



Expanded Power Analysis of the Channel Islands National Park Kelp Forest Monitoring Program

Natural Resource Report NPS/MEDN/NRR—2022/2485



ON THE COVER

Lobster discovered during kelp forest monitoring.

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Executive Summary

A 2020 protocol review of the Mediterranean Coast Network kelp forest monitoring program (Rassweiler et al. 2020) included power analyses tied to sample sizes. This report augments that protocol review by recalculating some of those power analyses to account for nonnormality of the data. It specifically augments:

- Precision in estimates of mean abundance
- Power to detect year-to-year change at a given site
- Power to detect trends in abundance

The overarching goal of this expanded power analysis is to answer whether an appropriate number of samples are being collected for each method and if any sampling efforts can be reduced without losing significant power to detect trends. These questions are restated in each section because they are addressed differently in each analysis method. For example, using the random point contact (RPC) method involves collecting data at 40 points at 15 replicates per site, so changes to both the number of points and the number of replicates per site could be considered.

The following conclusions were reached:

- The data include many zero counts, exhibit mean-variance relationships, and often fail to pass normality tests.
- The data exhibit a huge variation in precisions among species, sites, and years. Standard errors were relatively high compared to mean counts, leading to low precision for most species-site-year combinations.
- Power to detect year-to-year changes was low for many species-site-year combinations, but there was large variability across the species, sites, and year combinations and the assumption of normality was likely to be rejected for species-site-year combinations with low counts. When only examining the combinations where the assumption of normality failed to be rejected, the numbers of replicates would have to double for the 1-m quadrat, band transects, and RPC method in order to meet the desired requirements (80% power to detect a 40% change in abundance), but fewer 5-m quadrat replicates could be taken.
- The power analysis to detect trends in abundance in which we combined all sites and years into one model for each species showed power varied widely by species. The estimated power to detect a 10% annual change for 20 years was 49% for the purple sea urchin (*Strongylocentrotus purpuratus*), 79% for the red sea urchin (*Strongylocentrotus franciscanus*), 98% for the California spiny lobster (*Panulirus interruptus*), and 100% for the warty sea cucumber (*Parastichopus parvimensis*). For these analyses, all sites were included in one model and although the models allowed for variation in slope among sites and variation among years, the power was based on an overall, parkwide trend.
- The power analysis to detect trends in abundance by island (Appendix B) showed considerable variation in power among islands for purple and red sea urchins but was very high for the California spiny lobster and the warty sea cucumber. Estimated power to detect a 10% annual

change for 20 years was highest for the purple sea urchin on Anacapa Island although still well below the desired 80% power at all islands included in the analysis. Estimated power to detect a 10% annual change for 20 years for the red sea urchin was approximately 80% or higher for Anacapa, Santa Barbara and Santa Rosa islands, and only about 55% at Santa Cruz Island. Estimated power to detect a 10% annual change was very high after only 10 years for both the California spiny lobster and the warty sea cucumber on the four islands included in the analysis.

- The time and cost savings, as well as the feasibility and safety of any reduction in sampling must be considered for the many species monitored by each protocol before any changes are made to the long-term program. The analysis contained herein may be used to support changes in the sampling design, but because of the wide range of conclusions for each species, site, and year combination, it is not possible to use these results without consideration of the cost and large number of program objectives.

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Abbreviations

CHIS: Channel Islands National Park

CV: Coefficient of variation

ENSO: El Niño-Southern Oscillation

KFM: Kelp Forest Monitoring Program

MPA: Marine protected area

RPC: Random point contact

SD: Standard deviation

SE: Standard error

1. Introduction

1.1 Background

Channel Islands National Park's (CHIS) Kelp Forest Monitoring Program (KFM) began in 1982. It increased in scope in 2005 in order to monitor newly established marine protected areas (MPAs), and continues through the present day. Currently, 33 sites are monitored annually using 12 data collection methods: 1-m quadrats; 5-m quadrats; band transects; random point contacts (RPCs); visual fish transects; roving diver fish counts (RDFCs); fish-size frequencies; video transects; natural habitat size frequencies; artificial recruitment modules (ARMs); species checklists; and monitoring of hourly temperatures. The methods are described in detail in an update to the sampling protocol handbook currently in progress by D. Kushner and J. Sprague and in Table 1.

Table 1. Data collection and analysis methods for Channel Islands National Park kelp forest monitoring metrics. All methods are listed, but only a few of them were analyzed (indicated by an "X") in this report. The analysis methods are described in this report and are based on the analyses from Rassweiler et al. (2020).

Data Collection Method	Type of Data Collected	Precision in Estimates of Mean Abundance	Power to Detect Year-to-Year Change at a Given Site	Power to Detect Trends in Abundance
1-m quadrats	Counts/replicate	X	X	X ^A
5-m quadrats	Counts/replicate	X	X	not analyzed
Band transects	Counts/replicate	X	X	X ^B
Random point contacts (RPCs)	% cover/replicate	X	X	not analyzed
Visual fish transects	Index of abundance	not analyzed	not analyzed	not analyzed
Roving diver fish counts (RDFCs)	Index of abundance	not analyzed	not analyzed	not analyzed
Fish-size frequencies	Fish lengths	not analyzed	not analyzed	not analyzed
Video-taped transects	Index of abundance	not analyzed	not analyzed	not analyzed
Natural habitat size frequencies	Species-specific size measurements	not analyzed	not analyzed	not analyzed
Artificial recruitment modules (ARMs)	Index of abundance; species-specific size measurements	not analyzed	not analyzed	not analyzed
Species checklists	Index of abundance	not analyzed	not analyzed	not analyzed
Oceanographic conditions	Temperature	not analyzed	not analyzed	not analyzed

^A Power to detect trends in abundance for the 1-m quadrat method was conducted for purple sea urchin (*Strongylocentrotus purpuratus*), red sea urchin (*Strongylocentrotus franciscanus*), and the warty sea cucumber (*Parastichopus parvimensis*).

^B Power to detect trends in abundance for the band transect method was conducted for the California spiny lobster (*Panulirus interruptus*).

It is often important to reassess a monitoring program after it is established to ensure its sampling protocols are effective. One way to assess a monitoring program is through a power analysis that tests whether the collected data will be able to detect long-term trends and changes in populations sizes or densities. KFM underwent a detailed review in 1994 (Schroeter et al. 1994), after which sampling at each site was reduced slightly. Other minor modifications have been made to the program over the years, but the methods and species sampled have generally remained consistent since the program's inception. In 2020, Rassweiler et al. (2020) conducted a second power analysis review. This report expands upon some of the power analyses conducted in Rassweiler et al. (2020) (Table 1).

The overarching goal of this expanded power analysis is to determine whether an appropriate number of samples are being collected for each method and if any sampling effort can be reduced without losing significant power to detect trends. We focused on the core data collection methods (1-m quadrats; 5-m quadrats; band transects; random point contacts) because these methods produce data-rich results, include multiple replicates per site, and have been used since data collection began in 1982. The 5-m quadrat sampling is new from 1996 but is included in this grouping because it follows a similar protocol as for the 1-m quadrat sampling.

2. Overview of the Data Collection and Power Analysis Methods

We used data from 33 sites collected at CHIS between 1996 and 2018. During this 22-year period, sampling methods were consistent, and it is the same times series analyzed by Rassweiler et al. (2020). Sites are defined as the area along the permanent line transect associated with each location. At each site, multiple replicates for each data collection method are taken; the number of replicates depends on the method (Table 2). For each replicate, there is a count of each species on the checklist associated with the data collection method. Additional detail on the sampling methods and lists of the species that are currently surveyed with each method will be forthcoming in an update to the sampling protocol handbook currently in progress by D. Kushner and J. Sprague.

Table 2. For the four core data collection methods, the number of replicates (n) taken per site, the area sampled in a replicate, and the total number (N) of possible replicates for each site for the kelp forest monitoring program at Channel Islands National Park.

Method	n	Area Sampled	N
1-m quadrats	12	1 m x 2 m	100
5-m quadrats	40	5 m x 2 m	40
Band transects	12	3 m x 20 m	33
Random point contacts (RPCs)	15	n/a	100 ^A

^A Based on the assumption that the strings on the RPC bar extend out approximately 0.5 m on either side of the bar.

In each section we restate the questions of whether we have sufficient statistical power to detect trends and whether or not sampling can be reduced without significantly reducing power because they are addressed differently for each data collection method. For example, the random point contact (RPC) method involves collecting data from 40 points at 15 locations (i.e., replicates) per site, so changes to both the number of points and the number of replicates per site could be considered.

2.1 Abundance and density calculations

We sometimes use the terms *abundance* and *density* interchangeably. For the 1-m quadrat, 5-m quadrat, and band transect methods, both terms represent the organism counts per replicate, that is, an index to abundance. For the RPC method, only what is directly under the knot of the sampling rope is recorded and the terms refer to the percent cover of the organism. Mean density is calculated as the sum of the replicate counts divided by the area associated with the replicates. For the 1-m quadrats, the replicate area is 1 m². For the 5-m quadrats, the replicate area is 5 m². For the band transects, the replicate area is 30 m². For the RPC method, the recorded values are the percent cover of the organisms, and therefore the values would not undergo any conversion. However, the mean density conversions are linear transformations of the counts and would not change the conclusions of the power analysis; therefore, the raw counts are used in the power analysis and are generally referred to as the densities.

