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Development of a Monitoring Protocol to Detect Ecological Change in the Intertidal Zone of Sitka National Historical Park, Alaska

Scientific Investigations Report 2008–5139

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

Cover: Photograph of intertidal sampling along a transect at Sitka National Historical Park, Alaska, looking down a transect with Geoffrey Smith, the park biologist, sampling and Kristi Link recording. Kayakers and a cruise ship are in the background. Photograph taken by Gail V. Irvine, U.S. Geological Survey, July 31, 2003.

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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)

Development of a Monitoring Protocol to Detect Ecological Change in the Intertidal Zone of Sitka National Historical Park, Alaska

By Gail V. Irvine and Erica N. Madison

Abstract

A pilot study to develop and test a probability-based intertidal monitoring protocol for Sitka National Historical Park was conducted from 1999 to 2003. In 1999, the basic design, with a focus on sampling the whole of the designated intertidal was created, and sampling was conducted for sessile species and large mobile invertebrates by point-intercept sampling of vertical transects and band surveys along transects, respectively. In 2002 and 2003, the same types of sampling were conducted, but quadrat sampling for small mobile invertebrates was added and then modified. This project has produced basic data on the presence, abundance, and spatial distribution of substrates and intertidal biota. Additionally, statistical power analyses conducted on the biological data have allowed assessment of the ability of the sampling to detect trends in the abundance of the predominant species. Current sampling has an 80 percent probability to detect +10 percent annual changes in abundance of all targeted species with an $\alpha = 0.05$; the ability to detect –10 percent trends is not as uniformly high. Various options are discussed for decreasing the spatial variance of the data. The information presented provides a basis for discussion of the major questions being asked, how the sampling design might be reconfigured to be consistent in approach, and how the intertidal monitoring should interface with other potential intertidal monitoring.

Introduction

Sitka National Historical Park (NHP) is a small park in southeast Alaska created in 1910 to commemorate the Battle of Sitka between the Russians and the native Tlingits. The park is situated in Sitka Sound on the western outer shore of Baranof Island and contains 50.5 ha, including historical parklands adjoining a 1-km coastline (fig. 1). The park leases and manages 6,497 m^2 of tidelands from the City and Borough of Sitka and 4,451 m^2 from the State of Alaska. The City of Sitka issued a 55-year lease in March 1972, and the State of Alaska issued a 55-year lease in March 1973. These long-term leases aid in protection of the park's natural and cultural resources (Eckert and others, 2006).

In 1998, the National Park Service (NPS) asked the U.S. Geological Survey (USGS) to develop a protocol to monitor changes in the intertidal communities that occupy the tidelands. The USGS devised a probability-based sampling design and conducted field studies in 1999, 2002, and 2003 to test methods of monitoring. This report presents results of the pilot study and includes (1) initial findings on the beach (fig. 2) and its biota, (2) details on the probability-based sampling design, and (3) analysis and discussion of design options for the long-term monitoring protocol.

Marine intertidal areas often are populated by highly productive biological communities with strong links to marine and terrestrial ecosystems. As has been demonstrated by the *Exxon Valdez* oil spill, the intertidal zone is vulnerable to anthropogenic effects; additional anthropogenic vectors of change to the intertidal zone could include other types of discharges and pollution, trampling, harvests, invasive species, and climate change. Although Sitka NHP (fig. 1) has a short marine coastline, about 1 km in length, the threats to this coastline are readily apparent. Cruise ships and other vessels that commonly are anchored or plying the waters directly off the rocky Sitka coasts could hit submerged rocks or the coast if navigational or mechanical mishaps occurred.

The protection and management of intertidal environments, such as that at Sitka NHP, depend on being able to detect ecological changes and to understand the causes of such changes. The data obtained through well-designed monitoring of the intertidal zone will increase the knowledge of the biological communities and the patterns of their change, thus providing a base of information that can be used for impact assessment as well as for more general resource-management needs. When patterns of natural variability are understood, recognizing and managing changes caused by humans may become possible.

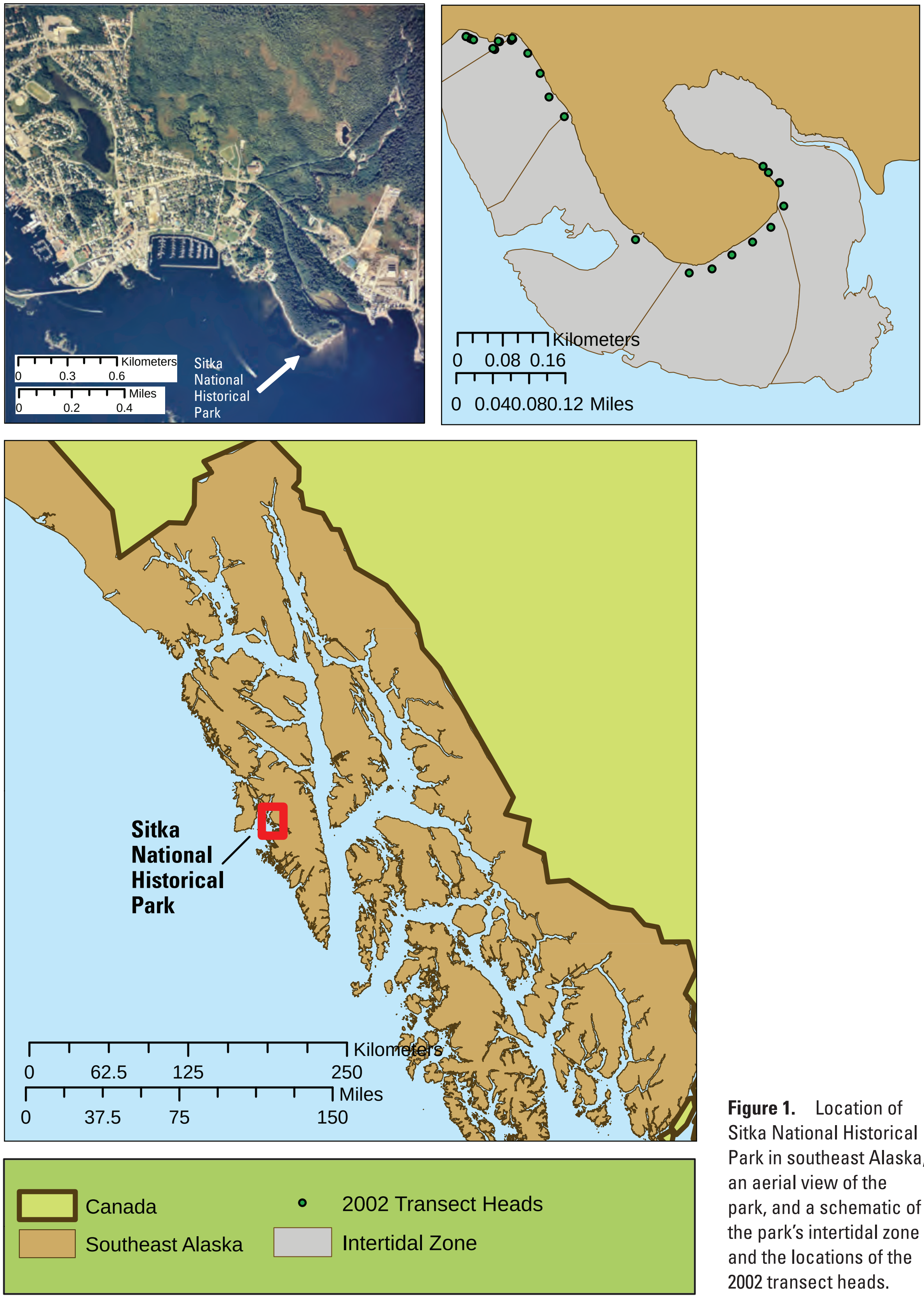

Figure 1. Location of Sitka National Historical Park in southeast Alaska, an aerial view of the park, and a schematic of the park's intertidal zone and the locations of the 2002 transect heads.

Figure 2. Sitka National Historical Park beach, Alaska.

A. Sitka National Historical Park beach at high tide.

B. Intertidal zone of Sitka National Historical Park beach exposed when the tide is out. Arrows indicate the two large pool areas where previous excavations for gravel occurred.

Sitka NHP occupies an important location, both biogeographically and as a bellwether of influences that may arise farther upstream (south) along the Alaska Coastal Current, which traverses the shores of Alaska in a counterclockwise direction (fig. 3). As the most upstream of a string of eight coastal national park units that border the Gulf of Alaska, Sitka NHP could provide important information about the responsiveness of biological communities to change, particularly directional change. For example, planktonic larval forms of invasive species being transported north from introductions along the west coast of the United States and Canada are likely to settle first, in terms of national parks, in Sitka. The Sitka area also has high biological diversity and has been recognized as a place where two biogeographical provinces intersect. As such, the Sitka area is the northernmost limit of many marine species (Ricketts and Calvin, 1962; Dr. Sandra Lindstrom, University of British Columbia, oral commun., 2003). In climate change scenarios that predict increasing sea temperatures, Sitka could be the first of the Alaska national parks to experience range extensions of species from farther south, although shifts in biogeographical boundaries within the State could be complex.

The ability to detect such biogeographic and directional changes is dependent on biological information. Prior marine biological data from Sitka NHP are sparse. In 1997, Amy Fish (National Park Service, oral commun., 1997) collected intertidal algae and vascular plants. The algae she collected were identified by Dr. Sandra Lindstrom and now are part of the park's herbarium collection. From a broad perspective, the nearest intertidal monitoring has occurred at Glacier Bay National Park and Preserve (NPP) to the north of Sitka NHP (Irvine, 1998, 2002) and at a national park in British Columbia to the south. A broad-scale, west coast biogeographical study (Partnership for Interdisciplinary Studies of Coastal Oceans) with sites extending into Alaska also may contribute important information on shifts in species distributions (P. Raimondi, University of California, Santa Cruz, oral commun., 2007).

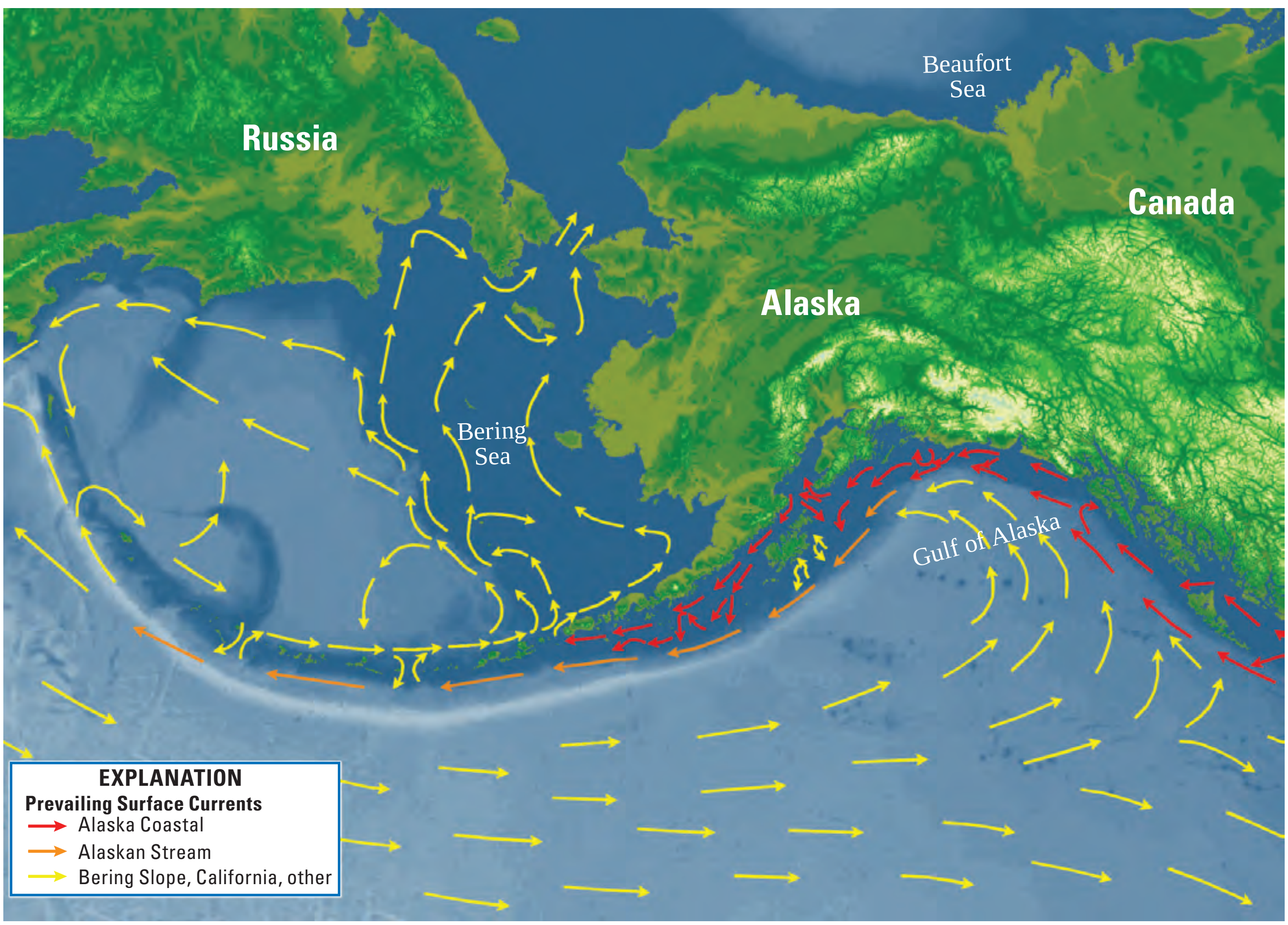

Image adapted from Phyllis Stabeno, National Oceanic and Atmospheric Administration, Pacific Marine Environmental Laboratory

Figure 3. Major current systems in the northeast Pacific. The Alaska Coastal Current hugs the coastline from British Columbia to the area where the Gulf of Alaska meets the Bering Sea.

Following the *Exxon Valdez* oil spill of 1989, the Alaska Region of the NPS made a commitment to develop coastal inventories and monitoring for those park units with marine coastlines. Currently (2007), the NPS national inventory and monitoring program is being designed and implemented through park networks. The Southeast Alaska Network (SEAN) recently identified intertidal monitoring at Sitka NHP as one of its vital signs for long-term monitoring. The sampling plan being developed for Sitka NHP could interface and become integrated with regional (SEAN), statewide, and national NPS inventory and monitoring programs.

In this report, results and analyses are presented for 3 years of intertidal sampling data, and discussions are presented on how the results and the questions being asked can affect the sampling design for long-term intertidal monitoring at Sitka NHP with the goal of detecting ecological change. The pilot study objectives are as follows:

- Develop a probability-based sampling design and protocols that allow detection of change in predominant members of the intertidal biological community (levels of temporal change and the confidence level for detecting change to be defined in consultation with the NPS).
- Estimate the spatial and temporal patterns in abundance of select species or groups of species inhabiting the intertidal zone.
- Determine whether any modifications are needed to the sampling design developed during this testing phase.

Methods

Study Design

The purpose of this study was to develop a probability-based sampling design and protocols that would enable robust monitoring of the intertidal biota of Sitka NHP. A probability-based sampling design allows the results of the discrete sampling to be extrapolated to the entire defined intertidal region of the park (the sampling frame). The particular sampling types were designed to target different elements of the intertidal biota, such as sessile species of plants (primarily algae) and invertebrates, small mobile invertebrates, and select large mobile invertebrates. The general sampling history is presented in this section along with details of the study area, design, and sampling types.

In 1999, staff from the USGS, NPS southeast coastal cluster, and Sitka NHP began the first year of intertidal monitoring protocol development using a modification of the design being tested at Glacier Bay NPP (Irvine, 1998). At Sitka NHP, the entire intertidal zone down to the 0-m (0-ft) tide level (minus tide pool areas previously excavated) was defined as the sampling frame. In contrast, the sampling frame at Glacier Bay NPP consisted of a defined habitat type within Glacier Bay proper, which was sampled at 25 randomly selected sites.

The intent at Sitka NHP was to obtain 3 years of data to analyze the effectiveness (power) of the sampling design to detect change in the abundance of intertidal species. Therefore, the intertidal was resampled in both 2002 and 2003 by USGS and NPS staff. Many of the observers and volunteers varied from year to year. In 2003, Dr. Sandra Lindstrom, an algal expert with the University of British Columbia, also participated in the sampling and collected and identified algae. Some aspects of the sampling techniques and layout were modified with time as described later.

All sampling of the intertidal zone was conducted during July and August (August 26–28, 1999; July 11–13, 2002; and July 28–August 1, 2003). The greatest species richness most likely occurs in the spring and early summer (Dr. Sandra Lindstrom, University of British Columbia, oral commun., 2003). The decisions to sample later in the year during this pilot study were driven primarily by competing schedules for other field projects.

Sampling Frame

The sampling frame was defined as the intertidal region extending from the western side of Sitka NHP to the Indian River and encompassing the area from the mean high high-water (MHHW) level to the 0-m tide level. The horizontal length of the beach at the MHHW level, measured in 1999 as about 1 km, defines the "horizontal segment line," which is the upper border of the sampling frame. The horizontal length included extents of beach that could not be sampled because of the presence of large depressions (pools on a low tide) in the intertidal zone that were the result of historic excavations for gravel (Eckert and others, 2006, citing Antonson and Hanable, 1987; figs. 1 and 2). Thus, although the horizontal segment line borders sections of unsampled beach, the sampling frame excludes those areas (the excavated areas and the sections of beach above and below the excavated areas).

In 2002, because of staff turnover at the park and consequent difficulty locating supporting documentation, the western boundary of the beach was reset. The point at which the western boundary intersects with the location of the MHHW level, or horizontal segment line, is called the "origin." That point is pivotal to the layout of the sampling frame. In 2002, some of the 1999 documentation was located after sampling had begun, and the newly established beach origin was judged to be about 7 to 9 m to the east of the 1999 origin. This new origin was used to demarcate the sampling frame in both 2002 and 2003.

The MHHW level is determined biologically and occurs at the bottom edge of the *Verrucaria* (black lichen) zone, defined as approximately 20 percent cover of *Verrucaria* and usually close to the juncture of the *Verrucaria* and barnacle zones. *Verrucaria* can be difficult to detect on small substrates as are common at Sitka NHP. On some sections of the beach, the beach wrack or beach grass was used as an indicator of the highest tide levels. The bottom border of the sampling frame, the 0-m tide level of the beach, was determined by the water level at times indicated in the software program, Tides and Currents (Nautical Software, Inc., 1993–1997). For the Sitka Sound tide station, the average tidal range is 2.35 m (7.7 ft) and the MHHW level is +3.0 m (+9.9 ft) (Tides and Currents software, 2002 tide dates; Nautical Software, Inc., 1993-1997).

Because of the low angle of most of the beach (usually a 1- to 2-degree slope), a broad extent of the beach is exposed at low tide. This has led to long transects (as much as 329 m in length; range 45 to 329 m) that extend from the MHHW level to the 0-m tide level on those parts of the beach with a gentle slope.

Random Selection of Transects

In each year of sampling, 15 transects (sample units) were systematically placed perpendicular to the shoreline, with a different random start each year (table 1). Transects were laid along the elevational gradient from the MHHW level to the 0-m tide level (‘vertical’). The distance between heads (beginnings) of transect lines along the horizontal segment line was determined in 1999 by dividing the length of the parts of the beach that could be sampled by 15, which yielded 43-m increments of beach that could be sampled. The random starting points were selected within the first 43 m.

Sampling Within Transects

Three sampling methods were conducted along transects to assess the abundance of different groups or types of species: point-intercept sampling for sessile species, band surveys for large mobile invertebrates, and quadrat sampling for small mobile invertebrates and barnacle recruits (spat) (fig. 4). A systematic sample with a random start was used to select subsample units. Point-intercept sampling and band survey sampling were conducted similarly in all 3 years, but quadrat sampling was not initiated until 2002 and was modified in 2003 (the number of quadrats was doubled from three to six per transect).

Sessile Species

Sessile species of invertebrates and plants were sampled by point-intercept sampling along transects (fig. 4). Transect lines (surveying tapes) were draped along the substrate as the lines were laid out, allowing for better assessment of cover on heterogeneous substrates. A systematic set of points was sampled at 1-point per meter (pt/m) intervals to provide estimates of the relative percent cover of biota along transects as well as the relative percent cover of underlying substrates. The choice was made to sample at 1-pt/m intervals because of the great length of many transects. The percent cover of a species was estimated by the total number of “hits” of a species counted along a transect divided by the number of points sampled. This type of sampling also provided information on spatial distribution, including zonation of species.

Table 1. Transect head location, relative to the segment line origin, and transect length for each year sampled, Sitka National Historical Park monitoring site, Alaska.

