

EVALUATION OF THE SAMPLING DESIGN FOR THE KELP FOREST MONITORING PROGRAM, CHANNEL ISLANDS NATIONAL PARK.

Volume I. Analysis & Discussion.

PREPARED FOR:

National Park Service
Channel Islands National Park
1901 Spinnaker Drive
Ventura, California 93001

December 5, 1994

TABLE OF CONTENTS VOLUME I

| | |
|--|----|
| Executive Summary..... | vi |
| Introduction..... | 1 |
| Field Methods | 2 |
| General Considerations | 2 |
| Quadrats..... | 2 |
| Band Transects..... | 4 |
| Estimating Percent Cover..... | 8 |
| Fish Transects..... | 10 |
| Sampling for Size Frequency..... | 11 |
| Data Base Structure | 15 |
| General | 16 |
| Quadrats..... | 16 |
| Band Transects..... | 16 |
| Fish Transects..... | 17 |
| Data Quality..... | 17 |
| QUADALL..... | 18 |
| BANDALL..... | 18 |
| RPCALL | 19 |
| FISHALL..... | 19 |
| SIZEALL..... | 19 |
| MACROALL..... | 20 |
| GORGOALL | 20 |
| Sampling Design | 20 |
| Precision of the Estimates of Mean Density and Percent Cover..... | 21 |
| Power to Detect Differences in Paired Means Among Surveys and Locations..... | 22 |
| Power to Detect Temporal Trends in Density | 27 |
| Size-Frequency Distributions | 28 |
| Detecting the Effects of an Oil Spill or Other Major Perturbation..... | 32 |
| Literature Cited..... | 33 |

TABLE OF CONTENTS

Volume II

- Appendix A1. Tables of average density of kelp forest species from quadrat counts.
- Appendix A2 Plots of average density of kelp forest species over time from quadrat counts.
- Appendix A3. Plots of average density of kelp forest species by location from quadrat counts.
- Appendix B1. Tables of average density of kelp forest species from band transect counts.
- Appendix B2 Plots of average density of kelp forest species over time from band transect counts.
- Appendix B3. Plots of average density of kelp forest species by location from band transect counts.
- Appendix C1. Tables of average density of kelp forest species from random point contact quadrats.
- Appendix C2 Plots of average density of kelp forest species over time from random point contact quadrats.
- Appendix C3. Plots of average density of kelp forest species by location from random point contact quadrats.

Volume III

- Appendix D1. Tables of average density of kelp forest fishes from fish transects.
- Appendix D2. Plots of average density of kelp forest species over time from fish transects.
- Appendix D3. Plots of average density of kelp forest species by location from fish transects.
- Appendix E1. Tables of average sizes of kelp forest species by location and year.
- Appendix E2. Plots of size frequency distributions for kelp forest species by location and year.
- Appendix E3. Plots of size frequency distributions for kelp forests species by grouped locations and year.

TABLE OF CONTENTS

Volume IV

- Appendix F1. Plots of coefficient of variability and relative precisions as functions of mean density for kelp forest species. Data from quadrat counts.
- Appendix F2. Plots of coefficient of variability and relative precisions as functions of mean density for kelp forest species. Data from band transects.
- Appendix F3. Plots of coefficient of variability and relative precisions as functions of mean density for kelp forest species. Data from random point contact quadrats.
- Appendix F4. Plots of coefficient of variability and relative precisions as functions of mean density for kelp forest species. Data from fish transects
- Appendix G1. Plots of power to detect observed differences in mean density between paired years by location. Data from quadrat counts.
- Appendix G2. Plots of power to detect observed differences in mean density between paired years by location. Data from band transects.
- Appendix G3. Plots of power to detect observed differences in mean percent cover between paired years by location. Data from random point contact quadrats.
- Appendix G4. Plots of power to detect observed differences in mean density between paired years by location. Data from fish transects.
- Appendix H1. Plots of power to detect observed differences in mean density between paired locations by year. Data from quadrat counts..
- Appendix H2. Plots of power to detect observed differences in mean density between paired locations by year. Data from band transects.
- Appendix H3. Plots of power to detect observed differences in mean percent cover between paired locations by year. Data from random point contact quadrats.
- Appendix H4. Plots of power to detect observed differences in mean density between paired locations by years. Data from fish transects.
- Appendix I1. Power to detect temporal trends in density for kelp forest species at each location, based on an autoregressive linear model. Data from band transects.
- Appendix I2. Power to detect temporal trends in density for kelp forest species at each location, based on an autoregressive linear model with linear and quadratic terms. Data from band transects.

TABLE OF CONTENTS

Volume IV (continued)

- Appendix J1. Power to detect temporal trends in density for kelp forest species at each location, based on an autoregressive linear model. Data from quadrat counts.
- Appendix J2. Power to detect temporal trends in density for kelp forest species at each location, based on an autoregressive linear model with linear and quadratic terms. Data from quadrat counts.
- Appendix K1. Power to detect temporal trends in density for kelp forest species at each location, based on an autoregressive linear model. Data from fish transects.
- Appendix K2. Power to detect temporal trends in density for kelp forest species at each location, based on an autoregressive linear model with linear and quadratic terms. Data from fish transects.
- Appendix L1. Power to detect temporal trends in density for kelp forest species at each location, based on an autoregressive linear model. Data from random point contact quadrats.
- Appendix L2. Power to detect temporal trends in density for kelp forest species at each location, based on an autoregressive linear model with linear and quadratic terms. Data from random point contact quadrats.

EXECUTIVE SUMMARY

The Kelp Forest Monitoring Program of the Channel Islands National Park was evaluated to determine the likelihood of detecting temporal trends in the abundance of benthic organisms and fishes, of detecting differences in abundance between locations or between surveys at a given location, and of identifying and tracking cohorts of various species through time. In order to accomplish this, we assessed the field methods, the structure of the data bases, the quality of the data, and the sampling design.

The field methods are based on standard techniques and are, in general, appropriate to the task. However, we have made a number of recommendations for changes to the protocols that would reduce sampling bias, increase the information content of the data, and reduce sampling error. Some benthic species which are counted in small quadrats should be sampled in big quadrats and vice versa. Most algae are not divided into size classes and the size classes used for giant kelp are not appropriate because they do not separate young-of-the-year from older individuals. In general, older, larger individuals should be counted in large quadrats and recent recruits should be counted in small quadrats. Invasive sampling should be conducted, off the transect if necessary. The protocols for fish include repeated observations that do not contribute to replication. Transects should be censused once during a survey and there should be more surveys. Estimates of percent cover are based on random point contacts within 25 approximately 1-m x 3-m quadrats. The placement of the points within the quadrat is neither random nor uniform. We suggest reducing the number of replicates and, for each replicate, sampling fewer points at more locations distributed more uniformly over the area surrounding the transect. We also suggest changes in the protocol that will reduce the overestimation associated with counting in small areas rather than under points. The protocols for measuring individuals of selected species do not specify a sampling design and require only 30 measurements. We suggest a formal sampling plan with a random component, a larger sample size, and a protocol than includes invasively sampling plots of known area.

The data base structure appears well thought-out and is generally appropriate. We identified a few instances where special knowledge was required in order to properly interpret the data field. We have made a number of suggestions for small changes in the structure of the data bases so that the data base structure accurately reflects the manner in which the data were collected. We also recommend that a single code be used for species and that designations for ages, stages, or sex be placed in a separate field. The practice of transcribing data on summary sheets in the field should be discontinued. Data from the field sheets should be entered directly and summing or other manipulations should be done with software.

We screened the data bases using software to search for entries outside the expected range of variables, impossible entries, values not contained in the Methods Handbook, etc.

Errors were found, communicated to Park Service personnel, and corrected. We also tabulated and plotted the data and summary statistics which exposed a few more mistakes that were also corrected. Statistical analyses were done on the corrected data bases. Many of the "errors" were values that had been used by Park Service personnel as codes (e.g., "0" to indicate a missing value). Therefore, previous calculations were done correctly. Potentially confusing codes were replaced. It is unlikely that correcting the errors in the data would cause significant changes in the average values reported in Annual Reports. We have generated summary statistics in the format used in the Annual Reports to facilitate comparison.

The sampling design results in generally good power to detect differences between locations or surveys in the mean density or percent cover of benthic organisms which occur at relatively high densities. However, many of the organisms are uncommon during a large proportion of the surveys or at many of the locations. As a result, the proportion of the possible comparisons for which the power to detect a significant difference is 80% or greater is small. For most of the comparisons for which power is at least 80%, the difference in the means is greater than 60 % of the larger value. There is generally very low power to detect differences in the mean abundance of fishes between locations or surveys, because there are only two replicates per location per year. There is also very little power to detect temporal trends in the average abundance of species. This is also related to sample size. The spatial replicates used to determine a mean can not be used in trends analysis. The annual means are the replicates. Therefore, the maximum sample size for temporal trends analysis is currently 13.

During the annual surveys, individual sizes are measured for a subset of the species. Although these measurements enable one to roughly estimate the size distribution within the population, they do not enable one to identify and track cohorts, nor to estimate individual growth rates or mortality rates. In general, the number of individuals measured during a survey (c. 30) is too small to allow accurate estimates of the proportion of individuals in the various size classes of interest. For sea urchins, the sample size is usually around 100. For these species, there is occasionally a mode present that can be interpreted as recruits of the previously year or two. However, there are very few cases where the modes remain sufficiently well-defined to allow one to follow them over time.

One of the uses to which these monitoring data may be put is the analysis of the effects of a major perturbation, such as an oil spill in the Santa Barbara Channel. Analyzing the power of the monitoring program to detect the effects of such an environmental insult is a very different statistical problem from that examined here. Based on the generally low power of the statistical tests of differences in means and of temporal trends, one might conclude that the monitoring program would also have low power to detect the effects of an oil spill. That is not necessarily so because the statistical model that would be used is very different. We recommend that such an analysis be done.

INTRODUCTION

The Channel Islands National Park has been conducting a Kelp Forest Monitoring Program since 1982. Annually, the abundance of 68 taxa is estimated at each of 16 permanent sites using various standard methods, and the size of individuals is measured for samples of a subset of the taxa. The National Park Service issued a Request for Quotes to evaluate the sampling design and the quality of the data. In particular, the Park Service wished to know the "level of change" that could be detected and the "level of confidence" in detecting change. The scope of work specified a "temporal trends power analysis" and specified that the results provide an indication of "(a) the degree of confidence to detect change in the densities (abundance) of each species (e.g., percent of mean), at each site, [and] (b) the ability of the data set to detect cohorts and annual cohort strength from the size frequency data...."

We have evaluated several elements of the Kelp Forest Monitoring Program: field methods, data base structure, data quality, and sampling design. Initially, we examined the data to insure that values were within expected ranges, that sample sizes were as described in the methods (Davis, 1988) and that there were no unexplained missing observations. The errors we discovered were corrected in the original data bases by Park Service personnel. The corrected data bases which were provided to us on diskettes were then used in all subsequent analyses. A few more errors were discovered during the course of the analysis. For the sake of expediency (and in violation of our usual protocols), we corrected our copy of the data bases using software. Park Service personnel made the same corrections to the original data bases. We then calculated summary statistics and plotted the data.

In general, the structure of the data bases was appropriate. However, in a few instances special knowledge was required in order to correctly interpret some of the data in some of the fields. We have suggested changes to the data bases so the data structure accurately represents the methods of collection. We evaluated the field methods from the point of view of the data analyst. We have indicated where the methods of data collection constrain statistical analyses.

The remainder of the report is devoted toward examining the sampling design in the context of the scope of work, that is to say, detecting biologically significant changes in abundance at a site and extracting demographic information from patterns in size-frequency distributions. However, we believe that the most important analyses that potentially may be required are not within the scope of work of this contract. We make recommendations concerning analyses necessary to determine the power of the sampling design to detect and estimate the size of changes resulting from environmental insults such as an oil spill in the Santa Barbara Channel. This is a qualitatively different problem from making a *posteriori* comparisons among surveys at a site or between sites.

Although not part of the scope of work, we have included tables of summary statistics and plots of abundance, percent cover, and size distributions in Volumes II and III of this report (Appendices A1 - E2). The plots especially are useful in understanding the data and should be of considerable biological interest to many readers, as they are to us. The summary statistics enable the reader to perform simple statistical analyses on a *posteriori* comparisons of interest. However, these tables and plots were generated with code that was written with efficiency of production rather than presentation in mind. In particular, some of the of the tables only have identifying information at the beginning of each listing.

The results of the analyses of precision, of the power to detecting differences in means, and of temporal trends are contained in Volume IV. These results are discussed in some detail below under the heading SAMPLING DESIGN.

FIELD METHODS

General Considerations.

The cruises upon which this monitoring program is based are overseen by National Park Service personnel who also form the core cadre for the field sampling. However, a large proportion of those doing the field work are volunteers with various backgrounds and skills. When one looks at the acknowledgments in the annual reports, one sees a Who's Who of California marine biologists, including members of the Department of Fish and Game, university faculty members and graduate students, professional collectors, and dive officers. However, there are also a large number of amateurs, some of whom are highly skilled and some of whom are not. Although the field leaders attempt to match the skills of the divers to the demands of the tasks, it is inevitable that jobs will often be done by divers who are less experienced than one would wish. It is therefore especially important that those elements of the tasks that have big effects on the quality of the data and the later analyses be explicitly identified.