2.2 Count values are averaged

For the 1-m quadrat sampling, two 1-m² quadrats are placed on the two sides of the site's line transect, and counts from each quadrat are recorded separately as an "A" count and a "B" count. To be consistent with previous protocol reviews, the average of the side-by-side pair counts is taken and used as the survey's count unless otherwise noted. The total area sampled with each replicate is 2 m², but once the average is taken, the area associated with each replicate is 1 m². Similarly, for the 5-m quadrat sampling, side-by-side A and B counts are taken and then averaged. For this method, the total area sampled with each replicate is 10 m², but the area associated with each replicate is 5 m² because of the averaging. Band transect sampling done on opposite sides of the line transect are similarly averaged, and again, the area associated with each replicate is half of the area shown in Table 2. For the RPC sampling, data are collected and recorded from four separate segments (Counts "A," "B," "C," and "D"), and the four counts are averaged to provide a single count.

2.3 Zero counts

For many species, the count for each replicate was zero. A zero count may occur because the species is absent from the site, because the species is absent from the survey area but occurs at the site, or because it goes undetected. Zero-inflated data is very common in ecology and may be a reason for a data set to not meet the normality assumption. Additionally, the excess zeroes may underestimate the variance calculations because variance is calculated using all values and not just the detections.

3. Precision in Estimates of Mean Abundance

The research question associated with this precision analysis is: how does a larger or smaller number of replicates (n) affect the precision of abundance estimates? In this context, precision refers to the variability associated with the density or abundance estimates. It is of interest to know how the precision changes if more or fewer replicates are collected. Examining how the precision estimates change for different density estimates also determines if there is a mean-variance relationship in the data over space and time. If the mean and variance covary, the data would not be normal, but instead would be better represented by a Poisson or negative binomial distribution.

The traditional statistics definition is that precision is equal to the inverse of the variance, while the precision of an average is often considered to be represented as the standard error (SE). However, the power analyses associated with the CHIS data have used different definitions of precision. Schroeter et al. (1994) defined precision (for each species i at site j in year t) as

$$t_{0.975, n-1} \cdot \frac{1}{\text{Mean}} \cdot \frac{SD}{\sqrt{n}} \cdot \sqrt{\frac{N-n}{n-1}} \quad (1)$$

where $t_{0.975, n-1}$ is the 97.5% quantile of a t -distribution with $n-1$ degrees of freedom; SD is the standard deviation estimate associated with the mean estimate; n is the sample size; and N is the population of possible sampling units. Therefore, this estimate of precision is the 95% confidence interval half-width as a proportion of the mean estimate. The t -statistic takes on a larger value for larger n .

Rassweiler et al. (2020) used a similar but slightly different definition of precision. In their calculations, Rassweiler et al. (2020) replaced the $t_{0.95, n-1}$ statistics with 1.96; 1.96 is an approximation of the value that $t_{0.975, n-1}$ approaches as $n \rightarrow \infty$.

Both references included a finite population correction when calculating the SE. If a significant proportion of the population of interest is sampled, then a finite population correction factor is added to the calculation of the standard error:

$$SE = \frac{SD}{\sqrt{n}} \sqrt{\frac{N-n}{n-1}} \quad (2)$$

If the sample size or sampled area is small relative to the population of interest, then no finite population correction is applied, and the standard error would be calculated as

$$SE = \frac{SD}{\sqrt{n}} \quad (3)$$

Contrary to Shroeter et al. (1994) and Rassweiler et al. (2020), we decided to not use a finite population correction in our analysis. For the CHIS data, N (Table 2) is the number of replicates that could be taken if the sites were sampled in their entirety. For example, for the 1-m quadrat data collection method, a 1 m² plot is sampled on each side of the line transect (2 m² total area covered for each sample) and 12 of these quadrats are sampled ($n = 12$). If the entire possible sampling area was

split into the 2 m² quadrats that are sampled, it would lead to a total possible of 100 sampling units, or replicates. Therefore, for this method, $N = 100$. Table 2 displays the number of replicates (n) and total number of possible replicates per site (N) for each data collection method.

This method of calculating and including the finite population correction assumes that the sampling area is equal to the desired area of inference. In reality, the sampling area is more limited than the ultimate desired area of inference. For example, Table 2 shows that the entire possible sampling area is sampled for the 5-m² quadrats, which leads to standard errors of 0 if the finite population correction is applied. However, for the data collected from this method, the interest is in the precision of the mean density estimate in order to extrapolate its value to represent the precision obtained for the larger, general site area. Because of this interpretation, the finite population correction is not included in the SE calculations.

3.1 Methods

In order to examine how the number of replicates affects precision, the raw data and mean density estimates for each species-site-year combination and the four primary data collection methods were plotted. They showed skewness in the data and the high frequency of zero counts.

3.1.1 Assessing normality

Normality is assessed through Shapiro-Wilk tests (with Type I error $\alpha = 0.05$) for each species-site-year combination and data collection method. Normality is only tested when the mean density for the species-site-year combination is greater than 0. Bonferroni-type corrections are not applied; therefore, type I errors are inflated, and more data may be robust to a normality assumption than the results imply. For each species, the following is recorded (See Appendix A, Tables A-1 to A-4):

- The number of site-years with data for each species (“Num. of Site-Years with Data”). This column is included because not all species are sought in all years of data collection. The data for a species-site-year combination may consist of all 0s, and these 0s have been noted in the database and included in the count.
- The number of sites that the species was detected at (“Num. of Sites with Data”). Again, if the data for a site consist of all 0s, then the site is still included in this count.
- The number of species-site-year combinations where the species was detected, that is, the mean density is greater than 0 (“Num. of Site-Years Ever Detected”). In this column, only nonzero species-site-year combinations are included in the count.
- For the combinations where the mean density is greater than 0, that is, there were nonzero counts, the proportion of the site-years where the species was detected that pass the Shapiro-Wilk test and are therefore assumed to be normal (“Proportion Normal”).
- For the combinations where the mean density is greater than 0, that is, the site-years where the species was detected, the proportion where the *median* density is 0 (“Proportion with Median = 0”), which is suggestive of excess 0s.

3.1.2 Comparing precisions

Precision is calculated for each species-site-year combination and data collection method. Precision, represented as the SE, is plotted against mean replicate counts to provide additional insight into the mean-variance relationships of the data and what distributions they may be approximated by (Figure 1). For example, if the mean-variance relationship is 1 to 1, that is representative of a Poisson distribution.

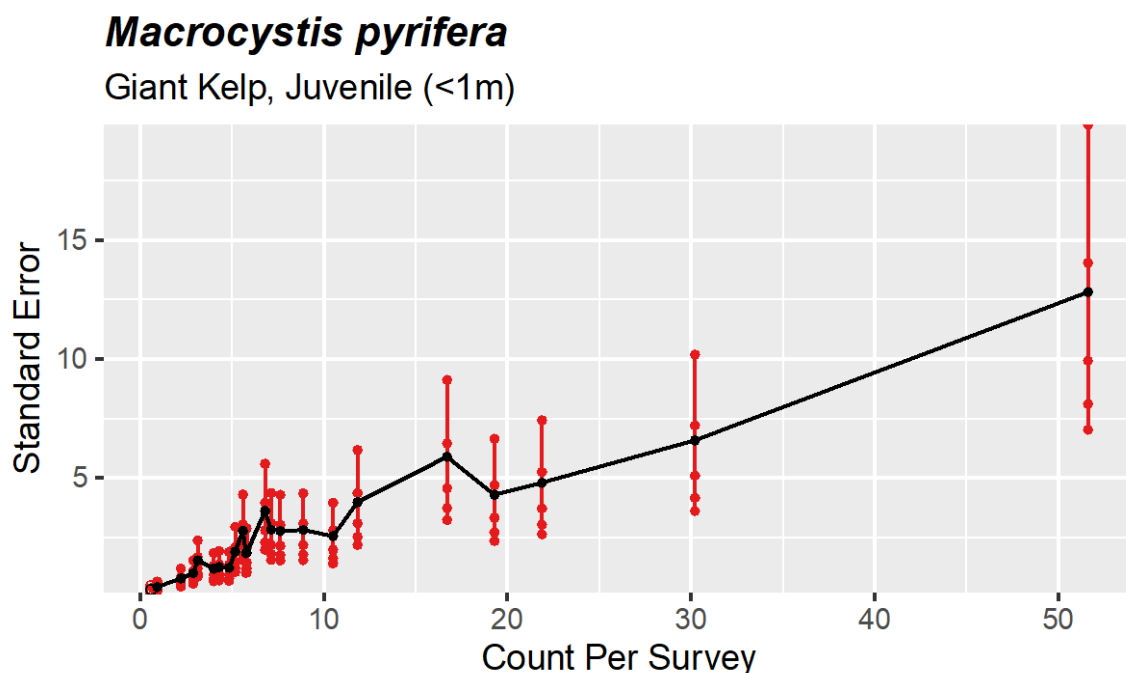


Figure 1. Example precision figure used to analyze juvenile giant kelp at the Landing Cove site of Anacapa Island, sampled with the 1-m quadrat method, for the kelp forest monitoring program at Channel Islands National Park. Because the standard error increases as the mean replicate count increases, it demonstrates a mean-variance relationship for this species. The black points are the standard errors estimated from the data for the various mean replicate counts. Counts per survey are the mean counts for each year of sampling. The points are connected to highlight their trend. The vertical sets of red points represent hypothetical standard errors if more replicates (the points below the black one) or fewer replicates (the points above the black one) are taken.

To answer the research question, precision was recalculated using additional or fewer replicates (n) than what is currently collected (Table 2). For this analysis, precision continued to be defined as the SE for simplicity and ease of interpretation. Precision was recalculated assuming the same SD for each species-site-year combination as the data provide, but with replicate sizes of 5, 10, 20, 30, and 40. Average SE values for each species are presented in Tables A5–A8 in Appendix A.