[These values vary from year to year because new random numbers were used to generate the location of the first transect. The other 14 transects were set systematic distances (43 meters of segment length that could be sampled) apart]

Transect No.	1999		2002		2003	
	Distance from origin (meter)	Transect length (meter)	Distance from origin (meter)	Transect length (meter)	Distance from origin (meter)	Transect length (meter)
1	17	111	0	106.8	15	120.6
2	60	136	43	146	58	136
3	103	174	86	185.6	101	191
4	146	188	129	184.3	144	178.6
5	189	202	172	198	187	192.4
6	232	194	215	194	230	196.3
7	275	184	258	210	273	209.8
8	318	190	301	231.1	530	226.85
9	644	193	344	193.2	644	204.5
10	687	227	387	237.4	687	212
11	730	218	430	222.2	730	214.6
12	773	167	473	169	773	185.6
13	816	329	516	175	816	319
14	859	160	559	144.1	859	133.1
15	902	68	602	44.61	902	68.05

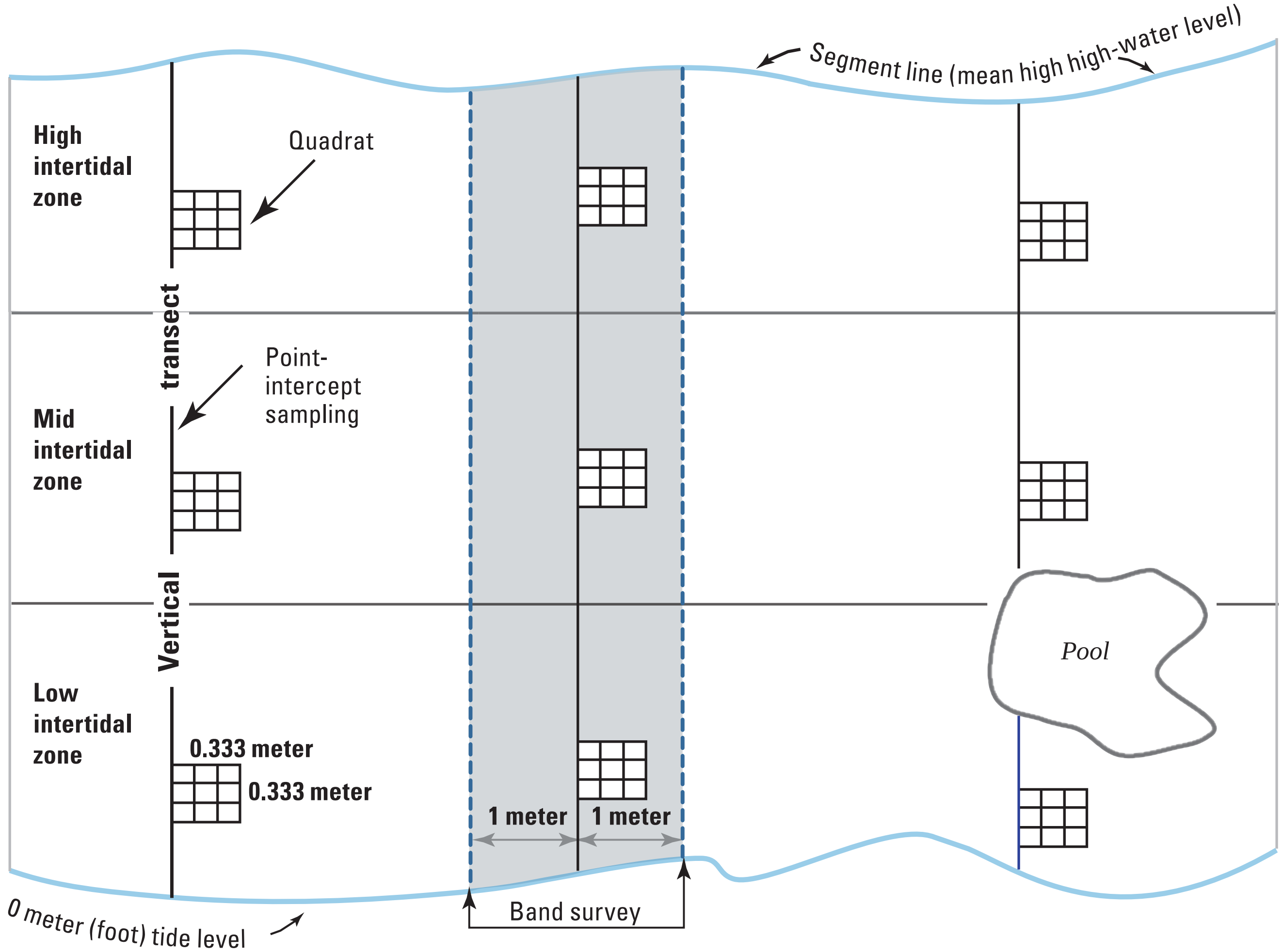

Figure 4. Layout of the various sampling types used at the Sitka National Historical Park monitoring site, Alaska. The three types of sampling (point-intercept, band surveys, and quadrats) were conducted along each transect.

Points were sampled three-dimensionally (3-D), noting the species and substrate under each point. The right edge of the tape and the distance hash marks along the tape were used as cross hairs to mark the point. Knitting needles were used to facilitate the 3-D sampling of the naturally heterogeneous topography. The knitting needles were used to follow the points perpendicularly from the tape to the substrate. All species underlying a point were recorded in order from the top down, including multiple “hits” or layers of the same species. The first substrate encountered also was recorded. Organisms were identified to the lowest taxonomic level possible in field sampling. Some taxa (for example, the barnacles *Semibalanus balanoides* and *Balanus glandula*) were grouped because they could not be discriminated in the field readily. Substrates were classified according to a modified Wentworth scale (table 2).

Table 2. Substrate categories used in sampling.

[Modified from Wentworth scale (Wentworth, 1922) mm, millimeter; >, greater than]

Substrate	Wentworth size	Description
Bedrock	Continuous rock surface	Not available
Boulder	>256 mm diameter	Head size or larger
Cobble	64–256 mm diameter	Billiard ball size to head size
Pebble	4–64 mm diameter	Pea size to billiard ball size
Gravel	2–4 mm diameter	BB size to pea size
Sand	1/16–2 mm diameter	Just gritty in fingers to pin head size
Mud/silt	Not available	Floury coating, not gritty, similar to clay
Shell	Not available	Whole shell or identifiable fragments

Large Mobile Invertebrates

Large mobile invertebrates were sampled visually by band surveys within a 1-m area to each side of the transect (fig. 4). This 2-m wide area was scanned for selected large mobile invertebrates, including starfish, sea urchins, and large chitons. Notations also were made of other large mobile invertebrates in the sampling area, including large crabs; crabs are highly mobile and are more likely to be affected by human activity than the other large mobile invertebrate species targeted in the sampling. The number and location of targeted species along a transect were recorded. Large mobile invertebrates were sampled in this manner because they are less likely to be well sampled by point or small quadrat sampling because of their relative rarity and mobility.

Small Mobile Invertebrates and Barnacle Recruits (Spat)

Numbers of small mobile invertebrates and barnacle recruits (spat) were counted within quadrats set systematically, with a random start, along each transect (figs. 5 and 6). All species except barnacle spat and littorine snails were sampled in a quadrat 33.33 cm on a side (area 1/9 m^2). Barnacle spat were sampled in a 5 × 5 cm (0.0025 m^2) subunit of the quadrat, and littorine snails were sampled in a 10 × 10 cm (0.01 m^2) subunit (fig. 6). Quadrat sampling was not initiated until 2002 when three quadrats were placed systematically, with a single random start, along each transect. Each transect was divided into three equal-sized segments, the low, mid, and high zones, then the length of the segments was multiplied by a random number (for example, 0.71) to determine the placement of the

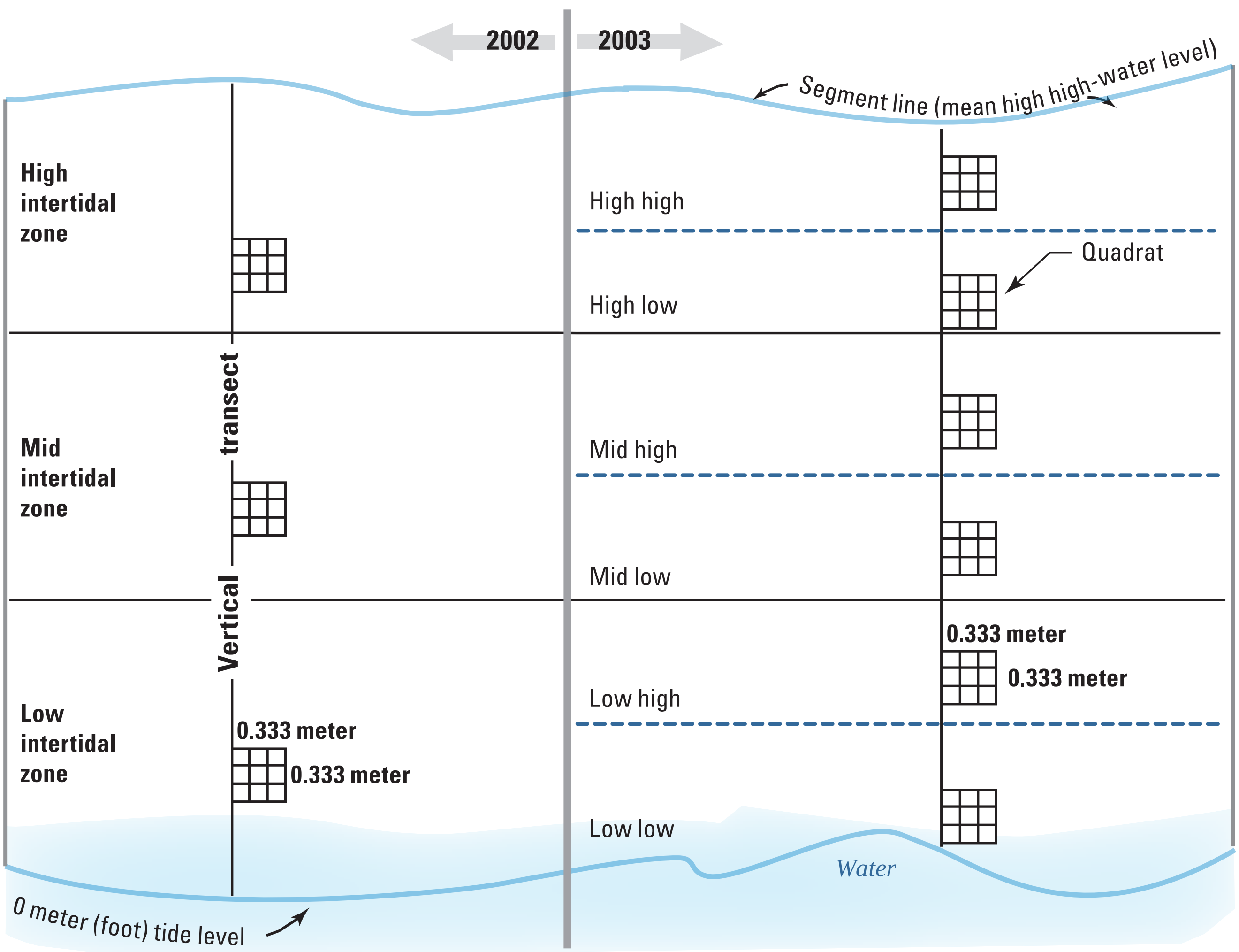

Figure 5. Different layouts of quadrat sampling used at the Sitka National Historical Park monitoring site, Alaska, 2002–03. The number of quadrats sampled per transect increased from three in 2002 to six in 2003. In 2002, transects were divided into three sections (the high, mid, and low intertidal zones). In 2003, transects were divided into six sections, with two sections encompassing each of the 2002 zones.

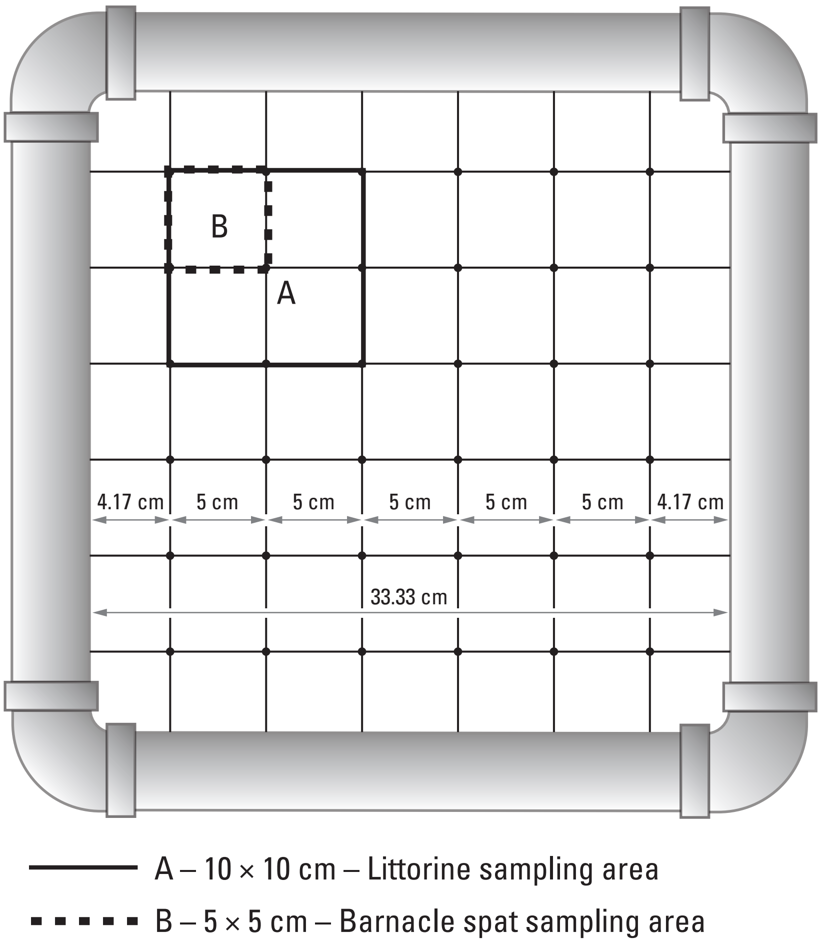

Figure 6. Example of a quadrat used for small mobile invertebrate and barnacle recruit sampling at the Sitka National Historical Park monitoring site, Alaska, 2002–03. Littorine snails and barnacle recruits were subsampled in the indicated areas.

quadrat within the low zone. The quadrats within the other two zones then were placed systematically with respect to the first quadrat. In 2002, different random numbers were used for each transect to determine quadrat placement. In 2003, the number of quadrats sampled along each transect was doubled, from three to six, because of perceived scale issues; professional judgment was that three quadrats of the size being used were too few to adequately sample the extensive areas defined by the transects, even though sampling was dispersed over high, mid, and low intertidal zones. The increase in the number of quadrats created sampling in what could be considered six zones, but the upper two zones of 2003 encompassed the same area as the 2002 high intertidal zone (fig. 5), the middle two 2003 zones equaled the 2002 mid intertidal zone, and the lower two 2003 zones equaled the 2002 low intertidal zone. The basic method for determining quadrat location was the same as in 2002; however, in 2003, the same random number to determine proportional placement of the quadrat within a zone was used for all transects.

Analytical Considerations and Methods

The types of analyses conducted on the pilot data were (1) trend analyses of existing data and (2) statistical power analyses. Details of the analyses are presented in appendix A. The trend analyses are exploratory because only 2 or 3 years of data were available. The emphasis was on the statistical power analysis of the sampling design.

Estimates of mean percent cover or density were affected by the design and execution of the sampling. The sampling units (for example, transects) differed in length as the width of the intertidal zone varied across the beach (table 1). The number of point samples and the size of sampled area for band surveys were proportional to the length of each transect. For quadrat sampling, equal numbers of samples were collected regardless of the length of transects. Using density as the monitoring measure (transect count per total number of points or transect count per band area) standardized the units across transects. However, this approach did not correct for the fact that each transect contained a different amount of information. That is, longer transects provided more information than shorter transects. The selected analysis method adjusted for this difference (appendix A). Subsampling proportional to size provides self-weighting of the data (Cochran, 1977).

The statistical power analyses focused on how many transects should be sampled each year to detect exponential changes of magnitude 10 percent per year, by 2011. Three different sampling scenarios were tested (annual, biennial, and triennial). Power was estimated only for those species for which approximate normal distributions could be assumed and employed Monte Carlo simulations. Two-tailed tests with $\alpha = 0.5$ and 0.10 were assumed; positive and negative 10 percent exponential trends were evaluated; the added trend began in 2004; the tested number of transects sampled each year was 10, 12, 15, and 18; the existing level of subsampling within transects was assumed; the current mean was estimated as the average of the existing 1999–2003 data (2 or 3 years of data, depending on sampling type). Further details are presented in appendix A.

Geomorphological, Biological, and Statistical Results

Data gathered in the Sitka NHP intertidal zone during field sampling included both geomorphological (for example, substrate types, their abundance and distribution, general observations) and biological information. The geomorphological and biological results are presented in the following sections. Results of the statistical power analyses then are described.

Beach Structure and Physiognomy

The general extent of the beach was described through the definition of the sampling area (MHHW level to 0-m tide level, and length of the horizontal segment line). The lengths of transects sampled each year provided information on the extensiveness of the beach (table 1). Transect lengths were longest on the southeast-facing part of the beach, with the longest transect 329 m in length. The shortest transects occurred on each end of the beach, where the beach tapers (fig. 2).

The two large pools in the beach were not sampled (fig. 2). The pools were a prominent part of the intertidal zone and may have some biological importance, but this has not yet been explored because submerged biota and substrate could not be seen and identified reliably using the current methods.

During the point-intercept sampling along the vertical transects, data were collected on the substrate type underlying each point. These data provided a quantitative assessment of the relative abundance of different substrate types, their distribution across the beach, and the differences in substrates sampled each year (table 3; figs. 7 and 8).

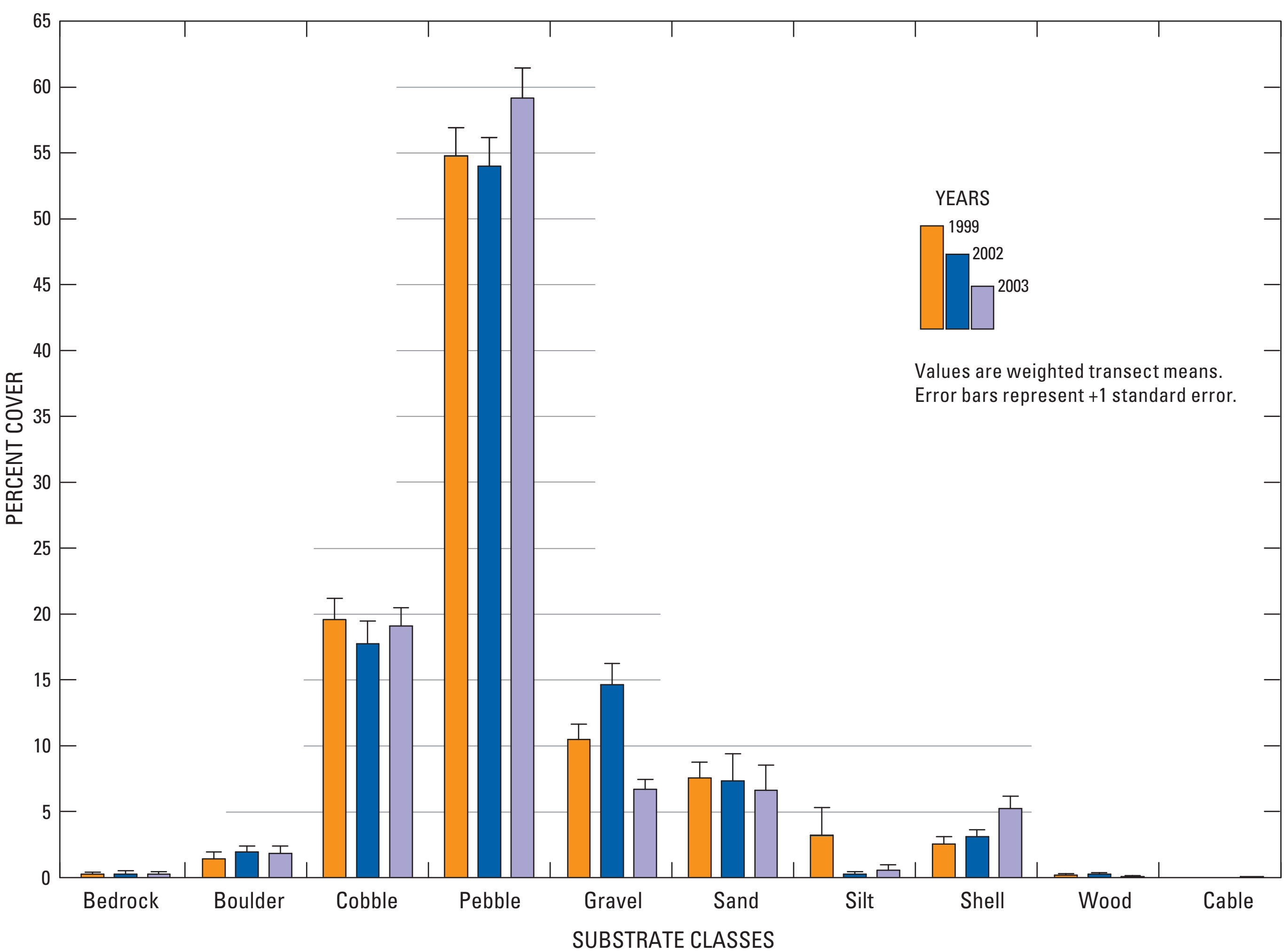

Figure 7. Composite percent cover of beach substrate sampled over the entire Sitka National Historical Park monitoring site, Alaska, 1999 and 2002–03.

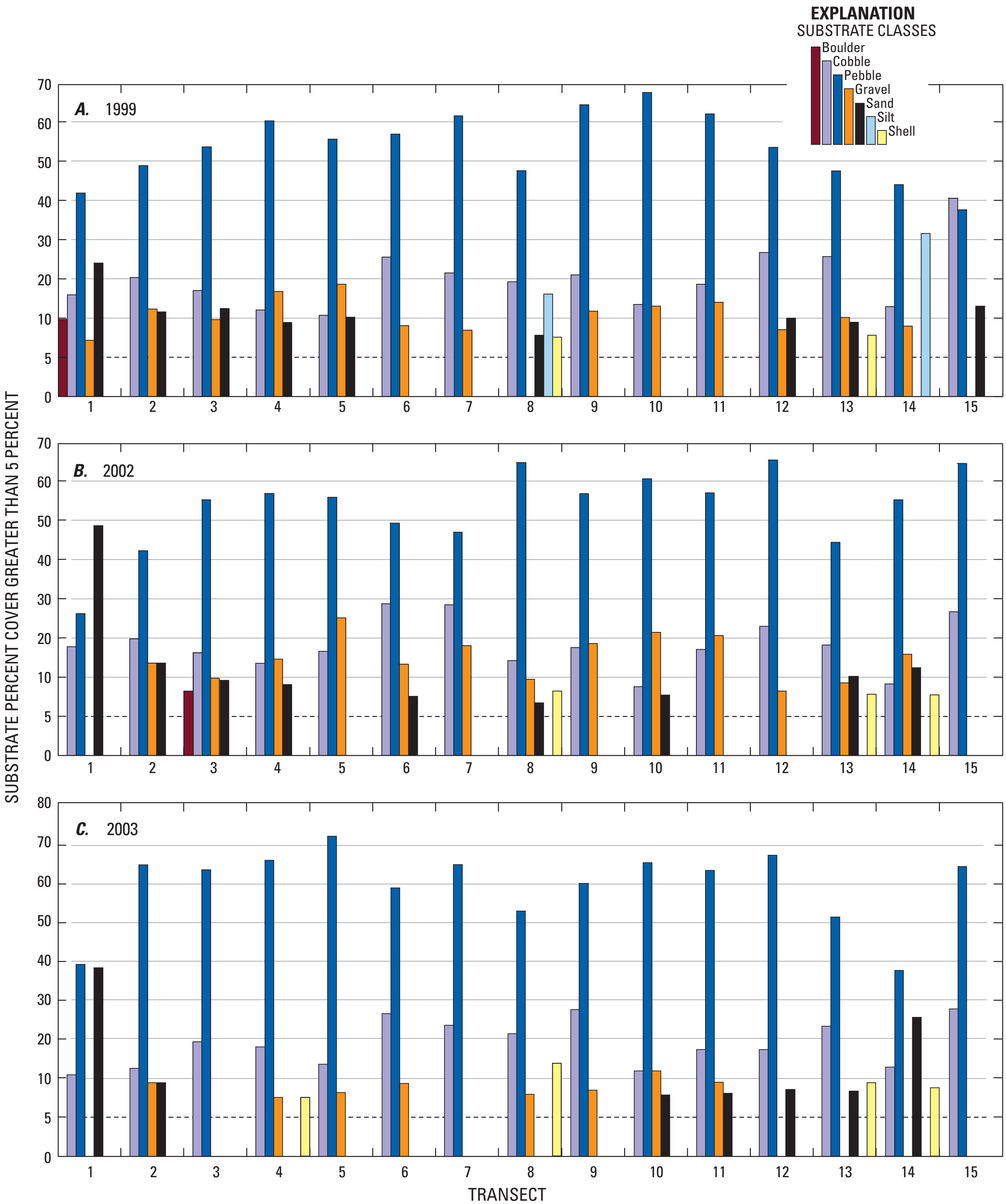

Figure 8. Substrate classes greater than 5 percent for each transect per year, Sitka National Historical Park monitoring site, Alaska, 1999 and 2002–03.

