0.05$.

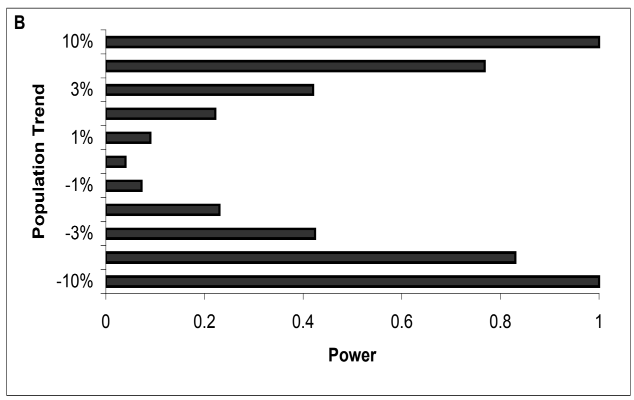
Barnacles

Population Trend	Power
-10%	1
-5%	0.904
-3%	0.458
-2%	0.28
-1%	0.092
0%	0.068
1%	0.094
2%	0.212
3%	0.446
5%	0.862
10%	1



Mytilus

Population Trend	Power
-10%	1
-5%	0.83
-3%	0.424
-2%	0.23
-1%	0.072
0%	0.04
1%	0.09
2%	0.222
3%	0.42
5%	0.768
10%	1



Fucus

Population Trend	Power
-10%	0.974
-5%	0.49
-3%	0.228
-2%	0.124
-1%	0.072
0%	0.052
1%	0.052
2%	0.132
3%	0.188
5%	0.422
10%	0.944

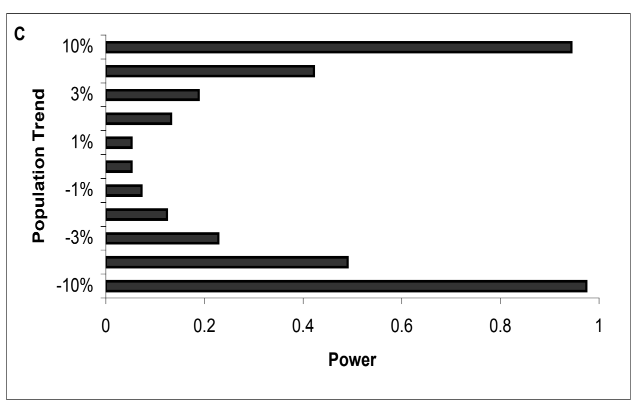
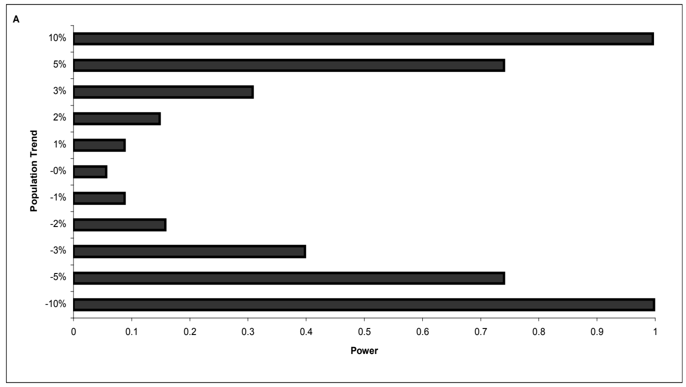


Figure 7. Power to detect population trends based on 4 years of data (1997–2001) in *A*. barnacles; *B*. *Mytilus*; and *C*. *Fucus*. Data are based on sampling of 25 sites, 6 transects, 1 point/meter. $\alpha = 0.05$.

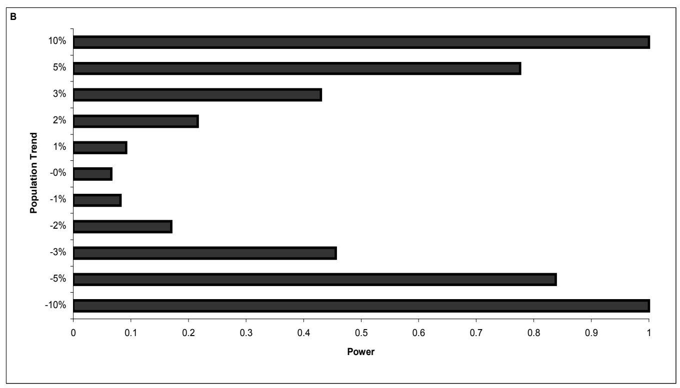
Barnacles

Population Trend	Power
-10%	0.998
-5%	0.74
-3%	0.398
-2%	0.158
-1%	0.088
-0%	0.056
1%	0.088
2%	0.148
3%	0.308
5%	0.74
10%	0.996



Mytilus

Population Trend	Power
-10%	1
-5%	0.838
-3%	0.456
-2%	0.17
-1%	0.082
-0%	0.066
1%	0.092
2%	0.216
3%	0.43
5%	0.776
10%	1



Fucus

Population Trend	
-10%	0.912
-5%	0.366
-3%	0.162
-2%	0.092
-1%	0.06
-0%	0.034
1%	0.062
2%	0.08
3%	0.158
5%	0.37
10%	0.86

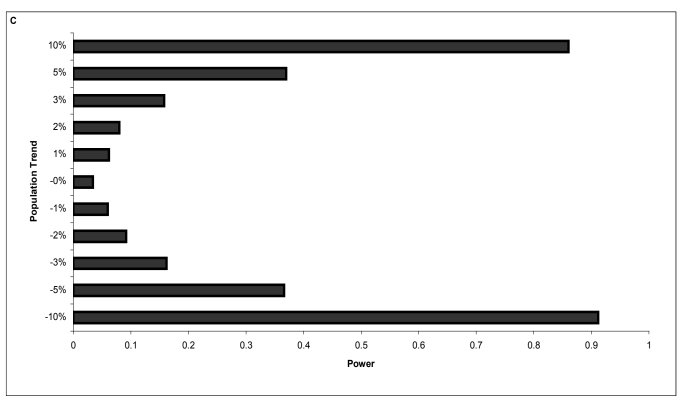


Figure 8. Power to detect population trends based on 3 years of data (1998–2001) in *A*. barnacles; *B*. *Mytilus*; and *C*. *Fucus*. Sampling was conducted at 25 sites, 6 transects, 5 points/meter. $\alpha = 0.05$.