3.2 Results

3.2.1 Qualitative assessment of plots

The density plots demonstrate a high occurrence of 0 counts at many sites. If most replicates at a given site have 0 counts, then the site-years that do have counts appear right-skewed. This is

expected because if the median count is 0, then any non-zero counts will inevitably seem high given the boxplot is based on the interquartile (25th–75th percentile) range. If all replicates at a site-year combination are greater than 0, then many densities appear normal.

For almost every species-site-year combination, as the mean density increases so does the SE, implying a mean-variance relationship.

3.2.2 Assessing normality

For most species-site-year combinations, the median density is 0; that is, the proportion of site-years with a median count of 0 is greater than 0.50 (See Appendix A, Table A-1 in). Although this result does not have a direct interpretation for the precision versus sample size calculations, it is noted here as it affects the normality assumption of the other power analyses. In general, less than half of the site-years with detections pass the Shapiro-Wilk normality test, and if a species has a high proportion of site-years with a median count of 0, it is likely to have a low proportion of site-years that pass the Shapiro-Wilk normality test. Only for a handful of species—1-m quadrat sampling of *Patiria miniate* (bat star), 1-m quadrat sampling of *Strongylocentrotus franciscanus* (red sea urchin), 1-m quadrat sampling of *Strongylocentrotus purpuratus* (purple sea urchin), band transect sampling of *Tethya aurantia* (orange puffball sponge), band transect sampling of *Undaria pinnatifida* (Wakame), and band transect sampling of *Urticina lofotensis* (white-spotted rose anemone), RPC sampling of bare substrate, RPC sampling of encrusting coralline algae, RPC sampling of miscellaneous invertebrates, and RPC sampling of red algae—do the data pass the Shapiro-Wilk test more than 40% of the time.

3.3 Discussion

Our results confirm the wide variation in precisions among species, sites, and years found by Rassweiler et al (2020). These wide variations mask any meaningful answers to how sample size affects precision. Obviously, more replicates always increase precision, but given the large number of comparisons, it is difficult to objectively say when additional or fewer samples would lead to the most cost-effective sampling regime. Additionally, standard errors are relatively high compared to mean counts per survey for all methods, suggestive of low precision for most species-site-year combinations. Data for most species and sites is not normal with a high proportion of 0 counts. Mean-variance relationships exist for nonnegative densities. The nonnormality should be considered before interpreting the precision of these data.

4. Power to Detect Year-to-Year Change at a Given Site

4.1 Methods

The following research question is associated with this power to detect year-to-year change analysis: is there 80% power to detect a 40% change in abundance between any two years at a given site? We also address the related question: given the estimated variances, and desired α , power level, and difference to be detected, what sample size (i.e., number of replicates) would be required to achieve those aims?

In addition to an estimate of the variance, one needs three of the following four values for a typical power analysis: α (type I error) level; the desired power level; sample size; and the difference in means detected or desired to be detected (Zar 2010).

Because of the notorious variability and noise in ecological data, $\alpha = 0.10$ is used, and the desired power level has already been given as 0.80. Variances are estimated from the data. The desired 40% difference in abundances needs to be converted to an absolute difference in mean density. The difference in mean density is calculated as the percent difference associated with the larger mean density for any given species-site-year combination to ensure that the percent difference ranges from 0 to 100%.

For each species and site, power estimates are computed for all year combinations in which both years have a count greater than 0 (equivalent to a mean density greater than 0), and power estimates are separately computed for the subset of combinations when both years follow a normal distribution (based on the Shapiro-Wilk test results from the previous section). All power estimates are conducted using t-tests with unequal variances, using the `power_t_test()` function from the “MESS” package in R (Ekstrøm 2019). Although the previous section suggested that the data often do not come from normal distributions, t-test are still applied here because of their simplicity given the large number of comparisons being made. However, if the data are not normal, then the power associated with those comparisons is not reliable.

4.2 Results

The normality assumption has a large effect on the power analysis. When all year combinations with non-zero counts are compared but the normality assumption is ignored, then the power analysis suggests that hundreds of replicates are needed to meet the desired power level and detectable difference in mean densities (*Power to detect year-to-year change at a given site*, in Appendix A). The power plots display the number of replicates needed to detect at 40% change in abundance with 80% power for the given species and site. For all sampling methods, the tests suggest 100 replicates or more would be needed to meet the power requirements when all data are considered. However, the previous section of this report demonstrated the strong nonnormality of the data for many species, sites, and years, and therefore the results of this analysis cannot be taken at face value. If one instead restricts the power analysis to the year combinations that pass the normality test, then an average of

- 29 replicates (12–54 across all species) would be needed for the 1-m quadrats,
- 17 replicates would be needed for the 5-m quadrats,

- 23 (12–41 across all species) replicates would be needed for the band transects, and
- 26 replicates (13–44 across all species) would be needed for RPCs

to meet the desired power level and detectable difference in means. For the 5-m quadrat sampling, only three site-year combinations for one species pass the normality test for both years, and therefore the suggestion of 17 samples is based on a small sample size associated with only one of the species. As a reminder the current sample sizes are 12 replicates for 1-m quadrats, 40 replicates for 5-m quadrats, 12 replicates for the band transects, and 15 replicates for RPCs.

4.3 Discussion

As mentioned in Rassweiler et al. (2020), the year-to-year analysis does not take advantage of the extensive time series and multiple sites available, and therefore any data analysis given the current sampling regime has more power than the results from this section imply.

The methods in this report differ from Rassweiler et al. (2020) in that the 40% detectable difference was used, and we separately conducted a power analysis for the data that passed the normality test. Rassweiler et al. (2020) mention that the power to detect a difference increased as the magnitude of the difference between densities increased. It is likely that this increase in ability to detect a difference is related to the year combinations that pass the normality test because very low densities are most often generated from the surveys with many 0 counts. Indeed, if all year combinations are included in the power analysis, a hundred samples may be required to meet the desired detectable difference, but if only the normal data are included in the power analysis, then the required sample sizes (i.e., number of replicates) are much more reasonable.

Based on the power analysis of the normal data, sample sizes would generally have to double for the 1-m quadrat, band transects, and RPC method in order to meet the desired requirements, but fewer 5-m quadrat replicates could be taken. However, as with the precision analysis, there is large variability across species, sites, and year combinations, and the analysis suggests a different number of required replicates for each combination. The number of replicates to be collected with each method must also consider costs, and perhaps a prioritization of which species and sites are most important to inform the number of replicates collected. Additionally, if more replicates are conducted at each site, then the replicates will get closer together in space and issues of non-independence between samples may have to be addressed.

5. Power to Detect Trends in Abundance

This section attempts to answer whether enough data are collected to detect an annual percent change of 3%, 5%, or 10% with 80% power if data are collected for an additional 5, 10, or 20 years.

5.1 Methods

The fitted model of the power analysis is based on the Piepho and Ogutu (2002) unreplicated linear mixed model from Tiszler et al. (2016), but with a few adaptations:

$$\log(y_{syk}) = \beta_0 + \beta_1 x_y + \beta_2 x_{MPA} + a_s + A_s x_y + b_y + e_{syk} \quad (4)$$

where

y_{syk} is the count associated with replicate k of site s sampled in year y

x_y is the year of the sample

x_{MPA} is an indicator variable and equals 0 for sites inside an MPA, 1 for sites outside

β_0 is the model intercept

β_1 is the effect associated with the year

β_2 is the MPA effect

a_s is the site random effect for the intercept, iid $N(0, \sigma_a^2)$

A_s is the site random effect for the slope

b_y is the year random effect, iid $N(0, \sigma_b^2)$

e_{syk} is the unexplained error, iid $N(0, \sigma_e^2)$

Rassweiler et al. (2020) used the log-linear model from Tiszler et al. (2016) in their report but without the site random effect slope. Therefore, each site had the same trend over time in that analysis. In this report, the site random effect slope is included so that the trend over time can vary from site-to-site. The models also include an MPA (Marine Protected Area) covariate (as a categorical variable indicating if a site is inside or outside of an MPA) to explain some of the variance and to signal whether counts are different depending on their location inside versus outside of the MPA. The power to detect an MPA effect can additionally be tested. Finally, as with the Tiszler et al. (2016) report, the model includes a year covariate to model the annual trend over time, a year random effect to account for variability over time that is beyond what is explained by the fixed effect, and a site random effect for the intercept so that each site can have a different mean count.

For the model structure, Tiszler et al. (2016) used a log-transformation of the response variable and then fit linear models. A small fraction was added to each count to avoid numerical issues from taking logarithms of zero counts. In this report, we also use a log-transformation, sum the “A” and

“B” counts associated with each replicate, and add 0.5 to the summed counts to avoid the numerical issues. Negative binomial generalized linear mixed effects models with a log-link response function were also fit to the data, using the summed counts without the 0.5 addition as the response variable. The response variable in a negative binomial is a nonnegative integer, which matches the summed count data collected from the monitoring. Both log-linear and negative binomial regression models were fit to the data initially. All species displayed high levels of overdispersion when Poisson models were fit; therefore, those models are not discussed further. The log-linear models led to very similar results and similar diagnostics associated with model fit; either could be an appropriate model structure for this power analysis. However, the log-linear models were chosen because they led to slightly better diagnostics plots.

Parameter and variance estimates are obtained from the fitted model, and the parameter estimate associated with the year fixed effect covariate is altered to match the desired trend for inference (i.e., $\beta_1 = 0.03, 0.05, \text{ or } 0.10$). Data are then simulated from the model, and power is calculated as the proportion of the simulations for which the β_1 estimate is significant at the $\alpha = 0.05$ level.