Table 3. Percent cover of substrate classes by transect for each year of sampling.

[Substrates are BR, Bedrock; BO, Boulder; CO, Cobble; PE, Pebble; GR, Gravel; SA, Sand; SI, Silt; SH, Shell; CA, Cable; WO, Wood. Note the general preponderance of pebble substrate]

Transect No.	Substrate class									
	BR	BO	CO	PE	GR	SA	SI	SH	CA	WO
1999										
1	0.89	9.82	16.07	41.96	4.46	24.11	0.00	0.89	0.00	1.79
2	2.19	.73	20.44	48.91	12.41	11.68	.00	3.65	.00	.00
3	1.71	1.71	17.14	53.71	9.71	12.57	.00	3.43	.00	.00
4	.00	.00	12.17	60.32	16.93	8.99	.00	1.59	.00	.00
5	.00	.99	10.84	55.67	18.72	10.34	.00	3.45	.00	.00
6	.00	3.59	25.64	56.92	8.21	4.62	.00	.51	.00	.51
7	.00	3.24	21.62	61.62	7.03	3.78	.54	1.08	.00	1.08
8	.00	2.62	19.37	47.64	3.14	5.76	16.23	5.24	.00	.00
9	.00	.52	21.13	64.43	11.86	1.55	.00	.52	.00	.00
10	.00	.00	13.60	67.54	13.16	4.39	.00	1.32	.00	.00
11	.00	.00	18.72	62.10	14.16	4.11	.00	.91	.00	.00
12	.00	.00	26.79	53.57	7.14	10.12	.00	2.38	.00	.00
13	.00	.00	25.76	47.58	10.30	9.09	1.52	5.76	.00	.00
14	.00	.00	13.04	44.10	8.07	.00	31.68	3.11	.00	.00
15	.00	4.35	40.58	37.68	2.90	13.04	.00	1.45	.00	.00
2002										
1	0.93	3.74	17.76	26.17	2.80	48.60	0.00	0.93	0.00	0.00
2	4.08	4.08	19.73	42.18	13.61	13.61	.00	2.04	.00	.68
3	.00	6.49	16.22	55.14	9.73	9.19	.00	3.78	.00	.00
4	.00	1.62	13.51	56.76	14.59	8.11	.00	3.24	.00	2.16
5	.00	1.01	16.58	55.78	25.13	1.51	.00	.00	.00	.00
6	.00	2.56	28.72	49.23	13.33	5.13	.00	.51	.00	.51
7	.00	3.32	28.44	46.92	18.01	.95	.00	2.37	.00	.00
8	.00	1.72	14.22	64.66	9.48	3.45	.00	6.47	.00	.00
9	.00	.00	17.53	56.70	18.56	4.64	.00	2.58	.00	.00
10	.00	.42	7.56	60.50	21.43	5.46	.00	4.62	.00	.00
11	.00	.45	17.04	56.95	20.63	2.24	.00	2.69	.00	.00
12	.00	.59	22.94	65.29	6.47	2.35	.00	2.35	.00	.00
13	.00	2.27	18.18	44.32	8.52	10.23	1.70	5.68	.00	.00
14	.00	.00	8.28	55.17	15.86	12.41	2.07	5.52	.00	.00
15	.00	2.22	26.67	64.44	4.44	.00	2.22	.00	.00	.00
2003										
1	4.13	4.13	10.74	38.84	1.65	38.02	0.00	2.48	0.00	0.00
2	.73	.73	12.41	64.23	8.76	8.76	.00	4.38	.00	.00
3	.00	3.65	19.27	63.02	4.17	4.69	.00	4.69	.00	.52
4	.56	1.12	17.88	65.36	5.03	4.47	.00	5.03	.00	.00
5	.00	2.07	13.47	71.50	6.22	2.07	.00	4.66	.00	.00
6	.00	3.05	26.40	58.38	8.63	2.03	.00	1.02	.00	.00
7	.00	3.33	23.33	64.29	3.81	1.43	.00	3.81	.00	.00
8	.00	6.61	21.15	52.42	5.73	.44	.00	13.66	.00	.00
9	.00	.49	27.32	59.51	6.83	2.44	.49	1.46	.00	.00
10	.00	.47	11.74	64.79	11.74	5.63	.00	4.69	.00	.00
11	.00	.00	17.21	62.79	8.84	6.05	.00	4.65	.00	.00
12	.00	.54	17.20	66.67	4.30	6.99	.54	3.76	.00	.00
13	.00	.00	23.13	50.94	5.94	6.56	4.06	8.75	.63	.00
14	.00	.75	12.69	37.31	14.18	25.37	.00	7.46	.00	.75
15	.00	.00	27.54	63.77	2.90	.00	.00	1.45	.00	.00

These data also allow investigation of substrate and species relations (although a species lying under a point is not necessarily attached to the substrate directly beneath the point; this can be true for large species with lateral spread [*Fucus*], for species attached to the side of a rock, or for epibionts). The most predominant substrate was pebble, both among years (fig. 7) and on individual transects (either 14 of 15 or 15 of 15 transects each year; fig. 8). On a beach-wide basis, cobbles had the next highest percent cover, then gravel, followed by sand (fig. 7). On a spatial basis, pebbles comprised greater than 40 percent of the substrate on all transects except, in some years, on transect 1 or 15 (fig. 8). Bedrock only occurred at the beginning of the first several transects and was indicative of the bedrock headlands that occurred there. Sand generally was less common on the middle transects and increased towards the periphery of the site (fig. 8). The most compelling conclusion regarding substrate was that this is primarily a pebble beach with an assortment of less abundant substrates present in varying spatial patterns.

Intertidal Biota

Information on the presence and abundance of intertidal biota (both plants and invertebrates) is a product of this study. A taxonomic list of all species sampled is presented in table 4, while species sampled by point-intercept sampling each year are listed in table 5. All seaweed species that have been collected and identified from the Sitka NHP intertidal are listed in table 6. Analyses of trends in species abundance were based on only 2 or 3 years of data and should be considered preliminary.

Sessile Species

The brown algal species, *Fucus distichus* var. *evanescens* (formerly *Fucus gardneri*), also called rockweed or popweed, was consistently the most abundant sessile species in the intertidal of Sitka NHP, with mean percent cover ranging from about 18 to 42 percent (fig. 9). Barnacles were the next most abundant species group, with the *Balanus glandula*/*Semibalanus balanoides* group comprising the largest part of the total barnacle cover (fig. 9). The mussel, *Mytilus trossulus*, normally one of the predominant species on rocky coasts in this area, had a relatively low abundance on this pebble-dominated beach. Other species or species groups that were among the more abundant, but with relatively low abundance compared to *Fucus* and barnacles, included the red algae, *Neorhodamela*/*Odonthalia* spp. and *Mastocarpus papillatus*; the seagrass, *Zostera marina*; halophytes, *Puccinellia nutkaensis* and *Plantago maritima*; the barnacle, *Semibalanus cariosus*; and the total for all algal crusts (fig. 9).

Large Mobile Invertebrates

Although more than 5,000 m^2 of area were assessed by band surveys in each year, the large mobile invertebrates of interest were rare (tables 7 and 8). The most abundant was the starfish, *Pisaster ochraceus*. This was the only species for which it was possible to do a preliminary trend analysis at this time (appendix A). Results for the preliminary analysis indicated that, although a significant positive trend occurred in the presence of *P. ochraceus*, based on logistic regression, no significant trend occurred in positive densities (conditional normal regression; appendix A, table A2).

The low densities of many of the large mobile invertebrates were not necessarily unexpected because most were more common in the low intertidal and the band surveys were conducted along the vertical transects. When the data were examined from the perspective of location relative to the proportion of transect length from low to high (for example, lowest 10 percent of transect length), the preponderance of detections in the low elevations became clear and was especially marked for *P. ochraceus* (fig. 10).

Small Mobile Invertebrates

The most abundant of the small mobile invertebrates, sampled via zonal quadrats, was the small grazing snail, *Littorina sitkana*. When the counts from the subsampled area of the quadrats were scaled up to densities per square meter, *L. sitkana* had mean densities of about 200 to 1,000 per square meter with highest mean densities in the mid intertidal zone (fig. 11). The next most abundant small mobile invertebrate species was another littorine snail, *Littorina scutulata*. The group comprising all littorine species, including small littorine snails not identifiable to species, had the greatest abundances among the small mobile invertebrates (fig. 11).

When these three abundant species/groups are not included in the graphic, the magnitude and variability in the densities of the other, less abundant, small mobile invertebrate species can be seen (fig. 12). In general, the most abundant of these species groups were the Lottiidae and all limpets, with mean densities ranging from about 10 to 500 per m^2. Lottiidae includes all small limpets less than 8 mm and occasional limpets that could not be identified by an observer. The Lottiidae values drive the total limpet counts (fig. 12).

The only significant trends at this time for small mobile invertebrates were for the crab *Hemigrapsus* spp., amphipods, and hermit crabs (all positive, appendix A, table A3). Because these three small mobile invertebrates can be somewhat cryptic, the trends may reflect a difference in observer behavior (for example, more searching under substrates). As previously mentioned, any trends noted after two sampling events spanning a 1-year interval should be considered preliminary.

Table 4. Taxonomic list of species sampled at the Sitka National Historical Park monitoring site, Alaska.

Kingdom	Phylum	Family	Genus	Species
Monera	Cyanophyceae	Rivulariaceae	*Calothrix*	spp.
Plantae	Chlorophyta	Acrosiphoniaceae	*Acrosiphonia*	spp.
		Kornmanniaceae	*Blidingia*	*minima*
		Ulvaceae	*Enteromorpha*	*intestinalis*
			Ulva	*fenestrata*
		Prasiolaceae	*Prasiola*	*meridionalis*
	Phaeophyta	Desmarestiaceae	*Desmarestia*	*aculeata*
				viridis
		Dictyosiphonaceae	*Dictyosiphon*	*foeniculaceus*
		Punctariaceae	*Punctaria*	spp.
			Soranthera	*ulvoidea*
		Chordariaceae	*Chordaria*	*flagelliformis*
			Eudesme	*virescens*
		Corynophlaeaceae	*Leathesia*	*difformis*
		Ectocarpaceae	*Pilayella*	*littoralis*
		Ralfsiaceae	*Ralfsia*	*fungiformis*
		Fucaceae	*Fucus*	*distichus* var. *evanescens*
		Laminariaceae	*Laminaria*	*saccharina*
		Scytosiphonaceae	*Petalonia*	*fascia*
		Sphacelariaceae	*Sphacelaria*	spp.
	Rhodophyta	Hildenbrandiaceae	*Hildenbrandia*	spp.
		Dumontiaceae	*Cryptosiphonia*	*woodii*
			Farlowia	*mollis*
		Endocladiaceae	*Endocladia*	*muricata*
			Gloiopeltis	*furcata*
		Cruoriaceae	*Petrocelis*	spp.
		Gigartinaceae		
		Helminthocladiaceae	*Nemalion*	*helminthoides*
		Phyllophoraceae	*Mastocarpus*	*papillatus*
		Rhodomelaceae	*Osmundea*	*spectabilis*
			Odonthalia	*floccosa*
			Pterosiphonia	spp.
			Polysiphonia	spp.
		Rhodymeniaceae	*Halosaccion*	*glandiforme*
		Corallinaceae	*Corallina*	*frondescens*
	Magnoliophyta	Zosteraceae	*Zostera*	*marina*
		Poaceae	*Puccinellia*	*nutkaensis*
		Plantaginaceae	*Plantago*	*maritima*
		Chenopodiaceae	*Atriplex*	*patula*
	Bacillariophyta			
Fungi	Ascomycota	Verrucariaceae	*Verrucaria*	spp.

Table 4. Taxonomic list of species sampled at the Sitka National Historical Park monitoring site, Alaska.—Continued

Kingdom	Phylum	Family	Genus	Species
Animalia	Porifera	Halichondriidae	*Halichondria*	spp.
		Chalinidae	*Haliclona*	spp.
	Cnidaria	Actiniidae	*Urticina*	*felina*
	Platyhelminthes	Amphiporidae	*Amphiporus*	spp.
		Emplectonematidae	*Emplectonema*	*gracile*
	Mollusca	Lepidochitondidae	*Tonicella*	spp.
		Trochidae	*Margarites*	spp.
		Acmaeidae	*Acmaea*	*mitra*
		Littorinidae	*Littorina*	*scutulata*
				sitkana
			Lacuna	spp.
		Lottiidae	*Lottia*	*pelta*
				strigatella
			Tectura	*persona*
				scutum
		Nucellidae	*Nucella*	*lima*
				lamellosa
		Buccinidae	*Lirabuccinum*	*dirum*
		Mytilidae	*Modiolus*	*modiolus*
			Mytilus	*trossulus*
	Annelida	Nereidae		
		Pectinariidae	*Pectinaria*	*granulata*
		Spirorbidae		
	Arthropoda	Archaeobalanidae	*Semibalanus*	*balanoides*
				cariosus
		Balanidae	*Balanus*	*glandula*
		Chthamalidae	*Chthamalus*	*dalli*
		Sphaeromatidae	*Gnorimosphaeroma*	*oregonense*
		Varunidae	*Hemigrapsus*	spp.
		Paguridae	*Pagurus*	*hirsutiusculus*
		Cancridae	*Cancer*	*productus*
		Bdellidae	*Neomolgus*	*littoralis*
	Echinodermata	Asteropseidae	*Dermasterias*	*imbricata*
		Asteriidae	*Evasterias*	*troschelii*
			Lepasterias	*epichlora*
			Pisaster	*ochraceus*
			Pycnopodia	*helianthoides*
		Strongylocentrotidae	*Strongylocentotus*	*droebachiensis*
				franciscanus
	Chordata	Cottidae	*Oligocottus*	*maculosus*

Table 5. Species sampled each year by point-intercept sampling in the intertidal, organized by taxonomic categories, Sitka National Historical Park, Alaska.

[Asterisk (*) indicates which years each species was sampled]

Taxonomic categories		Species/Group	1999	2002	2003
Cyanobacteria	Blue-green Algae	*Calothrix*			*
Algae	Algae	Thin brown crust		*	
	Brown Algae	*Chordaria flagelliformis*		*	*
		Desmarestia aculeata	*		
		Desmarestia spp.		*	*
		Desmarestia viridis		*	
		Dictyosiphon foeniculaceus			*
		Fine filamentous browns/*Ectocarpales*	*	*	
		Fucus distichus var. *evanescens*	*	*	*
		Laminaria saccharina	*		*
		Leathesia difformis			*
		Neorhodamela cf. aculeata			*
		Odonthalia floccosa	*		
		Osmundea spectabilis			*
		Petalonia fascia			*
		Pilayella littoralis			*
		Punctaria spp.			*
		Ralfsia fungiformis			*
		Ralfsia spp.			*
		Small foliose brown		*	
		Soranthera ulvoidea	*		
		Sphacelaria spp.			*
		Thick brown crust	*	*	
	Green Algae	*Acrosiphonia* spp.		*	*
		Blidingia minima			*
		Enteromorpha intestinalis	*	*	*
		Enteromorpha sp.		*	
		Prasiola meridionalis		*	
		Small filamentous green	*	*	
		Ulva fenestrata	*	*	*
		Ulvales		*	*
	Red Algae	*Corallina frondescens*			*
		Cryptosyphonia woodii	*	*	*
		Encrusting coralline algae		*	
		Endocladia muricata	*	*	*
		Eudesme virescens			*
		Farlowia mollis	*		
		Gigartinaceae	*	*	
		Gloiopeltis furcata			*
		Halosaccion americanum		*	*
		Hildenbrandia spp.	*		*
		Mastocarpus papillatus	*	*	*
		Nemalion helminthoides			*
		Neorhodamela/*Odonthalia* spp.	*	*	*
		Petrocelis spp.			*
		Polysiphonia/*Pterosiphonia* spp.	*	*	
		Red crust-fleshy	*		
		Small filamentous red		*	*
		Small foliose red		*	
	Diatoms	*Diatoms* (*Bacillariophyta*)	*	*	*

Table 5. Species sampled each year by point-intercept sampling in the intertidal, organized by taxonomic categories, Sitka National Historical Park, Alaska.—Continued

[Asterisk (*) indicates which years each species was sampled]

Taxonomic categories		Species/Group	1999	2002	2003
Flowering Plants	Halophylic Plants	*Atriplex patula* (or *A. patula var. alaskensis*, or *A. alaskensis*)	*	*	*
		Plantago maritima	*		*
		Puccinellia nutkaensis	*	*	*
	Seagrasses	*Zostera marina*	*	*	*
Invertebrates	Barnacles	*B. glandula/S. balanoides*	*	*	*
		Balanomorpha	*	*	
		Chthamalus dalli	*	*	*
		Semibalanus balanoides			*
		Semibalanus cariosus	*	*	*
		Spat/Cyprids <1mm		*	*
	Cnidarians	*Urticina crassicornis*			*
	Crustaceans	*Amphipoda*		*	*
	Hermit Crabs	Paguridae	*	*	*
	Limpets	*Lottia pelta*		*	*
		Lottia strigatella (=*paradigitalis*)		*	
		Lottidae <8mm	*	*	*
		Tectura persona		*	*
		Tectura scutum	*		
	Mussels	*Modiolus modiolus*		*	
		Mytilus trossulus	*	*	*
	Polychaetes	*Polychaete*, unidentified	*		
		Spirobidae		*	
	Seastars	*Leptasterias epichlora*			*
		Pisaster ochraceus			*
	Shore Crabs	*Hemigrapsus* spp.		*	
	Snails	*Lacuna* spp.	*		*
		Littorina scutulata	*	*	*
		Littorina sitkana	*	*	*
		Littorina spp.		*	*
		Nucella egg case			*
		Nucella lima			*
		Nucella spp.		*	
	Sponges	*Halichondria*		*	
		Haliclona	*		
Lichens	Lichens	*Verrucaria* spp.	*	*	*
Other	Unidentified	Egg mass, unidentified		*	
	Wrack	Wrack	*	*	*

Table 6. Seaweed (algal) species that have been collected and identified from the intertidal of Sitka National Historical Park, but not necessarily sampled.

[Species with no shading were those identified prior to 2000; species in dark gray shading were added in spring 2000; species in light gray shading were added in summer of 2003. Courtesy of Dr. Sandra Lindstrom, University of British Columbia]

Sitka National Historical Park Seaweeds
Acrosiphonia arcta (Dillwyn) Gain
Acrosiphonia saxatilis (Ruprecht) K.L. Vinogradova
Ahnfeltia fastigiata (Endlicher) Makienko
Analipus japonicus (Harvey) M.J. Wynne
Blidingia minima (Naegeli ex Küetzing) Kylin
Bossiella orbigniana subsp. orbigniana (Decaisne) P.C. Silva
Bossiella plumosa (Manza) P.C. Silva
Ceramium pacificum (Collins) Kylin
Chondracanthus exasperatus (Harvey et Bailey) Hughey in Hughey, Dudash et Kjeldsen
Chordaria flagelliformis (O.F. Müeller) C. Agardh
Chordaria gracilis Setchell et N.L. Gardner
Cladophora sericea (Hudson) Küetzing
Clathromorphum circumscriptum (Stroemfelt) Foslie
Codium fragile (Suringar) Hariot
colonial diatoms
Colpomenia peregrina (Sauvageau) Hamel
Constantinea subulifera Setchell
Corallina frondescens Postels et Ruprecht
Corallina officinalis var. chilensis (Decaisne in Harvey) Küetzing
Cryptopleura ruprechtiana (J. Agardh) Kylin
Cryptosiphonia woodii (J. Agardh) J. Agardh
Cymathaere triplicata (Postels et Ruprecht) J. Agardh
Desmarestia aculeata (Linnaeus) Lamouroux
Desmarestia viridis (O.F. Müeller) Lamouroux
Dictyosiphon foeniculaceus (Hudson) Greville
Dumontia alaskana V. Tai, S.C. Lindstrom et G.W. Saunders
Endocladia muricata (Endlicher) J. Agardh
Enteromorpha intestinalis (Linnaeus) Nees
Enteromorpha linza (Linnaeus) J. Agardh
Enteromorpha clathrata (Roth) Greville
Enteromorpha prolifera (O.F. Müeller) J. Agardh
Eudesme virescens (Carmichael in Berkeley) J. Agardh
Farlowia mollis (Harvey et Bailey) Farlow et Setchell in Collins, Holden et Setchell
Fucus distichus subsp. evanescens (C. Agardh) Powell
Gloiopeltis furcata (Postels et Ruprecht) J. Agardh
Gloiosiphonia capillaris (Hudson) Carmichael in Berkeley
Grateloupia postelsii Parkinson in Chapman & Parkinson
Halochlorococcum moorei (N.L. Gardner) Kornmann et Sahling
Halosaccion glandiforme (S. G. Gmelin) Ruprecht
Haplogloia andersonii (Farlow) Levring
Laminaria groenlandica Rosenvinge sensu Druehl
Laminaria saccharina (Linnaeus) Lamouroux

Sitka National Historical Park Seaweeds
Laminaria yezoensis Miyabe
Leathesia difformis (Linnaeus) Areschoug
Mastocarpus "papillatus" clade 1
Mastocarpus "papillatus" clade 5
Mazzaella heterocarpa (Postels et Ruprecht) Fredericq in Hommersand et al.
Mazzaella splendens (Setchell et N.L. Gardner) Fredericq in Hommersand, Fredericq et Freshwater
Melanosiphon intestinalis (Saunders) M.J. Wynne
Monostroma grevillei (Thuret) Wittrock
Nemalion elminthoides (Velley in Withering) Batters
Neodilsea borealis (I.A. Abbott) S.C. Lindstrom
Neorhodomela aculeata (Perestenko) Masuda
Neorhodomela larix (Turner) Masuda
Neorhodomela oregona (Doty) Masuda
Odonthalia floccosa (Esper) Falkenberg
Osmundea spectabilis (Postels et Ruprecht) Nam in Nam, Maggs et Garbary
Palmaria callophylloides Hawkes et Scagel
Palmaria mollis (Setchell et N.L. Gardner) van der Meer et Bird
Pilayella littoralis (Linnaeus) Kjellman
Plocamium pacificum Kylin
Polysiphonia hendryi var. gardneri (Kylin) Hollenberg
Polysiphonia pacifica Hollenberg
Polysiphonia urceolata **(Lightfoot ex Dillwyn) Greville**
Porphyra cf. abbottiae V. Krishnamurthy
Porphyra cuneiformis (Setchell et Hus in Hus) V. Krishnamurthy
Prionitis lanceolata (Harvey) Harvey
Pterosiphonia bipinnata (Postels et Ruprecht) Falkenberg
Ptilota filicina J. Agardh
Pugetia firma Kylin
Punctaria chartacea Setchell et N.L. Gardner
Punctaria cf. tenuissima (C. Agardh) Greville
Ralfsia fungiformis (Gunnerus) Setchell et N.L. Gardner
Ralfsia cf. pacifica Hollenberg in G. M. Smith
Sarcodiotheca gaudichaudii (Montagne) Gabrielson
Saundersella simplex (Saunders) Kylin
Scinaia confusa (Setchell) Huisman
Scytosiphon lomentarius (Lyngbye) Link
Smithora naiadum (Anderson) Hollenberg
Sparlingia pertusa (Postels et Ruprecht) G. Saunders, Strachan et Kraft
Streblonema irregularis Saunders
Ulva fenestrata Postels et Ruprecht