Quadrats.

Two contiguous 1-m² quadrats are sampled by two divers at each of 20 random points (40 in a few early surveys) along each 100-m transect. Within each quadrat, the diver counts 3 species of small demersal fishes, 9 species of common invertebrates, and 4 species of kelp. These quadrats are sampled non-invasively or "non-destructively", that is to say, rocks are not turned over and sea urchins are not pulled off the substrate. Therefore, there are 20 independent, replicate 2-m² quadrats for analysis.

In the case of the macroalgae, counting in small quadrats is appropriate for young individuals, but generally not for the larger, less abundant adults. High density for *Macrocystis pyrifera* older than about 1 year is 1-2 / 10 m². In the National Park's monitoring program "adult" giant kelp are all individuals > 1 m long. Most of those counted are in fact young-of-the-year, many will not survive the winter, and many are not part of the surface canopy. Those designated "Juveniles" are no doubt young-of-the-year, however by August or September, when the counts are made, most new recruits will be larger than 1 m. As a result, there are no good estimates of the standing stock of canopy-producing adults or of the density of recruits (although this information can be pieced together by examining density and size distribution together).

The other species of macroalgae generally occur at average densities less than 1 / m² and, except for young-of-the-year which are often quite abundant, would be more efficiently sampled in larger quadrats. These species are not distinguished by size or stage when counted.

Invertebrates such as *Cypraea spadicea* and *Strongylocentrotus purpuratus* which are generally most abundant in cryptic habitats (e.g., under boulders) and juveniles of most species will be undercounted in the quadrats. The bias will vary among sites, being most severe where the proportion of cryptic habitat is high. As a result, for these species differences among sites will be difficult to interpret.

Recommendations:

Macroalgae should be counted in size categories: 3 or 4 for giant kelp and perhaps 2 for all other species. The idea is to differentiate, on average, young-of-the-year from older individuals. For *Macrocystis pyrifera* the categories used by Dean *et al.* (1984) are useful: blades (single blade), juveniles (at least 2 fronds & < 1 m); subadults (> 1 m, but no haptera above the primary dichotomy); adults (> 1 m & haptera above the primary dichotomy) which generally have > 6 fronds and reach the sea surface. Small plants should be counted in 1-m² quadrats and large individuals should be counted in 15-m² quadrats within the band transects (1.5 m x 10 m). Besides enabling one to distinguish new recruits, this protocol will result in fewer quadrats with 0 values and a more statistically tractable data set.

For motile invertebrates, rocks should be turned and large urchins moved in order to count small individuals occurring within the spine canopy. All motile species now counted in band transects should be included in these invasive samples. Park Service biologists feel strongly that samples along the permanent transects should be taken without disturbing the substrate. To avoid disturbance, these samples could be taken off the transect. However, we believe that if done carefully, a single invasive survey each year is unlikely to affect population estimates of either motile or sessile species, since the same 1-m² section of

bottom is unlikely to be sampled a second time for several years. This intuition that invasive sampling is relatively benign if done correctly could be tested experimentally.

To examine the effect of sample size on the precision of the estimates of mean density, we randomly selected 6 sites (for ease of plotting). We calculated precision as $\frac{1}{2}$ 95 % confidence interval (expressed as a percentage of the mean) and plotted it against sample size (using the actual variance observed in the samples designated with a solid symbol). We plotted all surveys for each of the six locations for three common species (bat stars, purple sea urchins, and sea cucumbers). Precision increases slowly after around 10 replicates (Figures 1 - 3). A cost-benefit analysis would be worthwhile to determine if some of the effort expended on replication for quadrat counts might better be used for other tasks.

Band Transects.

The stated purpose of the band transects is to sample rare or clumped organisms. Seven species of conspicuous sessile invertebrates (sponges, corals, anemones, and gorgonians) and 10 species of motile invertebrates (snails, including abalone, scallops, sea urchins, sea stars, sea hares & lobster). The "band transects" are really simply large quadrats. Each band transect is made up of two contiguous 30-m² quadrats placed end-to-end, perpendicular to and touching the permanent transect. Twelve pairs of these quadrats are randomly placed along the 100-m transect (Although the manual (Davis 1988) indicates that the points are spaced a minimum of 2 m apart, in fact they must be 3 m apart to avoid overlap). Therefore, for purposes of analysis, there are 12 replicate 60-m² quadrats.

According to the Monitoring Handbook (Davis 1988), divers count designated taxa within 30-m² quadrats in about the same length of time as they do within 1-m² quadrats (average time for 1-m²: 10 min; for 30-m²: 10-13 min). On average when sampling band transects, the diver is censusing a 3-m² area in about a minute. Because of the rapidity with which these large quadrats are sampled, small individuals will be routinely underestimated, especially where there is a significant amount of cryptic habitat. White sea urchins (*Lytechinus anamesus*) mask with small bits of gravel and shell debris, and whelks (*Kelletia kelletii*) bury themselves in gravel, especially during periods of high surge. These species are probably always underestimated in band transects (e.g., Table 1). Occasionally, white sea urchins occur in large numbers and the field leader elects to count them in 1-m² quadrats rather than on the band transects. During those occasions density estimates are probably much more accurate, which presents a problem if one wishes to look at a time series where both sampling methods are represented.

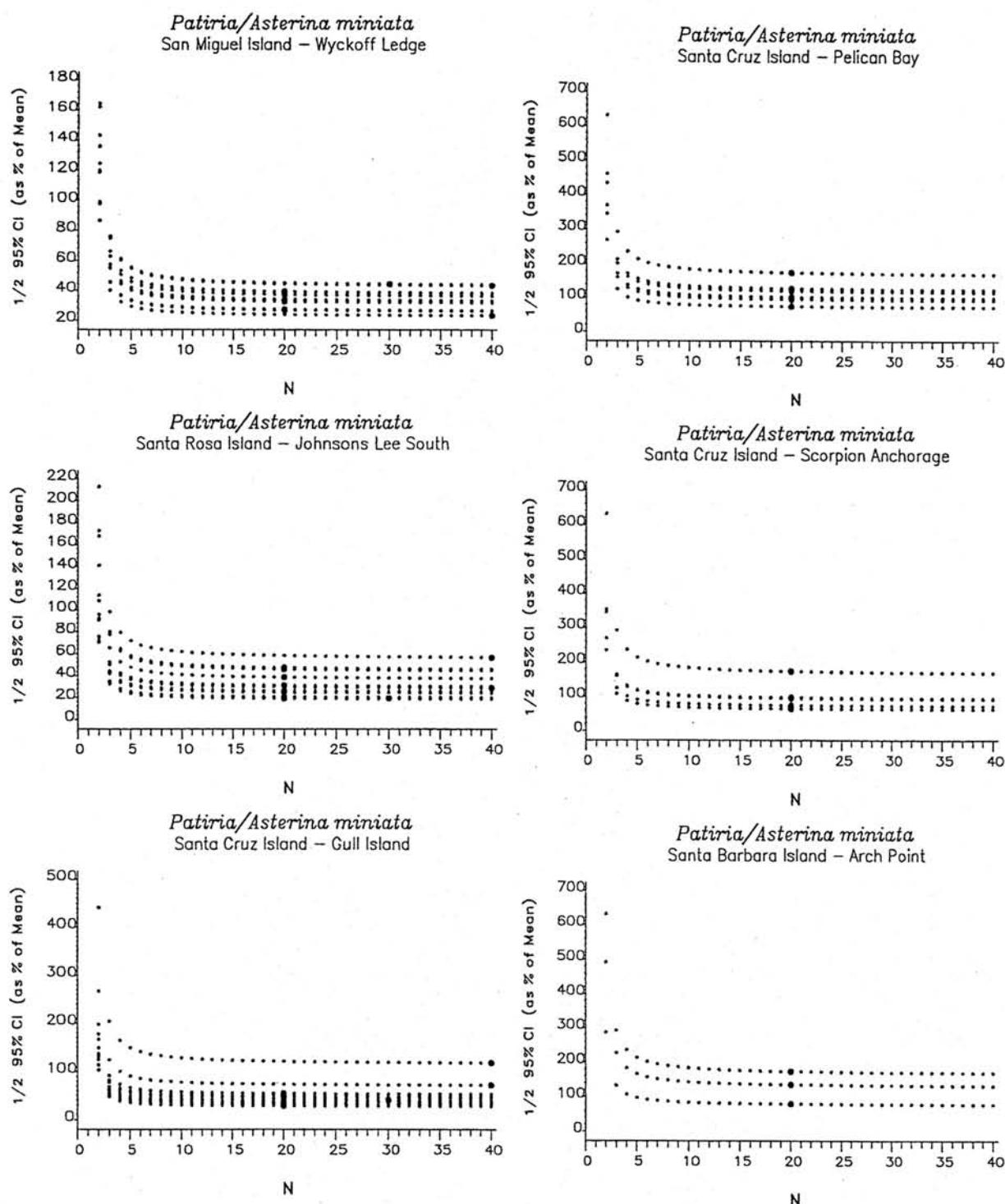


Figure 1. Relationship of the precision of the estimate of mean density to sample size for bat stars sampled in 2-m² quadrats. All surveys plotted for 6 randomly selected locations. Solid circles are actual data. The small circles are calculated precision based on the observed variance and the designated sample size.

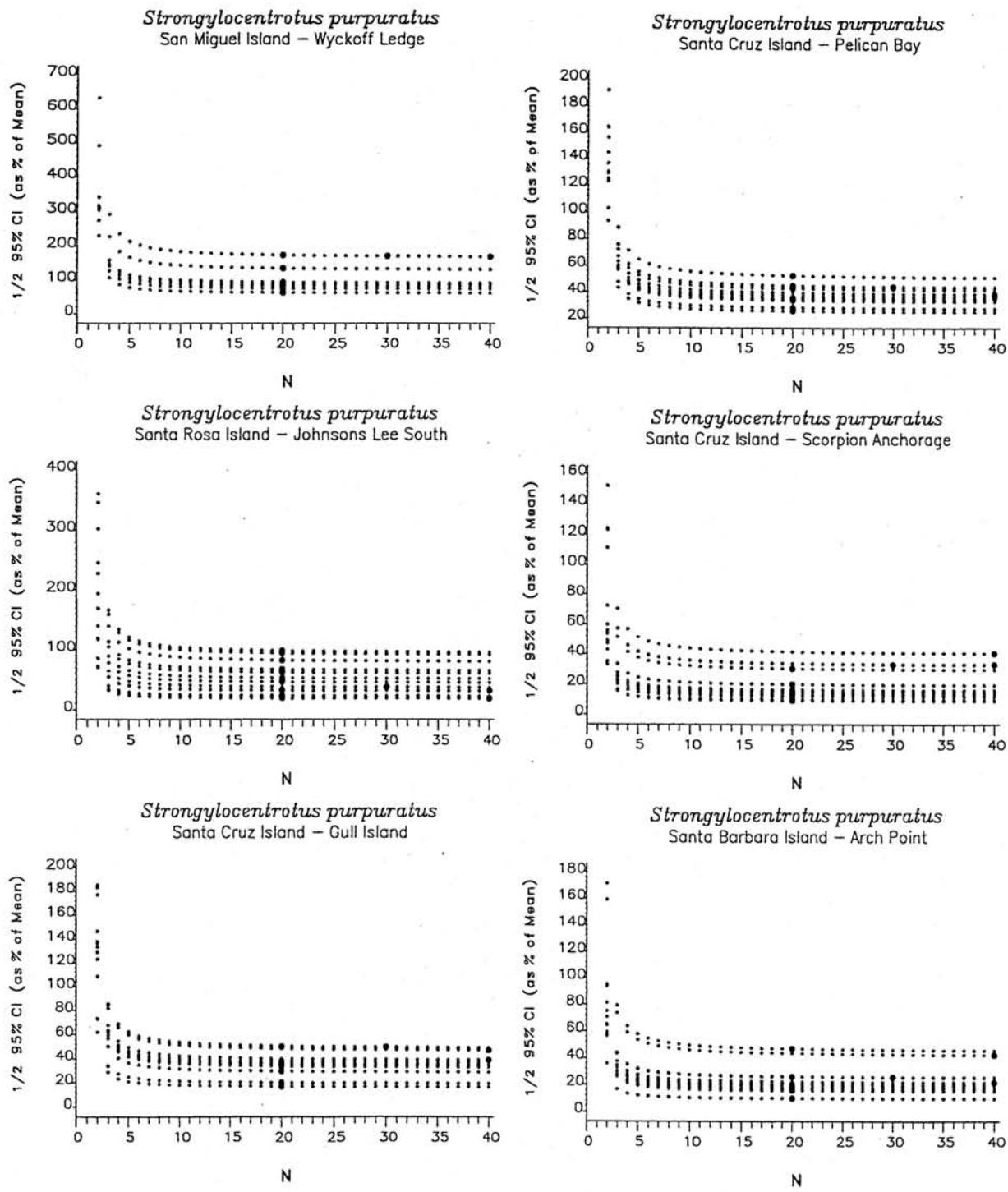


Figure 2. Relationship of the precision of the estimate of density to sample size for purple sea urchins sampled in random 2-m² quadrats. All surveys plotted for 6 randomly selected locations. Solid circles are actual data. The small circles calculated precision based on the observed variance and the designated sample size.