Because the MPA effect was included in the models, the data were limited to the 24 MPA-associated sites (Table 3), and the years included in the models were limited to 2005–2018, because some of the sites were first sampled in 2005 only. For Anacapa, Santa Cruz, Santa Barbara, and Santa Rosa islands, there are 3 sites inside the MPAs and 3 sites outside but near the MPA to monitor for changes in the system related to the MPAs. An MPA effect was included in the models as a known source of variability, leading to better variance estimates, and to allow for a power analysis on testing for an MPA difference across sites.

Although the power analysis model is similar to the Tiszler et al. (2016) report, this report estimates power through a simulation-based approach. Tiszler et al. (2016) used asymptotic approximations to estimate power but admitted that the approach is liberal and leads to higher power estimates than what may exist. The simulation-based approach is applied through the “simr” package in R, and the power calculations are based on the Kenward and Roger modification to the Wald test statistic (Green and MacLeod 2016; Halekoh and Højsgaard 2014). The significance of increasing trends was tested because populations can theoretically increase indefinitely, while decreasing trends would not be detectable for species that are already rare with many 0 counts.

Power was calculated to detect a 3%, 5%, or 10% annual change in abundance over 5, 10, or 20 years. Rassweiler et al. (2020) calculated power for a 3% annual increase for 12 or 24 years; these values were chosen because they mimic the Tiszler et al. (2016) report. A 3% annual increase leads to a 40% increase in abundance for the 12-year time period and a 100% increase for the 24-year time period. However, as seen in the urchin time series below, when populations undergo fluctuations, they are likely to more than double in a much shorter time period and then experience a die off shortly after. Therefore, we also tested the power of detecting larger 5% and 10% trends. Examples of resulting densities from such trends within the log-linear framework are shown in P 4.

Table 3. Sites included in the power analysis to detect trends over time for the kelp forest monitoring program at Channel Islands National Park.

Island Name	Location of Site in Relation to Marine Protected Area	Site Name
Anacapa Island	inside	Black Sea Bass Reef
Anacapa Island	inside	Cathedral Cove
Anacapa Island	inside	Landing Cove
Anacapa Island	outside	Admiral's Reef
Anacapa Island	outside	East Fish Camp
Anacapa Island	outside	Lighthouse
Santa Barbara Island	inside	Graveyard Canyon
Santa Barbara Island	inside	SE Sea Lion Rookery
Santa Barbara Island	inside	Southeast Reef
Santa Barbara Island	outside	Arch Point
Santa Barbara Island	outside	Cat Canyon
Santa Barbara Island	outside	Webster's Arch
Santa Cruz Island	inside	Cavern Point
Santa Cruz Island	inside	Potato Pasture
Santa Cruz Island	inside	Scorpion Anchorage
Santa Cruz Island	outside	Devil's Peak Member
Santa Cruz Island	outside	Little Scorpion
Santa Cruz Island	outside	Pedro Reef
Santa Rosa Island	inside	Chickasaw
Santa Rosa Island	inside	South Point
Santa Rosa Island	inside	Trancion Canyon
Santa Rosa Island	outside	Cluster Point
Santa Rosa Island	outside	Johnson's Lee North
Santa Rosa Island	outside	Johnson's Lee South

The power analysis was completed for four species: the purple sea urchin, red sea urchin, California spiny lobster, and the warty sea cucumber. The urchins were chosen because they are important indicator species of kelp ecosystems, and therefore there is a strong desire to understand if they are sampled adequately (pers. comm with D. Kushner, Channel Island National Park marine biologist, July 29, 2020). The lobster is a keystone predator in the system, and therefore there is similarly a strong desire to know if they are sampled adequately (pers. comm with D. Kushner, Channel Island National Park marine biologist, July 29, 2020). Sea cucumbers have been heavily fished outside of the MPAs since that fishery started in 1996. Beyond impacting adult numbers, the commercial fishery may also lead to lower recruitment of sea cucumbers inside the MPA. NPS staff desired to know how well the sampling protocol could detect population changes for this species.

Table 4. Examples of resulting populations from varying initial counts and annual trends for the kelp forest monitoring program at Channel Islands National Park.

Initial Mean Count	Annual Trend	Mean Count			Year 5 Percent Increase	Year 10 Percent Increase	Year 20 Percent Increase
		Year 5	Year 10	Year 20			
0.5	3%	0.58	0.67	0.9	16%	34%	80%
1	3%	1.16	1.34	1.81	16%	34%	81%
2	3%	2.32	2.69	3.61	16%	34%	80%
10	3%	11.59	13.44	18.06	16%	34%	81%
20	3%	23.19	26.88	36.12	16%	34%	81%
50	3%	57.96	67.2	90.31	16%	34%	81%
0.5	5%	0.64	0.81	1.33	28%	62%	166%
1	5%	1.28	1.63	2.65	28%	63%	165%
2	5%	2.55	3.26	5.31	27%	63%	165%
10	5%	12.76	16.29	26.53	28%	63%	165%
20	5%	25.53	32.58	53.07	28%	63%	165%
50	5%	63.81	81.44	132.66	28%	63%	165%
0.5	10%	0.81	1.3	3.36	62%	160%	572%
1	10%	1.61	2.59	6.73	61%	159%	573%
2	10%	3.22	5.19	13.45	61%	160%	572%
10	10%	16.11	25.94	67.27	61%	159%	573%
20	10%	32.21	51.87	134.55	61%	159%	573%
50	10%	80.53	129.69	336.37	61%	159%	573%

5.2 Results

Models with and without the MPA fixed effects, and with and without the year random intercepts and random slopes were fit for each species. The full model refers to the model with all fixed and random effects, that is, Equation 1 in chapter 3 of this report.

5.2.1 Purple sea urchin

The full model was selected as best-fitting for this species, and diagnostic plots associated with the residuals from the model fit (e.g., histograms, residuals vs. fitted value plots, and qq-plots) suggest that the model is a reasonable choice for the data. However, an examination of the fitted values demonstrates that the model does not capture all of the trends for each site (Figure 2).

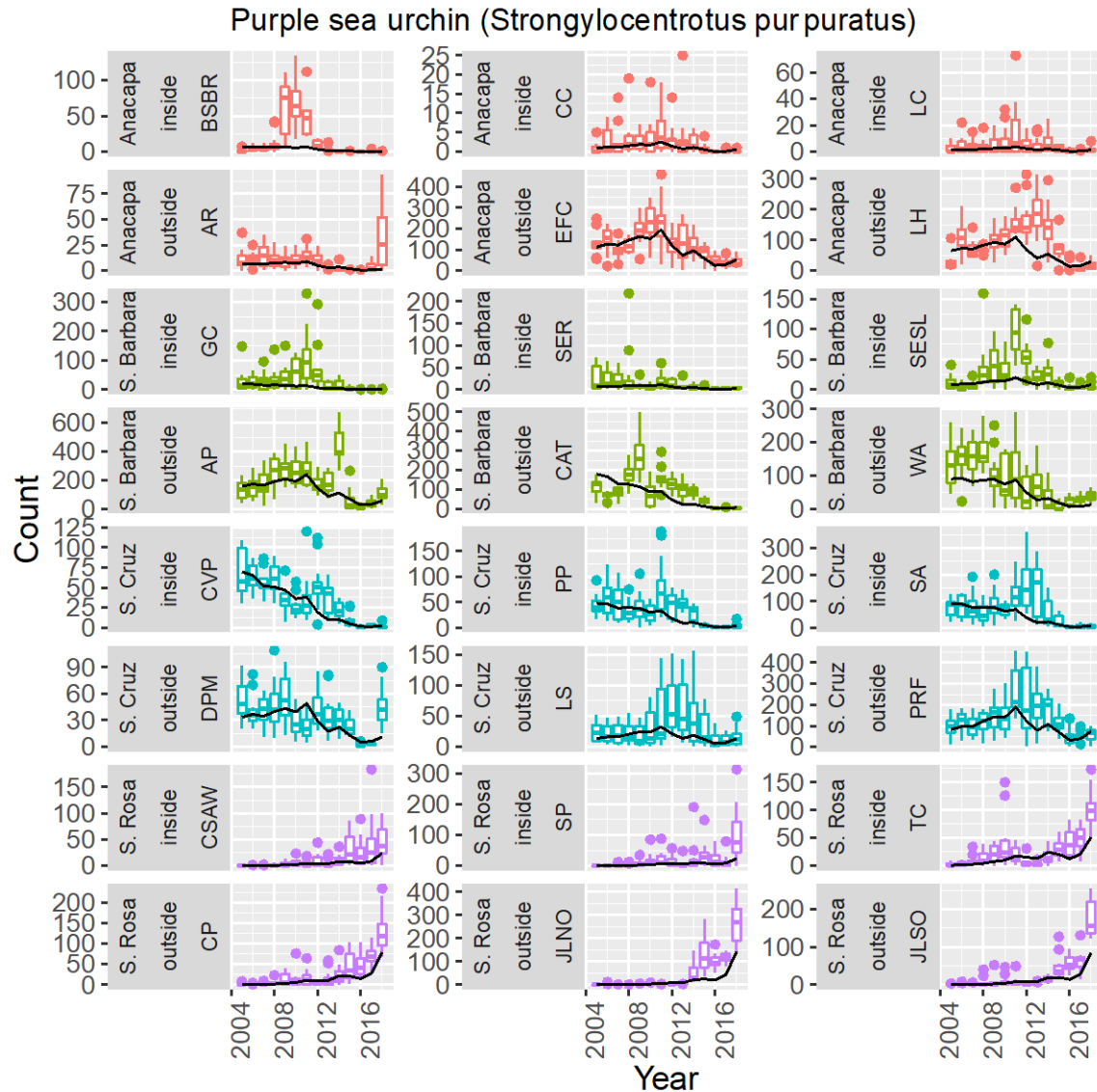


Figure 2. Purple sea urchin counts from the 1-m quad sampling method (boxplots) and the fitted values from the model (black line), with a separate plot for each site for the kelp forest monitoring program at Channel Islands National Park. The text along the y-axis provides the site context: the island name, whether the site is inside or outside of an MPA, and the following site code abbreviations: BSBR = Black Sea Bass Reef, CC = Cathedral Cove, LC = Landing Cove, AR = Admiral's Reef, EFC = East Fish Camp, LH = Lighthouse, GC = Graveyard Canyon, SER = Southeast Reef, SESL = SE Sea Lion Rookery, AP = Arch Point, CAT = Cat Canyon, WA = Webster's Arch, CVP = Cavern Point, PP = Potato Pasture, SA = Scorpion Anchorage, DPM = Devil's Peak Member, LS = Little Scorpion, PRF = Pedro Reef, CSAW = Chickasaw, SP = South Point, TC = Trancion Canyon, CP = Cluster Point, JLNO = Johnson's Lee North, JLSO = Johnson's Lee South.