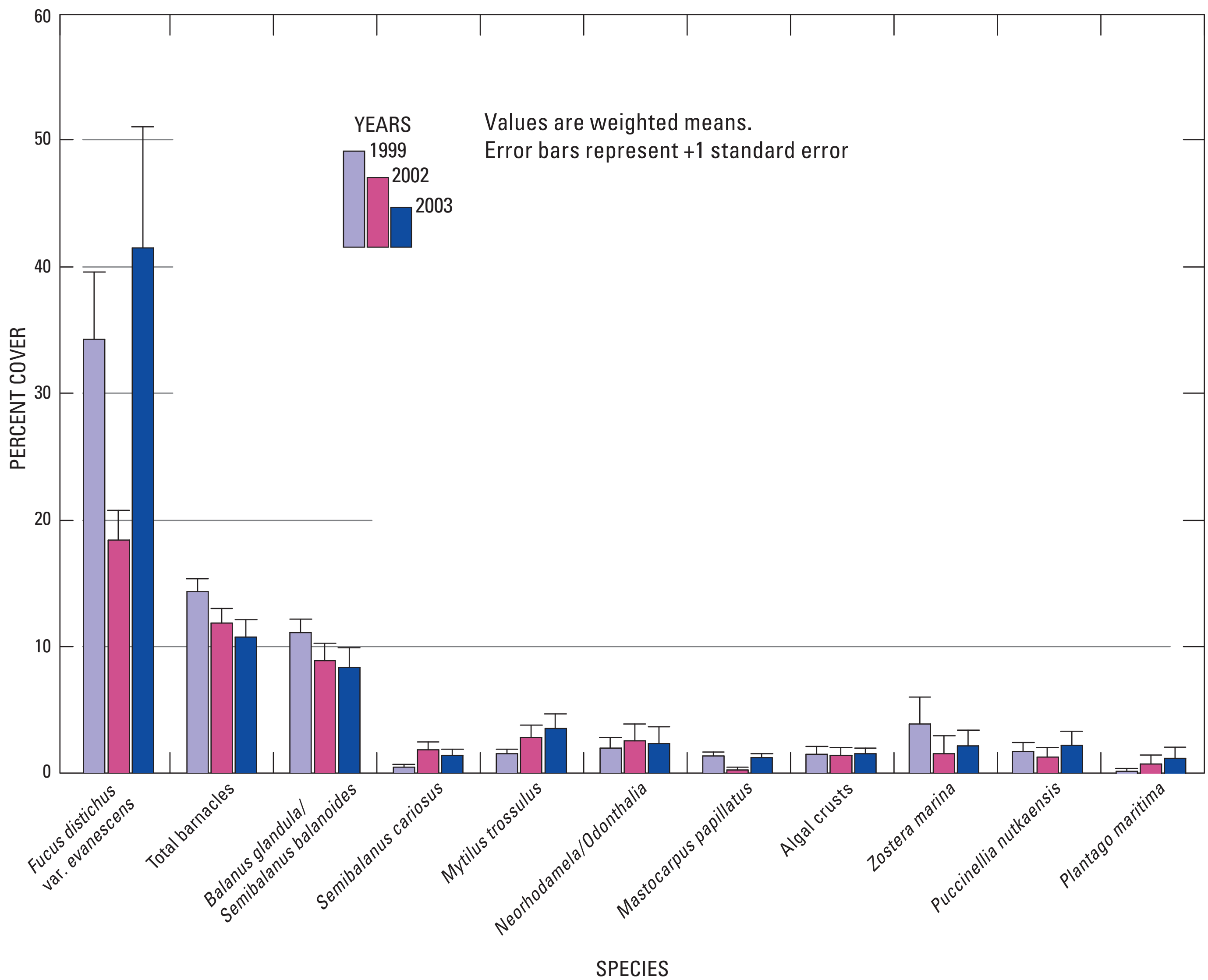

Figure 9. Percent cover of the most abundant sessile species through time for the entire Sitka National Historical Park monitoring site, Alaska.

Barnacle Recruits

Although barnacles are sessile species, barnacle recruits (spat) are considered herein because they were subsampled within the quadrats. When the densities of barnacle recruits were scaled up to numbers per square meter, the mean values in an elevational zone ranged from about 300 to 7,000 per m^2 (fig. 13). High variability exists in the values, both between years and among zones (fig. 13), but preliminary trend analysis indicated a significant negative trend between 2002 and 2003 (appendix A, table A3).

Power Analyses

Power analyses on trend data for the more abundant species sampled were conducted by TerraStat Consulting and are presented in appendix A. Analyses were conducted both on individual species as well as on groups of species (tables 9 and 10). In addition to species sampled, the species listed in the tables include some species that were not detected during the sampling and have not necessarily been detected at the site but could be present in the Sitka area.

Table 7. Total counts of large mobile invertebrates and size of intertidal area sampled each year in the band surveys at the Sitka National Historical Park monitoring site, Alaska.

Species name	Common name	Total count		
		1999	2002	2003
Pisaster ochraceus	Purple Starfish	5	27	31
Evasterias troschelli	Mottled Starfish	1	3	1
Leptasterias epichlora	Six-armed Starfish	1	0	0
Dermasterias imbricata	Leather Star	0	0	1
Pycnopodia helianthoides	Sun Star	0	0	1
Strongylocentrotus droebachiensis	Green Sea Urchin	0	0	2
Cancer productus	Red Rock Crab	0	1	0
Total area sampled, in square meters		5,482	5,280.62	5,576.8

Table 8. Density of large mobile invertebrates sampled each year in the intertidal of Sitka National Historical Park, Alaska.

Species name	Common name	Density (number per square meter)		
		1999	2002	2003
Pisaster ochraceus	Purple Starfish	0.000912	0.005113	0.005559
Evasterias troschelli	Mottled Starfish	0.000182	0.000568	0.000179
Leptasterias epichlora	Six-armed Starfish	0.000182	0	0
Dermasterias imbricata	Leather Star	0	0	0.000179
Pycnopodia helianthoides	Sun Star	0	0	0.000179
Strongylocentrotus droebachiensis	Green Sea Urchin	0	0	0.000358
Cancer productus	Red Rock Crab	0	0.000189	0

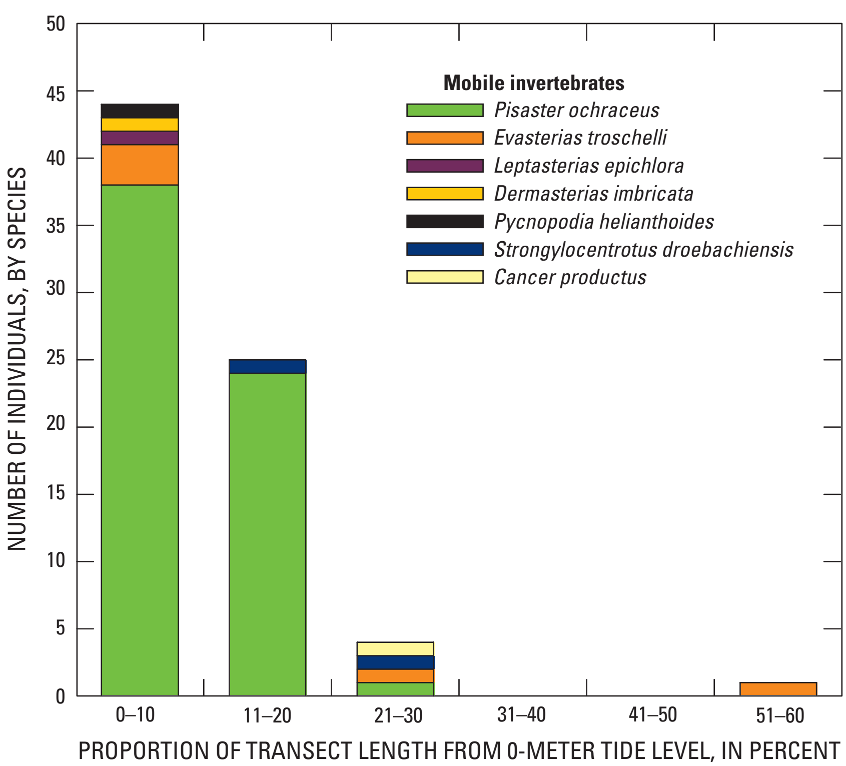

Figure 10. Occurrence of large mobile invertebrates by proportion of transect length from the 0-meter tide level, Sitka National Historical Park monitoring site, Alaska. Large mobile invertebrates were counted in 2-meter bands along transect lines. Because transect length varies among transects, data from different transects are combined according to 1/10 intervals of transect length. Thus each column represents 1/10 of the area sampled by transects. Note that these invertebrates occur predominantly in the lower intertidal regions (0 to 20 percent categories).

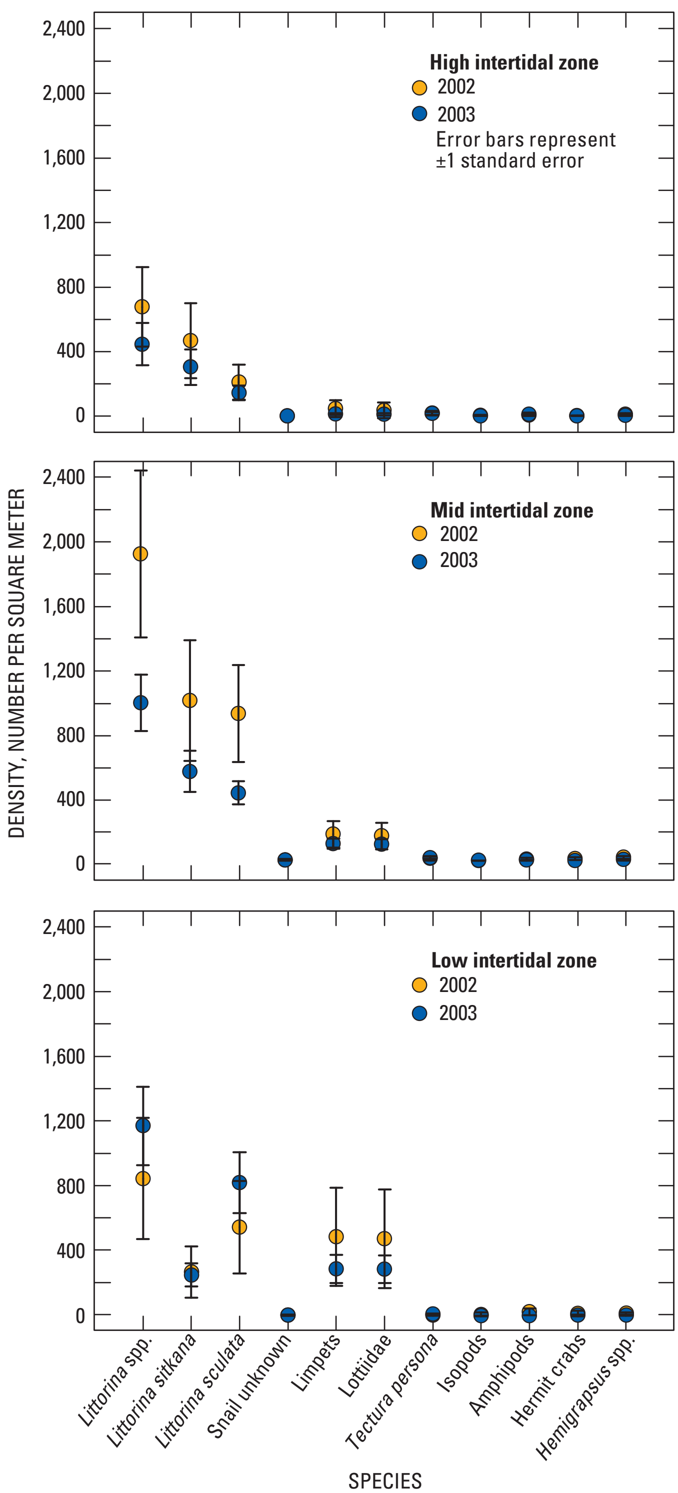

Figure 11. Densities of the most abundant small mobile invertebrates in each zone by year, Sitka National Historical Park monitoring site, Alaska, 2002–03. Small mobile invertebrates were only sampled in 2002 and 2003. For comparability, data from the two subzones used in 2003 that comprised a single zone in 2002 were combined.

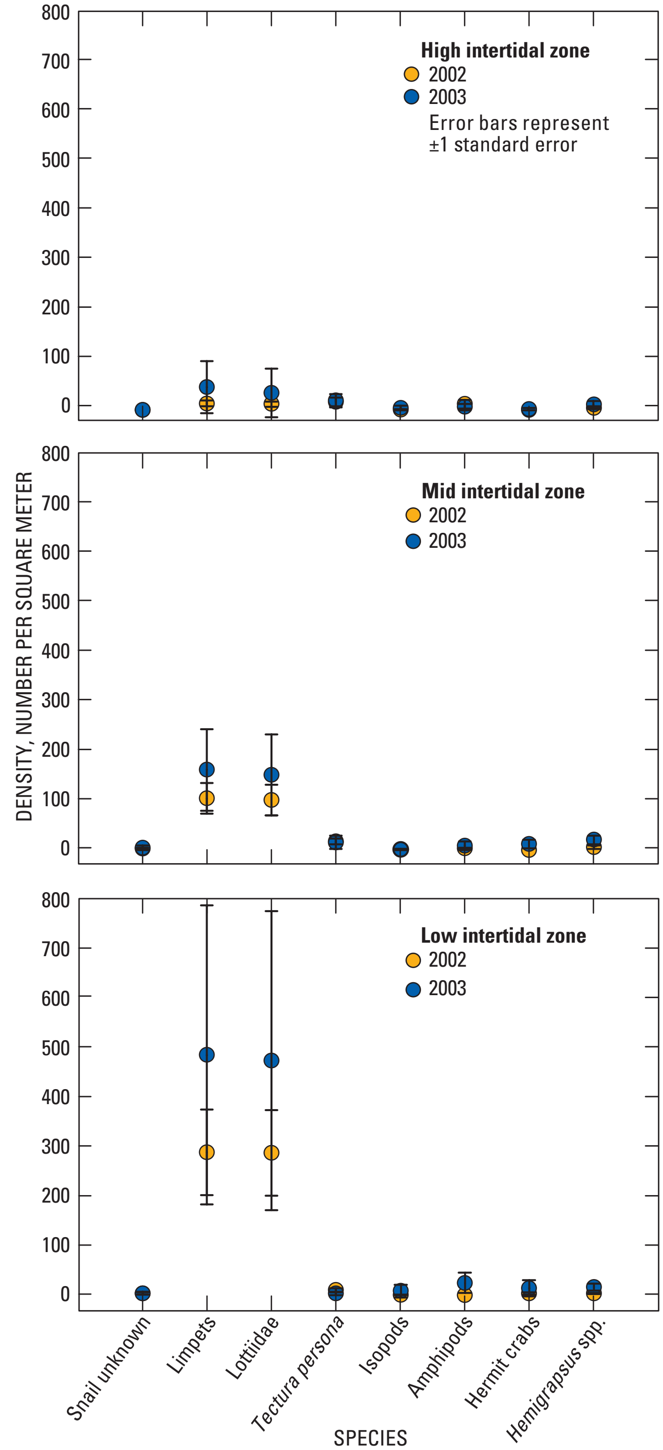

Figure 12. Densities of the most abundant small mobile invertebrates, not including *Littorina* species, through time, Sitka National Historical Park monitoring site, Alaska, 2002–03. Note the change in values on the y-axis compared to those in figure 11. Small mobile invertebrates were sampled only in 2002 and 2003. For comparability, data from the two subzones used in 2003 that comprised a single zone in 2002 were combined.

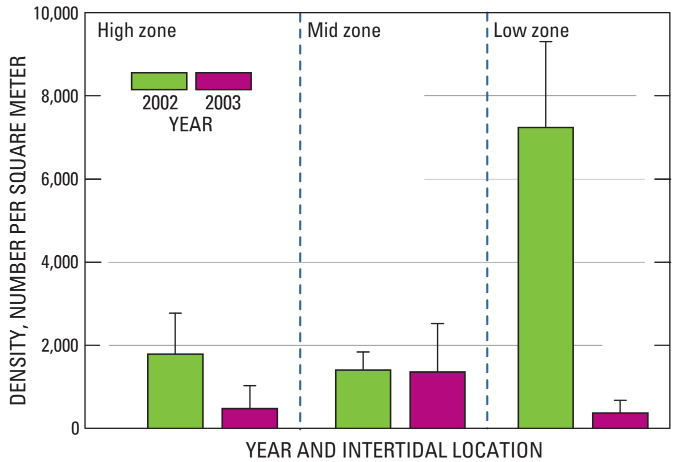

Figure 13. Densities of barnacle recruits through time, as determined from quadrat sampling in high, mid, and low intertidal zones, Sitka National Historical Park monitoring site, Alaska, 2002–03. Barnacle recruits were sampled only in 2002 and 2003. For comparability, data from the two subzones used in 2003 that comprised a single zone in 2002 were combined.

Table 9. Sessile species (from point-intercept data) used in statistical power analyses.

[Species codes listed also include some species that were not detected at the site but could be present. Species IDs refer to the species number on the list of species in the Microsoft© Access database]

Species name	Species code	Species IDs
Fucus distichus var. *evanescens*	FU	27
Barnacles, total	BG,SB,BS,BA,CD,SC	95,436,93,94,96,97
B. glandula/S. balanoides	BG,SB	95,436
Semibalanus cariosus	SC	97
Mytilus trossulus	MY	87
Neorhodamela/Odonthalia,Total	NEO,NEOA,NEOL,NEOR,ODF	10,332,333,334,335
Mastocarpus papillatus	MA	9
Algal crusts, total	RE,BC,TBC,HL,RA,RAF,PETR	15, 440,150,34,144,427,428,413
Zostera marina	ZO	42
Puccinellia nutkaensis	PN	145
Plantago maritima	PLA	147

Table 10. Small mobile invertebrate species and barnacle recruits (spat), from quadrat sampling, used in statistical power analyses.

[Species codes listed also include some species that were not detected at the site but could be present. Species IDs refer to the species number on the list of species in the Microsoft© Access database]

Name of category	Species code	Species IDs
Littorina spp.	LSC, LSI, LIT	61,62,63
Littorina sitkana	LSI	62
Littorina scutulata	LSC	61
All limpets	LO,DI,LD,LP,TF,TP,TES,ACM,LOS,LOU	75,77,78,79,80,81,82,76,362,364
Lottidae < 8mm	LO	75
Tectura persona (limpet)	TP	81
Nucella spp. (predatory snails)	NC, NUE, NLI, NUC, NLL	66,68,69,70,434
Amphipods	AM	99
Isopods	GNO, IS	375,100
Hermit crabs	HC, PAGH	102, 376
Hemigrapsus spp. (crab)	HG	103
Barnacle spat (not mobile)	BS	93

The power analyses focused on determining how many transects should be sampled each year to detect exponential changes of magnitude of ±10 percent per year by 2011. Further details of the test parameters and sampling scenarios are presented in the section "Methods" and in appendix A (which includes more detailed results, graphs, and discussion than those described herein).

All species examined had 100 percent power for detecting +10 percent exponential trends regardless of the number of transects (10, 12, 15, 18 were considered) if sampling was conducted annually from 2006 to 2011 (tables 11 and 12). However, the statistical power for detecting -10 percent exponential trends for different sampling scenarios, at $\alpha = 0.05$, varied considerably from poor to excellent across species. The highest power was shown by the BGSB (the barnacles, *B. glandula*/*S. balanoides*), BARN (all barnacles), and LITT (all *Littorina* spp.); the least power was shown for LO (Lottiidae) and BS (barnacle spat) (tables 11 and 12).

Among the sessile species examined (BGSB, BARN, *Fucus*, and *Mytilus*), only for *Mytilus* was it not possible to attain 80-percent power to detect a -10 percent trend (table 11). If the α level is changed to 0.10, then annual sampling of 15 or 18 transects would provide at least an 80 percent power to detect a -10 percent trend (appendix A, table A7).

Results of the power analyses for small mobile invertebrate species (table 12) were more varied than those for the sessile species. As previously mentioned, the power to detect trends (both ±10 and ±5 percent) was high for LITT (all *Littorina* spp.). Other species for which it was possible to detect both ±10 percent trends when at least 15 transects were sampled annually included the littorine snails LSI (*Littorina sitkana*) and LSC (*Littorina scutulata*) and the limpet TP (*Tectura persona*). As would be expected, the power to detect trends increased when the value of α was increased from 0.05 to 0.10 (appendix A, table A8).

The power analyses basically support the conclusion that the sampling design used in 2002 and 2003, has good power to detect +10 percent trends for those species examined. The ability to detect -10 percent trends is more varied and may be affected by population size; it is more difficult to detect declines in small populations (Taylor and Gerrodette, 1993). This disparity in ability to detect positive and negative trends should provide a basis for discussion of which species to monitor and potential alterations to the sampling plan that would reduce the variation and increase power.

Discussion

The main focus of this project has been the design of a probability-based sampling plan for intertidal biota that has sufficient power to allow detection of trends for the more abundant species. In pursuit of this goal, the project has provided:

1. Basic information on the species present and their abundance and spatial distribution (1999–2003);
2. Quantitative descriptions of the substrate comprising the sampled intertidal zone;
3. Temporal data on the relative abundance of intertidal species and preliminary trend analyses;
4. Statistical power analyses of the data to evaluate the ability of the sampling design, as executed thus far, to detect trends in the more abundant species.

The analyses and reviews indicate the basic sampling design is sound, with a modification discussed below for quadrat sampling that would make it consistent in approach to the other sampling. Additional suggestions for changes to the sampling of large mobile invertebrates and transect selection will be mentioned, but all these need to be set within the framework of the goals and questions.

Therefore, a discussion is needed to determine (1) what is the primary question being asked, (2) how does the question affect the sampling design and the choices for modifications to the design, (3) how should proposed intertidal monitoring at Sitka interface with other NPS intertidal monitoring, both planned and in development; and (4) which species should be monitored. Additionally, details of the sampling as it has been conducted will be discussed below. A number of questions and issues raised during the sampling and subsequent analysis and reporting phases are presented as discussion points in appendix B.