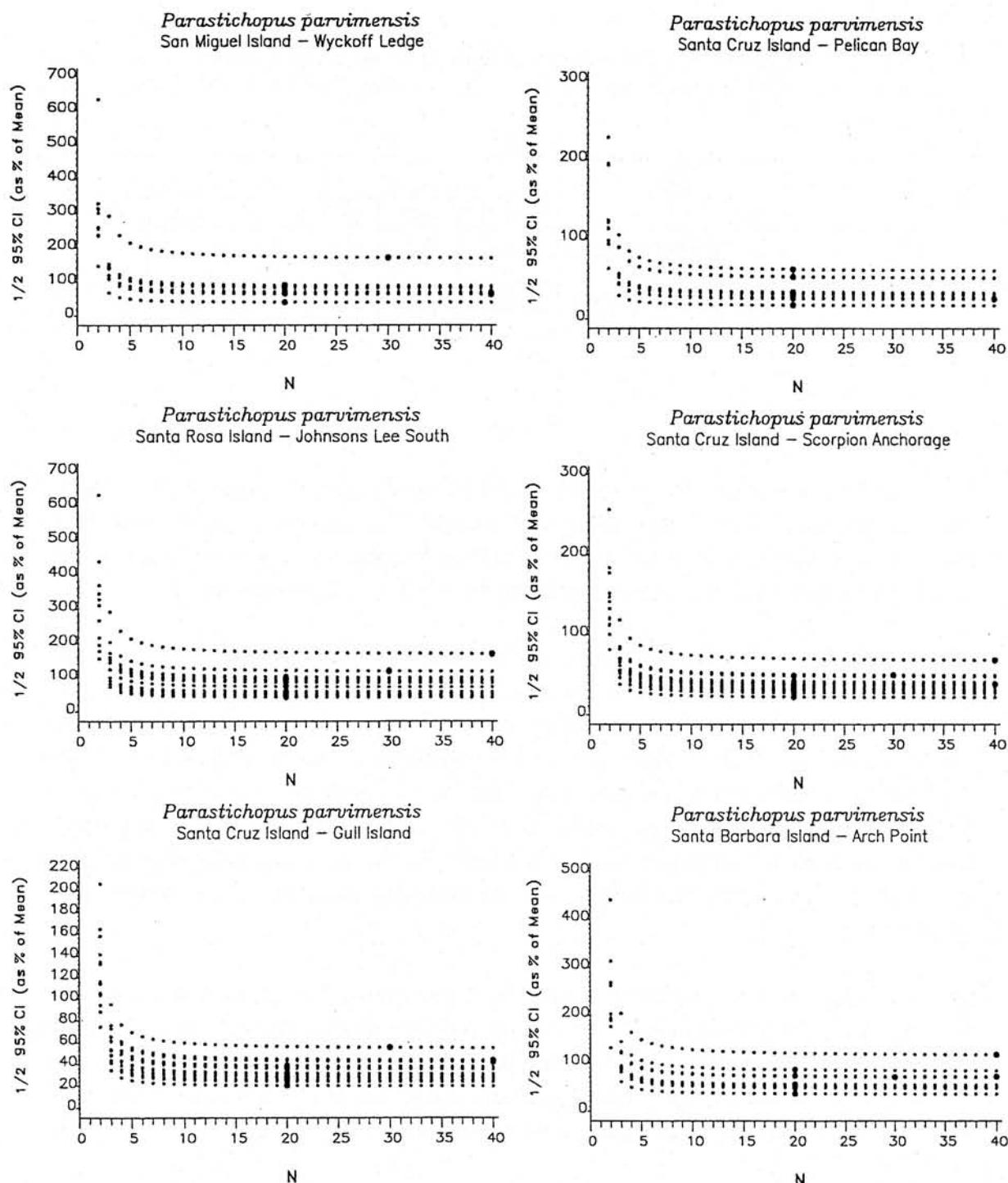


Figure 3. Relationship of the precision of the estimate of mean density to sample size for sea cucumbers sampled in 2-m² quadrats. All surveys plotted for 6 randomly selected locations. Solid circles are actual data. The small circles are calculated precision based on the observed variance and the designated sample size.

Table 1. Comparison of the estimated density of white sea urchins from quadrat counts and band transect counts on four occasions when both methods were employed.

| YEAR | SITE | Quadrats | | | Band Transects | | |
|------|-----------------------|----------|------|----|----------------|------|----|
| | | MEAN | S.D. | N | MEAN | S.D. | N |
| 1986 | Rodes Reef | 7.2 | 11.8 | 20 | 2.7 | 1.4 | 12 |
| 1986 | Gull Island | 4.4 | 7.3 | 20 | 4.1 | 1.6 | 12 |
| 1989 | S.E. Sea Lion Rookery | 15.6 | 15.6 | 20 | 6.0 | 2.7 | 12 |
| 1994 | Scorpion Anchorage | 0.6 | 0.8 | 20 | 0.05 | 0.1 | 12 |

Recommendations:

The selection of quadrat size is usually based on logistic considerations and on the density and spatial distribution of the species of interest. In general, species which occur in relatively low numbers or which are very patchily distributed on a small scale, should be counted in larger quadrats so as to minimize the number of zero observations.

In the Kelp Forest Monitoring program, the groups that should be counted in the large quadrats that make up the Band Transects are large individuals of the macroalgae and species of invertebrates that are relatively large as adults and which tend to occupy exposed habitats. If small individuals of the invertebrate species occupy cryptic habitats, then those species should be counted in two size categories. Small cryptic individuals should be counted in invasively sampled, 1-m² quadrats and large exposed individuals should be counted in large quadrats on the Band Transects. In no case should animals of a given size be counted in both kinds of samples, unless similar methods and effort are devoted to searching.

We also suggest that instead of censusing 2 contiguous 3-m x 10-m quadrats at each random point along the transect, that 2 random points within each of 12 strata be selected. If this is done, the samples will be independent and can be used as replicates and the divers should still be in sight of one another. Additional analysis might indicate that less effort would still provide a sufficiently precise estimate of the mean.

Estimating Percent Cover.

Twenty-five randomly selected numbers between 0 and 100 are chosen at each survey to position the sampling areas along the transect. Substrate composition and the cover of sessile species is estimated using the random point contact (RPC) method. The points are identified by five knots at least 20 cm apart on each of 2 strings attached near the ends of a 1.5-m bar. One string is 1.8 m long and attached to ends of the bar; the other is 1.2 m

long and attached 25 cm from the ends. To sample, a knot is grasped and the string pulled taut. The position of the knot then defines the "random" point at which a sample is taken. This is repeated for both strings, first on one side of the bar and then on the other. After sampling at each of the 20 knot locations, the bar is flipped over to the other side of the transect and the process is repeated. As a result an area about 3 m x 1 m is sampled by points arrayed around 2 sets of concentric ellipses placed end-to-end in an elongated figure-of-eight.

Although each 3-m long sampling area is randomly placed, the sample points appear to be fixed. As a result of the constraints of the strings, the points do not sample randomly or uniformly. Effort is concentrated near the ends of the sampling bar, especially near the transect. For purposes of analysis there are 25 replicate estimates of cover.

In the kelp forest monitoring program, each species intersected by mentally projecting the sampling point vertically 1 m into the water column is identified. If a species occurs at more than one height, it is recorded repeatedly. Height above the bottom is not recorded. Therefore, individual species can occur at more than 100 % cover, the percent of the substrate covered by a particular species can not be calculated (although the overestimation is probably modest), and there is no information concerning layering other than it exists. Unoccupied substrate is a separate category and its abundance is estimated directly.

A source of considerable inaccuracy in estimating percent cover by the random point contact method is the *de facto* use of a circular area rather than a point (e.g., Greig-Smith, 1964). For example, cover estimated using a "point" $\frac{3}{4}$ inch in diameter resulted in an over estimation as large as 99% compared with the result of directly measuring the area covered (Hutchings and Holmgren, 1959 cited in Greig-Smith, 1964). As implemented in the Kelp Forest Monitoring Program, RPC counts probably routinely result in significant overestimates of cover. The common practice of using sets of points instead of single points is also a potential source of inaccuracy because these points are likely not independent samples. For estimating percent cover a common rule-of-thumb is to sample few points at many places (e.g., Greig-Smith, 1964). As currently implemented, the random point contact estimates of percent cover are probably overestimates and may be biased.

Recommendations:

First, the purpose of the data should be defined. If percent cover is intended as a proxy for biomass, then perhaps it is important to include subcanopy algal species and continue to sample all plants within 1 m of the bottom. Similarly, if one is interested in shading. However, if these are the motivations, then contacts should be recorded in at least two layers (e.g., ≤ 15 cm & > 15 cm above the bottom). If, on the other hand, one is primarily

interested in demography, counts are better where appropriate. Percent cover could then be done for turf-producing species and species which do not occur as discrete individuals, and for the attachment portion of larger individuals. This would provide an estimate of the percent cover open space and the major space holders. The current method of recording multiple contacts for a single species without recording layering information should be altered. Either record a species once, or record multiple "hits" and the layer or height stratum.

In any event, the sampling protocol should be changed to insure that the sampled "point" is very small, rather than a substantial area. In order to accomplish this, one could only sample algae near the bottom using the end of a thin horizontal rod inserted into frame to define the point. In this way, the diver could easily sight along the end of the rod without obstructions to his vision. If subcanopy plants are to be sampled, a 1-m nylon rod with a line etched and painted on one side could be used to define sampling points. Many other physical arrangements could accomplish the same objective.

In the current protocol the points are not independent and they do not sample the plot randomly or uniformly. We suggest that the sampling protocol be changed so that the points are randomly and independently placed. This is not as draconian a requirement as it may first appear. There are many ways of placing the points that are logically feasible and do not increase the effort expended. We also suggest that less overall effort be spent on estimating percent cover. This could be accomplished by reducing the replication at a site. To examine the effect of sample size on the precision of the estimate of mean cover, we used the same 6 sites as for quadrat counts. We again calculated precision as $\frac{1}{2} 95\%$ confidence interval as a percentage of the mean and plotted it against sample size (using the actual variance observed in the sample designated with a solid symbol). We plotted all surveys for each of the six locations for an alga, an invertebrate, and a substrate category (articulated coralline algae, *Corynactis californica*, and bare rock). It is evident that precision increases markedly up to about 6 replicates, substantially from 6 to 10 or 12 replicates, and slowly thereafter (Figures 4 - 6). There is probably little benefit from increasing the sample size beyond about 10. We recommend that the number of replicates be reduced and the savings in time be spent on an improved protocol.

Fish Transects.

Twice each year, during late summer or early fall, the abundance of 12 species of fish is estimated by counting individuals occurring within 3 m of the bottom along a 2-m by 100-m swath. Two divers swim together at a rate of about 20 m min^{-1} along the transect line. One or both count within the defined volume of water. Therefore if both count, the counts are duplicates, not replicates. The two divers swim and count along each transect four times in succession. This is analogous to counting, say, sea urchins in a 1-m² quadrat,

waiting a half-hour, and counting them again. Although there will be some movement in and out of the counting area, in neither case are the counts independent and they cannot be used as replicates. In the case of fish, however, the counting activity is more likely to bias subsequent observations. On the one hand, the passing divers may cause individuals to leave the immediate area causing an ephemeral decrease in numbers. On the other hand, it is common to see some species follow divers which may cause an ephemeral increase in local abundance. Regardless of whether the repeated swims result in a biased estimate of density, there is no replication at a time. There is substantial variability between simultaneous counts by two divers censusing the same area and among the 4 counts of a single diver. Locations are resampled from 1 week to 2 months later, which provides the only real replication within a year.

Recommendations:

Two divers counting within the same volume at the same time is an excellent training or calibration procedure and should definitely be continued. However, the duplicate observations should be recorded only if both divers are about equally skilled. Better yet, one could code the diver identification to indicate whether the count is to be used as a duplicate for calculating a mean count, or treated as calibration only. Fish transects should be censused only once per survey. The effort currently being expended in repeated counts along the same transect is wasted since it does not increase the sample size and probably does not increase the accuracy of the estimates. If possible, effort should be shifted to sampling on more occasions each year. Such temporal replication would be most useful from a monitoring point-of-view. Alternatively, additional transects at a location or additional locations could be sampled during a survey, or the effort shifted to other types of observations. Although more expensive, cine-transects would no doubt be more accurate and subject to much less sampling error.

Sampling for Size Frequency.