The model results suggest low power to detect even 10% annual trends for the purple sea urchin (Figure 3). This result is likely due to the large population fluctuations already seen for the species, and the large amount of variability among islands and sites. For this species, the initial densities are 10.5 urchin/m² inside an MPA and 43.7 urchin/m² outside an MPA. A 10% increase would lead to

mean densities of 17 and 70 urchin/m² after 5 years, 23 and 113 urchin/m² after 10 years, and 71 and 294 urchin/m², respectively, after 20 years. Despite large increases in simulated abundance over 20 years, power did not approach the desired 80%. For this reason, we performed additional analyses to examine power for each island individually (Appendix B). Power to detect a 10% change in the purple sea urchin over 20 years increased slightly for Anacapa Island (>60%), but power remained very low for Santa Barbara, Santa Cruz, and Santa Rosa islands (See Appendix B, Figure B-1).

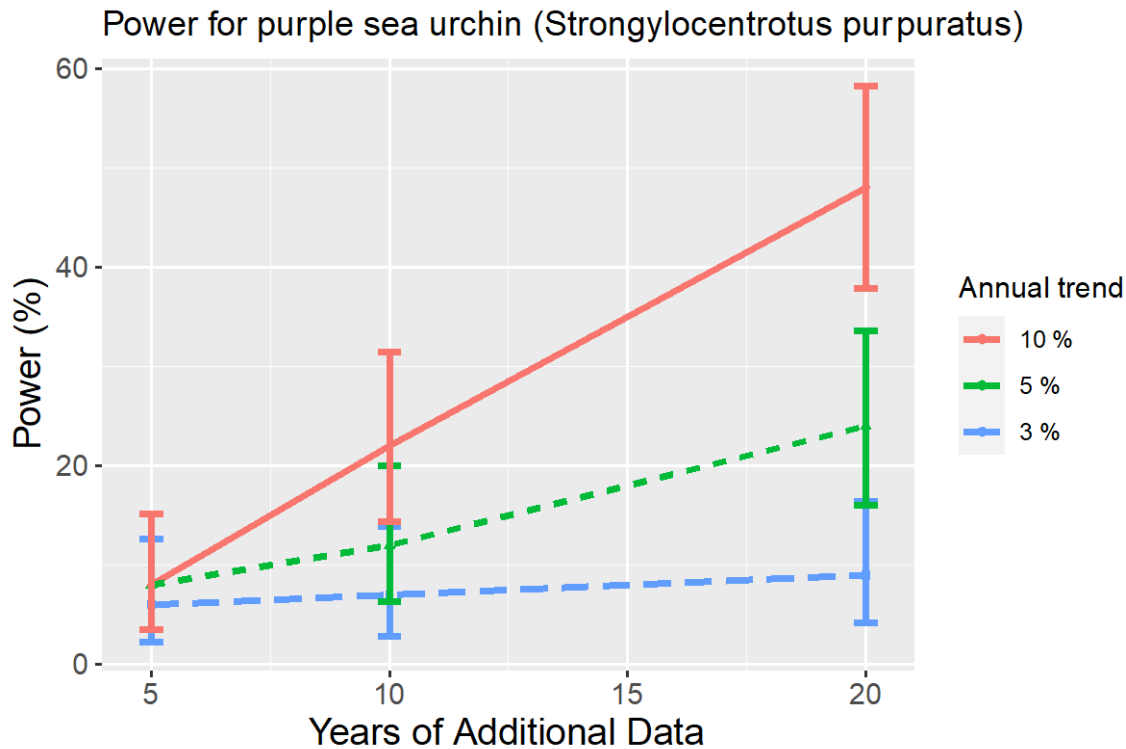


Figure 3. Power analysis results associated with the purple sea urchin for the kelp forest monitoring program at Channel Islands National Park. The error bars represent the 95% confidence intervals from 100 simulations associated with the power estimates. The 10% annual trend line is the top line, the 5% annual trend line is the middle line, and the 3% annual trend line is the lowest line.

5.2.2 Red sea urchin

The full model was selected as best-fitting for this species, and diagnostic plots associated with the residuals from the model fit (e.g., histograms, residuals vs fitted value plots, and qq-plots) suggest that the model is a reasonable choice for the data. However, an examination of the fitted values demonstrates that the model does not capture all of the trends for each site (Figure 4).

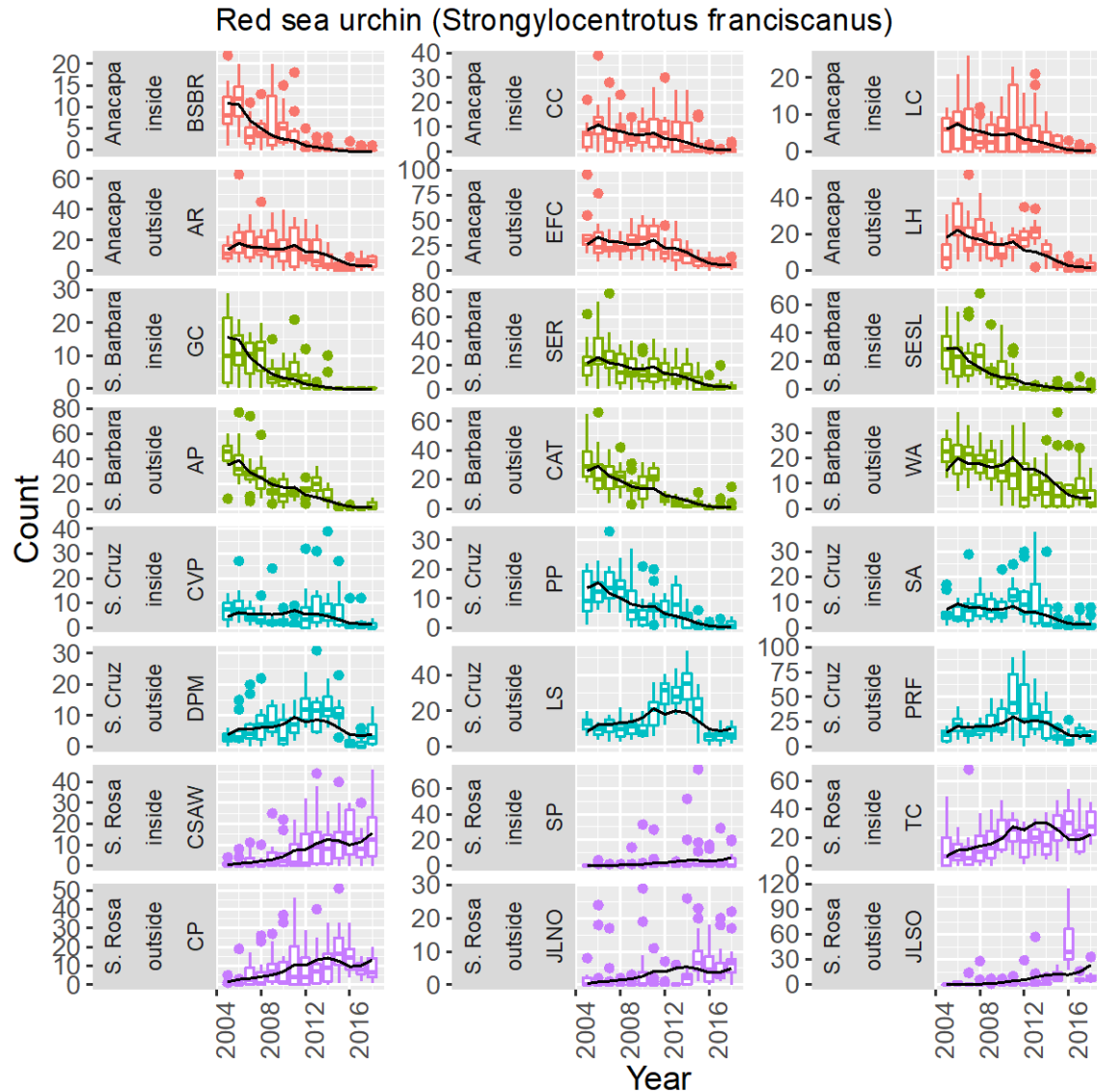


Figure 4. Red sea urchin counts from the 1-m quad sampling method (boxplots) and the fitted values from the model (black line), with a separate plot for each site for the kelp forest monitoring program at Channel Islands National Park. The text along the y-axis provides the site context: the island name, whether the site is inside or outside of an MPA, and the following site code abbreviations: BSBR = Black Sea Bass Reef, CC = Cathedral Cove, LC = Landing Cove, AR = Admiral's Reef, EFC = East Fish Camp, LH = Lighthouse, GC = Graveyard Canyon, SER = Southeast Reef, SESL = SE Sea Lion Rookery, AP = Arch Point, CAT = Cat Canyon, WA = Webster's Arch, CVP = Cavern Point, PP = Potato Pasture, SA = Scorpion Anchorage, DPM = Devil's Peak Member, LS = Little Scorpion, PRF = Pedro Reef, CSAW = Chickasaw, SP = South Point, TC = Trancion Canyon, CP = Cluster Point, JLNO = Johnson's Lee North, JLSO = Johnson's Lee South.