Basic Questions and Two Main Approaches

The basic question is: Can trends in the abundances of the predominant species on the Sitka beach be detected over time? Using approaches that create inference to the sampling frame (the designated beach), we can define two major emphases: (1) sampling for trend detection that increases spatial inference (for example, maximizes inference to the whole beach/sampling frame), and (2) sampling for trend detection that decreases spatial variation, thereby increasing trend detection (fig. 14). Our sampling has been designed largely to increase spatial inference to the whole beach (emphasis 1), with re-randomization of sampling locations each year and sampling proportional to area (or transect length as a proxy of area). The only exception is the quadrat sampling, which has been based generally on elevational bands (fractional divisions of transect length—thirds or sixths). Therefore, most of our sampling has emphasized trend detection with increased spatial inference (Note: asterisked boxes in figure 14 indicate sampling methods used in this study). Each transect, whether 45 or 329 m in length, can be considered a sample of the intertidal, but long transects sample a greater area of the whole and, thus, should be weighted accordingly. Sampling transects

Table 11. Estimated statistical power for sessile species (point-intercept sampling) with α = 0.05.

[Data adapted from TerraStat Consulting Group, table A5, appendix A; highlighting added. All numbers, including trends, are in percent. All results with power ≥80 percent are shaded. Details of the power analyses and sampling scenarios are presented in appendix A. SS1 represents annual sampling, SS2 is biennial sampling, and SS3 is triennial sampling. The numbers (10, 12, 15, 18) are the number of transects sampled for each scenario. Trends are exponential, annual changes. Species codes are BGSB, *Balanus glandula*/*Semibalanus balanoides*; BARN, barnacles; FU, *Fucus distichus* var. *evanescens*, and MY, *Mytilus trossulus*]

Species code	Trend	SS1				SS2				SS3			
		18	15	12	10	18	15	12	10	18	15	12	10
BGSB	+10	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	-10	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**99**
	+5	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	-5	**96**	**97**	**91**	**90**	**91**	**92**	**82**	79	**87**	**86**	77	74
BARN	+10	**100**	**100**	**100**	**100**	**100**	**100**	**100**	100	**100**	**100**	**100**	**100**
	-10	**100**	**100**	**100**	**100**	**100**	**100**	**100**	100	**100**	**100**	**100**	**100**
	+5	**100**	**100**	**99**	**98**	**99**	**96**	**94**	84	**97**	**90**	**84**	70
	-5	**100**	**100**	**100**	**100**	**100**	**100**	**100**	99	**99**	**100**	**99**	**98**
FU	+10	**100**	**100**	**100**	**100**	**100**	**100**	**100**	100	**100**	**100**	**100**	**100**
	-10	**100**	**100**	**99**	**98**	**98**	**97**	**95**	94	**96**	**95**	**91**	**90**
	+5	77	61	67	51	56	42	44	31	49	34	36	25
	-5	**85**	**86**	68	69	73	78	58	62	71	70	54	56
MY	+10	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	-10	69	66	51	51	54	52	37	35	47	42	31	28
	+5	57	55	52	46	49	46	43	38	48	44	41	40
	-5	22	24	15	14	17	16	11	12	14	13	11	9

at 1-pt/m intervals creates proportional sampling because the number of points sampled is directly related to transect length. The band surveys also are proportional because one of their sample unit dimensions is the transect length. If the decision is made to adopt this approach (increased spatial inference), then the quadrat sampling needs to be reconfigured to be proportional to transect length. This is discussed further in appendix B (point 9). Sampling for large mobile invertebrates, although proportional to the transect length, is not efficient (few such invertebrates are sampled); thus, this also needs modification (discussed in appendix B, point 11).

More traditional intertidal sampling has emphasized trend detection with a concomitant decrease in spatial variation (emphasis 2 above). This usually has involved organizing sampling in relation to vertical zonation, which is one of the more widely known aspects of rocky intertidal ecology. To increase trend detection by decreasing spatial variance (fig. 14), fixed transects or quadrats are sampled and sampling is based on elevation or zones (for example, Richards and Davis, 1988) or attributable to those elevations or zones (V. Gallucci, University of Washington, oral commun., 2007). If randomization is included, more often a stratified random approach has been used (for example, Houghton and others, 1996). A disadvantage of this often horizontally based approach is that shifts in zonation may not be detected until they become very large changes (a change in strata); apparent decreases in the abundance of a species may not reflect a decrease in the abundance of a species on a beach, just a shift in its location vertically. This problem in interpretation has been noted in California at mainland monitoring sites, where fixed quadrats were set originally in areas (zones) dominated by particular species (P. Raimondi, University of California Santa Cruz, written commun., 2008).

An alternative or modification to the horizontally based zonal studies is the use of vertical transects, which are laid along the elevational gradient, from high tide to low, and which sample across the gradient of greatest change (Irvine, 1998, 2002; Miller and Ambrose, 2000; P. Raimondi, University of California Santa Cruz, oral commun., 2007). Vertical transect sampling can be used in different ways: as a means of proportional sampling (as in this study), or zonally (with a set numbers of points per transect; P. Raimondi, University of California Santa Cruz, oral commun., 2007). However, Raimondi (written commun., 2008) notes that there can be some similar problems with vertical transects as for zonally set plots, such that some species could shift upward to areas that previously had no marine biota when the sites were set up.

The major advantage of sampling that is set with respect to zonation or elevation is that it should reduce the variation in abundances of species because sampling is concentrated in zones that are similar in physical conditions and presumed ecological influences. Thus, trends in species' abundances through time should be easier to detect.

Table 12. Estimated statistical power for small mobile invertebrate species and barnacle recruits (quadrat sampling) with α = 0.05.

[Data adapted from TerraStat Consulting Group, table A6, appendix A; highlighting added. All numbers, including trends, are in percent. All results with power ≥ 80 percent are shaded. Details of the power analyses and sampling scenarios are presented in appendix A. SS1 represents annual sampling, SS2 is biennial sampling, and SS3 is triennial sampling. The numbers (10, 12, 15, 18) are the number of transects sampled for each scenario. Trends are exponential, annual changes. Species codes are LO, Lottidae; LSI, *Littorina sitkana*; LSC, *Littorina scutulata*; BS, Barnacle spat; TP, *Tectura persona*; HG, *Hemigrapsus*; LIMP, All limpets; and LITT *Littorina* spp.]

Species code	Trend	Sampling scenarios											
		SS1, annual				SS2, biennial				SS3, triennial			
		Number of transects				Number of transects				Number of transects			
		18	15	12	10	18	15	12	10	18	15	12	10
LO	+10	**100**	**100**	**100**	**100**	**100**	**100**	**99**	**97**	**99**	**99**	**98**	**96**
	-10	46	57	36	38	38	48	30	31	42	42	26	27
	+5	47	32	39	32	39	23	34	27	31	24	32	24
	-5	9	18	7	9	8	15	7	9	10	14	7	7
LSI	+10	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	-10	**99**	**97**	**94**	**89**	**96**	**90**	**82**	75	**93**	**82**	69	66
	+5	75	69	70	60	58	58	58	48	52	54	52	44
	-5	65	51	40	34	50	38	28	23	49	33	23	19
LSC	+10	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	-10	**100**	**100**	**99**	**98**	**100**	**99**	**94**	**93**	**99**	**98**	**91**	**88**
	+5	56	40	50	39	42	29	40	30	33	30	38	29
	-5	**81**	**83**	64	69	72	77	54	58	76	72	50	55
BS	+10	**100**	**100**	**100**	**100**	**100**	**100**	**98**	**94**	**100**	**99**	**94**	**85**
	-10	28	34	25	27	28	33	23	26	33	34	25	31
	+5	27	30	25	21	19	19	18	15	18	18	16	13
	-5	8	10	7	8	10	12	11	11	12	13	11	12
TP	+10	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**99**	**100**	**100**	**100**	**99**
	-10	**86**	**84**	79	74	77	73	68	63	73	67	62	58
	+5	58	62	50	44	45	43	36	32	39	39	30	26
	-5	37	33	29	28	29	29	27	24	30	25	23	22
HG	+10	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	-10	27	31	21	18	14	20	11	8	12	14	8	7
	+5	**81**	74	77	67	71	57	62	50	62	53	53	45
	-5	2	4	1	2	1	2	1	1	2	2	1	1
LIMP	+10	**100**	**100**	**100**	**100**	**100**	**100**	**99**	**97**	**99**	**98**	**98**	**94**
	-10	47	55	35	36	37	48	27	27	40	41	25	26
	+5	57	46	52	42	45	35	42	35	35	34	38	31
	-5	9	14	7	7	7	13	7	8	10	15	5	9
LITT	+10	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	-10	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**99**	**98**
	+5	**98**	**95**	**97**	**88**	**91**	**87**	**89**	77	**82**	**81**	**83**	70
	-5	**98**	**96**	**91**	**89**	**92**	**90**	75	73	**91**	**83**	65	61

Approaches to Reduce Variation, but Maintain Proportional Sampling

Another alternative, if the decision is to continue the "whole beach/ increased spatial inference" emphasis, is to consider approaches that would reduce variation (fig. 14). One approach is to use permanent transects whose selection includes a random component; the same type of selection (systematic with a random start) as used previously should be used to maintain the inference to the sampling frame. Although suggestions have been made to select transects with probability proportional to length, this idea has received mixed reviews from statisticians.

Using permanent transect locations would make it easier to detect changes in vertical distributions of species. Additionally, the interannual variation caused by sampling transects in different locations each year would be reduced. For example, the high interannual variation in *Fucus* abundance (fig. 9) is most likely a result of the re-randomization of transect locations each year. *Fucus* is a perennial plant, so large-scale fluctuations are not expected unless high recruitment and/or high mortality

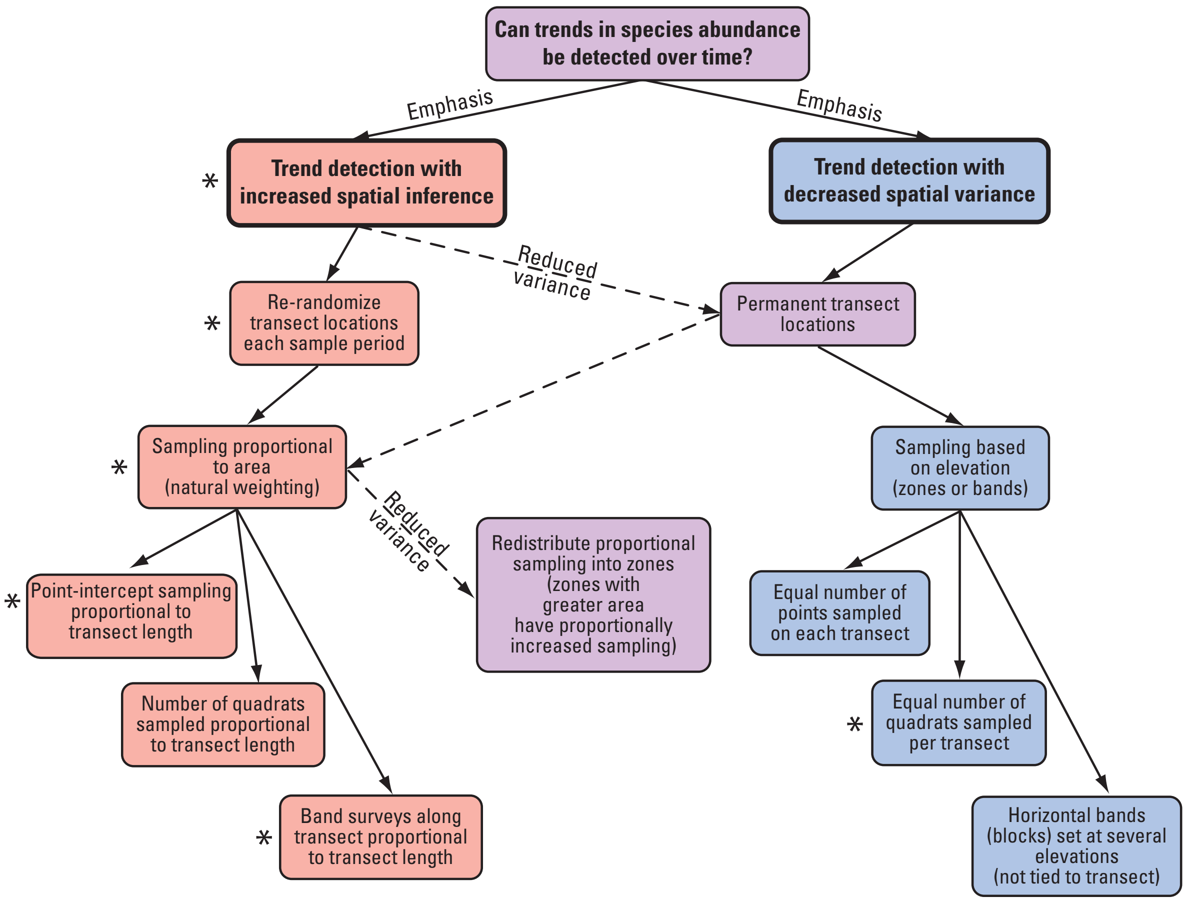

Figure 14. Options for sampling at Sitka National Historical Park that depend on the question and emphasis selected. Even with an initial selection of an emphasis on increased spatial inference, there are options in sampling or redistribution of data that should reduce variation in sampling results. Current sampling methods are marked with an asterisk (*).

occur. The re-randomization of transect locations each year makes it more difficult to detect these types of changes, as well as shifts in zonation; however, further analysis of the 3-D sampling results might provide support for shifts in population structure. Permanent transect locations possibly could be set up through the use of permanent markers in some locations and differential global positioning systems (GPS). The error margins for use of differential GPS need to be investigated to determine the utility of this method, especially for determination of low intertidal transect locations. The predominantly pebble beach plus the inability to find any of the rebar placed in the high intertidal in 1999 to mark transect head locations suggests that placing permanent markers along most of the beach would be ineffective, except perhaps in the areas with bedrock substrate (only near the origin) or in supratidal/terrestrial areas.

Disadvantages of using permanent transect locations are (1) some loss of knowledge as to how species across the sampling frame are changing and (2) potential for effects on the biota near/under the transect lines as a result of the focused presence of people sampling (for example, trampling effects). The potential of the latter disadvantage should be placed within the context of total visitation on the beach, which may be very high during the summer. Trampling effects in the intertidal have been described for several areas, including for Cabrillo National Monument in California, but several factors that are not present at Sitka may have contributed to the response [for example, a bedrock intertidal, preponderance of small turf algae, and extremely high visitation rates (Zedler, 1978; Davis and Engle, 1991)]. Although the negative effects of sampling on intertidal biota at Sitka may be minimal thus far, given the pebble beach with its greater "give" and the use of small foam knee pads when sampling quadrats, both the laying out of transect lines and their sampling entail walking along, or close to, the transect line location. If proportional sampling is adopted and the number of quadrats sampled becomes proportional to transect length, then the number of quadrats sampled on long transects will be increased (as much as two to three times), and the number of quadrats sampled on short transects will be decreased. Perhaps these effects should be evaluated; at a minimum, procedures or protocols should discuss ways to reduce the effects of sampling on the biota.

Another approach to reducing variation in the “increased spatial inference” emphasis is to redistribute proportional sampling data into zones (fig. 14). This would require mapping of the beach, with areas defined by elevation bands (for example, 1-m vertical elevation bands). Presumably, this would only have to be done once, using good quality aerial photography, differential GPS, and surveying. Then, sampling data could be analyzed with respect to elevation, and the bands with larger areas also would have proportionally more data. Variability in the data should be reduced.

One concern with analyzing proportional data (for example, quadrat data) by transect, rather than being able to separate it into zones, is the effect of combining data and losing the ability to detect changes that may be happening at different elevations. For example, compare the densities of the small limpets, Lottiidae, and all limpets between years and, more pertinently, between zones within 2003 (fig. 15). In the low intertidal zones (bottom panel of graphics), the lower abundance and lower variability of the 2003 low-high data are swamped by the higher densities and higher variability of the 2003 low-low data when they are all combined (the 2003 low-high + low-low data). This is less apparent in the littorine snail data (fig. 16), but some increase in variability occurs when the 2003 data are combined (rightmost panel of graphs). Aggregating and analyzing data by elevation should allow greater trend detection through reduction of variability.

Interfacing Sitka National Historical Park Intertidal Monitoring with Other National Park Service Monitoring

Another important consideration is how the Sitka NHP intertidal monitoring should interface with other NPS monitoring, both in southeast Alaska and in other networks. Because, at the minimum, some modifications to the Sitka sampling need to be made to make it consistent in approach (for example, all proportional sampling), this is the time to consider whether to create an approach that would allow broader comparability of data. This discussion also should include whether data are comparable to other broad-scale sampling approaches (for example, Partnership for Interdisciplinary Studies of Coastal Oceans); however, critical evaluation and the limitations of those approaches need to be recognized. It is important to first decide what sampling would best meet Sitka’s needs.

Which Species to Monitor

Another major topic for discussion is which species should be monitored. Although much discussion has taken place in the literature regarding selection of sentinel species (Jones and Kaly, 1996; Murray and others, 2006), we have taken a broad-species sampling approach in this study (see also Murray and others, 2006). There are several reasons for this. First, we do not know which external stressors will be most important in the long-term, and temporal and probably spatial variation in the relative importance of different stressors at Sitka NHP can be expected. Second, indications of which species are most likely to change in abundance, or in which direction, are not clear. Third, we can only assess trends in the more abundant species, and, in the long-term, the species composition may change and different species may become prominent enough to be evaluated quantitatively. Additionally, from a practical standpoint, once sampling has begun there is a relatively small cost in obtaining more detailed information. This may not be the case in quadrat sampling, however, because of the time needed to enumerate all small mobile invertebrate species. The quadrat sampling can be made more efficient by subsampling the Lottiidae, which are numerically abundant. One of the largest concerns regarding the broad-species sampling approach is the difficulty of identifying the many different species that inhabit the intertidal. This difficulty means the results are sensitive to the taxonomic expertise of the observers. This is not at all a trivial issue and warrants further discussion (see appendix B, point 15). More intensive training of observers, use of well-trained sampling teams, and testing for detection differences among observers are all points for discussion.

Sampling Methods That Target Different Groups

In addition to deciding which species to monitor, the different sampling methods and their effectiveness should be evaluated. The three sampling methods used (described in “Methods”section) target different components of the intertidal communities: sessile species (sampled by vertical transects), large mobile invertebrates (sampled by band surveys), and small mobile invertebrates and barnacle recruits (sampled by quadrats). Discussions of these sampling methods are presented below by target group.

Sessile Species

Point-intercept sampling along transects targets sessile plants and invertebrates, providing estimates of percent cover of these species or species groups. One advantage of vertical transects, versus horizontal transects or other sampling within zones, is that they allow more continuous sampling across the greatest gradient of change (Irvine, 1998). We can expect differences or shifts in vertical distributions of species with changes in ocean conditions (for example, temperature changes associated with regime shifts or other more unidirectional climate change), changes in species interactions (for example, loss of predators or competitors; addition of invasive species), etc.

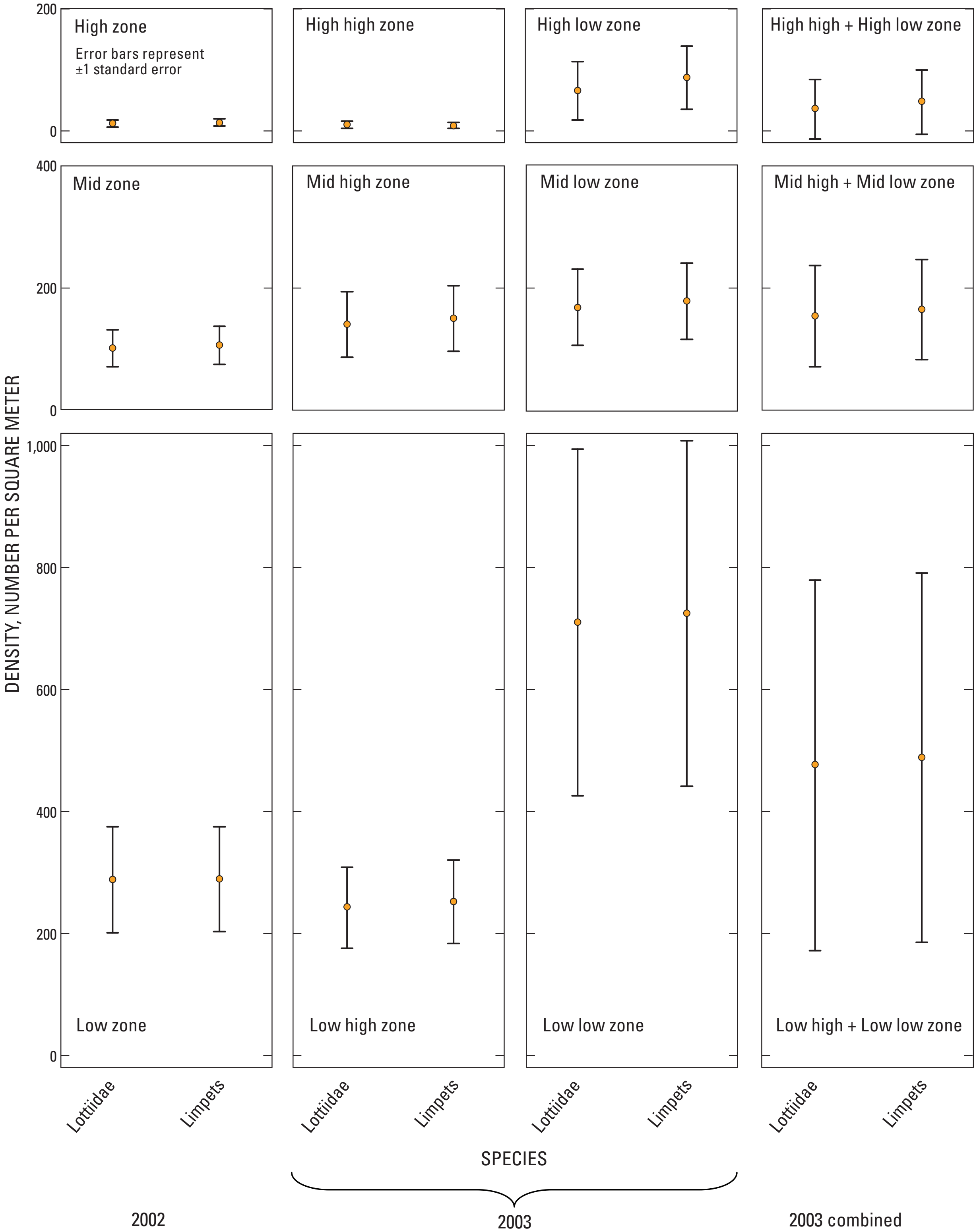

Figure 15. Densities of two small mobile invertebrate groups, Lottiidae and all limpets, through time for individual intertidal zones in 2002 and for both individual and combined zones in 2003, Sitka National Historical Park monitoring site, Alaska. The latter combined zones reflect the 2002 high, mid, and low zones. Note the differences in variability of the values. Small mobile invertebrates were only sampled in 2002 and 2003.