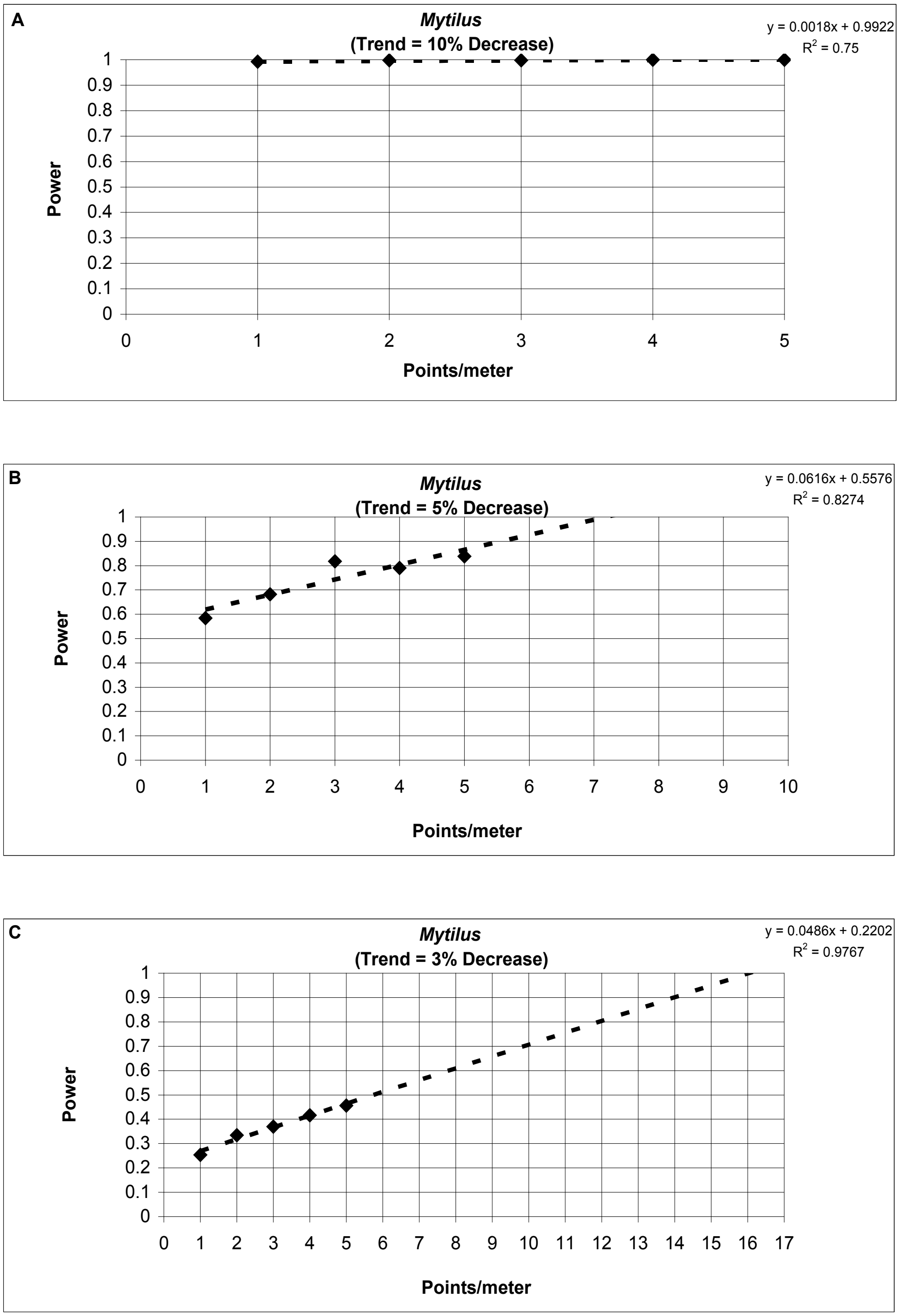


Figure 9. Power to detect decreases in *Mytilus* populations as related to the number of points sampled per meter of each transect. Data are based on 3 years of sampling (1998–2001) at 25 sites, 6 transects at each site. α = 0.05. *A*. 10 percent decrease; *B*. 5 percent decrease; *C*. 3 percent decrease. Points on graphs indicate data; lines are linear projections of the trends suggested by these data.

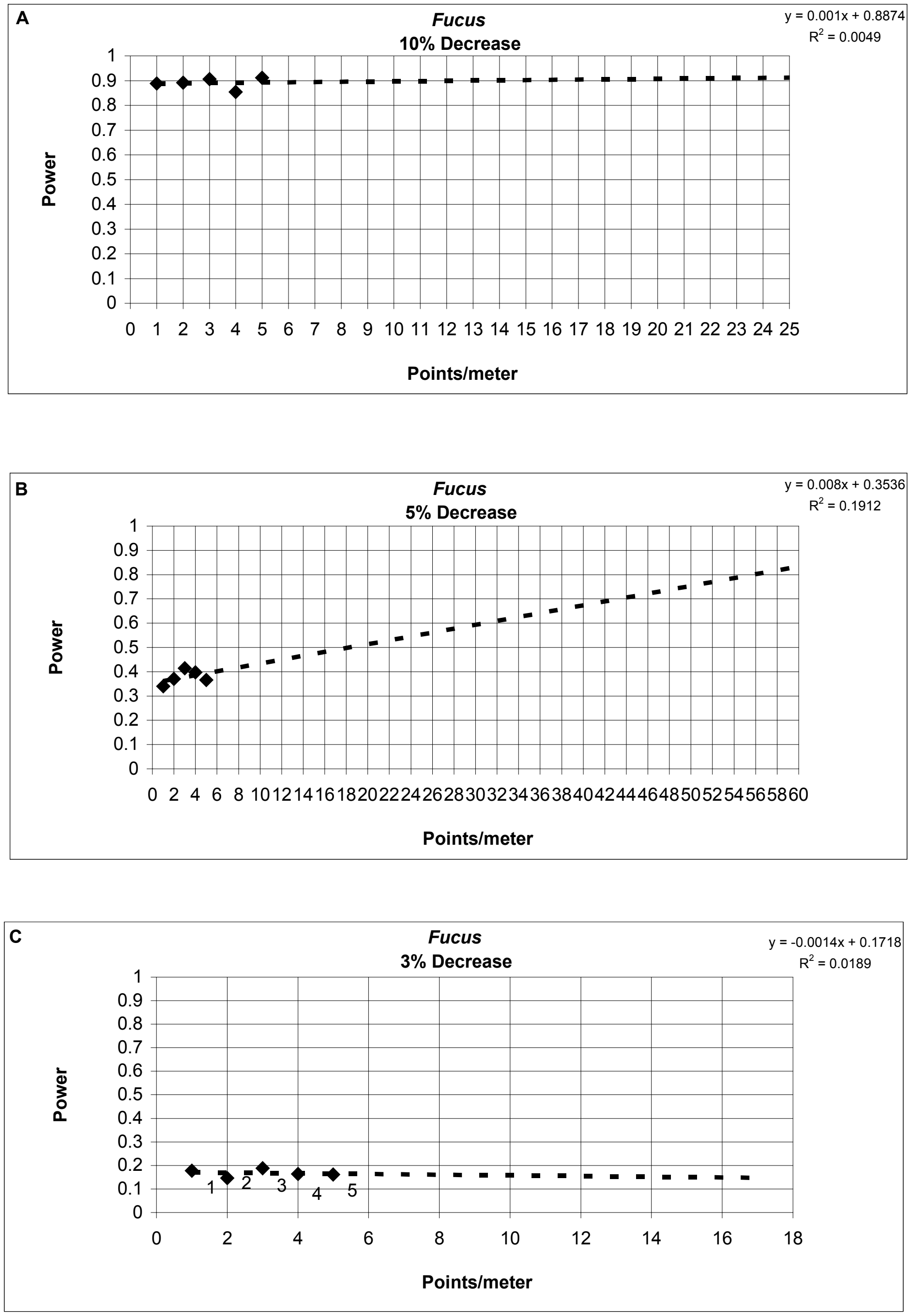


Figure 10. Power to detect decreases in *Fucus* populations as related to the number of points sampled per meter of each transect. Data are based on 3 years of sampling (1998–2001) at 25 sites, 6 transects at each site. α = 0.05. *A*. 10 percent decrease; *B*. 5 percent decrease; *C*. 3 percent decrease. Points on graphs indicate data; lines are linear projections of the trends suggested by these data.