The model results suggest low power to detect 3 or 5% annual trend, and almost 80% power to detect a 10% increase over 20 years (Figure 5). As with the purple sea urchin, it is likely that the relatively low power exists due to the large population fluctuations already seen for the species, and the large amount of variability from site to site. For this species, the initial densities are 8 urchin/m² inside an

MPA and 16 urchin/m² outside an MPA. A 10% increase would lead to mean densities of 12 and 26 urchin/m² after 5 years, 20 and 42 urchin/m² after 10 years, and 51 and 110 urchin/m², respectively, after 20 years. The supplemental power analyses by island (Appendix B) showed that power to detect a 10% trend over 20 years was near or above 80% for Anacapa, Santa Barbara, and Santa Rosa islands (See Appendix B, Figure B-2). Power to detect trends over time in red sea urchins at Santa Cruz Island remained low (<60%).

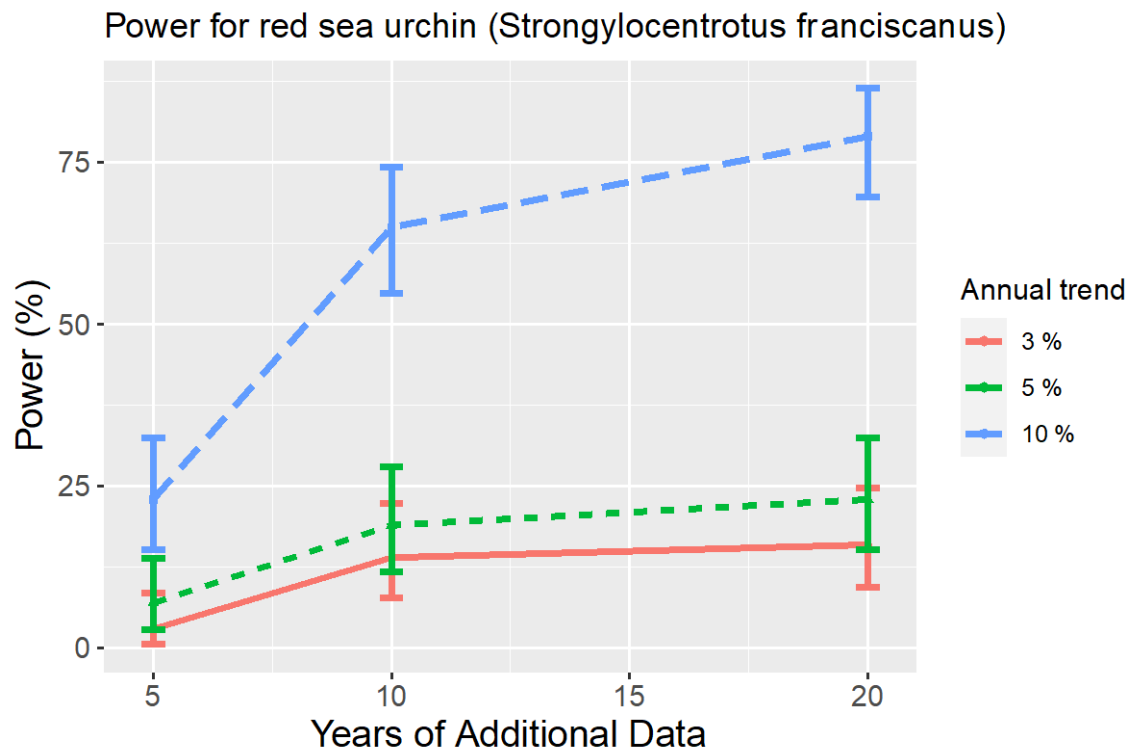


Figure 5. Power analysis results associated with the red sea urchin for the kelp forest monitoring program at Channel Islands National Park. The error bars represent the 95% confidence intervals from 100 simulations associated with the power estimates. The 10% annual trend line is the top line, the 5% annual trend line is the middle line, and the 3% annual trend line is the lowest line.

5.2.3 Spiny lobster

For this species, models with a year random effect led to singularity errors, and therefore the model without that random effect was selected as best fitting. Diagnostic plots associated with the residuals from the model fit (e.g., histograms, residuals vs fitted value plots, and qq-plots) suggest that the model is a reasonable choice for the data. However, an examination of the fitted values demonstrates that the model does not match the trends for all sites (Figure 6). In particular, the model predicts an increasing trend for sites where counts remain at or near zero. Although the exponential increase shown for some of the Santa Rosa Island sites looks extreme, the trend is suggestive of an increase from 0 to only 0.012 lobsters/replicate over the 2005–2018 time period.

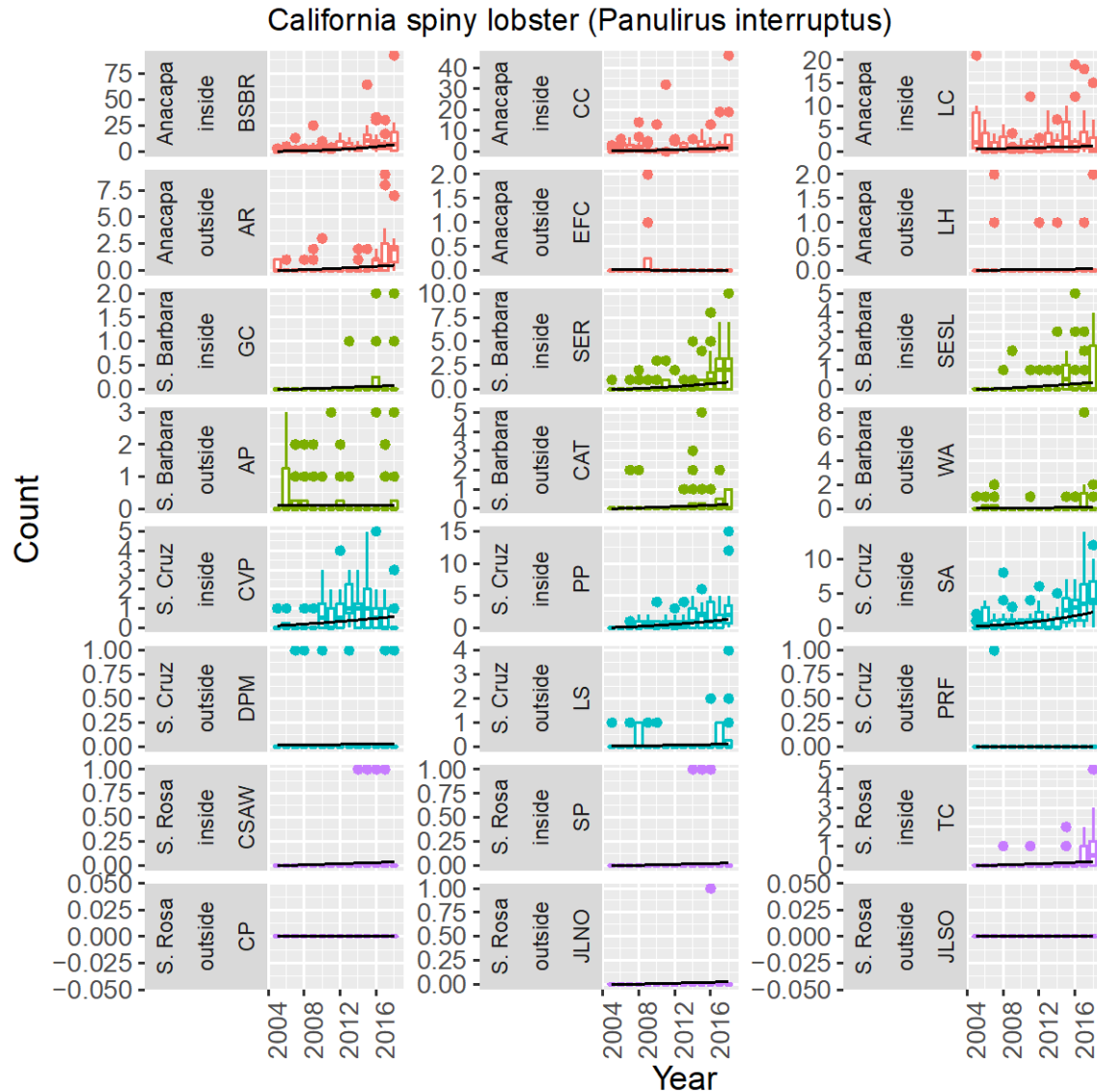


Figure 6. California spiny lobster counts from the band transect sampling method (boxplots) and the predicted values from the model (black line), with a separate plot for each site for the kelp forest monitoring program at Channel Islands National Park. The text along the y-axis provides the site context: the island name, whether the site is inside or outside of an MPA, and the following site code abbreviations—BSBR = Black Sea Bass Reef, CC = Cathedral Cove, LC = Landing Cove, AR = Admiral's Reef, EFC = East Fish Camp, LH = Lighthouse, GC = Graveyard Canyon, SER = Southeast Reef, SESL = SE Sea Lion Rookery, AP = Arch Point, CAT = Cat Canyon, WA = Webster's Arch, CVP = Cavern Point, PP = Potato Pasture, SA = Scorpion Anchorage, DPM = Devil's Peak Member, LS = Little Scorpion, PRF = Pedro Reef, CSAW = Chickasaw, SP = South Point, TC = Trancion Canyon, CP = Cluster Point, JLNO = Johnson's Lee North, JLSO = Johnson's Lee South.