As is pointed out in the Handbook (Davis 1988), it is important that individuals of the various size classes occur in the sample in the same proportion as in the population. This imposes constraints on the field protocols. First, it is important to define the population that is being sampled in terms of spatial extent. Within the delineated area, standard sampling protocols should be followed. Some type of stratified random scheme is probably most convenient. Quadrats or equivalents should be used to define sample areas and all individuals within the quadrat should be collected. Second, cryptic habitats must be searched and all boulders turned. If there is inaccessible habitat, it should be noted. The protocols used to select individuals for measurement are not specified in the Monitoring Handbook. According to a Park biologist (D. Kushner, personal communication), the

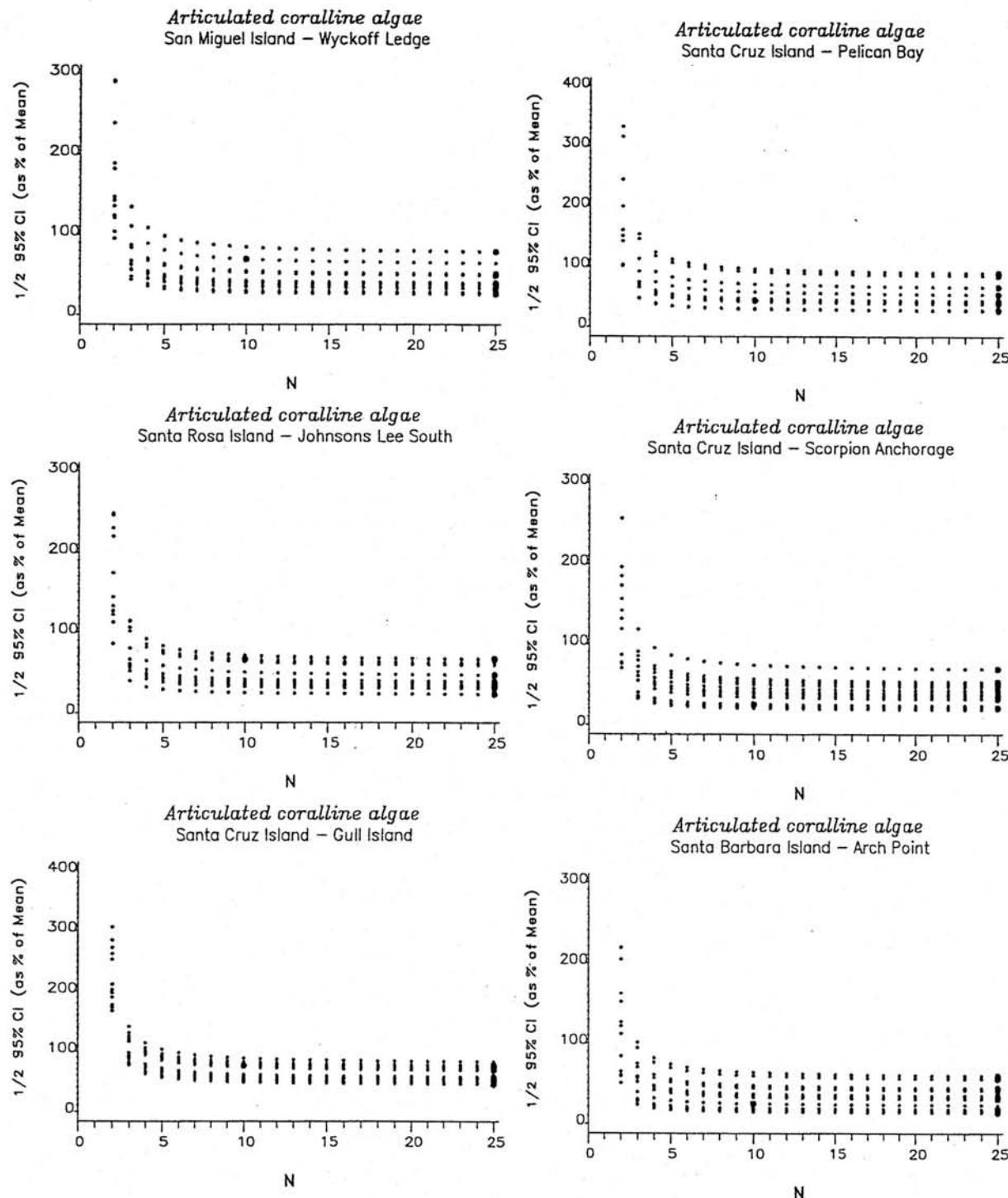


Figure 4. Relationship of the precision of the estimate of mean percent cover to sample size for articulated coralline algae sampled in random point contact quadrats. All surveys plotted for 6 randomly selected locations. Solid circles are actual data. The small circles are calculated precision based on the observed variance and the designated sample size.

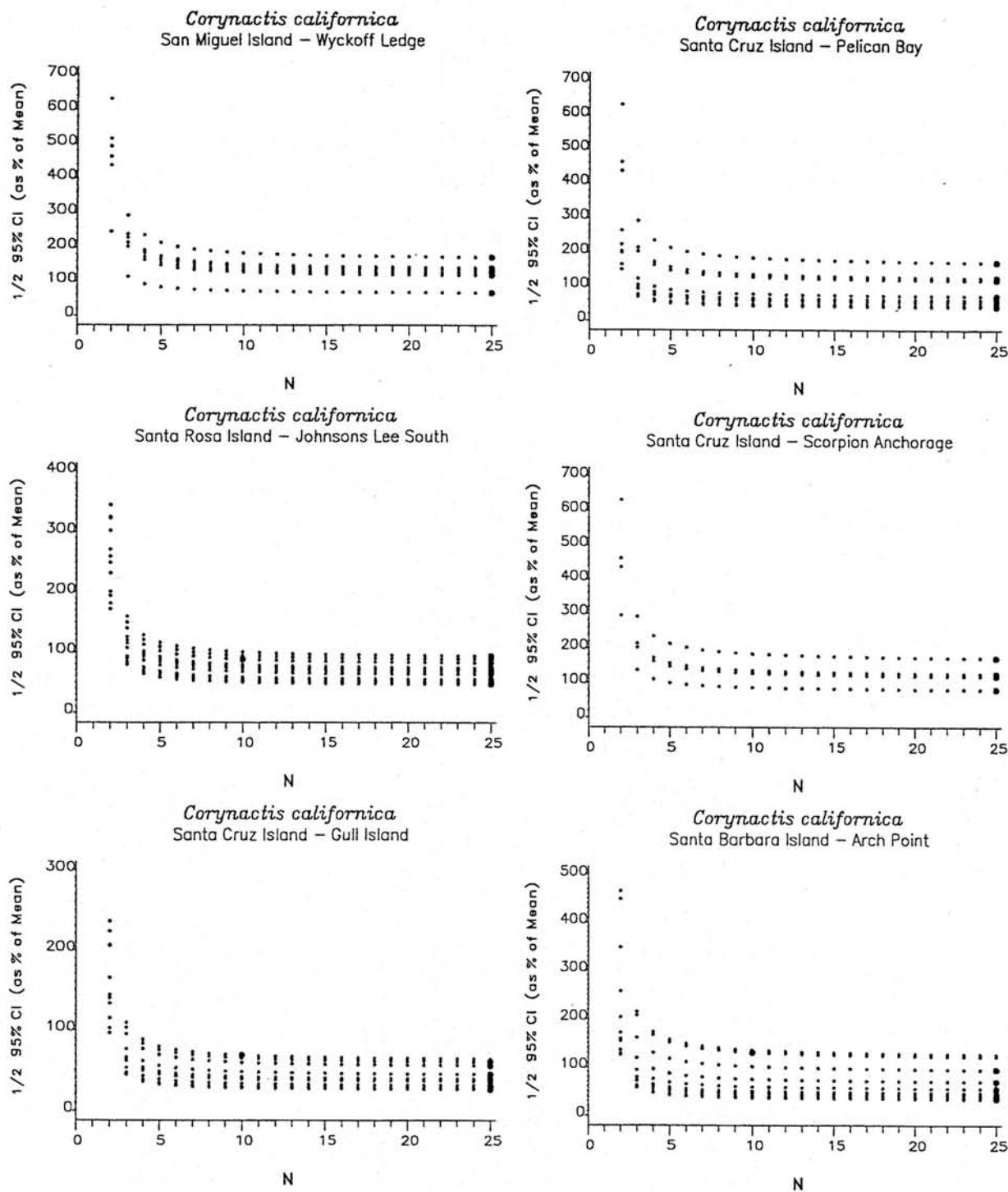


Figure 5. Relationship of the precision of the estimate of mean percent cover to sample size for the strawberry anemone sampled in random point contact quadrats. All surveys plotted for 6 randomly selected locations. Solid circles are actual data. The small circles are calculated precision based on the observed variance and the designated sample size.

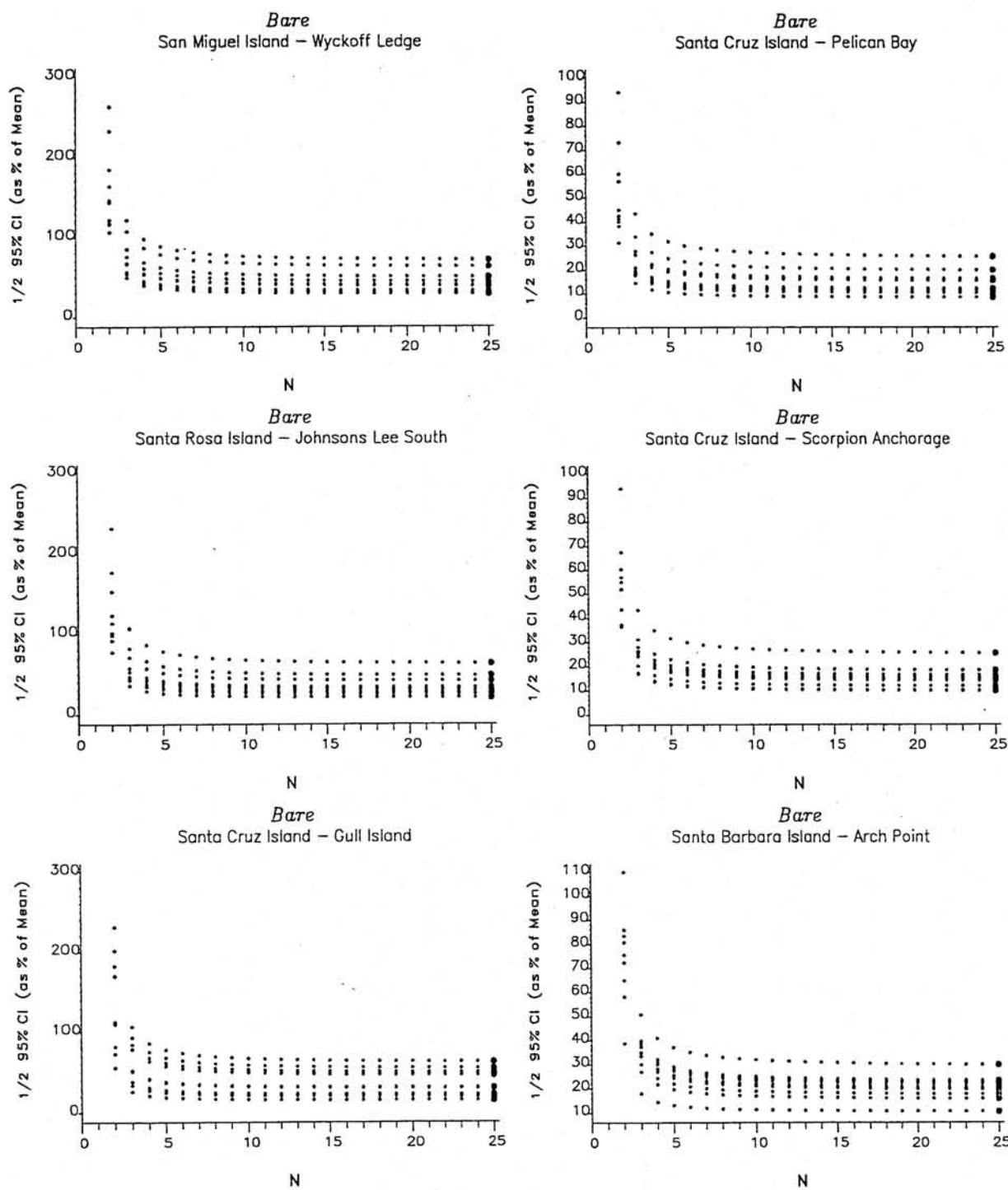


Figure 6. Relationship of the precision of the estimate of mean percent cover to sample size for bare substrate sampled in random point contact quadrats. All surveys plotted for 6 randomly selected locations. Solid circles are actual data. The small circles are calculated precision based on the observed variance and the designated sample size.

Handbook. According to a Park biologist (D. Kushner, personal communication), the sampler is told to work parallel and to one side of the transect. No device is used to keeptrack of the portion of the bottom sampled and the area sampled is not recorded. Although, the sample for size-frequency distribution is supposed to be non-destructive, some divers search under rocks and under red sea urchins. The use of different protocols by different divers will tend to increase the variability in the data. The intended protocol will result in a bias toward larger sizes for two reasons. First, cryptic habitats are generally not sampled. Second, since there is no protocol specifying the dimensions of the area searched, divers will tend to notice and measure larger individuals some distance away, but will pass over small individuals.

Recommendations:

Sampling for sizes presents a design problem not unlike sampling for abundance. It is important to specify the area being sampled and to draw samples using a protocol with a random component. The intent is that each individual in the population has an equal chance of being measured. Logistic considerations usually dictate that sampling is done along belt transects since divers have to search relatively large areas to obtain a reasonable sample size for many species.

We suggest that the diver should select a starting point and direction with a random component. A 2-m stick should be used to aid in maintaining orientation, and providing a reference for sampling. By keeping track of the number of times the stick is moved, the area sampled can also be calculated. The diver should sample a specified distance (1-2 m) to each side of the stick and search all cryptic habitat within the delineated area. A tape measure or stick should be used to insure that animals are within the defined area. Even though they may be visible, animals farther away should not be measured.