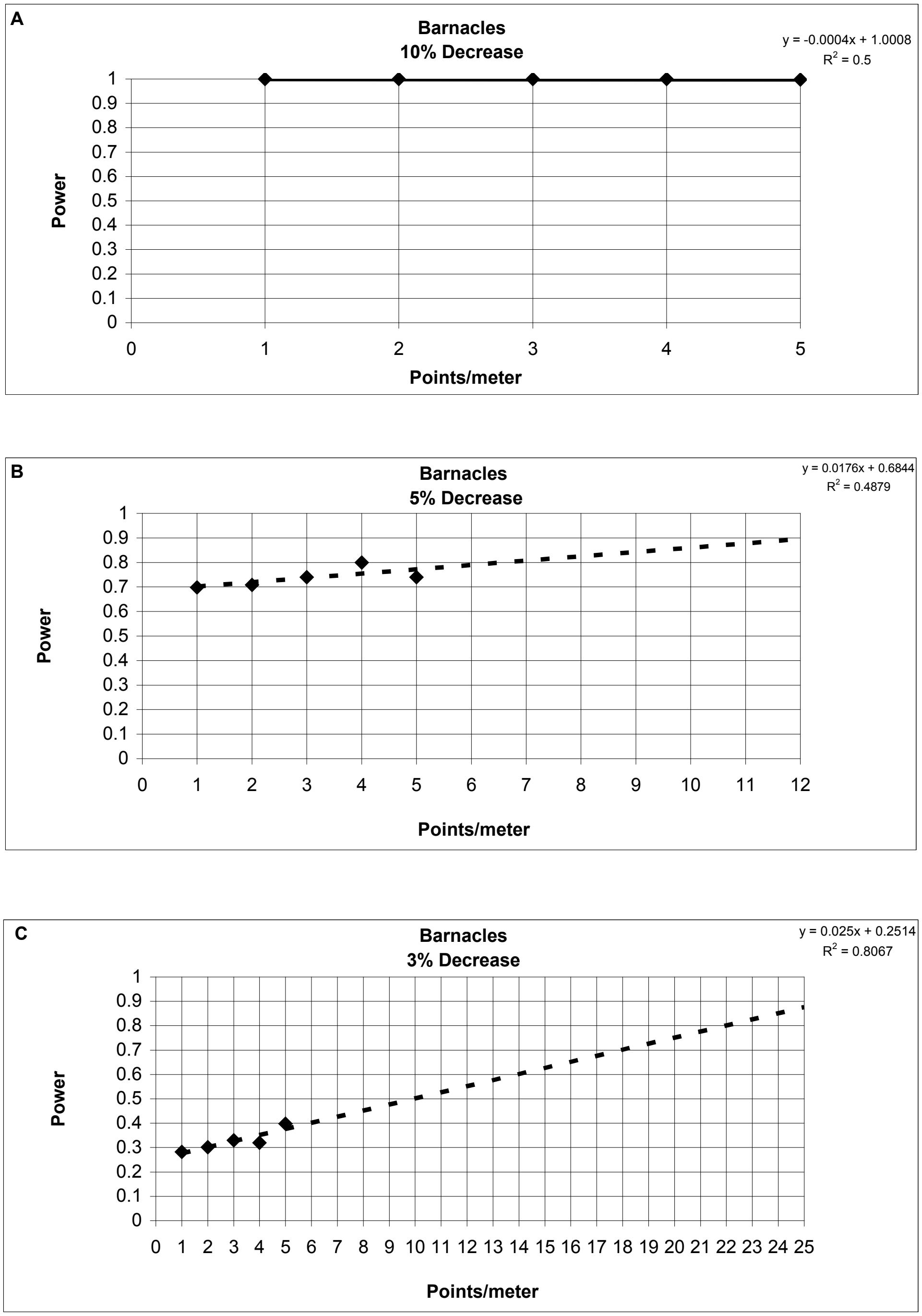


Figure 11. Power to detect decreases in barnacle populations as related to the number of points sampled per meter of each transect. Data are based on 3 years of sampling (1998–2001) at 25 sites, 6 transects at each site. α = 0.05. *A*. 10 percent decrease; *B*. 5 percent decrease; *C*. 3 percent decrease. Points on graphs indicate data; lines are linear projections of the trends suggested by these data.

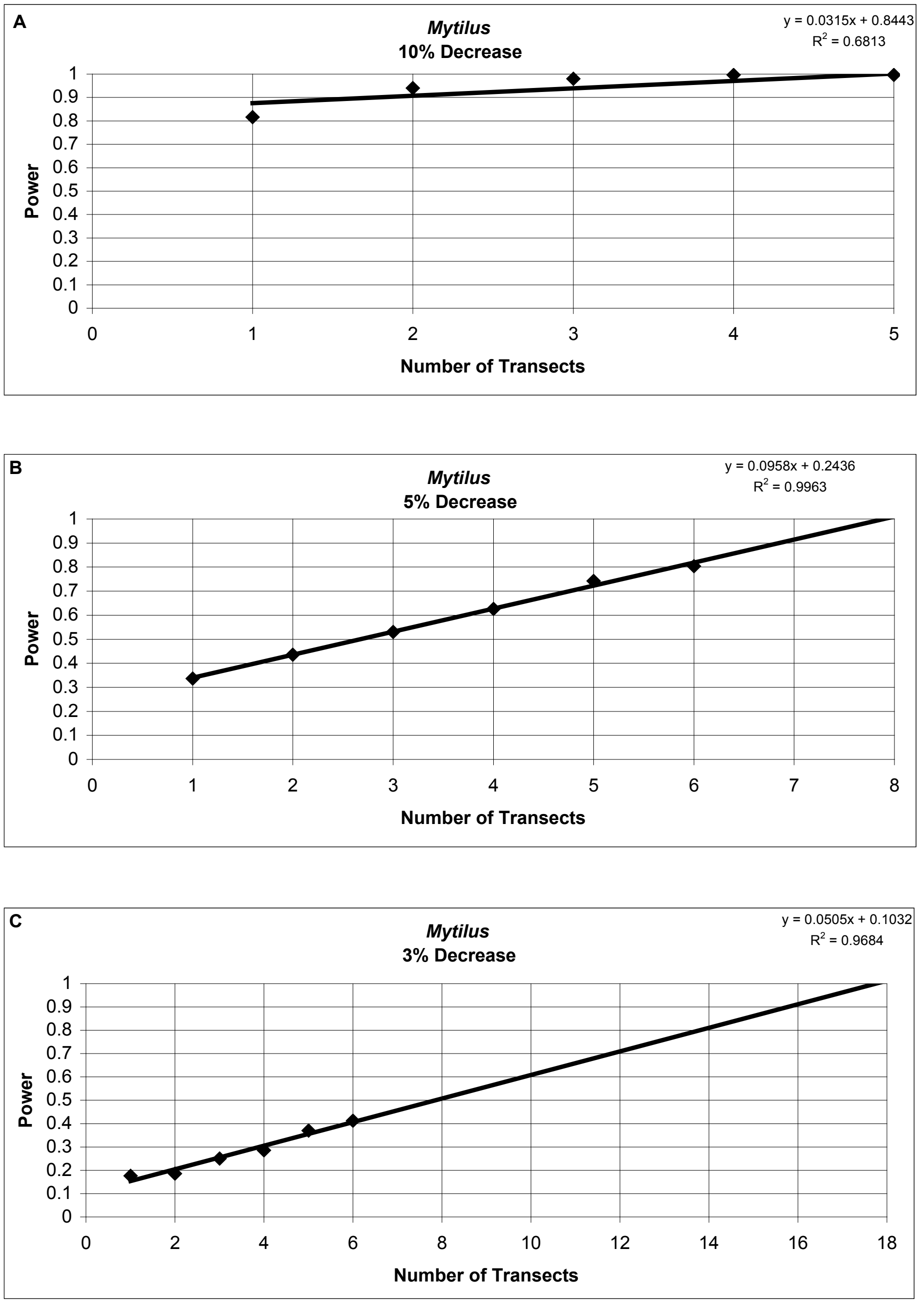


Figure 12. Power to detect a decrease in *Mytilus* populations as a function of the number of transects sampled at each site. Data are based on 3 years of sampling (1998–2001), 25 sites sampled, transects sampled at a frequency of 5 points/meter. *A*. 10 percent decrease; *B*. 5 percent decrease; *C*. 3 percent decrease, $\alpha = 0.05$. Points on graphs indicate data; lines are linear projections of the trends suggested by these data.