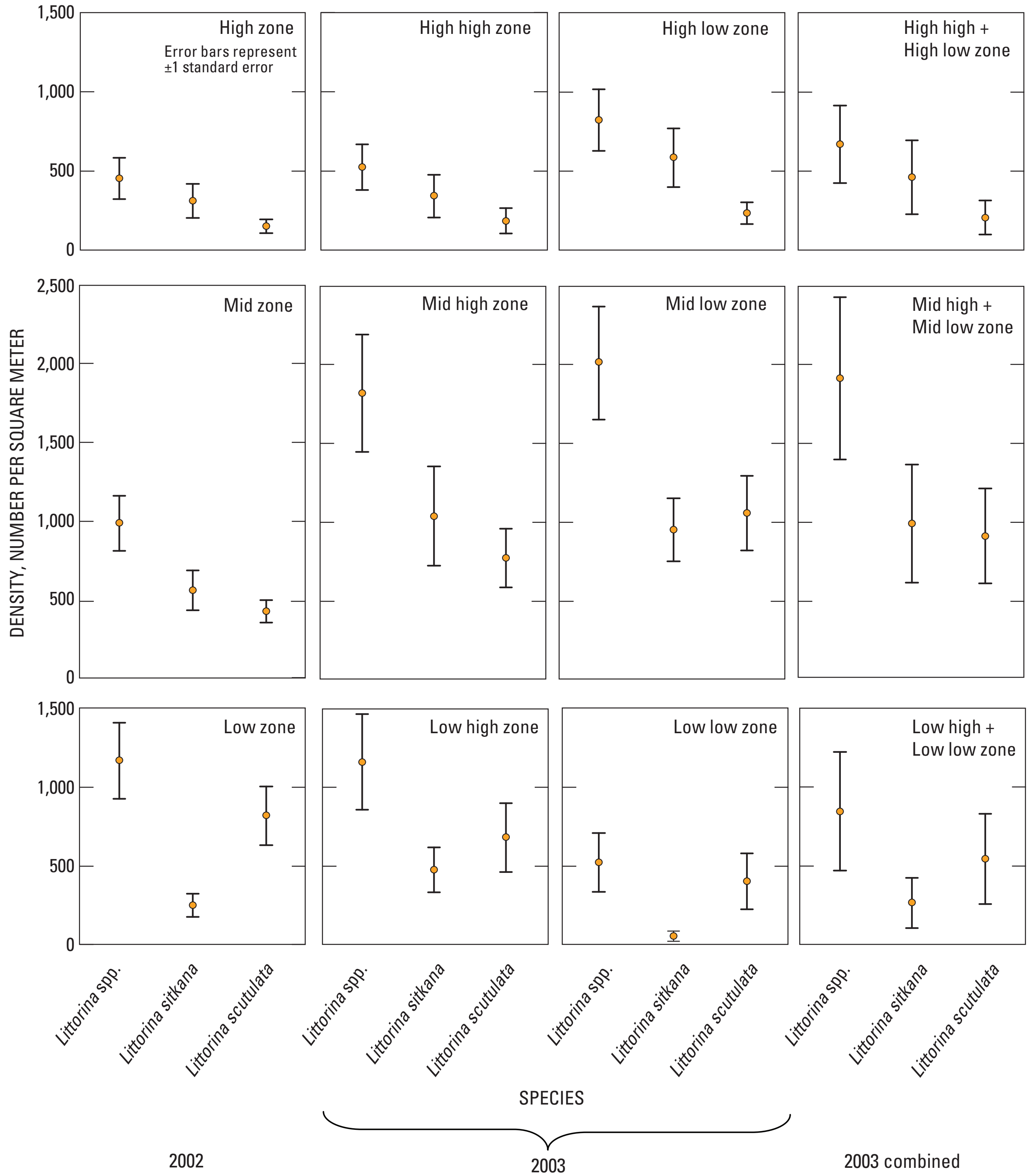

Figure 16. Densities of three small mobile invertebrate species/groups, *Littorina* spp., *Littorina sitkana*, and *Littorina scutulata*, through time for individual intertidal zones in 2002 and for both individual and combined intertidal zones in 2003, Sitka National Historical Park site, Alaska. The latter combined zones reflect the 2002 high, mid, and low zones. Note the differences in variability of the values. Small mobile invertebrates were only sampled in 2002 and 2003.

Transect sampling is reasonably efficient. After being established, sampling along transects is fairly fast. We have used a 3-D point-intercept sampling approach, which entails sampling vertically through the "canopy" down to the substrate, recording each species present in turn. Epibionts are counted as well as multiple layers of the same species. The 3-D approach provides a more detailed biological assessment of the community and its structure. For example, the data would allow one to infer if dense or large *Fucus* plants (more layers at a point) versus small, single-layer plants had been sampled. The sampling does not provide an assessment of the relative abundance of primary space-holders (those species attached to substrate) but rather provides an assessment of the relative biological composition of the intertidal assemblage. Another advantage of the point-intercept sampling approach is the corresponding substrate information that is obtained. However, a species detected at a point may be attached to a different substrate than that which underlies the point. Thus, species and substrates generally may be examined for correlation but not for relation to the occupation of primary space by a species. This latter topic is one which often is examined in mechanistic studies of intertidal ecology, where space frequently has been shown to be limiting (for example, Connell, 1961).

Large Mobile Invertebrates

Band surveys target large mobile invertebrates known to affect intertidal-zone communities: starfish, sea urchins, and large chitons. From the results presented in table 9, it is apparent that although more than 5,000 m^2 are being assessed each year, few large mobile invertebrates are being counted. The most abundant species in this group is *P. ochraceus*, the classic "keystone" species identified by Paine (1966) for its importance in structuring intertidal assemblages in Washington. Analyses indicated a significant positive trend in its presence but not a trend in density given that it was present. Given the few years of data, this should be considered a preliminary finding.

The rarity of the targeted large mobile invertebrates at low tide most likely does not represent their distribution at high tide, when their foraging range in the intertidal zone may be increased; however, they are not necessarily fast movers. Examination of their distribution along transects indicates they are most frequently detected in the low reaches of the sampled intertidal zone (fig. 10). Based on the 3 years of accumulated data, it is suggested that the current sampling be continued while initiating a test of a different type of band or block sampling that is stratified, but more focused on the low intertidal. In this case, multiple horizontal blocks, perhaps 4 m high × 25 m wide (width equals horizontal distance), could be established independent of the transect line per se and large mobile invertebrates within the blocks could be counted. The design will be affected by decisions made to focus on elevational or proportional sampling (previous discussion; fig. 14).

Small Mobile Invertebrates and Barnacle Recruits (Spat)

Quadrat sampling targets two groups: barnacle recruits (spat) and small mobile invertebrates. In some intertidal systems, recruitment limitation is thought to drive patterns of species abundances and the strength of species interactions (for example, Roughgarden and others, 1988). Whether recruitment limitation has a significant role in Alaska or whether its effect might change with time is unknown. Thus, sampling barnacle recruits provides some information that may help evaluate the relative importance of recruitment to this particular system. Because individuals up to 2 mm are being counted, an approximate estimate of recruitment over a broad time (until an organism had a chance to grow to 2 mm; mortality of smaller settlers also could be affecting these counts) is being captured. Barnacles can recruit massively in the spring; at Glacier Bay, large recruitment pulses have been detected in early May (Irvine, personal observation).

Barnacles are prominent members of intertidal communities and the larger sessile individuals are being sampled by point-intercept sampling associated with vertical transects. The small size of barnacle recruits may affect the ability of observers to detect, identify, and discriminate them. The quadrat subsampling provides a better means to estimate their density. The percent cover of barnacles over the whole beach ranges from about 11 to 14 percent (fig. 9). The mean density of barnacle recruits (within a zone, in a year) can range from about 300 to 7,000 per m^2 (fig. 13).

The most common species of small mobile invertebrates sampled within the quadrats is *L. sitkana*, a species that first was described from the Sitka area. Data showing a maximum mean density (within a zone, in a year) of about 1,000 per m^2 (fig. 11) support the decision to subsample this species. Other individuals in the same genus (*L. scutulata*; and all littorine snails, including those too small to identify: LITT) also are subsampled in the quadrats in the same manner. The next most abundant species group is the Lottiidae (fig. 11; note that the abundance of all limpets, LIMP, is driven by Lottiidae). Based on the high abundances that can occur, primarily in the low and mid intertidal zones, this species group also should be considered for subsampling at the same scale as the littorine snails. If quadrat sampling is altered to be proportional to transect length (see appendix B, point 9), the number of quadrats sampled will increase; thus, the efficiency gained by subsampling this species group will help offset the increased effort. Decisions about subsampling should be made in the context of overall design, methods used to reduce variation (because of elevational differences in the relative abundances of some species/groups, including Lottiidae), and previous power analyses.

Summary/Where Next?

This report presents the results of a pilot study whose goal was to design a probability-based intertidal monitoring protocol and test the ability of this protocol to detect trends in the predominant species in the intertidal zone of Sitka National Historical Park. The sampling, as designed, has inference to the entire designated intertidal (the sampling frame). Three different sampling methods, organized along vertical transects, targeted different types of species: point-intercept sampling of sessile species, band surveys of large mobile invertebrates, and quadrat sampling of small mobile invertebrates and barnacle recruits. Power analyses of the data obtained in 1999, 2002, and 2003 have shown the sampling to have at least an 80 percent probability (power) of detecting +10 percent trends in abundances of all targeted species, with an $\alpha = 0.05$. The ability of the sampling to detect -10 percent trends is not as uniformly good for all species. These power analyses can provide part of the foundation for discussing how the sampling design might be altered to reduce spatial variation.

During the course of data analysis and review, suggestions were made to make the sampling more consistent in approach (for example, all proportional to area). Various options for modifying the sampling design have been discussed in detail. This document can serve as a platform for discussion with the National Park Service (see appendix B for discussion points) to define (1) how intertidal monitoring at Sitka National Historical Park should interface with other projected or existent National Park Service monitoring, (2) the primary question(s) to be addressed at Sitka, and (3) how monitoring should be designed based on these broader issues/questions. A final intertidal sampling design could result from these discussions.

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Statistical Review of Sampling and Analysis Methods for Intertidal Monitoring at Sitka NHP: Final Report

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Introduction

There have been three years of intertidal sampling at Sitka NHP, starting in 1999. This report includes a review of appropriate sampling and analysis methods for the intertidal trend monitoring, trend analysis of the existing data, results of a statistical power analysis, and recommendations for future sampling and analysis at this site.

Sampling Methods

In each year of sampling (1999, 2002, 2003), 15 vertical transects are systematically selected across a one kilometer beach, with a different random start each year. Three types of sampling along the transect are used to accommodate different types of species. In brief:

- Sessile species - point samples are taken every one meter along the transect, and cover for each species is estimated by the total counted on the transect divided by the number of points sampled.
- Large macroinvertebrates – total counts are taken for one-meter wide bands on both sides of each transect. The variable of interest is density of species (counts/ area sampled).
- Small mobile species – quadrats (size varies by species) are taken systematically along transect, and counts/area or density are monitored. Sampling was not done in 1999. In 2002, three quadrats were sampled on each transect. In 2003, six quadrats were sampled on each transect.

The population units (i.e., transects) differ in length as the width of the intertidal zone varies across the beach. The number of point samples and the size of sampled area for band samples is proportional to the length of the transects. For quadrat sampling, equal numbers of samples are taken regardless of the length of the transect. Using density as the monitoring measure (transect count / total number of points *or* transect count / band area) standardizes the units across transects. However, it does not correct for the fact that each transect contains a different amount of information. That is, longer transects provide more information than shorter transects. The selected analysis method needs to adjust for this difference.

Comments on Sampling Methodology
The current sampling methodology is statistically sound. The only change that should be considered is to vary the number of quadrat samples on each transect to match the other sampling methods (discussion follows). This recommendation does not include sample sizes (number of transects and number of samples on each transect), which is discussed in the context of statistical power later in this document. This section is intended as a general discussion of different approaches that might prove more efficient for future sampling at other sites.

For long-term monitoring of the beach it might be preferable to use permanent transects if possible. This could substantially reduce the year-to-year variation in the sample, allowing trends to be more easily detected. The benefit would be greatest if the species counts along transects are correlated from year-to-year. For example, if habitat conditions are consistent from year-to-year at each transect location. It may be difficult to re-locate permanent transects, but there is potential for benefit even if the transects are not exactly in the same position. Again, this depends on the habits of the species being sampled, and it may vary substantially among species.

For the current method, vertical transects are selected with equal probability. According to Cochran (1977, p 299) the most efficient estimators of within-year cover for the beach would be found by selecting transects with probability equal to transect size – even if the size is estimated rather than known. To accomplish this with a systematic sample, the lengths of all possible transects would have to be estimated (e.g., using GIS), so that the sum of the lengths for each possible systematic sample could be used to weight the samples (i.e., the sample set with the greatest total length of transects would have highest probability of being selected). The estimators and the analysis of trend would differ if this method were used.

Selecting the number of subsamples proportional to the length of the transect is generally preferred in practice. Although there may be slight gains in efficiency from equal numbers of subsamples on each transect, there are other properties of subsampling proportional to size that are desirable (e.g., self-weighting; Cochran, 1977). The numerical difference between the two methods is negligible with reasonable sample sizes. The current sampling design contains a mixture of methods, however, with the quadrat sub-sample sizes equal among transects. It would be preferable to standardize the approach across the different types of sampling where possible. In this case, I recommend sticking with the proportional sampling method, which means that the quadrat sampling method should be revised.

Analysis Methods

Point Sampling
Primary population units of unequal size (transects) are selected with equal probability, and then subsampled. For the analysis of status in a particular year, the mean cover estimate should be:

$$\bar{y} = \frac{\sum_{i=1}^{n} M_i \overline{y_i}}{\sum_{i=1}^{n} M_i}, \qquad \textbf{(Equation 1)}$$

where:

n is the number of sampled transects,

M_i is the number of possible subsamples on transect i,

$$\overline{y_i} = \frac{\sum_{j=1}^{m_i} y_{ij}}{m_i},$$

y_{ij} is the species count for the jth subsample on the ith transect, and

m_i is the number of subsamples taken on transect i.

The variance of the estimator is approximated by:

$$v(\bar{y}) \cong \frac{\sum_{i=1}^{n} M_i^2 (\overline{y_i} - \bar{y})^2}{n(n-1)\overline{M}^2}, \qquad \textbf{(Equation 2)}$$

where $\overline{M} = \frac{\sum_{i=1}^{n} M_i}{n}$. The formula is approximate because another variance term, the variance within a transect, becomes relevant if the proportion of the population sampled (i.e., the proportion of possible transects sampled) becomes non-negligible. In this case, n = 15 transects out of a possible total of 500 (1000m beach minus 290m unusable, divided by 2m wide transect) is a fairly small proportion. However, if the number of transects were to be greatly increased, this formula should be adjusted.

For point sampling, M_i is not known (or is infinite), but m_i is proportional to M_i, so m_i can be substituted into the above equations without loss of generality. Equation 1 simplifies to:

$$\bar{y} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m_i} y_{ij}}{\sum_{i=1}^{n} m_i}. \qquad \textbf{(Equation 3)}$$

For trend analysis with more than two years, a single regression or correlation analysis between year and species cover is an appropriate trend tool. A weighted regression (weighted by sample size or transect length) would yield the most efficient estimator of slope or trend. The statistical distribution of transect densities varies by species. Species with higher densities may be approximately normal or transformable to normal. Species with a high number of zero transect densities are not likely to fit a standard statistical distribution. Nonparametrics could be used, but it is not clear how the weighting would be applied. In this case, I recommend a tiered parametric weighted linear regression as follows:

- If the residuals from the normal weighted regression of a particular species were approximately normally distributed, the regression would be used as the test of trend.
- If the residuals from a normal weighted regression applied to transformed data (e.g., square root or log) are approximately normally distributed, the transformed regression would be used as the test of trend.
- If no transformation is found to be satisfactory the analysis would be split into a weighted logistic regression (modeling presence/absence on transects) paired with a normal or Poisson regression on the positive transect densities.

This tiered analysis method is demonstrated on the current data in the analysis section of this report.

Band Sampling
For band sampling, there is no subsampling, but each unit is of unequal size. This is like single-stage cluster sampling, and equations 1 and 2 above are appropriate with M_i equal to the length of the transect *i*. The trend analysis methods are also the same, with the weights equal to the length of the transect.

Quadrat Sampling
Counts are taken on equal-sized quadrats (within a species) and with equal numbers of quadrats on each transect. Quadrats are located systematically along the transect, with a random start. Existing data are for two years, with different numbers of quadrats for the two years (three in 2002 and six in 2003). For status estimates, equations 1 and 2 above are appropriate with M_i equal to the length of transect *i*. The differing sampling intensity between the two years is not a big issue for the normal regressions because transects are the primary population units. The trend analysis methods are also the same. However, the logistic regressions are not valid for different sample sizes among years. The quantity being modeled in this case is the probability of seeing the species on a transect. Even if the number of species present has not changed, you are twice as likely to see the species in 2003. For species that do not have normal (or transformable to normal) residuals, the differences between 2002 and 2003 can be assessed using a nonparametric t-test. In future years, the 2002 data would not be included in the logistic regression analysis.

Trend Analysis of Existing Data

For each species, a weighted linear regression was fit, relating year to species density (point samples: counts/#points sampled; band samples: counts/m^2; quadrat samples: counts/quadrat) for each transect. Normality of residuals was assessed using Shapiro-Wilks goodness-of-fit test with alpha = 0.05. If the test was rejected, densities were square root transformed, the model re-fit, and the residuals retested. If this test was rejected, the process was repeated with log (base e, +1) transformation. If one of these transformations was successful, a significant slope parameter indicates a trend.

If none of the transformations was successful, the analysis was divided into an analysis of presence/absence of species combined with a conditional regression analysis on density of species given that the species was observed. First, the probability of the species being observed on transects was fit using weighted logistic regression as a function of year. If the slope parameter is significant, this indicates a temporal trend in species occurrence spread across the beach. The second part of the analysis is to take the observed density of species when it occurs and fit this using a weighted linear regression. For quadrat samples in this category, a nonparametric t-test was used to test for differences between 2002 and 2003. Logistic regression is not appropriate on quadrat samples because different numbers of quadrats were sampled in the two years.

Results of this analysis on current data are displayed in Tables 1 through 3. For those species for which normal regressions were not used, there are some cases with a trend in presence of a species, but not a trend in density given that the species is present. This can be taken to mean that a species is reduced (or increased) in spatial coverage, but not necessarily in density when observed. In other words, there may be fewer clumps of the species, but the clumps are of comparable size. Of course, these conclusions must be made with statistical power in mind.

Statistical Power Analysis

The power analysis discussed in this section focused on the question of how many transects should be sampled in each year in order to detect exponential changes of magnitude 10% per year, by 2011. Power was estimated for species for which approximate normal distribution could be assumed (with or without transformation). Thus, no large macroinvertebrates have been included. Because the methods for other species were different and more complex, we will assume that the power is lower for these species. A next phase of power analysis may consider rare species.

Statistical power was assessed using Monte Carlo simulations. The statistical power for detecting trend is the probability of rejecting the null hypothesis of zero slope in a weighted-least-squares linear regression, given that a 10% annual increase exists. Other specifications of the power analysis are:

- Two-tailed tests with alpha = 0.05 and 0.10 were assumed.
- Positive and negative 10% exponential trends were evaluated.
- The added trend began in 2004, and continues until the end of sampling.
- The tested number of transects sampled each year will be 10, 12, 15, 18.
- The existing level of subsampling (within transects) was assumed.
- Three sampling scenarios were tested:
  - SS1: 2006, 2007, 2008, 2009, 2010, 2011
  - SS2: 2007, 2009, 2011
  - SS3: 2008, 2011

- The current mean was estimated as the average of the existing two or three years of data (1999-2003).
- The distribution of residuals, which includes sampling error as well as year-to-year variability, was estimated from the existing three years of data after removing linear trend from un-transformed data. Trend was removed regardless of whether the trend was statistically significant for these three years.

The flowchart in Figure 1 shows the framework for the power simulations. The transect lengths are positively correlated with the residuals. Therefore, to select appropriate residuals it was necessary to segregate the residuals into three groups according to length classes. The division of length classes was set objectively at the 1/3 and 2/3 quantiles of the existing distribution of transect lengths. Thus, the residual distributions used for simulations varied by transect length.

Table 4 displays the parameters and distributions used for the power simulations for each species. The starting mean and residual distributions are estimated on untransformed data. Transformations, if required based on current data, are performed prior to analysis for each simulated data series. The parameters displayed for lognormal distributions are the mean and standard deviation of the logged data. Since lognormal distributions are strictly positive, a constant greater than the largest negative residual had to be added to the residuals prior to estimating parameters for the lognormal distributions. The same constant was then subtracted from the sample value generated for each simulation run. Lognormal residual distributions are truncated to avoid unrealistically high average point or quadrat counts. The truncation points were selected by trending the maximum observed transect average to one year past the period of trend for the power analysis (i.e., max observed x 1.1^9).

Results and Discussion

Several species had 100% power for all scenarios with +/- 10% exponential trend, so 5% trend scenarios were added. Tables 5-8 display the power estimates in tabular form. Figures 2 through 5 display the power estimates graphically.

Remarkably, all species have 100% power for detecting +10% exponential trends regardless of the number of transects if sampling is done every year from 2006 to 2011. The statistical power in other situations varies from poor to excellent across the species. BGSB, BARN, and LITT have the highest power, and LO and BS have the lowest power overall. The difference between power for positive versus negative trends varies among species, depending on proximity to zero, starting mean, and residual variance. For example, HG, LIMP, and MY have extremely low power for detecting negative trends, but moderate power for detecting positive trends.

For most species the improvement in statistical power for sampling 18 transects instead of 15 is not large enough to warrant the increased cost. Decreasing the number of transects to 12 does not appear to result in a major loss of power. Decreasing from 15 to 10 transects, according to these simulations, would result in a significant loss of power for some species. For example, a reduction to 10 transects would reduce the power to detect a +5% trend in TP from 62% to 44% (sampling scheme SS1, alpha = 0.05). For some species, the power appears to slightly decline with an increase in sample size – this is due to sample error in the simulation results and should not be viewed as a remarkable difference.

The reduction in power for using sampling scheme SS2 instead of SS1 or SS3 instead of SS2 are proportional to the number of years not sampled. SS2 is half the number of years sampled from SS1, and the reduction in power is greater than that between SS2 and SS3, which is two versus three years.

Final Recommendations

The final recommendations are as follows:

1.) Consider a sampling scheme with the number of quadrats per transect varying by transect length. A proportional quadrat sampling scheme should improve the efficiency of sampling.
2.) For species with lower power results (power for 10% trend less than 50%, for example) alpha=0.10 should be used.
3.) The number of transects should not be increased to 18. If it is necessary to decrease the number of transects, 10 transects may be too few.
4.) Sample as many years as possible, but it may not be necessary to sample every year. Sampling every-other or every-third year does not decrease power substantially, but it will increase the time needed before a trend (if present) is confirmed.