DATA BASE STRUCTURE

For the sake of quality control, after data are collected in the field they should be entered into data bases essentially unchanged. In addition, the data base structure should reflect the way in which the data was collected in the field and should not require special ancillary information to interpret fields. Any necessary manipulations should be accomplished through the use of computer software. When the inevitable errors are discovered, they should be noted on the field sheets, corrected in the lowest level data files and data base establishment software rerun. Software "fixes", wherein changes to the data are part of an establishment or analytical program, should not be used. Each data base should have a history text file associated with it wherein error corrections are recorded and initialed by an authorized person. When calculations are done or graphs prepared, the resultant tables

and plots should have associated with them flow diagrams which indicate both the data bases and the computer programs used. If these simple procedures are followed, there will be a clear audit trail from the raw data sheets to the results of any analyses that are performed.

In general, the data bases for the Kelp Forest Monitoring Program appear well thought out and appropriate. However, we suggest the following changes in protocols and data structures:

General.

There are separate codes for Male/Female or Adult/Juvenile for the same species. Most of the data bases do not include the date of the survey.

Recommendations:

There should be a single code for species and additional variable fields in the data base to identify SEX and STAGE. All data bases should have a date field that contains the actual date of each observation. One can then calculate the duration of the survey, time between observations, mid-date of the survey for plotting purposes, *et cetera*.

Quadrats.

Two contiguous 1-m² quadrats are sampled by two divers at each random point. On the boat, the data from the two quadrats are summed by hand and the results are transcribed onto a summary sheet from which the data are entered into a data base. As a result density is recorded as number per 2 m².

Recommendations:

The data from the original field sheets should be entered directly without first combining by hand. This entails adding one column to the data base. By skipping the transcription in the field, one reduces the chance for errors and increases the information available (e.g., information on levels of spatial patchiness). A single line of code in establishment software will sum the two columns to produce density in the combined quadrat.

Band Transects.

Four contiguous 1.5-m x 10-m quadrats are sampled by two divers at each of 12 random points along each 100-m transect. Each of two divers counts within a 1.5 m wide band

along each side of a 10-m band transect (perpendicular to the permanent transect), recording data for the 30-m² area on a single sheet. On the boat, the data from the two sheets are summed by hand and the results are transcribed on a summary sheet from which the data are entered into a data base. As a result density is recorded as number per 60 m².

Recommendations:

The data from the original field sheets should be entered directly without first combining by hand. We also suggest recording data for each 1.5-m x 10-m section of the band transect which will increase the information content of the data base at no extra cost in the field.

Fish Transects.

The repeated censuses of the same transect within a survey are designated "replicates". Two divers count within the same volume of water. The first diver's counts are designated replicates 1-4 and the second diver's counts are designated replicates 5-8. Therefore, the data base does not reflect the actual field protocol.

Recommendations:

A column called "Duplicate Number" or "Diver ID" should be placed in the data base to identify duplicate counts by divers. A field called "Pass Number" or "Repeat" could be added to identify repeated counts. Other conventions are possible, but the data base structure and its description should make it clear that there is no replication and enable the analyst easily to identify diver duplicates and the order in which the counts were made. The diver id should include a code to indicate whether the observation is to be considered calibration or if it is to be considered a good count. To the extent possible, Park biologists should examine the existing data, identify the divers doing the counts and designate which count should be used in analyses. Examination of duplicate counts shows that there are very large differences between divers, and this contributes unnecessary variability to the data.

DATA QUALITY

Data were received from the Channel Islands National Park (CINP) in the form of dBase IV files compressed with PKZip and stored on 3.5" floppy diskettes. Upon receipt, the diskettes were labeled CINP# (# = sequential diskette received) and history files were updated to document dates received and correspondence with CINP. Data were transferred to our computers, and translated into SAS databases for analyses. SAS (Statistical Analysis System) software is a powerful analytical, graphics, and database

management tool. History files were created for each database to document creation, data problems, errors found and corrected, and any additional changes and information important to the file.

Several errors were found during translation to SAS databases and preliminary examination of the data. Some of these were major and it was necessary to write SAS code to check for errors using parameters listed in the Kelp Forest Monitoring Handbook and from discussions with CINP. There were some errors or irregularities in most databases. A list of errors was faxed to CINP, databases were corrected by CINP, and new corrected databases were sent to us.

Data were again translated to SAS databases, the code which checks for errors was modified to account for some of the irregularities found, and the data were again examined for errors. A few errors remained. Corrections were made to the SAS databases using software, and CINP was notified of the errors. The following are the history files for the data bases we received from Channel Islands National Park.

QUADALL (contains data from counts in quadrats):

1. There were 360 cases where Location = 50 and 360 cases where Location = 52 during 1988. These Locations are not listed in the Handbook or station code list. CINP determined that Location 50 is Location 14 that was sampled a second time in 1988. The identity of Location 52 could not be determined and was deleted from the database by CINP.
2. Observation number 59049 for Location 16 and Species 14026 had Year = 12. CINP determined that year 12 was supposed to be 92 and corrected the database.
3. Species 11004 (*Lytechinus anamesus*) present but not listed in the Species Code list with Technique Q (quadrat samples). This species was counted occasionally when densities were too high to count in Band Transects.

BANDALL (contains data from counts in band transects):

1. Species 5002 (*Tethya aurantia*) and 6008 (*Muricea californica*) were not listed in the species list as sampled in Band Transects but were very numerous in the databases. CINP said that *Tethya* has always been counted and should be used for analysis. *M. californica* has been counted regularly since 1991 and occasionally before then. Unfortunately, prior to 1991 it is not possible to distinguish between zeros and missing data. We were advised to disregard this species, unless we wish to look at it from 1991 to the present. The Technique Code listed in the Species Code list should be changed from Q to B for *Tethya* (no observations in QUADALL), and B added for *M. californica*.
2. Locations 50 and 52 present also in this database (as in QUADALL). Location 52 was deleted by CINP.
3. *Lytechinus* had cases where counts = -999. This is a missing value code that was used for this species on several occasions when abundance was too high to count, and quadrats were

done instead. Comparisons were made between cases where *Lytechinus* were counted in quadrats and band transects during the same survey. Unfortunately it may not be possible to use quadrat data to replace the missing values in the band transects, because differences in sampling technique resulted in much greater densities during quadrat counts.

RPCALL (contains data from random point contact estimates of percent cover):

1. Species code 13001 was present often in the database but not listed in the species code list in the handbook, nor in copies sent to us by CINP. The species code list in the kelp forest monitoring handbook incorrectly listed species 13000 as Miscellaneous Invertebrates instead of 13001.
2. There were 590 cases in 1984 where SPECIES = 0 and LOCATION = 0. They appear to be left-over observations from a template used to add data to the database. These observations were deleted by CINP.

FISHALL (contains data from fish transects):

1. There were 103 cases where Date = 930931. This is not a valid date. CINP changed the date to 931001. A few more cases were found and changed in our SAS databases for analyses.

Data are summarized in the CINP Kelp Forest Annual Reports by using all swims as replicates. Means, Standard Deviations, and N are calculated for each date using up to 8 'replicates' and the average for the year use up to 12 'replicates'. During our analysis, counts collected during the surveys with divers swimming along side each other were placed into the variables count1 for diver1 and count2 for diver2 with 'Transects' 5-8 renumbered to 1-4. The variable Count was recalculated as the mean of count1 and count2. The survey mean was then calculated as the mean of Count using 'Transects' 1-4. It is important to note that these 4 'Transects' are not replicates. The year mean was calculated using the 2 survey means as replicates.

SIZEALL (contains data from measurements of individual sizes):

1. There were numerous cases where size_mm = 0. CINP changed these to -99 to indicate missing values. These values were changed to missing values "." in the SAS databases.
2. There were 4 cases where Location = 19. This code is not listed in the handbook and was removed by CINP. We found 1 additional case with location 19, which was excluded from our analyses with software.
3. There were 2 species codes found in the database that were not listed in the species code list. (Species = 1002 & 1010). CINP found that 1002 should have been 11002 and corrected it in their databases. Species 1010 was deleted by CINP.
4. We were told by CINP (10-20-94) that sizes in this database were in millimeters, except for *Parastichopus* which were in centimeters. During analysis, we found that 1984 had values as large as 295. It appears that measurements were in millimeters during 1984. For 1984, sizes were divided by 10 in the analysis software. This change needs to be made in the CINP data bases. The maximum size found for *Parastichopus* in the database, after the 1984 corrections, was 37 cm. We believe these large values may be animals that were measured when not contracted.

MACROALL (contains size data for giant kelp):

1. All of 1984 had missing values for No_stipe and Width_cm. CINP found that there was a problem with the file structure of the 1984 data. This was corrected, and the 1984 data was appended to the bottom of the macroall.dbf file.
2. Observation 1500 had Location = 0. This error was deleted by CINP.
3. Observation 2801 had Year = 8. CINP found this should have been 1986 and corrected the database.
4. There were 1536 cases where Width_cm = 0. CINP explained that only the # of stipes were counted for 1984, 1985, and part of 1987. CINP changed the 0 values to -99 to indicate when no data were taken for holdfast width.
5. There were 45 cases where No_stipe = 0. CINP found that errors had been made in the field when divers measured holdfasts of *Macrocystis* with no stipes (i.e., dead). These observations should either be deleted or a new code, indicating dead holdfasts, should be placed in the data base.

GORGONALL (contains size data for gorgonians):

1. Observation numbers 129-145 had Year = 0.
2. Observation number 146 had Year = 8.
3. Observation 433 had Location = 0.
4. There were 603 cases where height_cm and width_cm both = 0.
5. There were 309 cases where species = 2002 (=309 of the above 613).

CINP corrected all errors in the database. The rerun of the error-check program found no additional errors.

Additional Notes:

During analyses there were several species codes found that were not in the species code list. Names for these species were found while searching through the SPSS jobs in the handbook or in the annual reports. The master species list and location 50 were added to the location code list used by us.

SAMPLING DESIGN

In order to assess the design of any sampling program it is first necessary to define its purpose. Although National Park Service documents (e.g., Davis 1988; NPS 1991; Richards, et al. 1993) do not explicitly present the questions this monitoring program was intended to answer nor specify expected statistical analyses, it is clear that the monitoring program is intended to provide information that will be useful in the practical task of managing the Park for conservation of kelp forest species. Within this context, there

appears to be a desire to document long-term dynamics within the kelp forest ecosystem, and to be able to document the effects of both natural and anthropogenic disturbances. In addition, it is expected that the size-frequency information being gathered will enable one to estimate population age structure, identify and monitor recruitment cohorts and calculate average individual growth rates and mortality rates (Davis 1988, page 14). Based on the scope of work in the Request for Quotes and on discussions with Park personnel, the immediate need is to determine the statistical power of detecting differences in comparisons between two temporal samples at a site or perhaps between two sites at a given time and of detecting trends in abundance at a particular site, and to determine the chances of recognizing cohorts and following them over time.

Precision of the Estimates of Mean Density and Percent Cover

First we examined the precision of the estimates of mean density or percent cover. For all locations and surveys for each species, we calculated the mean density and coefficient of variability, CV, and then plotted the latter as a function of the former. The coefficient of variability is equal to the standard deviation divided by the mean, that is to say, the standard deviation as a proportion or percentage of the mean. We have expressed the CV as a percentage. The precision of the estimate of the mean can also be expressed as a 95 % confidence interval. We have calculated the relative confidence interval as:

$$95\% \text{ C.I.} = \bar{x} \pm r \bar{x},$$

where r is the relative precision as a percentage of the mean. Since the number of possible number of sampling units was constrained by the sampling design, we have included a finite population correction in our calculations. The following relationship was used to calculate relative precision (Snedecor & Cochran, 1971; Thompson, 1992):

$$r = (t^2 \cdot CV^2/n)^{1/2} \cdot (N-n/N)^{1/2}$$

where, n = sample size, N = possible sample size, r = relative precision, t = t-value with $n-1$ degrees of freedom, and CV = coefficient of variation. For each type of kelp forest monitoring n , N , and t are fixed. Therefore, r = constant, $K \cdot CV$ (Table 2).

Table 2. Parameter values and the constant, K , used to convert the coefficient of variability to precision as expressed by $\frac{1}{2}$ 95 % confidence interval as a percent of the mean.

| SAMPLE TYPE | n | N | t | K |
|-----------------------|----|-----|--------|--------|
| Quadrats | 20 | 100 | 2.093 | 0.4186 |
| Band Transects | 12 | 33 | 2.201 | 0.5069 |
| Random Point Contacts | 25 | 100 | 2.064 | 0.3575 |
| Fish Transects | 2 | 91 | 12.706 | 8.8852 |

Given the sampling protocols, N is the possible number of sampling units that could be placed on a transect. In the case of fish, the sampling units are days and N is the number of days in the usual sampling season, June - September. In the plots, we have added a second y-axis, which is one half the 95 % confidence interval as a percentage of the mean and is calculated as $K \cdot CV$.

The results of these analyses for the various sampling programs are presented in Appendices F1 - F4. Not surprisingly, for nearly all the benthic species precision is poor when the mean density is near zero, improves rapidly with increasing density, and then levels off. The poor precision at very low densities probably reflects the fact that there are many zeros in the data. For the great bulk of the observations, the 95 % confidence interval is something less than ± 100 % of the mean, and for most species it is around ± 50 % of the mean less for densities greater than around 1 or 2 per square meter or percent covers greater than about 5 %. The situation for fishes is very different. The coefficient of variability is less than 100 % for a large proportion of the observations, but is completely unrelated to the average density (Appendix F4). However, because of the extremely small sample size ($n = 2 \text{ yr}^{-1}$), precision is very poor. The fact that the coefficient of variability decreases with an increase in average density for benthic species and not for fishes is interesting. We suspect that this is related to the facts that replication for benthic organisms is spatial, whereas that for fishes is temporal, and that the benthic organisms are sessile or far more sedentary relative the size of the sampling unit than are fishes.