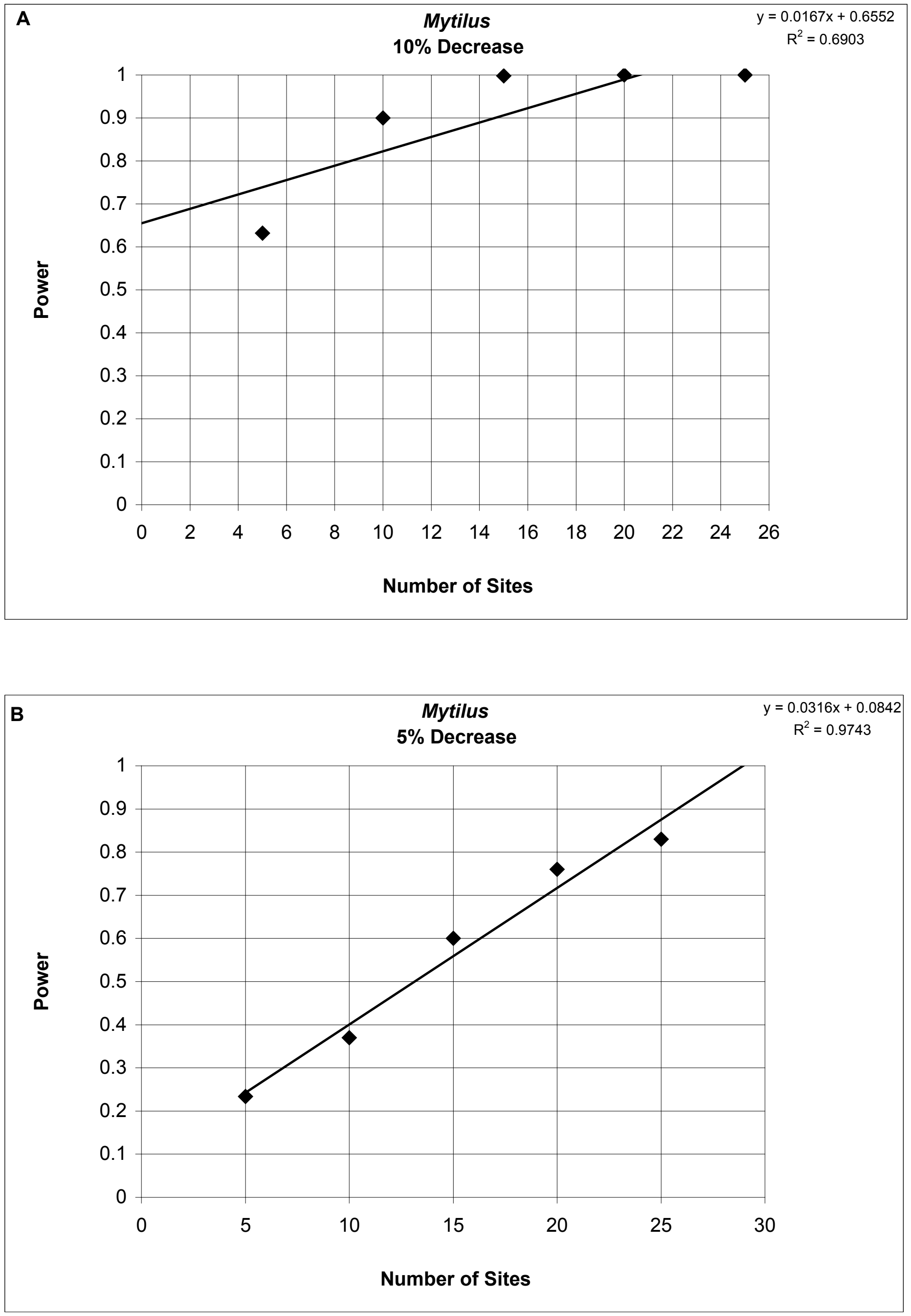
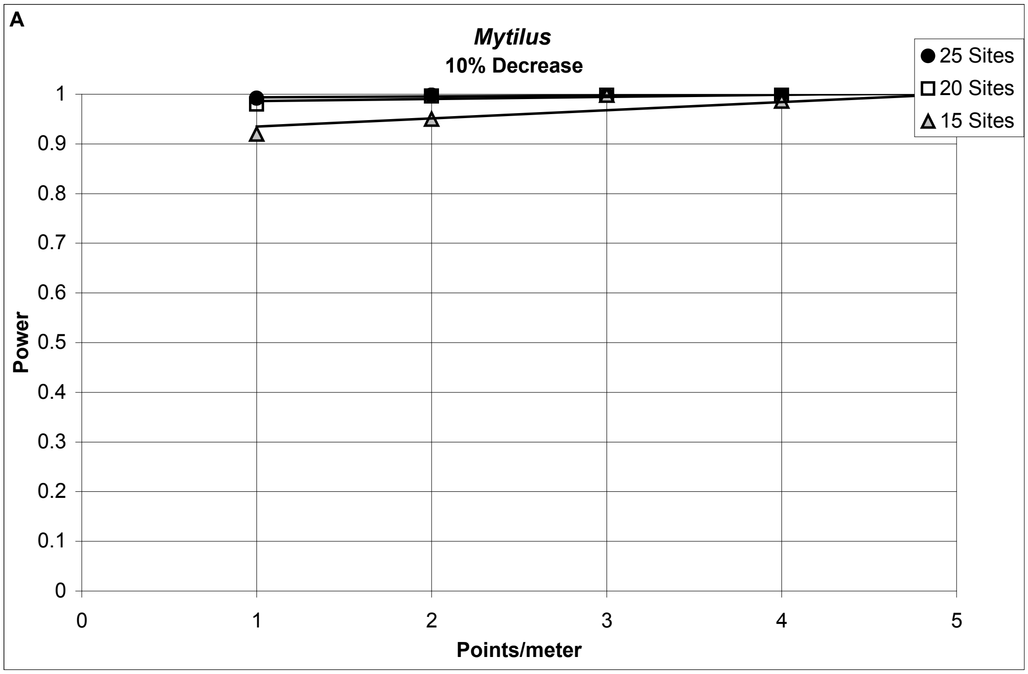


Figure 13. Power to detect a decrease in *Mytilus* populations in relation to the number of sites. *A*. 10 percent decrease; *B*. 5 percent decrease. Data are based on 4 years (1997–2001) sampling of 6 transects sampled at 1 point/meter at each site. α = 0.05. Points on graphs indicate data; lines are linear regressions of trends suggested by these data.



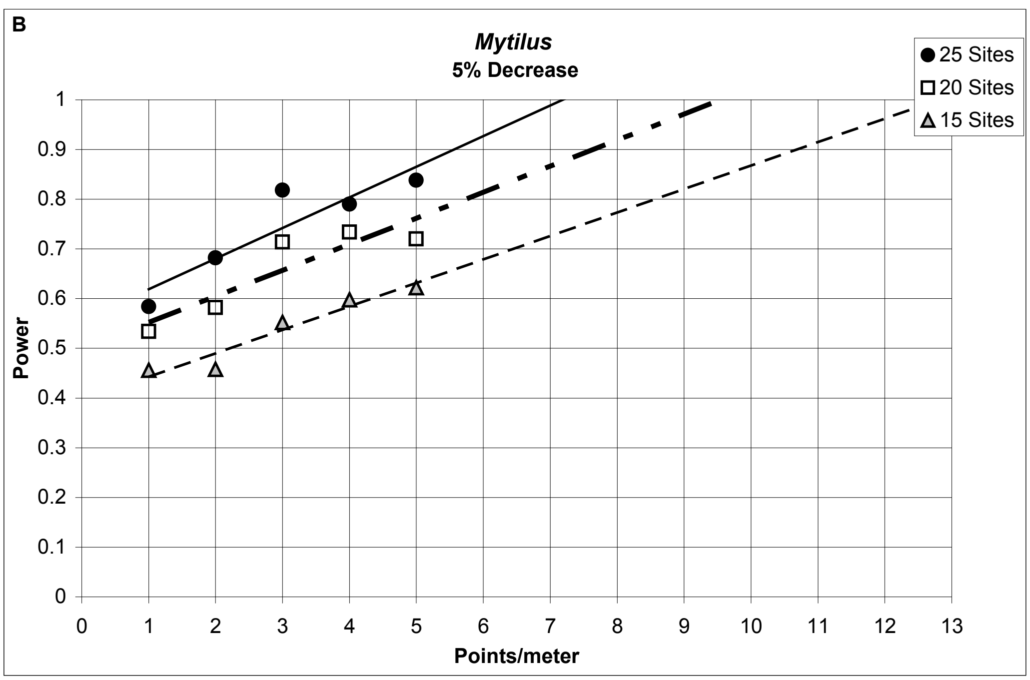


Figure 14. Change in the power to detect a decrease in *Mytilus* populations as a result of varying the number of points sampled per meter with respect to 25, 20, and 15 sites. *A*. 10 percent decrease; *B*. 5 percent decrease. Data are based on 3 years (1998–2001) of sampling 6 transects at each site. $\alpha = 0.05$. Points on graphs indicate data; lines are linear regressions of trends suggested by these data.