Analysis Methods Summary

After sampling has been conducted in future years, the following analysis approach is recommended:

1. Fit a normal weighted linear regression to the average result for each transect (y-variable) by year (x-variable) with transect lengths as weights. If the residuals from this regression are approximately normally distributed, a significant slope result indicates a significant trend.
2. If the residuals from the normal weighted regression are not normal, try applying standard transformations (e.g., square root or log) and re-running the weighted regression. If these residuals are approximately normal, then a significant slope result indicates a significant trend.
3. For point and band data, if no transformation is found to be satisfactory, run a weighted logistic regression on the presence/absence of species on each transect. A significant slope result indicates that there is a trend in occurrence of the species. Next, run a normal weighted regression as in step 1, on transects with positive (i.e., non-zero) results only. A significant slope (with normal residuals) indicates a significant trend in densities when the species is present.
4. For quadrat data with different numbers of quadrats among years, step 3 is not appropriate. A non-parametric multiple comparison among years would be the simplest approach. Other approaches, such as using a more complex random

effects model with quadrats as correlated replicates could be attempted when more data are available.

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Table 1. Results of Trend Analysis on Current Point Data
Units are species counts per meter (per point)

Normal Regressions on Density

Species or Group	Short Name	Transformation	Slope Estimate	Standard Error	t-value	p-value	Significant Trend?
Fucus garderni	FU	Square Root	-0.007	0.0178	-0.3933	0.696	NO
B. glandula/S. balanoides	BGSB	None	-0.007	0.0043	-1.6572	0.105	NO
Barnacles, Total	BARN	None	-0.009	0.0038	-2.3369	0.024	Negative
Mytilus trossulus	MY	Square Root	0.012	0.0074	1.6155	0.114	NO

Logistic Regressions for Transect Presence/Absence

Species or Group	Short Name	Slope Estimate	Null Deviance	Residual Deviance	Chi-square value	p-value	Significant Trend?
Neorhodamela/Odonthalia,Total	neod	-0.1495	10552.27	10430.02	122.25	0	Negative
Puccinellia nutkaensis	PN	-0.0735	10567.13	10537.63	29.5	0	Negative
Zostera marina	ZO	-0.0270	8067.817	8065.06	2.757	0.097	NO
Semibalanus cariosus	SC	0.2734	11386.66	10955.31	431.35	0	Positive
Mastocarpus papillatus	MA	-0.1433	10754.42	10644.75	109.67	0	Negative
Plantago maritima	PLA	-0.0268	7342.549	7340.159	2.390	0.1221	NO
Algal Crusts, Total	alga	0.0934	11141.87	11090.92	50.95	0	Positive

Normal Regressions on Positive Densities

Species or Group	Short Name	Transformation	Slope Estimate	Standard Error	t-value	p-value	Significant Trend?
Neorhodamela/Odonthalia,Total	neod	Square Root	0.0158	0.0171	0.9218	0.371	NO
Puccinellia nutkaensis	PN	None	0.0039	0.0054	0.7185	0.487	NO
Zostera marina	ZO	None	-0.0219	0.0222	-0.9838	0.358	NO
Semibalanus cariosus	SC	None	0.0029	0.0026	1.1329	0.271	NO
Mastocarpus papillatus	MA	Square Root	-0.0029	0.0042	-0.6935	0.495	NO
Plantago maritima	PLA	None	0.0143	0.0075	1.9205	0.127	NO
Algal Crusts, Total	alga	Square Root	-0.0027	0.0074	-0.3697	0.715	NO

Table 2. Band Data Analysis of Current Data
Units are Counts per Square Meter.

Logistic Regression on Transect Presence

Species	Short Name	Slope Estimate	Null Deviance	Residual Deviance	Chi-Squared Value	p-value	Significant Trend?
Pisaster ochraceus	PI	0.220	10358.77	10123.06	235.71	0	Positive

Conditional Normal Regression on Positive Densities

Species	short name	Transformation	Slope Estimate	Standard Error	t-value	p-value	Significant Trend?
Pisaster ochraceus	PI	N	0.0025	0.0018	1.3603	0.1987	NO

Table 3. Results of Trend Analysis on Current Quadrat Data

Units are species counts per quadrat

Normal Regressions on Density

Species or Group	Short Name	Transformation	Slope Estimate	Standard Error	t-value	p-value	Significant Trend?
Lottidae < 8mm	LO	Square Root	0.735	0.411	1.786	0.085	NO
Littorina sitkana	LSI	None	1.032	0.549	1.879	0.071	NO
Littorina scutulata	LSC	Square Root	0.0906	0.136	0.664	0.512	NO
Barnacle spat (not mobile)	BS	Square Root	-0.788	0.220	-3.59	0.0013	Negative
Tectura persona (limpet)	TP	Square Root	-0.0366	0.114	-0.322	0.750	NO
Hemigrapsus spp. (crab)	HG	Ln(X+1)	0.3232	0.076	4.271	0.0002	Positive
All limpets	Limp	Square Root	0.5772	0.420	1.373	0.1807	NO
Littorine spp.	Litt	None	1.3999	0.823	1.701	0.1000	NO

Nonparametric Wilcoxon test on Densities

Species or Group	Short Name	Average Density 2002	Average Density 2003	Wilcoxon Test p-value	Significant Trend?
Amphipods	AM	0.467	1.61	0.018	Positive
Hermit crabs	Hermit	0.111	0.933	0.0023	Positive
Nucella spp. (predatory snails)	Snail	0.222	0.222	0.37	NO
Isopods	ISO	0.0889	0.456	0.054	NO

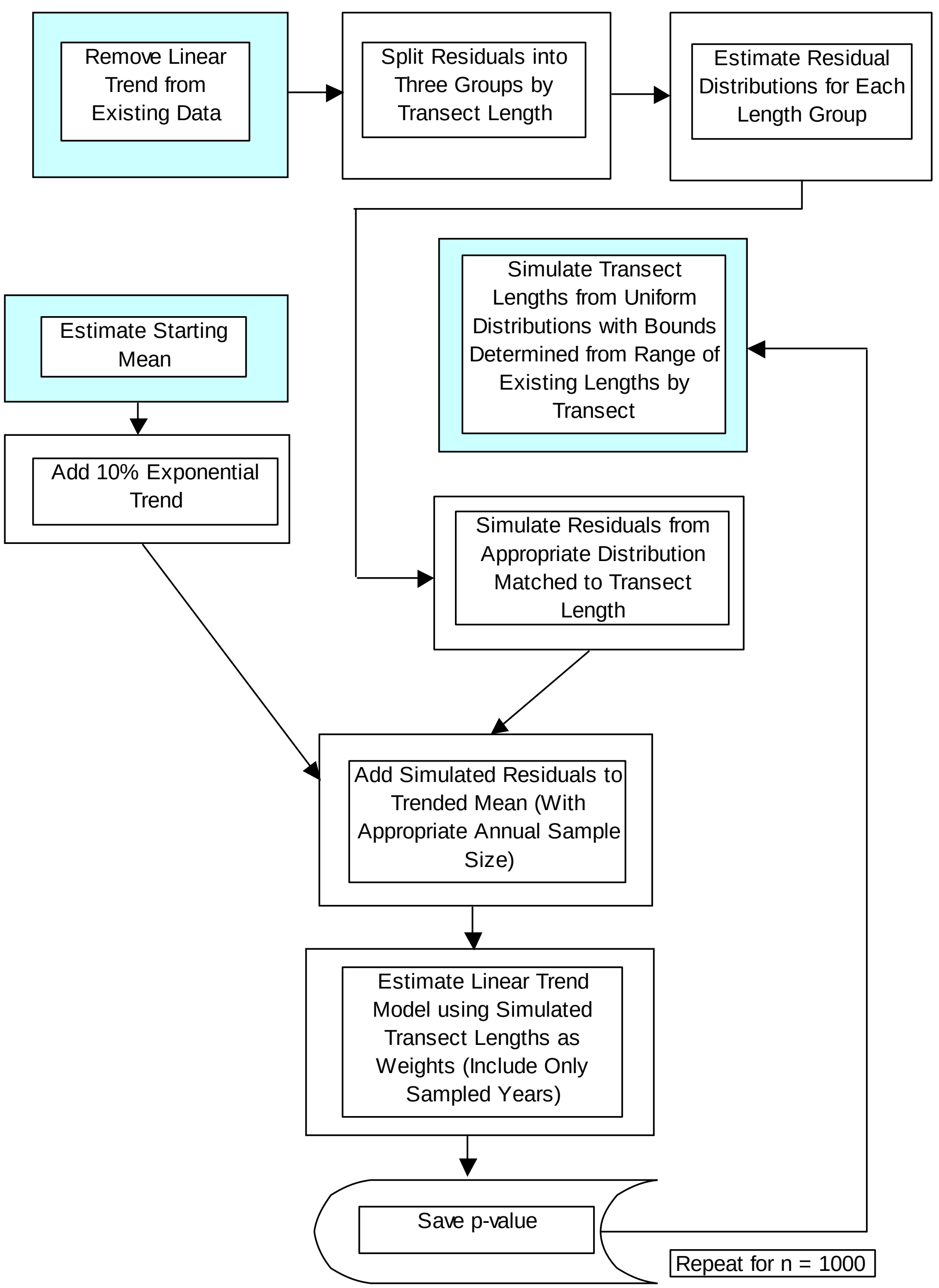

Figure 1. Flow chart showing the process followed for Monte Carlo simulations of trended intertidal data for statistical power analysis. Blue boxes show independent process starts.

Table 4. Parameter Estimates for Power Simulations

Sample Type	Species	Transformation For Trend Analysis	Starting Mean	Residual (Mean, Stdev) Short Transects (<175 m)	Mid-Length Transects (175-197 m)	Long Transects (>197 m)
Point Data (Counts per point)	BGSB	None	0.0928	(-0.0073,0.0432)	(-0.0052,0.0418)	(0.0050,0.0582)
	BARN	None	0.1196	(-0.0189,0.0439)	(-0.000664,0.0369)	(0.00729,0.0497)
	FU	SQRT	0.2910	(-0.159,0.104)	log(x+.25); (-1.65,0.847)	log(x+.25); (-1.45,0.853)
	MY	SQRT	0.0247	(-0.00991,0.0156)	log(x+.05); (-3.11,0.441)	log(x+.05); (-3.12,0.671)
Quadrat Data (Counts per Quadrat)	LO	SQRT	18.5	(-15.2,7.80)	(-2.56,14.3)	(10.2,22.2)
	LSI	None	4.47	(-2.06,2.20)	(1.08,3.39)	(0.233,2.86)
	LSC	SQRT	4.61	(-3.13,1.45)	(0.336,3.41)	(1.19,3.06)
	BS	SQRT	5.06	(-1.67,4.18)	(-0.256,3.15)	log(x+8); (1.71,1.29)
	TP	SQRT	1.49	log(x+1.7); (-0.0660,1.35)	log(x+1.7); (0.323,0.728)	(-0.217,1.17)
	HG	Ln(X+1)	1.05	log(x+1.5); (-0.221,1.12)	(-0.216,0.663)	(0.210,0.958)
	Limp	SQRT	18.6	(-14.1,6.74)	(-0.438,13.4)	(8.28,24.2)
	Litt	None	9.27	(-5.29,3.55)	(1.25,3.84)	(1.59,3.94)

Table 5. Estimated Statistical Power for Sessile Species (Point Sampling) with alpha = 0.05.

		SS1				SS2				SS3			
	Trend	18	15	12	10	18	15	12	10	18	15	12	10
BGSB	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	99%
	+5%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-5%	96%	97%	91%	90%	91%	92%	82%	79%	87%	86%	77%	74%
BARN	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	+5%	100%	100%	99%	98%	99%	96%	94%	84%	97%	90%	84%	70%
	-5%	100%	100%	100%	100%	100%	100%	100%	99%	99%	100%	99%	98%
FU	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	100%	100%	99%	98%	98%	97%	95%	94%	96%	95%	91%	90%
	+5%	77%	61%	67%	51%	56%	42%	44%	31%	49%	34%	36%	25%
	-5%	85%	86%	68%	69%	73%	78%	58%	62%	71%	70%	54%	56%
MY	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	69%	66%	51%	51%	54%	52%	37%	35%	47%	42%	31%	28%
	+5%	57%	55%	52%	46%	49%	46%	43%	38%	48%	44%	41%	40%
	-5%	22%	24%	15%	14%	17%	16%	11%	12%	14%	13%	11%	9%

Table 6. Estimated Statistical Power for Small Mobile Species (Quadrat Sampling) with alpha = 0.05.

		SS1				SS2				SS3			
	Trend	18	15	12	10	18	15	12	10	18	15	12	10
LO	+10%	100%	100%	100%	100%	100%	100%	99%	97%	99%	99%	98%	96%
	-10%	46%	57%	36%	38%	38%	48%	30%	31%	42%	42%	26%	27%
	+5%	47%	32%	39%	32%	39%	23%	34%	27%	31%	24%	32%	24%
	-5%	9%	18%	7%	9%	8%	15%	7%	9%	10%	14%	7%	7%
LSI	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	99%	97%	94%	89%	96%	90%	82%	75%	93%	82%	69%	66%
	+5%	75%	69%	70%	60%	58%	58%	58%	48%	52%	54%	52%	44%
	-5%	65%	51%	40%	34%	50%	38%	28%	23%	49%	33%	23%	19%
LSC	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	100%	100%	99%	98%	100%	99%	94%	93%	99%	98%	91%	88%
	+5%	56%	40%	50%	39%	42%	29%	40%	30%	33%	30%	38%	29%
	-5%	81%	83%	64%	69%	72%	77%	54%	58%	76%	72%	50%	55%
BS	+10%	100%	100%	100%	100%	100%	100%	98%	94%	100%	99%	94%	85%
	-10%	28%	34%	25%	27%	28%	33%	23%	26%	33%	34%	25%	31%
	+5%	27%	30%	25%	21%	19%	19%	18%	15%	18%	18%	16%	13%
	-5%	8%	10%	7%	8%	10%	12%	11%	11%	12%	13%	11%	12%
TP	+10%	100%	100%	100%	100%	100%	100%	100%	99%	100%	100%	100%	99%
	-10%	86%	84%	79%	74%	77%	73%	68%	63%	73%	67%	62%	58%
	+5%	58%	62%	50%	44%	45%	43%	36%	32%	39%	39%	30%	26%
	-5%	37%	33%	29%	28%	29%	29%	27%	24%	30%	25%	23%	22%
HG	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	27%	31%	21%	18%	14%	20%	11%	8%	12%	14%	8%	7%
	+5%	81%	74%	77%	67%	71%	57%	62%	50%	62%	53%	53%	45%
	-5%	2%	4%	1%	2%	1%	2%	1%	1%	2%	2%	1%	1%
Limp	+10%	100%	100%	100%	100%	100%	100%	99%	97%	99%	98%	98%	94%
	-10%	47%	55%	35%	36%	37%	48%	27%	27%	40%	41%	25%	26%
	+5%	57%	46%	52%	42%	45%	35%	42%	35%	35%	34%	38%	31%
	-5%	9%	14%	7%	7%	7%	13%	7%	8%	10%	15%	5%	9%
Litt	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	99%	98%
	+5%	98%	95%	97%	88%	91%	87%	89%	77%	82%	81%	83%	70%
	-5%	98%	96%	91%	89%	92%	90%	75%	73%	91%	83%	65%	61%

Table 7. Estimated Statistical Power for Sessile Species (Point Sampling) with alpha = 0.10.

		SS1				SS2				SS3			
		18	15	12	10	18	15	12	10	18	15	12	10
BGSB	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	+5%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-5%	99%	99%	96%	95%	95%	96%	90%	88%	93%	92%	87%	85%
BARN	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	+5%	100%	100%	100%	99%	100%	98%	97%	93%	99%	95%	93%	84%
	-5%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	99%	100%
FU	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	100%	100%	100%	99%	99%	99%	97%	96%	98%	97%	95%	94%
	+5%	92%	82%	84%	73%	79%	62%	66%	52%	69%	54%	56%	42%
	-5%	92%	93%	80%	81%	84%	86%	69%	72%	81%	81%	68%	67%
MY	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	84%	80%	67%	67%	69%	65%	51%	51%	60%	56%	43%	42%
	+5%	77%	72%	72%	66%	68%	65%	62%	56%	66%	61%	59%	54%
	-5%	36%	38%	26%	26%	27%	26%	22%	21%	24%	25%	18%	16%

Table 8. Estimated Statistical Power for Small Mobile Species (Quadrat Sampling) with alpha = 0.10.

		SS1				SS2				SS3			
		18	15	12	10	18	15	12	10	18	15	12	10
LO	+10%	100%	100%	100%	100%	100%	100%	100%	99%	100%	100%	99%	99%
	-10%	65%	75%	54%	55%	56%	65%	47%	45%	59%	59%	40%	39%
	+5%	68%	51%	61%	50%	57%	39%	52%	44%	49%	40%	48%	40%
	-5%	20%	31%	17%	19%	16%	29%	15%	17%	22%	25%	14%	15%
LSI	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	100%	99%	98%	96%	99%	95%	92%	86%	99%	92%	83%	78%
	+5%	88%	84%	82%	77%	77%	74%	73%	67%	69%	69%	68%	60%
	-5%	81%	69%	57%	53%	69%	56%	43%	39%	67%	48%	37%	34%
LSC	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	100%	100%	100%	100%	100%	100%	98%	98%	100%	99%	96%	93%
	+5%	74%	62%	70%	57%	61%	48%	57%	49%	52%	48%	55%	47%
	-5%	93%	93%	81%	85%	87%	90%	71%	75%	89%	84%	66%	69%
BS	+10%	100%	100%	100%	100%	100%	100%	100%	98%	100%	100%	99%	95%
	-10%	43%	50%	39%	41%	42%	47%	38%	39%	44%	47%	34%	40%
	+5%	46%	48%	42%	37%	35%	37%	32%	28%	33%	31%	30%	25%
	-5%	17%	19%	16%	17%	17%	21%	19%	18%	21%	23%	19%	20%
TP	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	94%	93%	91%	84%	88%	85%	82%	75%	86%	80%	75%	70%
	+5%	77%	78%	69%	64%	63%	63%	56%	50%	59%	56%	47%	44%
	-5%	55%	48%	46%	44%	48%	44%	40%	38%	45%	41%	38%	35%
HG	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	45%	50%	37%	33%	28%	36%	24%	19%	27%	28%	17%	16%
	+5%	92%	87%	88%	83%	84%	75%	77%	70%	79%	69%	72%	64%
	-5%	7%	10%	5%	5%	4%	5%	4%	3%	5%	5%	4%	4%
Limp	+10%	100%	100%	100%	100%	100%	100%	100%	99%	100%	100%	99%	98%
	-10%	66%	74%	52%	53%	54%	61%	42%	41%	57%	57%	39%	38%
	+5%	73%	65%	70%	62%	64%	51%	59%	52%	54%	50%	55%	49%
	-5%	20%	27%	13%	17%	17%	24%	14%	16%	20%	23%	13%	17%
Litt	+10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	-10%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	+5%	100%	98%	99%	97%	96%	95%	96%	88%	92%	92%	92%	84%
	-5%	100%	99%	97%	95%	98%	96%	88%	87%	96%	92%	81%	79%

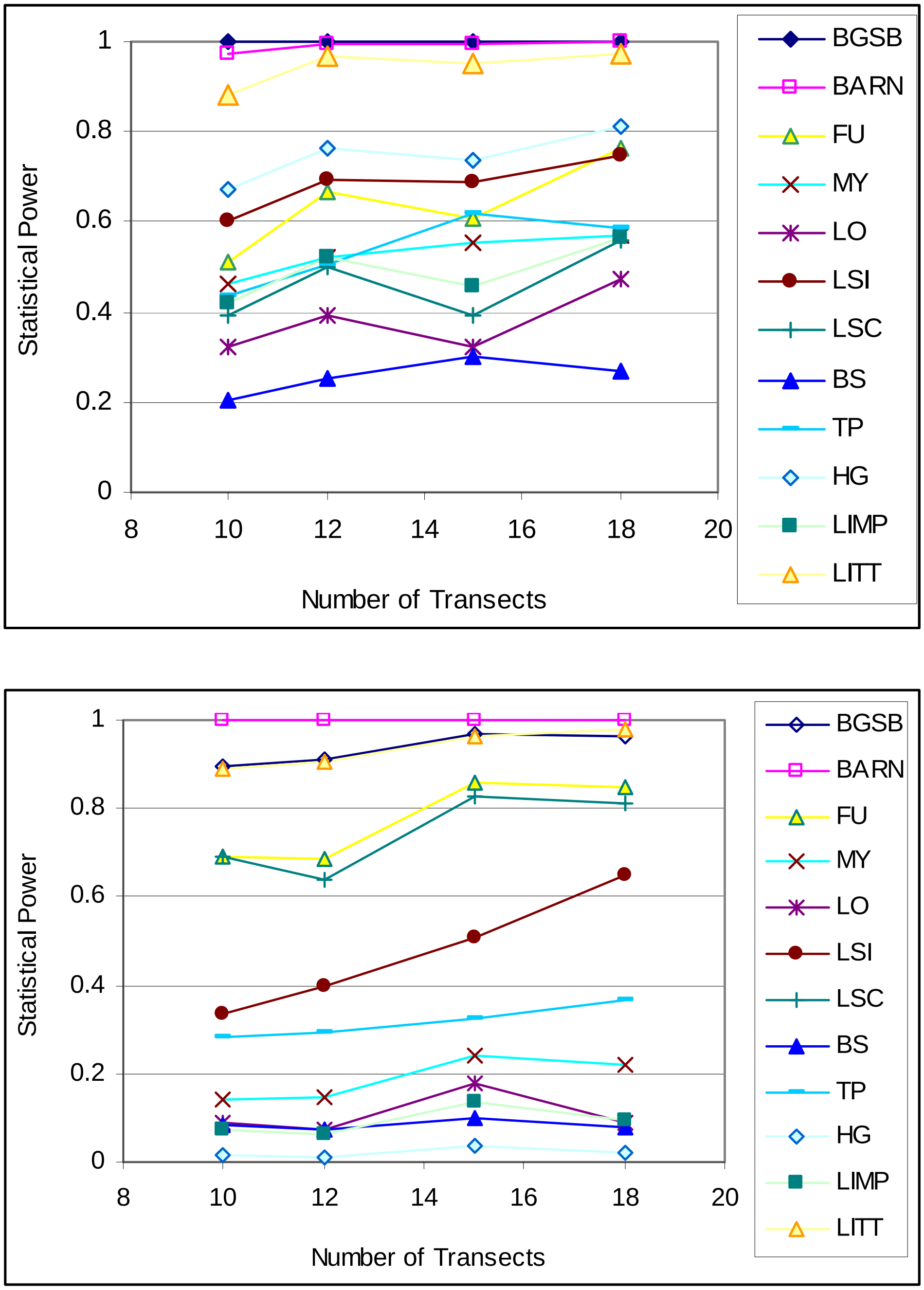

Figure 2. Estimated statistical power for all species for +5% exponential trend (top plot) and –5% exponential trend (bottom plot), with alpha = 0.05, with sampling strategy SS1.