Power to Detect Differences in Paired Means Among Surveys and Locations

There were no *a priori* comparisons of interest specified by the National Park Service in the scope of work. In examining power, there were a very large number of possible *a posteriori* comparisons that one could analyze. There were generally 16 stations, as many as 13 annual surveys, and 68 species. Were one to analyze all possible pair-wise comparisons of the 208 sets of observations (16×13), there would be 21,528 calculations for each of the 68 species, or 1,463,904 comparisons of density and calculations of power, without making comparisons among species. Although the computer enables one to do the mathematics in a reasonable amount of time, the individual results would be of doubtful utility. Undoubtedly many differences would be statistically significant and many would not; in many instances the power to detect the observed difference would be high, and in many instances it would be low. In an *a posteriori* exercise such as this the overall patterns are of more interest than any given answer.

One approach would be to do the calculations for a random subset of the data. We have chosen instead to use all the data and summarized the results in plots and tables that enable one to search for patterns in the data. For each species in the various types of samples, we calculated the power to detect differences of the observed magnitude using

all possible pairwise comparisons between surveys at each location and all possible pairwise comparisons between locations at each survey. For each pairwise comparison, we calculated the power to determine if the observed difference was significantly ($\alpha=0.05$) different from zero. First, we calculated the absolute difference in the means, determined the degrees of freedom, and calculated the standard error of the difference:

$$\begin{aligned} \text{Diff}_{ij} &= |\bar{X}_i - \bar{X}_j| \quad (i \neq j) \\ \text{df}_{\text{Diff}} &= n_i + n_j - 2 \\ \text{se}_{\text{Diff}} &= [((\text{var}_i \cdot (n_i - 1)) + (\text{var}_j \cdot (n_j - 1))) / \text{df}_{\text{Diff}}]^{1/2} \cdot [n_i + n_j - 2]^{1/2} \end{aligned}$$

Next, we calculated the critical value and the t-value for a two-tailed test ($\alpha = 0.05$):

$$C = \text{Diff}_{ij} - \text{se}_{\text{Diff}} \cdot (t_{0.975, \text{df}_{\text{diff}}})$$

$$t_{(1-\beta, \text{df}(\text{diff}))} = (C - 0) / \text{se}_{\text{Diff}}$$

Power was obtained by looking up the probability associated with $t_{(1-\beta, \text{df}(\text{diff}))}$.

To summarize the large number of results, we plotted the power of the test against the absolute difference, or "delta", between the means (Appendices G1-G4 & H1-H4). To further compress the results, we grouped the data by the size of the difference in the means and for each category tallied the number of cases where the power to detect a significant ($\alpha=0.05$) difference in the means was at least 0.80. We did this for each species over all locations (Tables 3-6).

The power to detect a change as large as a halving in density was poor for all types of samples. For differences greater than about 60% of the larger mean in quadrat counts (Table 3), roughly a third of the comparisons had good power. To put this in perspective, many species were always uncommon and one would not expect to be able to detect changes in abundance. For example, lobster (*Panulirus interruptus*) are not really sampled with quadrat methods and it is extremely unlikely that changes in abundance will ever be detected. For common and relatively abundant species such as red and purple sea urchins (*Strongylocentrotus franciscanus* and *S. purpuratus*) or bat stars (*Asterina miniata*) power is good for a bit less than half the comparisons where the difference in means is at least 60 % of the larger value. Appendices G and H present power as a function of the actual difference in density at each location and for each year. For red urchins, for example, power is usually good if the difference in density is at least 3 or 4 m⁻². Although the pattern is similar, the percent of comparisons with good power for band transects is smaller (Table 4). The power to detect changes in the abundance of fishes was almost

Table 3. Percent of comparisons (%) where the power to detect a difference in mean density with $\alpha=0.05$ was greater than 0.80. For each species, all possible pairwise comparisons between surveys were made for each location and the results were combined. N = number of comparisons (which may differ among sex or age classes). Data from quadrat counts.

| Species | Difference in the Means as a Proportion of the Larger Value | | | | | | | | | |
|---|---|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|
| | 0.0 - 0.2 | | 0.2 - 0.4 | | 0.4 - 0.6 | | 0.6 - 0.8 | | 0.8 - 1.0 | |
| | % | N | % | N | % | N | % | N | % | N |
| <i>Alloclinus holderi</i> | 0 | 69 | 0 | 75 | 3 | 115 | 22 | 85 | 37 | 300 |
| <i>Asterina miniata</i> | 0 | 119 | 0 | 140 | 12 | 123 | 51 | 164 | 40 | 428 |
| <i>Astraea gibberosa</i> | 0 | 1 | 0 | 3 | . | 0 | 0 | 3 | 0 | 1 |
| <i>Astraea undosa</i> | 0 | 106 | 0 | 105 | 10 | 137 | 57 | 164 | 44 | 420 |
| <i>Coryphopterus nicholsii</i> | 0 | 75 | 3 | 72 | 16 | 103 | 45 | 148 | 53 | 285 |
| <i>Cypraea spadicea</i> | 0 | 127 | 0 | 121 | 0 | 160 | 7 | 149 | 9 | 319 |
| <i>Eisenia aborea</i> | 0 | 46 | 0 | 58 | 0 | 67 | 10 | 61 | 6 | 439 |
| <i>Laminaria farlowii</i> | 0 | 68 | 0 | 60 | 2 | 96 | 10 | 94 | 20 | 446 |
| <i>Lytechinus anamesus</i> | 0 | 6 | 0 | 5 | 0 | 9 | 67 | 3 | 17 | 6 |
| <i>Lythrypnus dalli</i> | 0 | 13 | 0 | 18 | 8 | 26 | 22 | 27 | 29 | 175 |
| <i>Macrocystis pyrifera</i> (All) | 0 | 81 | 0 | 107 | 4 | 130 | 38 | 167 | 53 | 534 |
| <i>Macrocystis pyrifera</i> (Adults) | 0 | 93 | 0 | 85 | 3 | 119 | 23 | 116 | 41 | 377 |
| <i>Macrocystis pyrifera</i> (Juveniles) | 0 | 51 | 0 | 59 | 3 | 78 | 14 | 107 | 41 | 534 |
| <i>Parastichopus parvimensis</i> | 0 | 296 | 0 | 301 | 13 | 224 | 44 | 177 | 51 | 132 |
| <i>Pisaster giganteus</i> | 0 | 172 | 0 | 160 | 1 | 173 | 13 | 174 | 21 | 299 |
| <i>Pterygophora californica</i> | 0 | 42 | 0 | 61 | 2 | 44 | 10 | 52 | 16 | 369 |
| <i>Strongylocentrotus franciscanus</i> | 0 | 305 | 1 | 306 | 19 | 239 | 43 | 176 | 62 | 126 |
| <i>Strongylocentrotus purpuratus</i> | 0 | 160 | 5 | 184 | 21 | 203 | 53 | 253 | 78 | 351 |
| <i>Styela montereyensis</i> | 0 | 37 | 0 | 37 | 7 | 29 | 26 | 70 | 37 | 272 |

Table 4. Percent of comparisons (%) where the power to detect a difference in mean density with $\alpha=0.05$ was greater than 0.80. For each species, all possible pairwise comparisons between surveys were made for each location and the results were combined. N = number of comparisons (which may differ among sex or age classes). Data from band transects.

| Species | Difference in the Means as a Proportion of the Larger Value | | | | | | | | | |
|--------------------------------|---|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|
| | 0.0 - 0.2 | | 0.2 - 0.4 | | 0.4 - 0.6 | | 0.6 - 0.8 | | 0.8 - 1.0 | |
| | % | N | % | N | % | N | % | N | % | N |
| <i>Allopora californica</i> | 0 | 11 | 0 | 16 | 0 | 13 | 0 | 24 | 0 | 35 |
| <i>Aplysia californica</i> | 0 | 60 | 0 | 76 | 2 | 100 | 17 | 132 | 33 | 494 |
| <i>Haliotis corrugata</i> | 0 | 70 | 0 | 60 | 1 | 78 | 8 | 76 | 19 | 304 |
| <i>Haliotis fulgens</i> | 0 | 1 | . | 0 | 0 | 3 | . | 0 | 0 | 71 |
| <i>Haliotis rufescens</i> | 0 | 37 | 0 | 22 | 0 | 27 | 0 | 60 | 13 | 265 |
| <i>Hinnites giganteus</i> | 0 | 145 | 0 | 141 | 4 | 220 | 25 | 238 | 45 | 249 |
| <i>Kelletia kelletii</i> | 0 | 100 | 0 | 98 | 3 | 148 | 16 | 147 | 15 | 339 |
| <i>Lophogorgia chilensis</i> | 0 | 149 | 1 | 157 | 19 | 119 | 34 | 92 | 26 | 274 |
| <i>Lytechinus anamesus</i> | 0 | 27 | 4 | 26 | 18 | 50 | 41 | 44 | 33 | 487 |
| <i>Megathura crenulata</i> | 0 | 148 | 0 | 156 | 11 | 150 | 30 | 142 | 54 | 289 |
| <i>Muricea californica</i> | 0 | 24 | 0 | 22 | 0 | 13 | 5 | 21 | 13 | 32 |
| <i>Muricea fruticosa</i> | 0 | 39 | 0 | 39 | 0 | 43 | 0 | 40 | 1 | 215 |
| <i>Panulirus interruptus</i> | 0 | 46 | 0 | 52 | 0 | 45 | 0 | 45 | 0 | 210 |
| <i>Pycnopodia helianthodes</i> | 0 | 42 | 0 | 41 | 8 | 53 | 42 | 52 | 49 | 251 |
| <i>Tealia lofotensis</i> | 0 | 121 | 0 | 114 | 5 | 79 | 10 | 69 | 14 | 259 |
| <i>Tethya aurantia</i> | 0 | 164 | 0 | 188 | 12 | 177 | 36 | 140 | 32 | 273 |

always less than 80 % (Table 5), usually much less (Appendix G4). This is probably primarily a result of the small sample size ($n=2 \text{ yr}^{-1}$), since the variability is generally less than that for benthic species. There was generally better power to detect differences in percent cover than density (Table 6) and there were more comparisons for which there was good power to detect differences on the order of one-half the larger mean.

Table 5. Percent of comparisons (%) where the power to detect a difference in mean density with $\alpha=0.05$ was greater than 0.80. For each species, all possible pairwise comparisons between surveys were made for each location and the results were combined. N = number of comparisons (which may differ among sex or age classes). Data from fish transects.