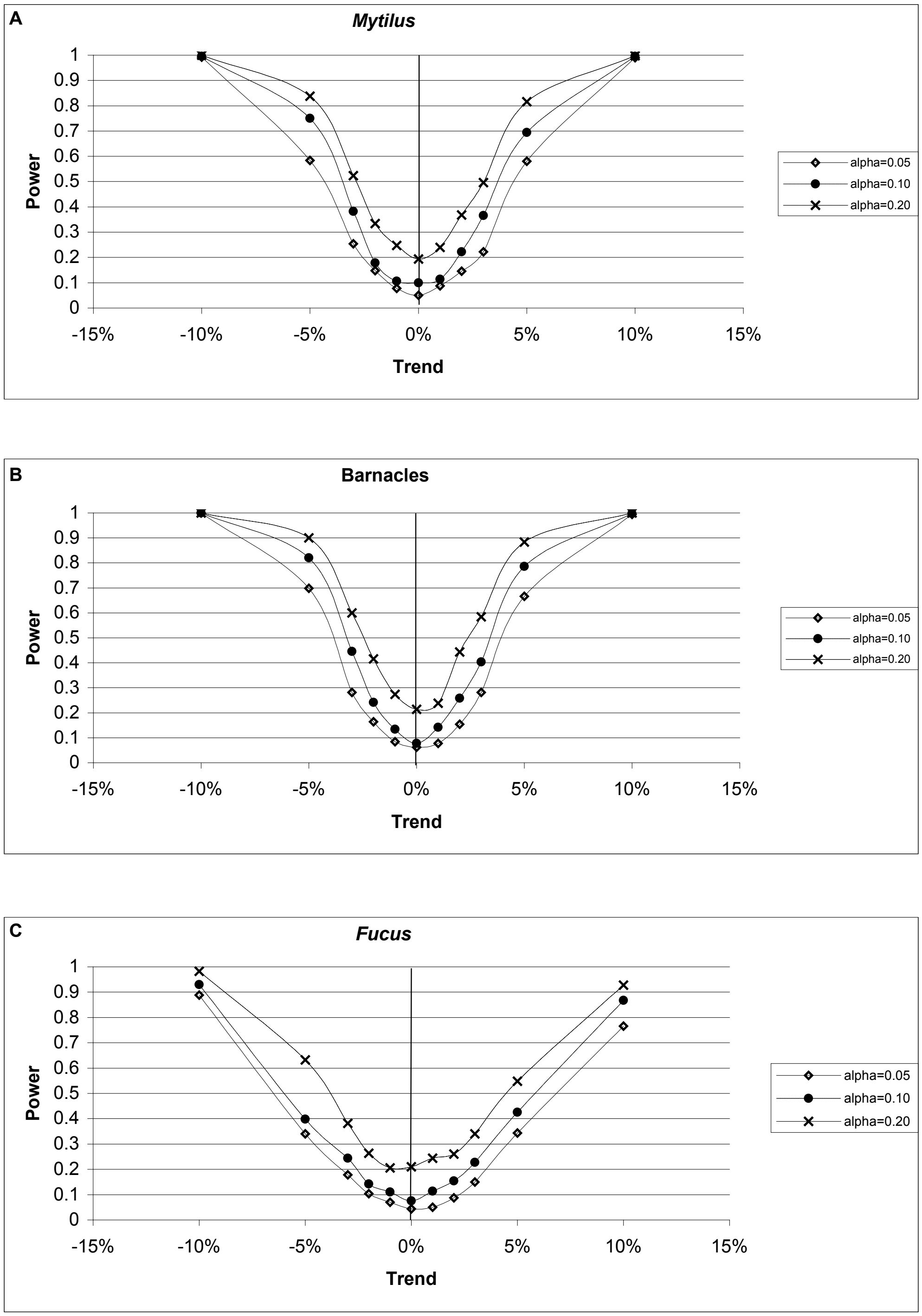


Figure 15. Power to detect trends of differing magnitudes at three levels of alpha (α = 0.05, 0.10, 0.20). Data are based on 4 years (1997–2001) of coarse-grained sampling: 25 sites, 6 transects/site, 1 point/meter. *A*. *Mytilus*; *B*. barnacles; *C*. *Fucus*.

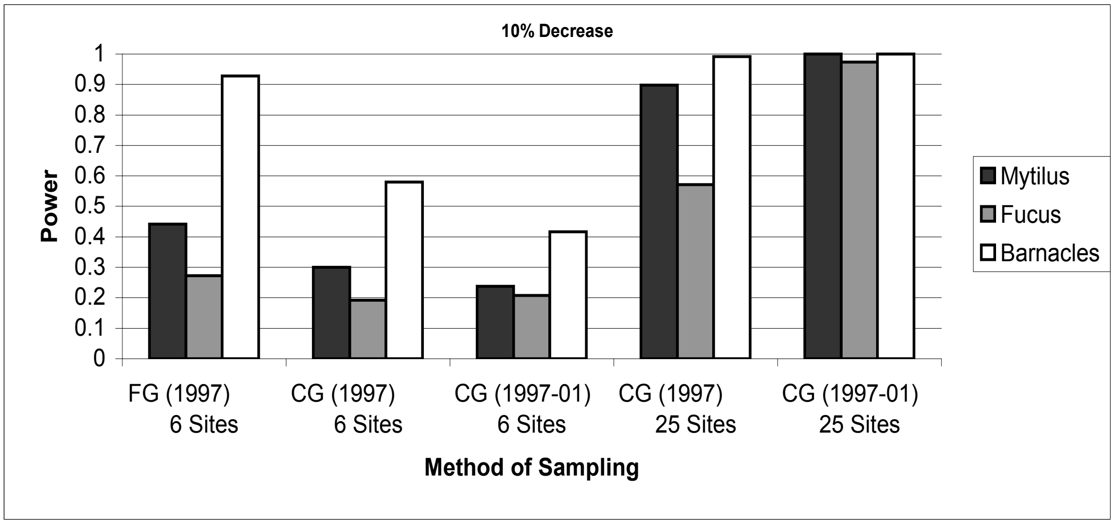
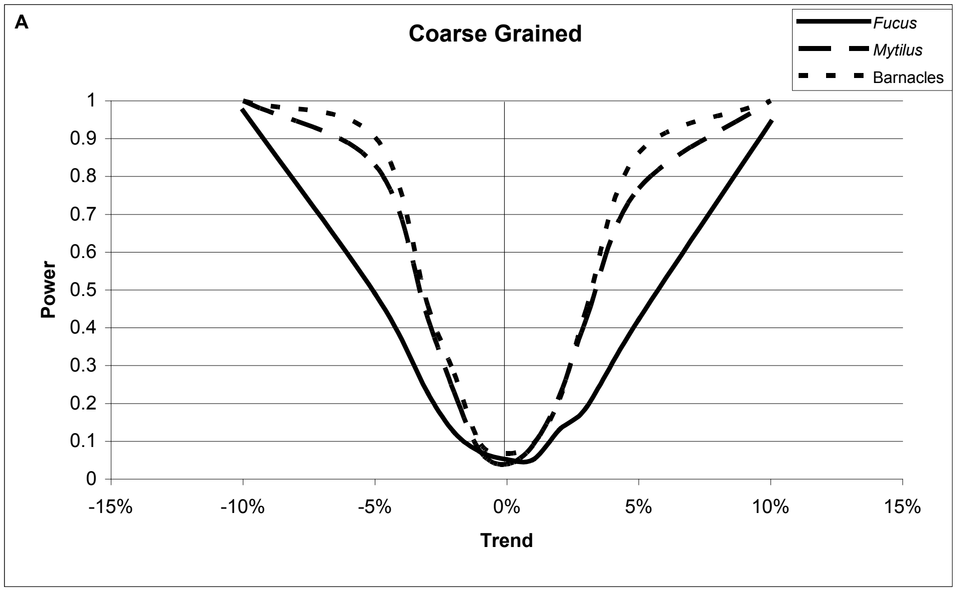


Figure 16. Comparison in the power of fine-grained and coarse-grained vertical transect sampling to detect a 10 percent decrease in *Mytilus, Fucus*, and barnacles. Fine-grained sampling (1997 only) included 10 transects at each of 6 sites, each transect sampled at 5 points/meter. Coarse-grained data (1997–2001) used in these analyses are derived from sampling 6 transects/ site at 1 point/meter. Analyses of both coarse-grained sampling at the 6 fine-grained sites and all 25 sites are included as a comparison.



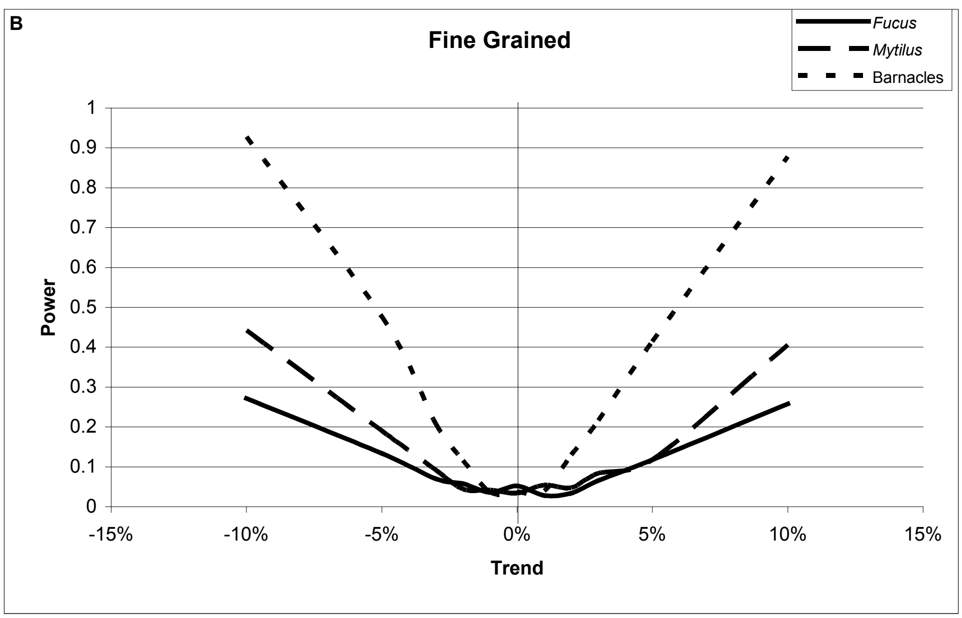


Figure 17. Comparison of the power of coarse-grained and fine-grained sampling methods to detect trends in the predominant sessile species. α = 0.05 *A*. Coarse-grained (1997–2001): 25 sites, 6 transects/site, 1 point/meter. *B*. Fine grained (1997): 6 sites, 10 transects/site, 5 points/meter.