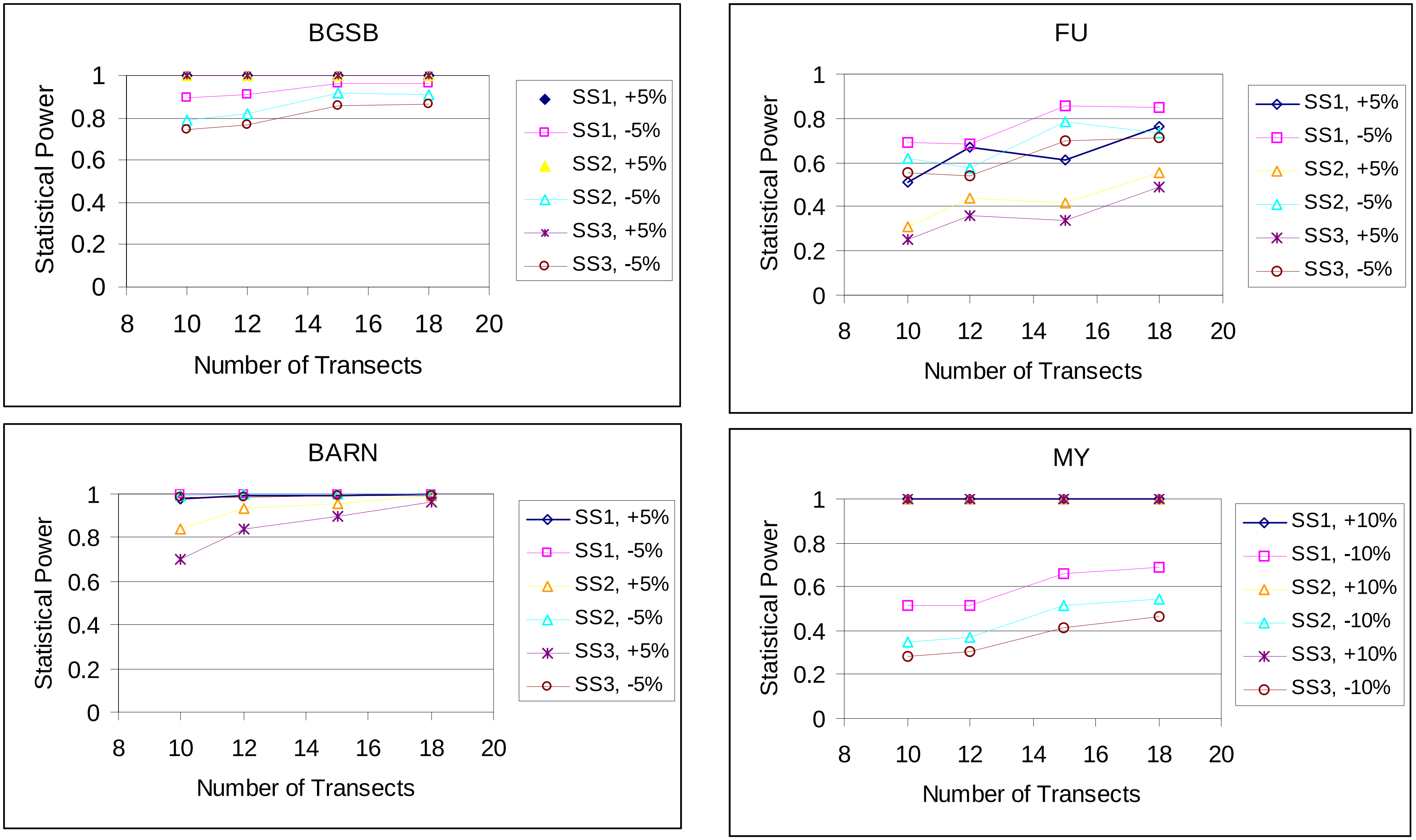

Figure 3. Estimated statistical power for sessile species with alpha = 0.05 for three sampling schemes and number of transects. Note that magnitude of trend differs among plots.

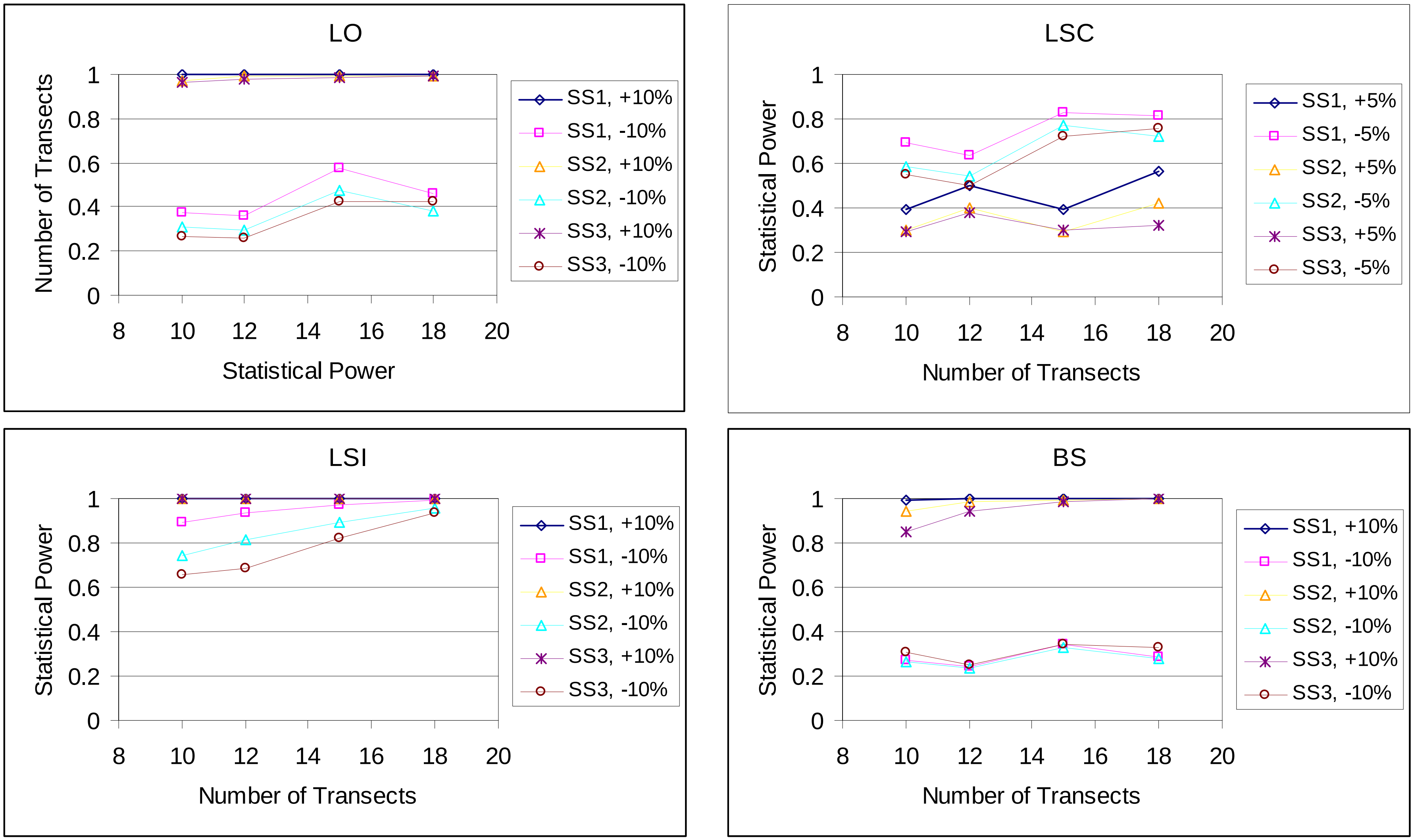

Figure 4. Estimated statistical power for small mobile species with alpha = 0.05 for three sampling schemes and number of transects. Note that magnitude of trend differs among plots.

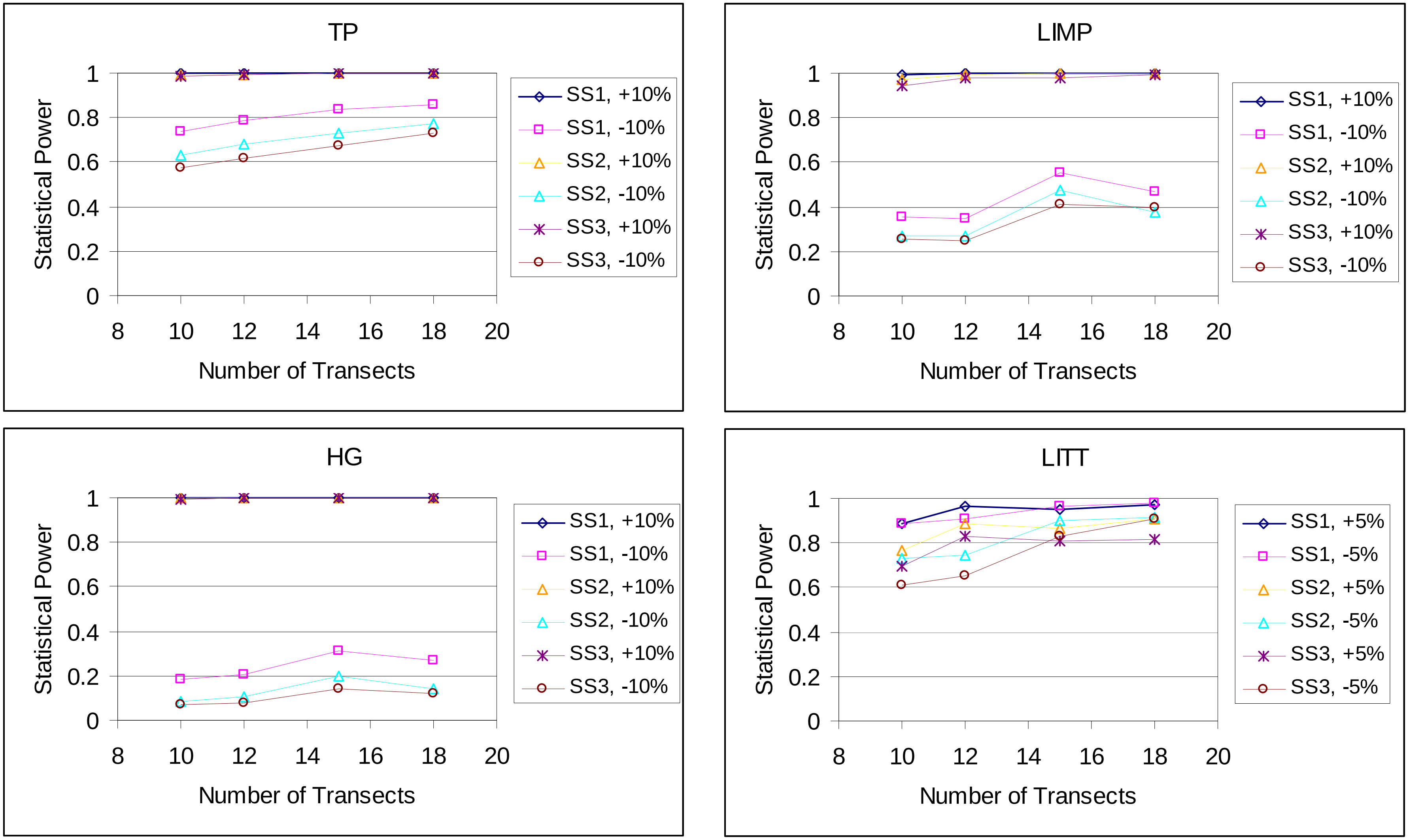

Figure 5. Estimated statistical power for small mobile species with alpha = 0.05 for three sampling schemes and number of transects. Note that magnitude of trend differs among plots.

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Appendix B. Discussion Points

This project has been a pilot study in which various methods were used to sample intertidal biota. During the course of sampling, data analysis, and review of the project, a number of issues emerged that were of importance to discuss. The level of importance varies; some points or questions are pivotal to making decisions about the sampling design, others are of lesser importance. These points provide, however, a basis for engaged discussion between National Park Service (NPS) and U.S. Geological Survey (USGS) staff that should improve the development of protocols for intertidal monitoring at Sitka National Historical Park (NHP).

1. Consider establishing similar methods for intertidal protocols at Sitka NHP and Glacier Bay National Park and Preserve (GLBA). Discussing this right at the beginning could affect decisions regarding sampling.

2. What is the primary question being posed in the monitoring? What level of change (effect level) and confidence level are desired? How do responses to these questions affect sampling design? Figure 14 details two approaches to trend detection with different emphases—(1) increased spatial inference and (2) decreased spatial variation. The results of the discussion will affect the sampling design.

3. If the NPS is interested in (1), increased spatial inference, coupled with sampling proportional to area, then the basic probability-based sampling design used thus far is sound, although some modifications would be needed to make the sampling consistent in approach (for example, quadrat sampling) or more effective (for example, band surveys).

4. Discuss methods to permanently mark and define the sampling frame (the beach); doing so will ensure consistency in the scope of sampling. Are there any residual statistical issues from the change in location of the sampling frame origin between 1999 and 2002? Establishing permanent markers on bedrock, riprap, or in the supratidal to mark beginning and end of the site extent will increase the likelihood of their persistence and usefulness. The same is true for marking transect locations if the choice is made to use permanent transects.

5. The systematic placement of transects with a random start has been the core of the probability-based sampling design; continuing this would maintain continuity of design. It may be worthwhile to consider whether selection of transects proportional to size presents any advantages, if done within the context of systematic sampling. Statisticians have varied in their views of whether selecting transects proportional to size would be an improvement; consequences for the other sampling associated with transects should be discussed.

6. Consider the pros and cons of establishing ‘permanent’ vertical transects and evaluate the ability to do so by differential global positioning systems (GPS) and permanent high intertidal or supratidal markers for reference. The major advantage of sampling permanent transects would be reduction in spatial variation. The cons include some decreased spatial inference and the possibility of trampling effects. Discuss issues of visitor trampling (see point 26) and the potential effects of intertidal sampling on biota.

7. Discuss power analysis results pertaining to the number of transects to be sampled. The current power analyses, based on sampling that re-randomized the location of transects each year, support continuing to sample 15 transects although there is some flexibility in deciding how many to sample without significantly affecting power. The analyses further support that the number of transects should not be increased to 18 nor decreased to 10 (appendix A). Re-evaluating this decision with time could maintain the efficiency of the sampling design, but any changes should be undertaken cautiously because other data linked to transects (for example, quadrats) might not be changing statistically in the same ways. If transect locations are made permanent, then an expected reduction in spatial variation could affect future design decisions.

8. Discuss the implications of different sampling approaches for point-intercept sampling of sessile species along transects. Sampling options include (1) sampling proportional to length (the current method), (2) sampling a set number of points along each transect, which is essentially elevational sampling, or (3) sampling proportional to length but redistributing the data into elevational bands.

9. If, after discussion, the NPS wants a consistent, proportional sampling scheme for all the sampling, then the quadrat sampling would need to be modified. In a proportional quadrat sampling scheme, the number of quadrats sampled per transect varies by transect length. A proportional quadrat sampling scheme should improve the efficiency of sampling. One option is to sample one quadrat each 15 meters (or 20 meters). At the one quadrat per 15 meters level of sampling, the minimum number of quadrats sampled on a transect would be three (based on the shortest transect sampled: 44.6 meters). The maximum number, for a transect of 329 meters, would be 21. Further evaluation would be needed to decide how best to deal with the fractional sections that remain (after dividing by 15 meters or 20 meters). Based on the 2003 sampling (transect lengths in table 1), and not sampling a remnant less than half the section length (15 meters or 20 meters), the number of quadrats sampled for 15-meter units would

be about 186; for 20-meter units it would be about 140. In 2003, by comparison, 90 quadrats were sampled. How will the power to detect change be altered by reducing the number of quadrats sampled on short transects and increasing the number on long transects? Will variability resulting from changes in abundances of species at different elevations be masked by proportional sampling? Discuss potential to reduce this variation by redistributing data into elevational bands (point 12).

10. Because Lottiidae are very abundant, it would be much more efficient to start subsampling them within quadrats rather than sampling the entire quadrat. The logical subsample unit would be the same small area (10 x10 centimeters) that is currently used to subsample littorine snails. This change to a more efficient form of sampling could be especially important if quadrat sampling is made proportional to transect length and the number of quadrats sampled is increased. If a change in sampling is made, then the NPS should consider having a period when new and old methods are both used to allow comparison of the methodologies and data.

11. Consider adding a new type of sampling for large mobile invertebrates that increases the area sampled in the lower part of the intertidal and runs along the greater axis of their abundance (for example, horizontally). This comment is based on the documented concentration of these relatively rare species in the lower parts of the intertidal (fig. 10). One scenario is to continue the current vertical band surveys but to add a set of horizontal blocks, perhaps 25 meters by 2 to 4 meters, with the lower bound being the 0-meter tide level. These would need to be set up independently of the vertical transects to eliminate the potential for overlapping sampling, given the implicit 2-meter wide universe of sampling units (vertical transects and associated bands) that make up the whole beach (Mark Udevitz, USGS Alaska Science Center, oral commun., 2007). A stratified systematic design that accounts for the differences in the stratum sizes could be used or sampling effort could be based on stratum variability (more organisms => larger variance => more samples; Bill Thompson, NPS, written commun., 2006).

12. If proportional sampling is chosen, then, to reduce variation and allocate results of sampling to zones, it becomes necessary to map the beach and determine the area of the beach that encompasses the different elevational bands (for example, meters of elevation). Then sampling can either be allocated (see suggestion for horizontal band sampling for large mobile invertebrates, point 11) or results of sampling redistributed to these bands for analytical purposes.

13. Sampling a broad array of species rather than just a few species preserves the flexibility of the sampling to detect unexpected changes in the long term.

14. Consider adding components to evaluate the detectability of species; this may be particularly important for quadrat and band assessments.

15. To obtain meaningful data, adequate knowledge or training of the observers is necessary. If the sampling is being conducted by in-house staff, then extensive taxonomic training may be necessary. This would need to include training in identifications of both invertebrates and algae (plus a few intertidal angiosperms). Such training also should include testing the ability of trained staff to make species identifications. A next step would be to design a method to evaluate observer variability. If trained staff leave, it would be important to plan on conducting additional intensive training. Even for experienced observers, it is a good idea to conduct training refreshers each year because of the complexity of the species identifications and to make sure that different observers are making the same species identifications. Alternatives to training local staff are to (1) import taxonomic expertise (USGS, government, university, consultant) or (2) develop NPS swat teams with trained expertise that would operate in the different coastal parks that may be interested in intertidal monitoring (for example, Sitka National Historic Park, Glacier Bay National Park and Preserve, Katmai National Park and Preserve, Kenai Fjords National Park, Lake Clark National Park and Preserve). It is advisable to decrease the role of volunteers, at least as they have been used in previous sampling, or to increase the effectiveness of volunteers by requiring that they are trained (at least with respect to species codes and to a certain extent to species) and that they volunteer for more than a day. High turnover and lack of training of volunteers at Sitka National Historical Park can lead to inefficiencies in data collection and errors in recording data. Electronic data entry, as described later (point 20), could reduce errors.

16. Developing a reference collection for invertebrates (and perhaps intertidal fishes) could facilitate training of observers and would be useful for others conducting research at the park. At present, there are good specimens of algae, seagrass, and some halophytic plants in the herbarium.

17. As part of the monitoring, the park would benefit by having specific guidelines for the collection, preservation, identification, and storage of unknown species detected in the intertidal (voucher specimens). It may be necessary to have some monies set aside, perhaps in the network inventory and monitoring program, to support preservation, identification, and curation of specimens.

18. Because this pilot project was begun before the network inventory and monitoring programs were developed, there was no concerted effort to do inventories of intertidal biota in advance of developing the monitoring

protocols. The work of Amy Fish (Sitka NHP, NPS) and involvement of Dr. Sandra Lindstrom (University of British Columbia) has led to collections and identifications of intertidal plants, but such a concerted effort for invertebrates has not been accomplished. Even with establishment of monitoring protocols, the park would benefit by conducting inventories of intertidal invertebrates, algae, and possibly fishes periodically (perhaps every 10 years). To support such an effort would require budgeting for needed taxonomic expertise.

19. For the intertidal monitoring, consider sampling as many years as possible. Annual sampling improves the ability to determine trends and also the ability to detect important events affecting the intertidal. However, based on current analyses, sampling every other or every third year does not decrease power substantially but does increase the time needed before a trend (if present) is confirmed (see appendix A). Note that the type of analytical method can affect the decision about whether it is best to collect some data each year (Bill Thompson, NPS, “Under an Empirical Bayes approach for estimating trend, it’s best to collect at least *some* data in all years rather than lots of data in some years.”).

20. Consider electronic data entry (for example, using personal digital assistants [PDAs], species assigned particular bar codes, bar code readers) to decrease transcription errors and increase efficiency.

21. In order to control data quality and track methods and changes, it is advisable to perform data entry, verification, and metadata protocols after every sampling period.

22. Archiving the data in several locations improves assurance of data longevity. Data to be archived include: both electronic and hard copies of datasheets and data, GPS positions, maps, photos, metadata, etc.

23. The usefulness of the monitoring will be increased by analyzing data following each sampling event (see recommended data-analysis procedures outlined in appendix A) and presenting findings in a written report. Alternative analytical procedures have been suggested by Bill Thompson, NPS, and are available from Gail Irvine (USGS, Alaska Science Center) or Scott Gende (Glacier Bay National Park and Preserve, NPS).

24. If changes are made to any protocols, it will be important to document the changes and in cases where methods are going to be changed, conduct dual sampling of methods over one to several sample periods to provide for comparability of data.

25. Interpretation of changes in intertidal biota with time may be enhanced through co-collection of physical data parameters (for example, water temperature, salinity). The park might want to consider attaching data loggers to locations in the intertidal zone or somewhat offshore. Are there any in the vicinity at present? Perhaps it would be possible to hang one off the Sheldon Jackson College dock, with their permission.

26. The Sitka NHP intertidal is a popular location for people. Because the large usage of the intertidal could result in trampling effects, it is advisable to develop procedures to document visitation levels to the intertidal (when it is exposed). It also is advisable to collect information on collection/harvest from the intertidal zone because this also could affect the abundances of certain invertebrates or algae.

27. As the monitoring develops, it will be important to be open to incorporating research elements as data and events suggest, and dollars allow, to facilitate understanding of causal mechanisms of change.

28. Because invasive species could have large effects on the biota in the Sitka intertidal, it is advisable for the park to coordinate with Alaska Department of Fish & Game’s invasive species program. Current species or pathogens on the radar screen include green crab (*Carcinus maenas*) and a pathogen affecting the testes of the starfish, *Pisaster ochraceus*. Perhaps collectors for green crab could be placed in Sitka NHP or the park could make a case for having some placed in waters near the park because of the potentially large effects green crab could have on intertidal species.

29. As the program develops, further support for the monitoring is likely to result if the results are communicated to managers and to the public. Interpretive materials may serve both to inform and to lessen effects of people on the intertidal.

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