| Species | Difference in the Means as a Proportion of the Larger Value | | | | | | | | | |
|--|---|-----|---------|-----|---------|-----|---------|-----|---------|-----|
| | 0.0-0.2 | | 0.2-0.4 | | 0.4-0.6 | | 0.6-0.8 | | 0.8-1.0 | |
| | % | N | % | N | % | N | % | N | % | N |
| <i>Chromis punctipinnis</i> (All) | 0 | 59 | 0 | 81 | 0 | 102 | 9 | 129 | 5 | 160 |
| <i>Chromis punctipinnis</i> (Adults) | 0 | 72 | 0 | 95 | 2 | 96 | 4 | 93 | 8 | 175 |
| <i>Chromis punctipinnis</i> (Juveniles) | 0 | 26 | 0 | 16 | 3 | 40 | 1 | 71 | 6 | 327 |
| <i>Damalichthys vacca</i> (All) | 0 | 47 | 0 | 52 | 3 | 69 | 8 | 90 | 9 | 168 |
| <i>Damalichthys vacca</i> (Adults) | 0 | 49 | 0 | 57 | 6 | 63 | 8 | 85 | 9 | 170 |
| <i>Damalichthys vacca</i> (Juveniles) | 0 | 1 | . | 0 | 0 | 3 | 0 | 6 | 1 | 93 |
| <i>Embiotoca jacksoni</i> (All) | 0 | 83 | 1 | 89 | 8 | 120 | 10 | 131 | 12 | 91 |
| <i>Embiotoca jacksoni</i> (Adults) | 0 | 83 | 0 | 98 | 8 | 117 | 10 | 115 | 14 | 98 |
| <i>Embiotoca jacksoni</i> (Juveniles) | 0 | 9 | 0 | 11 | 0 | 16 | 0 | 20 | 2 | 203 |
| <i>Embiotoca lateralis</i> (All) | 0 | 26 | 0 | 35 | 6 | 36 | 0 | 34 | 8 | 179 |
| <i>Embiotoca lateralis</i> (Adults) | 0 | 23 | 0 | 35 | 5 | 43 | 9 | 32 | 10 | 173 |
| <i>Embiotoca lateralis</i> (Juveniles) | 0 | 8 | 0 | 11 | 0 | 15 | 0 | 10 | 3 | 112 |
| <i>Girella nigricans</i> (All) | 0 | 53 | 0 | 56 | 2 | 54 | 2 | 83 | 4 | 179 |
| <i>Girella nigricans</i> (Adults) | 0 | 55 | 0 | 53 | 0 | 59 | 1 | 82 | 4 | 176 |
| <i>Girella nigricans</i> (Juveniles) | . | 0 | . | 0 | . | 0 | . | 0 | 0 | 46 |
| <i>Hypsypops rubicundus</i> (All) | 1 | 136 | 4 | 125 | 12 | 68 | 8 | 48 | 7 | 27 |
| <i>Hypsypops rubicundus</i> (Adults) | 0 | 140 | 4 | 124 | 9 | 68 | 9 | 45 | 11 | 27 |
| <i>Hypsypops rubicundus</i> (Juveniles) | 0 | 8 | 0 | 8 | 0 | 15 | 6 | 16 | 7 | 147 |
| <i>Oxyjulis californica</i> (All) | 0 | 59 | 1 | 74 | 1 | 92 | 8 | 111 | 6 | 209 |
| <i>Oxyjulis californica</i> (Adults) | 0 | 62 | 0 | 93 | 4 | 102 | 2 | 108 | 12 | 180 |
| <i>Oxyjulis californica</i> (Juveniles) | 0 | 7 | 0 | 11 | 0 | 21 | 0 | 25 | 3 | 331 |
| <i>Paralabrax clathratus</i> (All) | 0 | 92 | 0 | 122 | 0 | 104 | 2 | 95 | 8 | 103 |
| <i>Paralabrax clathratus</i> (Adults) | 0 | 88 | 0 | 119 | 0 | 110 | 2 | 83 | 9 | 100 |
| <i>Paralabrax clathratus</i> (Juveniles) | 0 | 28 | 0 | 14 | 0 | 23 | 9 | 35 | 4 | 261 |
| <i>Sebastes atrovirens</i> (All) | 0 | 48 | 0 | 48 | 0 | 76 | 10 | 88 | 10 | 204 |
| <i>Sebastes atrovirens</i> (Adults) | 0 | 56 | 0 | 51 | 1 | 75 | 7 | 87 | 10 | 192 |
| <i>Sebastes atrovirens</i> (Juveniles) | 0 | 3 | 0 | 5 | 0 | 3 | 0 | 13 | 4 | 135 |
| <i>Sebastes mystinus</i> (All) | 0 | 15 | 0 | 23 | 4 | 26 | 4 | 48 | 17 | 193 |
| <i>Sebastes mystinus</i> (Adults) | 0 | 21 | 0 | 26 | 3 | 33 | 8 | 50 | 21 | 86 |
| <i>Sebastes mystinus</i> (Juveniles) | 0 | 7 | 0 | 10 | 0 | 9 | 8 | 12 | 13 | 227 |
| <i>Sebastes serranoides</i> (All) | 0 | 22 | 0 | 38 | 0 | 57 | 0 | 46 | 8 | 213 |
| <i>Sebastes serranoides</i> (Adults) | 0 | 27 | 0 | 30 | 0 | 49 | 2 | 44 | 7 | 184 |
| <i>Sebastes serranoides</i> (Juveniles) | 0 | 3 | 0 | 8 | 0 | 12 | 0 | 9 | 6 | 191 |
| <i>Semicossyphus pulcher</i> (All) | 0 | 104 | 2 | 128 | 4 | 139 | 14 | 117 | 15 | 62 |
| <i>Semicossyphus pulcher</i> (Females) | 0 | 114 | 0 | 128 | 4 | 119 | 14 | 111 | 24 | 79 |
| <i>Semicossyphus pulcher</i> (Males) | 0 | 32 | 0 | 32 | 0 | 70 | 2 | 65 | 2 | 241 |

Table 6. Percent of comparisons (%) where the power to detect a difference in mean percent cover with $\alpha=0.05$ was greater than 0.80. For each species, all possible pairwise comparisons between surveys were made for each location and the results were combined. N = number of comparisons (which may differ among sex or age classes). Data from random point contact quadrats.

| Species | Difference in the Means as a Proportion of the Larger Value | | | | | | | | | |
|--|---|------|-----------|-----|-----------|-----|-----------|-----|-----------|-----|
| | 0.0 - 0.2 | | 0.2 - 0.4 | | 0.4 - 0.6 | | 0.6 - 0.8 | | 0.8 - 1.0 | |
| | % | N | % | N | % | N | % | N | % | N |
| Articulated coralline algae | 0 | 224 | 2 | 231 | 16 | 221 | 51 | 234 | 76 | 209 |
| <i>Astrangia lajollaensis</i> | 0 | 248 | 4 | 263 | 12 | 258 | 31 | 226 | 55 | 155 |
| <i>Balanophyllia elegans</i> | 0 | 208 | 0 | 210 | 14 | 217 | 34 | 202 | 16 | 266 |
| Bare | 0 | 199 | 11 | 206 | 44 | 163 | 78 | 104 | 90 | 180 |
| Cobble | 0 | 302 | 0 | 320 | 9 | 274 | 29 | 186 | 74 | 58 |
| <i>Corynactis californica</i> | 0 | 137 | 0 | 172 | 3 | 185 | 19 | 205 | 31 | 302 |
| <i>Cystoseira</i> spp. | 0 | 65 | 0 | 85 | 8 | 95 | 16 | 115 | 38 | 494 |
| <i>Desmarestia</i> spp. | 0 | 10 | 0 | 12 | 0 | 7 | 9 | 11 | 22 | 334 |
| <i>Diaperoecia californica</i> | 0 | 100 | 0 | 101 | 1 | 118 | 16 | 108 | 25 | 508 |
| <i>Diopatra ornata</i> | 0 | 161 | 0 | 156 | 0 | 166 | 9 | 117 | 18 | 450 |
| Encrusting coralline algae | 0 | 426 | 38 | 386 | 95 | 243 | 100 | 90 | 100 | 7 |
| <i>Gelidium</i> spp. | 0 | 28 | 0 | 30 | 0 | 48 | 0 | 23 | 21 | 431 |
| <i>Gigartina</i> spp. | 0 | 20 | 0 | 35 | 0 | 28 | 23 | 40 | 25 | 359 |
| <i>Laminaria farlowii</i> | 0 | 45 | 0 | 64 | 0 | 82 | 20 | 101 | 21 | 431 |
| <i>Leucetta losangelensis</i> | . | 0 | 0 | 1 | . | 0 | . | 0 | 10 | 20 |
| <i>Macrocystis pyrifera</i> (All) | 0 | 6 | 25 | 4 | . | 0 | . | 0 | 33 | 6 |
| Miscellaneous | 0 | 32 | 0 | 35 | 2 | 49 | 18 | 95 | 45 | 438 |
| Miscellaneous brown algae | 0 | 87 | 1 | 110 | 9 | 128 | 42 | 192 | 68 | 590 |
| Miscellaneous bryozoans | 0 | 104 | 2 | 123 | 19 | 115 | 64 | 144 | 74 | 210 |
| Miscellaneous green algae | 0 | 70 | 0 | 62 | 3 | 89 | 20 | 120 | 40 | 341 |
| Miscellaneous invertebrates | 0 | 220 | 11 | 251 | 58 | 265 | 89 | 219 | 98 | 197 |
| Miscellaneous red algae | 1 | 177 | 13 | 211 | 39 | 253 | 77 | 247 | 91 | 264 |
| Miscellaneous sponges | 0 | 88 | 0 | 91 | 2 | 101 | 20 | 137 | 36 | 244 |
| Miscellaneous tunicates | 0 | 90 | 0 | 102 | 6 | 132 | 35 | 109 | 53 | 227 |
| Mixed <i>Macrocystis</i> <i>Eisenia</i> <i>Pteryg.</i> | 0 | 75 | 6 | 93 | 33 | 75 | 71 | 72 | 57 | 308 |
| <i>Pachythyone rubra</i> | 0 | 8 | 0 | 7 | 0 | 8 | . | 0 | 56 | 32 |
| <i>Phragmatopoma californica</i> | 0 | 18 | 0 | 21 | 12 | 42 | 20 | 44 | 25 | 483 |
| <i>Polymastia pachymastia</i> | . | 0 | . | 0 | . | 0 | . | 0 | 0 | 2 |
| Rock | 2 | 1097 | 33 | 43 | . | 0 | . | 0 | . | 0 |
| Sand | 0 | 333 | 0 | 306 | 4 | 227 | 23 | 158 | 60 | 115 |
| <i>Sargassum</i> spp. | 0 | 1 | . | 0 | . | 0 | 0 | 3 | 0 | 9 |
| <i>Serpulorbis squamigerus</i> | 0 | 116 | 0 | 113 | 5 | 171 | 23 | 166 | 34 | 460 |

Power to Detect Temporal Trends in Density

When considering changes in abundance over time, it is useful to think of any particular series of numbers as being a single realization of a population of potential time series which varies about the mean of some underlying process (Stewart-Oaten, et al. 1986). When thought of in this way, it becomes obvious that spatial samples are not independent estimates of the process mean and do not provide replication in this context. The function of multiple spatial samples is to provide an accurate estimate of the actual population density at a particular time. Therefore, for most species counted as part of the Kelp Forest Monitoring Program, there were only 9 to 13 replicate observations which could be used to search for temporal trends in density.

The usual tool for trends analysis is ordinary least-squares regression, which is based on the assumption of independent errors. This assumption is often violated with time series data. If the errors are correlated, confidence intervals for parameters and probability values will be wrong. Another complicating factor is the fact that there is no *a priori* reason to believe that real trends should be linear. One is then faced with a plethora of non-linear models from which to choose.

We have chosen to examine the data both for linear trends and for non-linear trends that can be described using a quadratic term in the regression model. The power analyses for temporal trends were done in 3 steps for each type of survey (band transects, quadrats, fish transects, and random point counts). Cases in which all observations were zero or for which there were 4 or fewer surveys were identified and no further analyses were done. Data for combinations of species and locations passing this filter were then analyzed to determine whether there were significant non-linear patterns of change over time. We chose to add a quadratic term as representing the simplest non-linear effect. The quadratic model would be more likely to approximate a long cycle, for example a sine wave with a period of about half or three-quarters of the number of years observed. For this analysis, we conducted an ordinary least squares regression analysis using both a linear and a quadratic term for time:

$$y = b_0 + b_1 (\text{Time}) + b_2 (\text{Time})^2$$

The cases used in this analysis were divided into two groups: cases for which the significance level for the test of the quadratic term was less than or equal to 0.05 and those for which significance was greater than 0.05. The latter were considered to be cases for which there were no significant non-linear patterns of abundance over time. For these cases, the model was rerun without the quadratic term. For both those with and those without a quadratic term, an autoregressive model with a lag of 1 was fit. For cases with a

significant quadratic term the model was:

$$y = b_0 + b_1 (\text{Time}) + b_2 (\text{Time})^2 + \rho_1 v_{t-1} + \varepsilon_t$$

For cases without a significant quadratic term the model was:

$$y = b_0 + b_1 (\text{Time}) + \rho_1 \varepsilon_{t-1} + \varepsilon_t$$

Where: b_0 = intercept, b_1 = linear coefficient, b_2 = quadratic coefficient, $\varepsilon_t \sim N(0, \sigma^2)$, and $\varepsilon_{t-1} \sim N(0, \sigma^2/(1-\rho_1^2))$. $N(0, \sigma^2)$ is shorthand for normally and independently distributed with mean = 0, and variance = σ^2 .

Both analyses estimated the degree of autocorrelation with the Durbin-Watson statistic. In cases where the significance test for the Durbin-Watson exceeded 0.10, an ordinary least squares regression was done. In cases where the significance level was 0.10 or less, the Yule-Walker estimation technique was used, and the Durbin-Watson statistic was recalculated. Cases for which the significance level of the test of the Durbin-Watson statistic was ≤ 0.10 after the Yule-Walker method was applied were flagged and designated "non-correctable autocorrelations". In all cases for which there were sufficient data, regression parameters were estimated. For each parameter, the significance of the test that the parameter was non-zero, and the power to detect a parameter value different from zero were calculated.

The results of the analyses are presented in Volume IV of this report (Appendices I1 & I2, J1 & J2, K1 & K2, and L1 & L2). Due to a combination of significant quadratic effects, all observations equal to zero, or non-correctable auto correlations, only 57 % to 75 % of taxa by site combinations were analyzed for linear temporal trends (Table 7). Of these cases, between 7% - 25% had correctable autocorrelations. For the 4 survey methods, from 56 % to 75 % of the combinations of taxa and sites were amenable to the power analysis of linear temporal trends (Table 7). Depending on study type, from 11 % to 24 % of these observations had significant linear trends. The numbers of positive and negative trends were about equal for all of the study types except percent cover where positive trends outnumbered negative trends by about 3 to 1. The power to detect a linear trend was generally low. The number of cases for which power was greater or equal to 0.80 ranged from 6 % to 8 % of the possible linear cases for the four different survey methods (Table 7).

Size-Frequency Distributions

The size distribution of a population is determined by the rate of recruitment, by size-specific rates of individual growth and mortality, and by the variability in those average rates. Since size is much more easily measured than recruitment, growth, or mortality, and

large quantities of size data can be obtained at a relatively low cost, there has been much interest, especially in the fisheries community, in estimating population parameters from size distributions. Much effort has been devoted to identifying modes and separating size distributions into Gaussian components (e.g., Cassie, 1950; Bhattachary, 1967), to

Table 7. Summary of temporal trends power analysis. For each location and taxon, analyses were done to determine: 1) whether there was a significant quadratic term, 2) whether there was significant serial correlation and whether it was correctable. 3) for the remaining cases, the direction, significance, and power of the test for a non-zero slope.