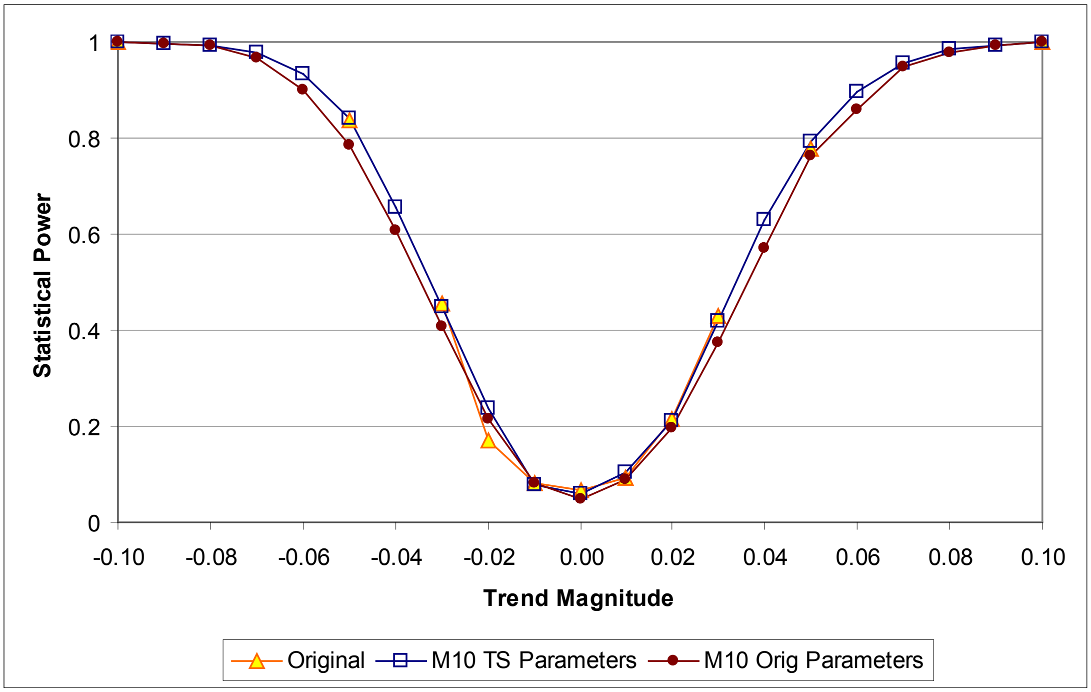


Figure 18. Statistical power comparison for *Mytilus* with 25 sites. Results from the original analyses are compared to those from two sets obtained with MONITOR, version 10: (1) using TerraStat parameters and (2) using the original parameters. See appendix B for more details.

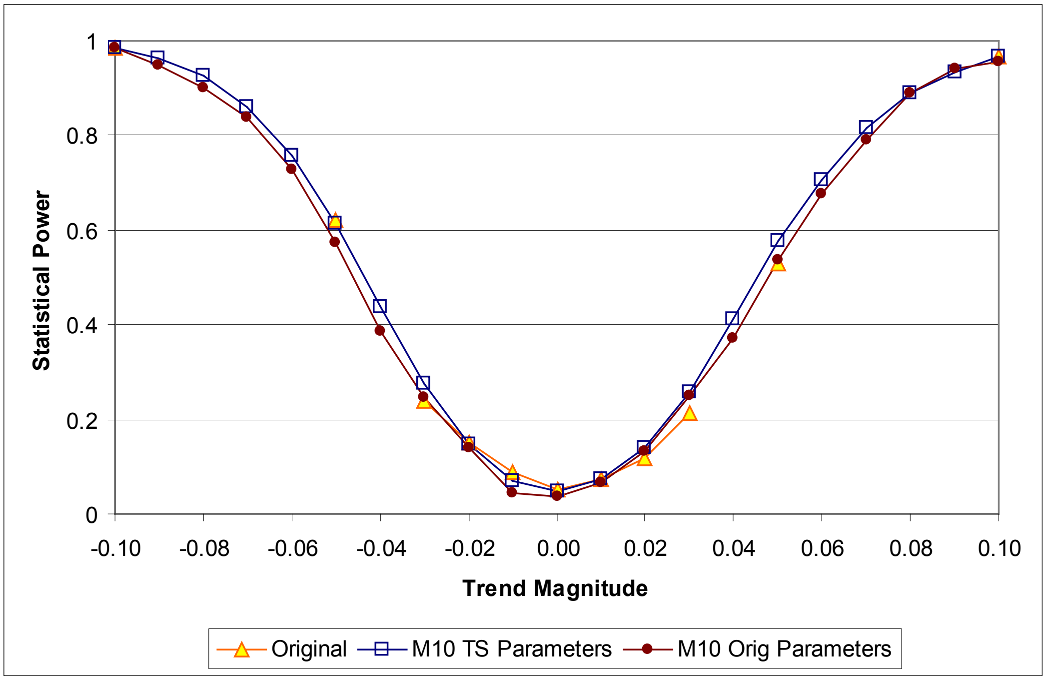


Figure 19. Statistical power comparison for *Mytilus* with 15 sites. See caption in figure 18 for more detail.

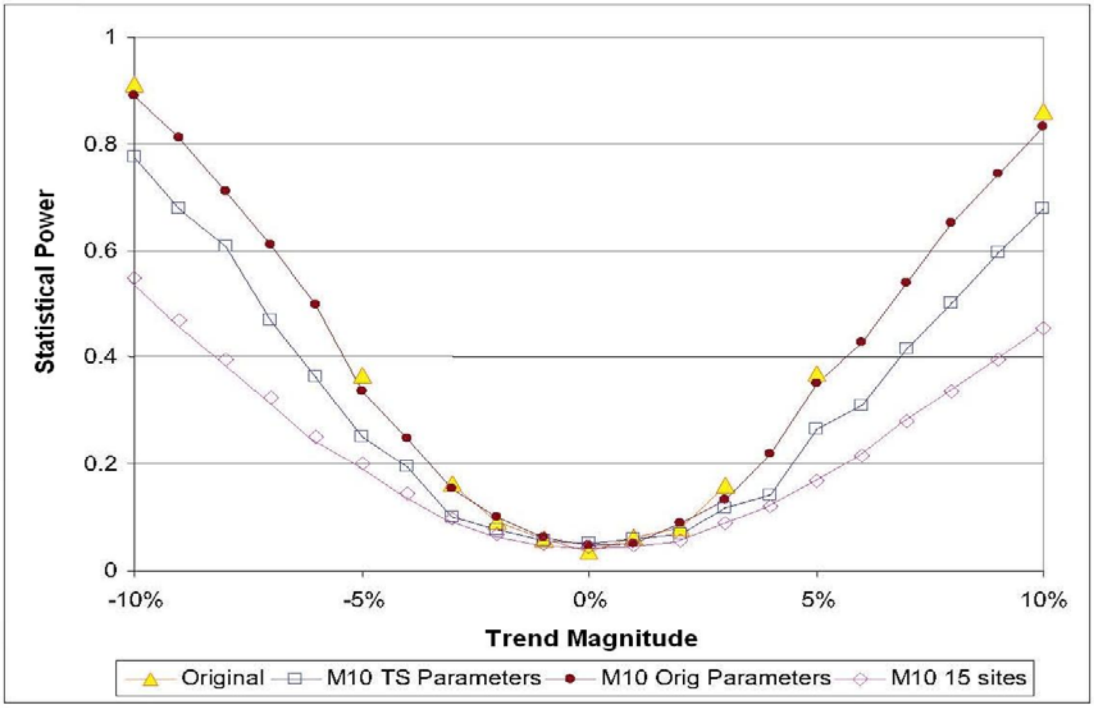


Figure 20. Statistical power comparison for *Fucus*. See caption figure 18 for greater detail. In addition to the three runs examining power for 25 sites, also there is a run of MONITOR 10 using data from 15 sites.