The model results suggest that annual trends as low as 3% per year can be detected with 80% power after 10 years, and there is high power to detect a 10% increase over 20 years (Figure 7). For this species, the initial mean densities are 0.1 lobsters/replicate inside an MPA and 0.01 lobsters/replicate outside an MPA. A 10% increase would lead to mean densities of 0.16 and 0.016 lobsters/replicate

after 5 years, 0.26 and 0.026 lobsters/replicate after 10 years, and 0.67 and 0.067 lobsters/replicate, respectively, after 20 years. The power analyses by island (Appendix B) showed that power was highest at Santa Rosa Island with power of 80% after just 5 years with a 3% increase in annual abundance. Power was lowest, but still relatively high for 5–10% changes after 10 or more years on Anacapa Island. In general, the monitoring for California spiny lobster appears sufficient to detect the trends of interest within 15–20 years (See Appendix B, Figure B-3) at most islands.

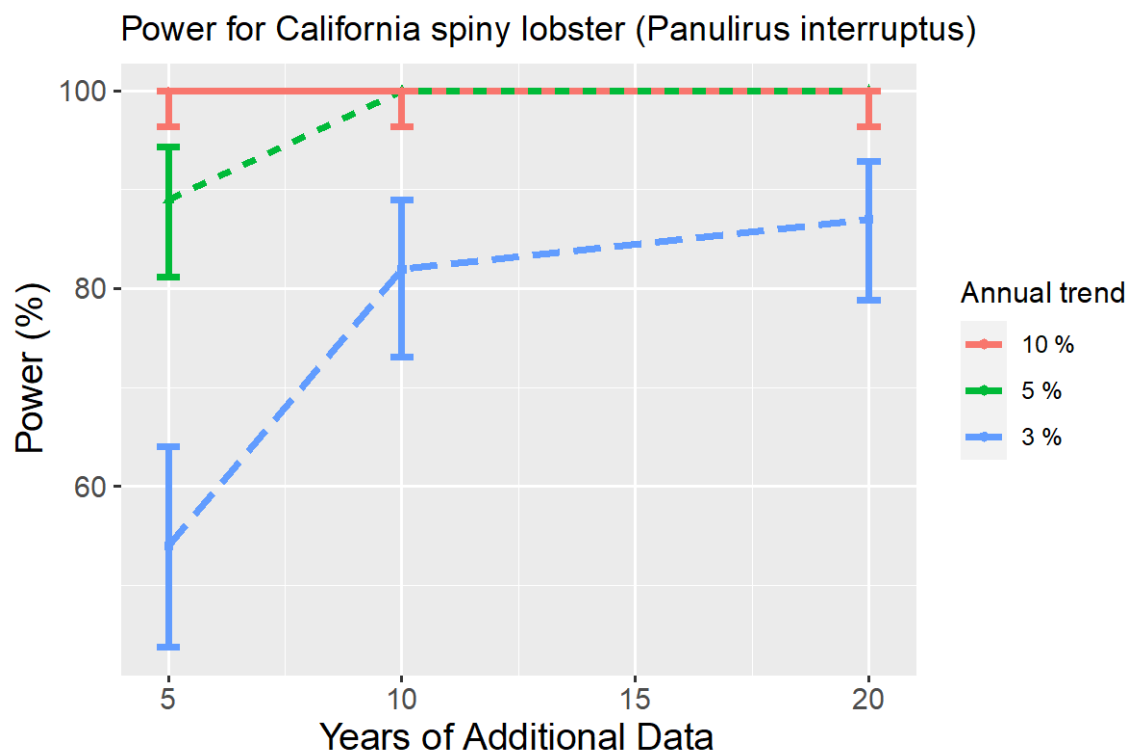


Figure 7. Power analysis results associated with the California spiny lobster for the kelp forest monitoring program at Channel Islands National Park. The error bars represent the 95% confidence intervals from 100 simulations associated with the power estimates. The 10% annual trend line is the top line, the 5% annual trend line is the middle line, and the 3% annual trend line is the lowest line.

5.2.4 Cucumber

For this species, models with a year random effect led to singularity errors and models with the MPA effect similarly led to errors. Therefore, the model without those variables was selected as best-fitting, and diagnostic plots associated with the residuals from the model fit (e.g., histograms, residuals vs fitted value plots, and qq-plots) suggest that the model is a reasonable choice for the data (Figure 8).

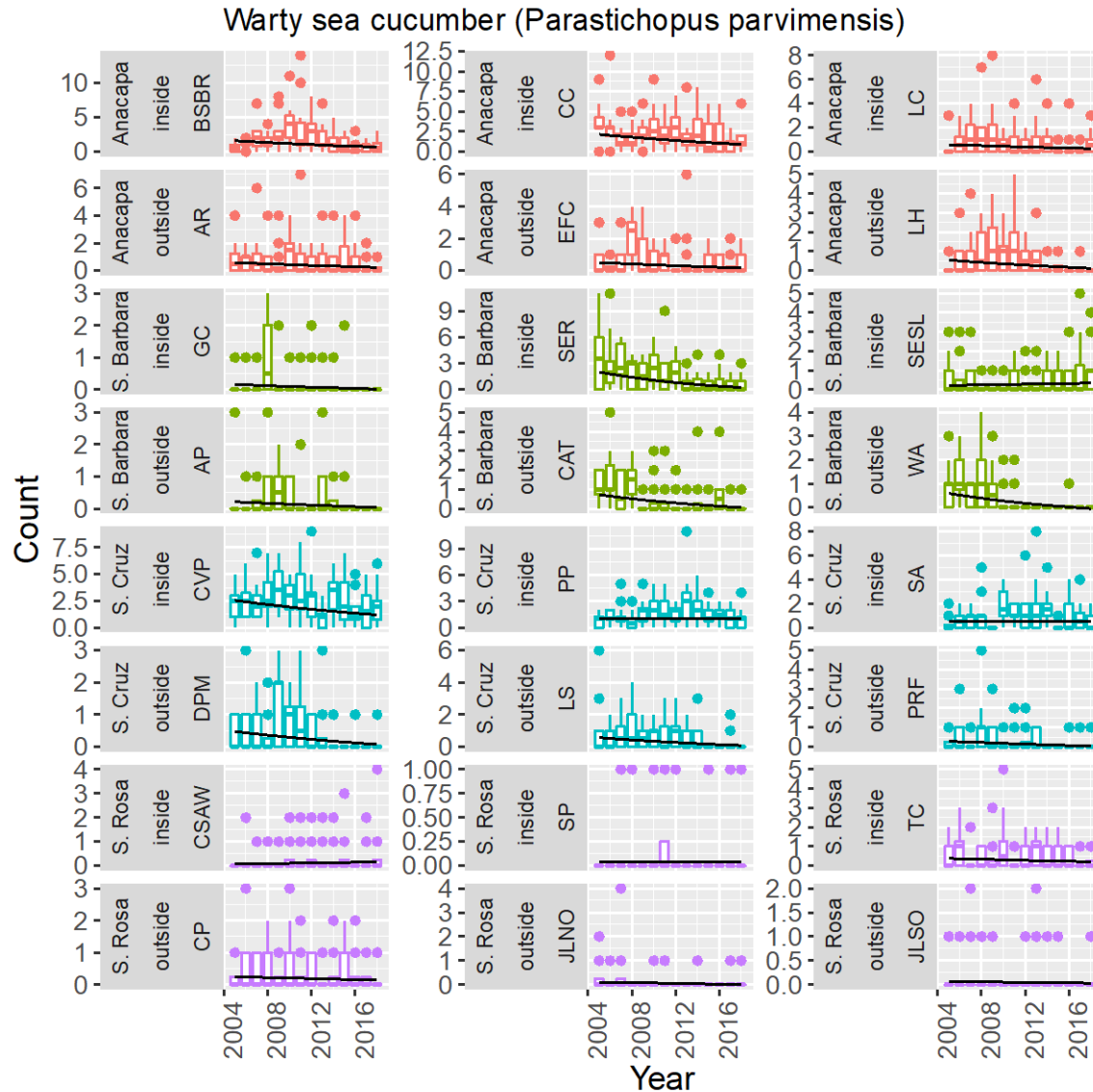


Figure 8. Warty sea cucumber counts from the 1-m quadrat sampling method (boxplots) and the predicted values from the model (black line), with a separate plot for each site for the kelp forest monitoring program at Channel Islands National Park. The text along the y-axis provides the site context: the island name, whether the site is inside or outside of an MPA, and the following site code abbreviations—BSBR = Black Sea Bass Reef, CC = Cathedral Cove, LC = Landing Cove, AR = Admiral’s Reef, EFC = East Fish Camp, LH = Lighthouse, GC = Graveyard Canyon, SER = Southeast Reef, SESL = SE Sea Lion Rookery, AP = Arch Point, CAT = Cat Canyon, WA = Webster’s Arch, CVP = Cavern Point, PP = Potato Pasture, SA = Scorpion Anchorage, DPM = Devil’s Peak Member, LS = Little Scorpion, PRF = Pedro Reef, CSAW = Chickasaw, SP = South Point, TC = Trancion Canyon, CP = Cluster Point, JLNO = Johnson’s Lee North, JLNO = Johnson’s Lee South.