A. Number of cases passing various statistical filters.

| Study Type | Total N | Significant Quadratic Term | < 4 or All 0 Observations | Non-Correctable Autocorrelation | Correctable Autocorrelation |
|---------------------|---------|----------------------------|---------------------------|---------------------------------|-----------------------------|
| Band Transects | 256 | 39 | 57 | 16 | 24 |
| Quadrats | 285 | 45 | 28 | 25 | 47 |
| Fish Transects | 384 | 28 | 75 | 9 | 20 |
| Random Point Counts | 434 | 76 | 8 | 23 | 64 |

B. Percent of cases without a significant quadratic term.

| Study Type | N | Significant Negative Slope | Significant Positive Slope | Power $b_1 < 0.80$ | Power $b_1 \geq 0.80$ | Appendices |
|---------------------|-----|----------------------------|----------------------------|-----------------------|--------------------------|------------|
| Band Transects | 144 | 8 % | 3 % | 94 % | 6 % | I1 & I2 |
| Quadrats | 187 | 11 % | 7 % | 92 % | 8 % | J1 & J2 |
| Fish Transects | 272 | 13 % | 11 % | 94 % | 6 % | K1 & K2 |
| Random Point Counts | 327 | 4 % | 14 % | 93 % | 7 % | L1 & L2 |

estimating mortality when growth parameters are known (e.g., Beverton & Holt, 1956; Ebert, 1981), and to estimating both growth and mortality parameters (e.g., Fournier & Breen, 1983; Ebert, 1987). In an attempt to gain insight into the factors that determine observed size distributions, workers have also created simple models that generate size distributions and have examined the effects of varying various parameters and assumptions (e.g., Barry & Tegner, 1990; Ebert et al., 1993; Botsford et al., 1994).

Although all these methods can be useful under certain circumstances, they are all assumption ridden. For example the following are the main assumptions of MULTIFAN (Otter Research Ltd), a computer program design to analyze length-frequency fisheries data:

- 1 Lengths in each age class are normally distributed around the mean length.
- 2 The mean lengths at age approximate a von Bertalanffy growth curve.
- 3 The standard deviations about the mean lengths are simple functions of the mean length at age.

4. After the first age class there is no size selectivity in sampling.

In order to use this program efficiently it is also necessary to have multiple temporal samples of the same population and large sample sizes. In an application of this method to Northern Shrimp (Fournier et al., 1991), each sample included thousands of individuals. Despite the sophistication of the program, acceptance of the results requires a large element of faith, or ancillary biological information (and a somewhat smaller element of faith).

The size frequency samples collected as part of the Kelp Forest Monitoring Program are too small to be used for more than a rough approximation of the size structure of local populations (Table 8). For most of the species, the number of individuals measured was less than 30, resulting in a precision of the estimated proportions of around ± 0.20 (Table 9). In other words, if the estimated proportion of, say, red urchins less than 25 mm was 0.20, the actual proportion would be between 0 and 0.40 with around 90 % certainty.

Table 8. Number of individuals measured in samples for size-frequency determinations.

| SPECIES | Mean Number of Individuals | Standard Deviation | MIN N | MAX N | Number of Samples |
|--|-------------------------------|-----------------------|----------|----------|----------------------|
| <i>Tethya aurantia</i> | 28 | 21 | 1 | 105 | 84 |
| <i>Haliotis rufescens</i> | 20 | 16 | 1 | 58 | 52 |
| <i>Haliotis corrugata</i> | 19 | 15 | 1 | 59 | 74 |
| <i>Haliotis fulgens</i> | 7 | 14 | 1 | 44 | 9 |
| <i>Cypraea spadicea</i> | 26 | 13 | 1 | 62 | 97 |
| <i>Kelletia kelletii</i> | 18 | 17 | 1 | 97 | 89 |
| <i>Astraea undosa</i> | 46 | 37 | 1 | 182 | 119 |
| <i>Astraea gibberosa</i> | 23 | 22 | 1 | 86 | 17 |
| <i>Megathura crenulata</i> | 25 | 17 | 1 | 86 | 114 |
| <i>Asterina (=Patiria) miniata</i> | 45 | 33 | 1 | 201 | 148 |
| <i>Pisaster giganteus</i> | 34 | 20 | 1 | 105 | 125 |
| <i>Pycnopodia helianthodes</i> | 25 | 18 | 1 | 67 | 48 |
| <i>Lytechinus anamesus</i> | 141 | 88 | 2 | 496 | 59 |
| <i>Strongylocentrotus franciscanus</i> | 111 | 39 | 4 | 266 | 171 |
| <i>Strongylocentrotus purpuratus</i> | 126 | 68 | 2 | 603 | 169 |
| <i>Parastichopus parvimensis</i> | 34 | 11 | 3 | 72 | 107 |
| <i>Hinnites giganteus</i> | 28 | 25 | 1 | 216 | 121 |

Table 9. Number of individuals that must be measured in order to insure that the estimated proportion in each size class (minimum of 3) is within d of the true proportion with various degrees of certainty (Thompson 1992, p.39).

| 100(1- α) | $d = 0.05$ | $d = 0.10$ | $d = 0.20$ |
|-------------------|------------|------------|------------|
| 95 % | 510 | 127 | 32 |
| 90 % | 403 | 101 | 25 |
| 80 % | 299 | 75 | 19 |

A large sample size is also required to detect differences in proportions of a particular size between samples (Table 10). A larger sample is needed to detect a given difference or change in proportion when the initial proportion is near 0.50 than if it is more extreme. However, even for small proportions, a sample size greater than 100 is needed to detect changes on the order of 0.10.

Although it is sometimes possible to follow cohorts through time by examining successive size distributions, this generally requires frequent sampling, large sample sizes, and a situation in which there is relatively little movement among dissimilar populations. However, where recruitment is infrequent, a single large event may be conspicuous for some time. Ebert (1983) measured 116 to 303 purple sea urchins on each of ten surveys conducted in the intertidal zone of Sunset Bay, Oregon between 1964 and 1978. A large recruitment event occurred in 1963. From 1964 to 1978 there was no or very little recruitment. The 1963 cohort was obvious through 1970.

Appendix E2 contains size-frequency plots through time. Although a mode which appears to represent recent recruits is sometimes present, there are few instances where a mode can be followed through time and very few cases where more than one mode can be followed. The best example of the latter is probably red sea urchins at Yellow Banks (Appendix E2-44). It is very unlikely that the larger modes represent cohorts. In Appendix E3, we grouped locations to increase sample size. However, it appears that the dynamics at the various sites are sufficiently different that grouping is not a very useful exercise.

Table 10. Sample sizes necessary to detect various increases in observed proportions with 80 % power ($\beta=0.2$) and $\alpha = 0.05$ (From Snedecor & Cochran, p. 221).

| *Initial Proportion | Increase in Proportion | | | | | |
|---------------------|------------------------|------|------|------|------|------|
| | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 |
| 0.05 | 435 | 138 | 73 | 46 | 33 | 24 |
| 0.10 | 687 | 198 | 97 | 59 | 40 | 29 |
| 0.15 | 908 | 249 | 118 | 70 | 46 | 33 |
| 0.20 | 1098 | 292 | 136 | 79 | 52 | 36 |
| 0.25 | 1256 | 328 | 150 | 86 | 55 | 38 |
| 0.30 | 1382 | 356 | 161 | 91 | 58 | 40 |
| 0.40 | 1540 | 387 | 171 | 95 | 59 | 15 |

In summary, the size frequency data can not be used to identify and follow cohorts through time, nor can they be used effectively to estimate growth or mortality rates. The animals collected for measurement are probably not unbiased samples of the population, the sample sizes are generally very small, for many species movement is probably substantial, and the analytical techniques require assumptions that are not justified for most of the species under consideration. Despite these short-comings, size frequency data are useful adjuncts to density data. Modest changes in field protocols and larger sample sizes would increase the utility of these data, but they still are unlikely to fulfill the expectations in the Handbook (Davis, 1988).

DETECTING THE EFFECTS OF AN OIL SPILL OR OTHER MAJOR PERTURBATION

Should there be a major environmental perturbation, such as an oil spill in the Santa Barbara Channel, the data resulting from the Kelp Forest Monitoring Program will undoubtedly be examined for evidence of the ecological consequences. Should such an event occur, the data and analysis will be held to a very strict standard by lawyers representing the organization responsible for the perturbation. We highly recommend that the Channel Islands National Park conduct the necessary study to determine before-the-fact the appropriate analyses to conduct, define a formal statistical model, and examine the data to determine the power of the test to detect effects of various magnitudes. This is a task well-outside the scope of work of this contract and requires a qualitatively different approach.

The best model currently available for examining the effects of an unreplicated perturbation using monitoring data is the BACI, which stands for Before/After-Control/Impact (Stewart-Oaten, *et al.*, 1986; Schroeter, *et al.*, 1993). In general, this approach requires one to pair the Impact location with one or more unaffected control locations at which populations behave similarly. The variate of interest is the difference in density between the Control and Impact sites at a survey. Each survey provides a single replicate. To test for an effect one compares the average difference in density Before the impact with the average difference After. It would be extremely useful for the Park Service to identify locations that could potentially be paired for such an analysis and then to calculate the power of the BACI test using those stations.

LITERATURE CITED

- Barry, J. P. and M. J. Tegner. 1990. Inferring demographic processes from size-frequency distributions: Simple models indicate specific patterns of growth and mortality. *Fishery Bulletin, U.S.* 88:13-19.
- Beverton, R. J. and S. J. Holt. A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. *Rapp. P.-V. Cons. Int. Explor. Mer* 140:67-83.
- Bhattacharya, C. G. 1967. A simple method of resolution of a distribution into Gaussian components. *Biometrics* 23:115-135.
- Botsford, L. W., B. D. Smith, and J. F. Quinn. 1994. Bimodality in size distributions: the Red Sea urchin *Strongylocentrotus franciscanus* as an example. *Ecological Applications* 4:42-50.
- Cassie, R. M. 1950. The analysis of polymodal frequency distributions by the probability paper method. *New Zealand Science Review* 8:90-91.
- Davis, G. E. 1988. Kelp Forest Monitoring Handbook. Channel Islands National Park, California. National Park Service, Channel Islands National Park. Ventura, California. 34 pages plus Appendices.
- Dean, T. A., S. C. Schroeter, and J. D. Dixon. 1984. Effects of grazing by two species of sea urchins (*Strongylocentrotus franciscanus* and *Lytechinus anamesus*) on recruitment and survival of two species of kelp (*Macrocystis pyrifera* and *Pterygophora californica*). *Marine Biology* 78:301-313.
- Ebert, T. A. 1981. Estimating mortality from growth parameters and a size distribution when recruitment is periodic. *Limnology and Oceanography* 26:764-769.
- Ebert, T. A. 1983. Recruitment in echinoderms. *Echinoderm Studies* 1:169-203.
- Ebert, T. A. 1987. Estimating growth and mortality parameters by nonlinear regression using average size in catches. Pages 35-44 In D. Pauly & G. R. Morgan, eds. Length-based methods in fisheries research. ICLARM Conf. Proc. 13, Manila, Philippines, and Kuwait Inst. Sci. Res., Safat, Kuwait.
- Ebert, T. A., S. C. Schroeter, and J. D. Dixon. 1993. Inferring demographic processes from size-frequency distributions: Effect of pulsed recruitment on simple models. *Fishery Bulletin, U.S.* 91:237-243.
- Greig-Smith, P. 1964. Quantitative Plant Ecology. Plenum Press, New York. 256 pages.

- Fournier, D. A. and P. A. Breen. 1983. Estimation of abalone mortality rates with growth analysis. *Transactions of the American Fisheries Society* 112:403-411.
- Fournier, D. A., J. R. Sibert, and M. Terceiro. 1991. Analysis of length frequency samples with relative abundance data for the Gulf of Maine Northern Shrimp (*Pandalus borealis*) by the MULTIFAN method. *Canadian Journal of Fisheries and Aquatic Science* 48:591-598.
- Hutchings, S. S. and R. C. Holmgren. 1959. Interpretation of loop-frequency data as a measure of plant cover. *Ecology* 40:668-677.
- National Park Service (NPS). 1991. Statement for management. Channel Islands National Park.
- SAS (Statistical Analysis Institute). 1993. SAS/ETS User's Guide. Version 6. Second Edition. SAS Institute, Cary, North Carolina.
- Schroeter, S. C., J. D. Dixon, J. Kastendiek, R. O. Smith, and J. R. Bence. 1993. Detecting the ecological effects of environmental impacts: A case study of kelp forest invertebrates. *Ecological Applications* 3:331-350.
- Snedecor, G. W. and W. G. Cochran. 1971. Statistical Methods. 6th edition. Iowa State University Press, Ames, Iowa; 593 pages.
- Stewart-Oaten, A., W. W. Murdoch, and K. E. Parker. 1986. Environmental impact assessment: "pseudoreplication" in time? *Ecology* 67:929-940.
- Richards, D., W. Avery, and D. Kushner. 1993. Kelp forest monitoring - Channel Islands National Park (1991 Annual Report). Technical Report No. NPS/WRUC/NRTR 93-05. Cooperative National Park Resources Studies Unit, University of California, Institute of Ecology, Davis, California.
- Thompson, S. K. 1992. Sampling. John Wiley & Sons, Inc., New York. 343 pages.