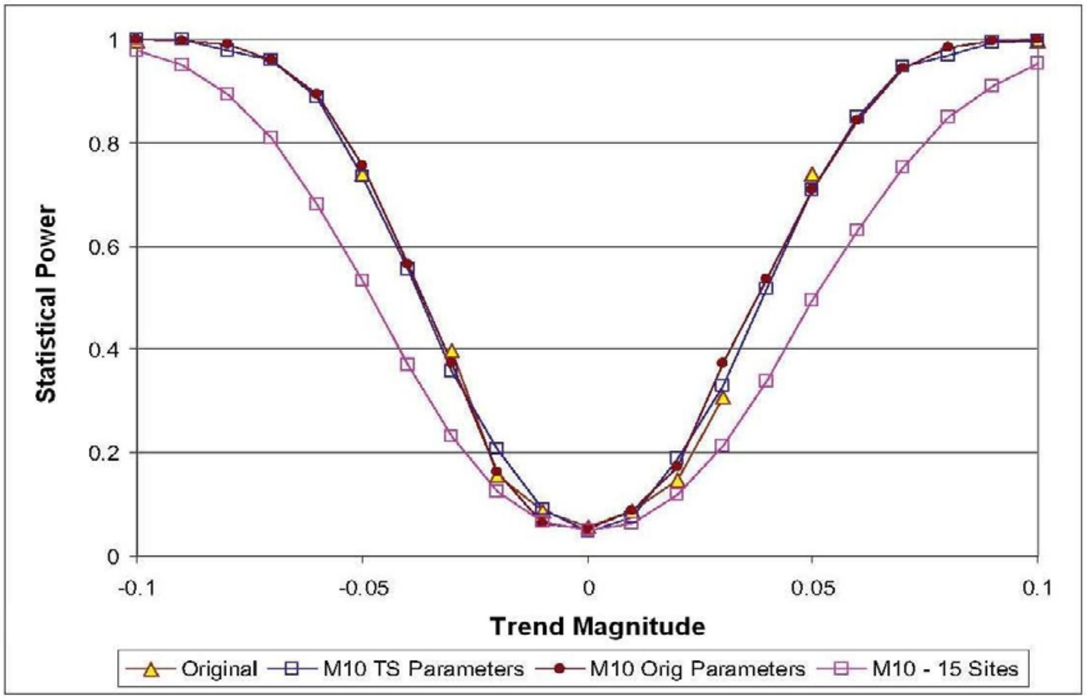


Figure 21. Statistical power comparison for barnacles. See captions for figures 18 and 20.

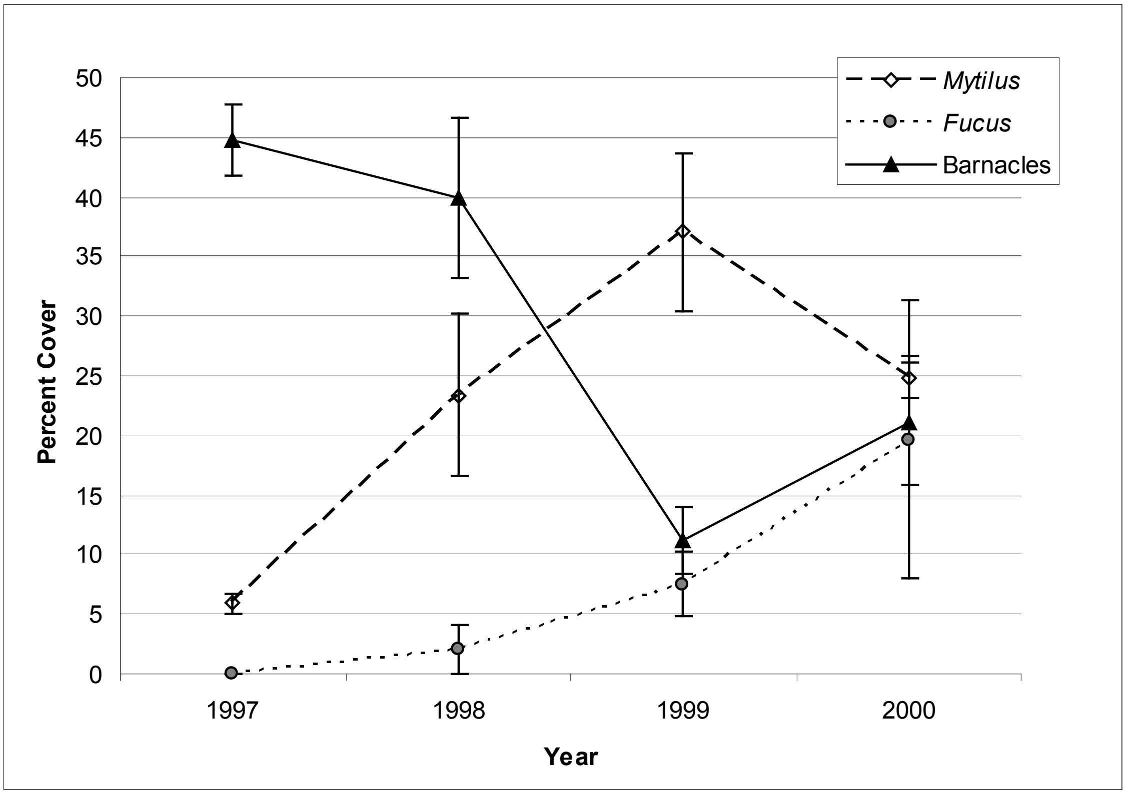


Figure 22. Mean percent cover of the predominant sessile species at Berg Bay. Data were collected in 1997–2000, from the sampling of six transects at 1 point/meter. Error bars represent ±1 standard error.

Table 1. Parameters used in the power analyses.

Parameter Categories	Parameter Options
Species	
Sessile dominants	*Mytilus*, *Fucus*, all barnacles
Sampling Attributes	
Sampling design	Coarse-grained (25 sites; multiyear sampling; 6 vertical transects/site; 1–5 points/m) Fine-grained (6 sites; 1997 only; multiple methods, including 10 vertical transects/site, 5 points/m)
Sampling method (fine-grained)	Vertical transects (10/site) Horizontal transects (30/site) Quadrats (30/site)
Number of sites	Coarse grained (25-site pool) Fine grained (6-site pool)
Number of transects	6 max. for Coarse-grained sampling 10 max. for Fine-grained sampling
Number of points per meter	1–5 points/m for coarse- and fine-grained sampling
Management Parameters	
Alpha level	0.05, 0.10, 0.20
Level of annual change to detect	10 percent, 5 percent, 3 percent

Table 2. The number of hits (counts) of a species or taxon during each year of sampling along the vertical transects.

[Data are from the 1998–2001 coarse-grained sampling of 25 sites, with 6 vertical transects/site sampled at 5 points/m intensity. The total number of hits can be greater than the total number of points sampled because layers of biota are recorded during the point-intercept sampling]

Taxonomic Groupings/Species	1998	1999	2001	Grand Total
PLANTS				
Bacillariophyta (Diatoms)				
Diatom	68	159	25	252
Chlorophyta (Green algae)				
Acrosiphonia spp.	103	70	152	325
Enteromorpha intestinalis	73	44	38	155
Prasiola meridionalis	10		1	11
Small filamentous green alga	40	112	149	301
Ulothrix spp.	14			14
Ulvales	573	894	1,341	2,808
Phaeophyta (Brown algae)				
Agarum clathratum			1	1
Alaria fistulosa	1			1
Alaria marginata	45	121	117	283
Alaria spp.	195		5	200
Cymathere triplicata	1			1
Desmarestia spp.		2	2	4
Fine filamentous brown algae	116	16	22	154
Fucus distichus subspecies *evanescens*	6,140	7,222	6,411	19,773
Laminaria saccharina		1		1
Leathesia difformis		2		2
Petalonia fascia	4	6	12	22
Scytosiphon/*Melanosiphon* spp.	7	8	2	17
Small foliose brown alga	6			6
Soranthera ulvoidea	9	20	15	44
Thick brown algal crust			4	4
Rhodophyta (Red algae)				
Cryptosyphonia woodii	17	22		39
Encrusting coralline algae	8	1	3	12
Endocladia muricata	8			8
Gigartinaceae	123	129		252
Gloiopeltis furcata	1			1
Halosaccion americanum	38	28	61	127
Mastocarpus papillatus	17	82	202	301
Neorhodamela/*Odonthalia* spp.	148	193	317	658
Palmaria callophylloides	135	201	406	742
Palmaria spp.	223	337	231	791
Polysiphonia/*Pterosiphonia* spp.	249	144	50	443
Porphyra spp.	72	56	50	178
Red algal crust- fleshy	3	7	2	12

Small filamentous red alga	1	7	4	12
Small foliose red alga			1	1
Angiospermae (Flowering plants)				
Elymus arenarius (beachgrass)	7		6	13
Lichen				
Verrucaria spp.	34	34	90	158
ANIMALS				
Porifera (Sponges)				
Halichondria spp.			1	1
Haliclona permollis	1			1
Cnidaria/ Anthozoa : Sea anemones				
Epiactis spp.	1			1
Urticina crassicornis	3		1	4
Nemertea (Nemertean worms)				
Amphiporus spp.	2	3	1	6
Emplectonema gracile		1	6	7
Paranemertes peregrina	2		1	3
Annelida / Polychaeta (Polychaete worms)				
Tube worm	17	1		18
Mollusca / Polyplacophora (Chitons)				
Katharina tunicata			3	3
Tonicella spp.	1			1
Mollusca / Gastropoda : Limpets				
Acmaea mitra	1			1
Lottia pelta	2		3	5
Lottidae <8mm	28	81	40	149
Tectura fenestrata	2			2
Tectura persona	70	16	79	165
Tectura scutum	38	12	4	54
Mollusca / Gastropoda: Snails				
Buccinum sp.	1			1
Lacuna spp.	19			19
Littorina scutulata	14			14
Littorina sitkana	733	656	463	1,852
Littorina spp.	121			121
Margarites sp.	1			1
Nucella canaliculata			2	2
Nucella egg case	2			2
Nucella lima	27	46	27	100
Nucella spp.	24		1	25
Searlesia dira		1		1
Snail, unidentified	4			4
Mollusca / Gastropoda - Other				
Archidoris/Anisodoris spp.			1	1
Nudibranch, unidentified	1			1
Siphonaria thersites	4			4
Mollusca / Bivalvia				
Hiatella arctica	8	1	2	11

Mytilus trossulus	6,244	4,519	4,140	14,903
Arthropoda / Crustacea: Barnacles				
Balanus glandula/Semibalanus balanoides	3,274	2,281	4,546	10,101
Balanomorpha	1,407	1	1,475	2,883
Barmacle spat/recruits <2mm	1,276	29	1,420	2,725
Chthamalus dalli	1			1
Semibalanus cariosus	71	132	134	337
Arthropoda / Crustacea: Isopods				
Isopoda	2	2		4
Arthropoda / Crustacea : Decapods (Crabs)				
Hemigrapsus spp.			1	1
Paguridae (hermit crabs)	6	3		9
Echinodermata / Asteroidea (Sea stars)				
Evasterias troschelli	4			4
Leptasterias epichlora	3		2	5
Echinodermata / Echinoidea (Sea urchins)				
Strongylocentrotus droebachiensis	24		2	26
Echinodermata / Holothuroidea (Sea cucumbers)				
Sea cucumber, unidentified	19			19
Urochordata / Ascidiacea (Tunicates)				
Tunicate, solitary	11			11
Total Number of Hits	**21,958**	**17,703**	**22,075**	**61,736**
Total Number of Points Sampled	**23,614**	**20,830**	**20,516**	**64,960**

Table 3. Trend results by site for percent cover of *Mytilus*.

[A linear regression was fit to log-transformed density data for each site to test for exponential trends. The trends are represented by the slopes. Significant negative (-) and positive (+) trends are indicated in the right-most column. Greater detail is in appendix B]

Site No.	Site Name	Slope	*p*-value	Trend
36	Bear Track	0.126	0.472	
69	Berg Bay	0.288	0.023	+
63	Between Pt Carolus & Ripple Cove	-0.385	0.109	
113	Blue Mouse Cove	0.076	0.273	
217	Drake Island - Lower	-0.107	0.111	
216	Drake Island - Mid	-0.434	0.001	–
218	Drake Island - Upper	-0.200	0.089	
89	Geikie Inlet - Lower	0.036	0.747	
88	Geikie Inlet - Upper	0.154	0.150	
59	Lester Island	-0.218	0.209	
215	Little Sturgess Island	-0.059	0.803	
143	Mt Abdallah Outwash	-0.112	0.242	
12	Muir Inlet - Lower	0.405	0.002	+
2	Muir Inlet - Upper	0.813	0.000	+
62	Pt Carolus	-0.167	0.100	
151	Rendu Inlet	0.102	0.763	
200	Russel Island	-0.471	0.010	–
108	Scidmore Bay	-0.024	0.886	
220	Shag Cove	-0.135	0.212	
214	Sturgess Island	-0.224	0.177	
142	Tarr Inlet	-0.014	0.867	
164	Tidal Inlet - Lower	-0.071	0.576	
163	Tidal Inlet - Upper	-0.389	0.004	–
223	Willoughby Island - East	-0.282	0.029	–
224	Willoughby Island - West	-0.692	0.001	–

Table 4. Trend results by site for percent cover of *Fucus*.

[A linear regression was fit to log-transformed density data for each site to test for exponential trends. The trends are represented by the slopes. Significant negative (-) and positive (+) trends are indicated in the right-most column. Greater detail is in appendix B]

Site No.	Site	Slope	p-value	Trend
36	Bear Track	-0.611	0.055	
69	Berg Bay	1.17	0.000	+
63	Between Pt Carolus & Ripple Cove	0.641	0.111	
113	Blue Mouse Cove	0.068	0.908	
217	Drake Island - Lower	-1.01	0.002	–
216	Drake Island - Mid	0.411	0.047	+
218	Drake Island - Upper	0.157	0.339	
89	Geikie Inlet - Lower	0.818	0.001	+
88	Geikie Inlet - Upper	0.555	0.015	+
59	Lester Island	0.444	0.211	
215	Little Sturgess Island	0.410	0.407	
143	Mt Abdallah Outwash	-0.120	0.564	
12	Muir Inlet - Lower	0.152	0.652	
2	Muir Inlet - Upper	0.253	0.451	
62	Pt Carolus	0.317	0.097	
151	Rendu Inlet	0.310	0.471	
200	Russel Island	-1.212	0.006	-
108	Scidmore Bay	0.103	0.743	
220	Shag Cove	0.107	0.660	
214	Sturgess Island	0.217	0.510	
142	Tarr Inlet	-0.352	0.267	
164	Tidal Inlet - Lower	0.421	0.055	
163	Tidal Inlet - Upper	-0.653	0.088	
223	Willoughby Island - East	-0.149	0.655	
224	Willoughby Island - West	0.665	0.064	

Table 5. Trend results by site for percent cover of barnacles.

[A linear regression was fit to log-transformed density data for each site to test for exponential trends. The trends are represented by the slopes. Significant negative (-) and positive (+) trends are indicated in the right-most column. Greater detail is in appendix B]

Site No.	Site	Slope	*p*-value	Trend
36	Bear Track	-0.011	0.974	
69	Berg Bay	0.071	0.771	
63	Between Pt Carolus & Ripple Cove	0.116	0.713	
113	Blue Mouse Cove	0.449	0.019	+
217	Drake Island - Lower	0.002	0.989	
216	Drake Island - Mid	0.097	0.557	
218	Drake Island - Upper	0.093	0.676	
89	Geikie Inlet - Lower	-0.014	0.887	
88	Geikie Inlet - Upper	0.279	0.333	
59	Lester Island	0.570	0.057	
215	Little Sturgess Island	0.437	0.026	+
143	Mt Abdallah Outwash	0.373	0.004	+
12	Muir Inlet - Lower	-0.169	0.076	
2	Muir Inlet - Upper	0.494	0.018	+
62	Pt Carolus	-0.039	0.899	
151	Rendu Inlet	0.462	0.092	
200	Russel Island	0.426	0.013	+
108	Scidmore Bay	0.468	0.083	
220	Shag Cove	0.044	0.668	
214	Sturgess Island	0.007	0.979	
142	Tarr Inlet	0.363	0.259	
164	Tidal Inlet - Lower	0.008	0.962	
163	Tidal Inlet - Upper	0.049	0.795	
223	Willoughby Island - East	0.470	0.006	+
224	Willoughby Island - West	0.350	0.022	+

Table 6. Conversion of short-term trends, expressed as percent change per year, into long-term trends.

[The latter is the total percent change expected over periods ranging from 5 to 20 years, if the annual trend occurs during each of the 5, 10, 15, or 20 years. In effect, this is like compounding interest, and is calculated easily, for example, -3 percent over 15 yrs = $(0.97)^{15}$ = 0.6333, or 100 percent - 36.67 percent]

Trend per year	Short-term versus long-term trends		
	-5 percent	-3 percent	-2 percent
Trend over 5 years	-22.62 percent	-14.13 percent	-9.61 percent
Trend over 10 years	-40.13 percent	-26.26 percent	-18.29 percent
Trend over 15 years	-53.67 percent	-36.67 percent	-26.14 percent
Trend over 20 years	-64.15 percent	-45.62 percent	-33.24 percent