The model results suggest high power to detect a 10% annual trend, and almost 80% power to detect a 5% increase over 20 years (Figure 9). Because of the low initial densities (0.22 cucumbers/m² for the 2015–2018 model and 0.74 cucumbers/m² for the 2005–2018 model), a 10% increase over 20 years would lead to mean densities of 1.27 and 4.26 cucumbers/m².

Power analyses by island suggested that again power was highest on Santa Rosa Island, where power was near 80% to detect a 3% trend after 10 years (Appendix B). For all four islands, power to detect a 10% annual trend was >80% with 10 years of data (See Appendix B, Figure B-4).

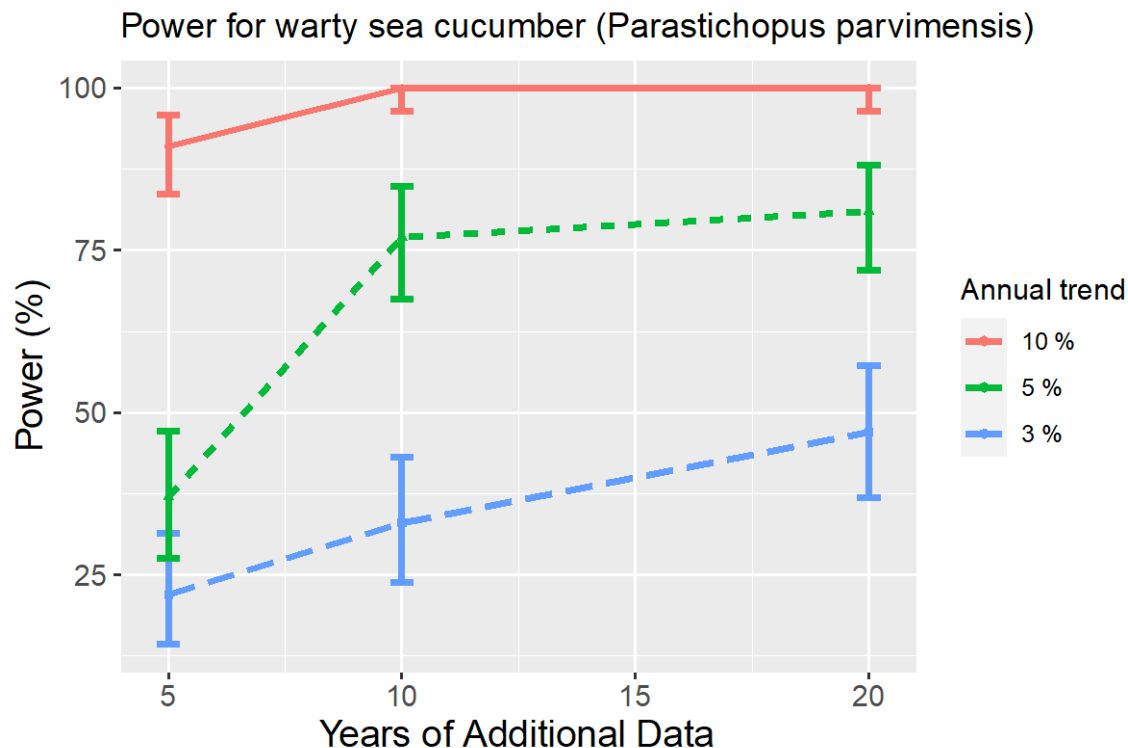


Figure 9. Power analysis results associated with the warty sea cucumber for the kelp forest monitoring program at Channel Islands National Park. The error bars represent the 95% confidence intervals from 100 simulations associated with the power estimates. The 10% annual trend line is the top line, the 5% annual trend line is the middle line, and the 3% annual trend line is the lowest line.

5.3 Discussion

In order to determine whether the data have power to detect trends in abundance, a model must first be decided upon to estimate the trends. When this question is asked as part of a management objective, the implication is often the desire to detect a linear trend associated with a linear regression model. However, the trends over time for the collected CHIS data are highly non-linear. For most species and sites, there are years with counts of zero, followed by years with positive counts, and often then followed by zero counts again, (e.g., *Macrocystis pyrifera* (giant kelp) at Hare Rock of San Miguel Island). The populations follow cyclical trends from natural, decadal oceanic oscillations where the species may completely disappear from a site and then reappear sometime later. Therefore, a power analysis based on a linear trend over a long time period may not be the most appropriate model to assess the power of the sampling design. Additionally, because of the MPAs and biogeographic regions, we expect completely different trends at the sites for most species.

The conclusions for hypothesis tests for the significance of a parameter estimate, and therefore the power to detect a non-zero trend, are based on the given model and data. As seen in the examples in this report, the relationship between densities and year changes over time and from site to site. In the current model, these variabilities are accounted for with random effects. If it is believed that the observed values represent true trends and not just random variability, a different model may be a better choice for the power analysis. Other models to be fit to the data may include linear mixed effects models with additional environmental covariates, generalized additive models, and multivariate models where multiple species are modeled together.

The current models suggest that the sampling design has low power to detect trends in the urchin populations and higher power to detect trends in the lobster and cucumber populations. This may be because counts have been lower and more stable over the 2005–2018 time period for the lobster and sea cucumber populations. The large numbers of zero counts likely led to lower variance estimates for these models, and increasing the associated power. Meanwhile, the urchin populations changed dramatically over that time (e.g., mean densities from 0 to 337 for the Arch Point site for purple sea urchin), but because the trend was nonlinear and not uniform across all sites, the power analysis model estimated the trend through the random effects. Therefore, the variances associated with the random effects are relatively large for the urchin models, making trends more difficult to detect according to the given model, and leading to low power for these species. In future power analyses, environmental covariates may be included to explain these effects and thus reduce unexplained variation and improve power estimates. The lobster and urchin models were also not fit with the year random effect because these models had singularity issues. The exclusion of this variance component implies that the year-to-year variation is zero, which contributes to the relatively higher power for these species.

Simulations from fitted models for the lobster and sea cucumber led to similar numbers of zero counts as were observed in the count data, suggesting that the zero counts are explainable through the overdispersion terms associated with the models. This further suggests that a zero-inflation model structure is not necessary for many species but is only necessary if the species is completely absent from some sites but has high counts at others. For the lobster and cucumber, all counts were low, so the zeros were expected from the models.

6. Conclusions

6.1 Precision

The precision calculations demonstrated huge variation in precision among species, sites, and years. Standard errors were relatively high compared to mean counts, leading to low precision for most species-site-year combinations. In addition, low precision was observed for the species-site-year combinations with nonnormal data. Future precision calculations should try a log-transformation of the data before assessing precision and normality. The log-transformation would improve normality for many site-year combinations but may not be appropriate for all species given the large numbers of 0 counts. We are unable to recommend any changes to the KFM sampling design as a result of this analysis.

6.2 Power to detect year-to-year changes

Power to detect year-to-year changes was low for many species and sites, but the year-to-year analysis did not take advantage of the extensive time series and multiple sites available. Additionally, there was large variability across the species-site-year combinations and the assumption of normality was likely to be rejected for species-site-year combinations with low counts. When only examining the combinations where the assumption of normality failed to be rejected, the numbers of replicates would have to double for the 1-m quadrat, band transects, and RPC method in order to meet the desired requirements, but fewer 5-m quadrat replicates could be taken. As with the precision calculations, a log-transformation of the counts may lead to more normalized data and therefore more combinations that are appropriate to compare using a t-test. However, the number of replicates to be collected must also consider costs and a prioritization of which species are most important to inform the sampling designs.

6.3 Power to detect trends in abundance

The power analysis to detect trends in abundance combined all sites and years into one model for each species. For the two urchin populations, the estimated power to detect trend was relatively low, even to detect a 10% annual change for 20 years (48% for the purple sea urchin and 77% for the red sea urchin). For these analyses, all sites were included in one model and although the models allowed for variation in slope among sites and variation among years, the power was based on an overall, parkwide trend. However, each island and biogeographic region can be expected to experience different trends and responses to ecosystem shifts (see Appendix A). Whether or not a site is in an MPA may also affect counts. The urchin species appeared to demonstrate significant, nonlinear trends in density over the 2005–2018 time period. The models have random effects to explain the variation, but it may be more appropriate to allow for nonlinear trends in density within the model, to choose shorter time periods for both the model fitting and power analysis, or to change the response variable from urchin counts to urchin biomass.

6.4 Overall sample size considerations

The key goal of this expanded power analysis was to determine the level of statistical power to detect trends the data provide, and whether any sampling effort could be reduced without losing significant power to detect trends. As demonstrated throughout this report, power calculations vary from species

to species, site to site, and over time. The data include many zero counts, exhibit mean-variance relationships, and often fail to pass normality tests. Therefore, traditional power tests, such as the t-test, are not always an appropriate way to measure power and may lead to misleading conclusions on the power of the sampling design. Simulation-based approaches to estimate power, as we used, may be more appropriate for the nonnormal data.

For the data that did meet the model and test assumptions, power was sometimes low, but sampling logistics limit the options to change the sampling design. For example, counts A and B are taken for the 1-m quadrat, 5-m quadrat, and band transect methods and counts A, B, C, and D are taken for the RPC method because, logistically, two divers need to be closer to each other for safety. However, if divers could be up to 10 m apart, then the sampling efforts could be cut in half by only taking one count per side on the line transect (i.e., only take the A counts).

The time and money savings of any change must be studied to ensure the sampling reduction does indeed save significant resources. Additionally, a change in sampling leads to potential incompatibility with historical data; how the change affects analyses of the data should be examined thoroughly before changes are made. Furthermore, the program's many objectives would need to be prioritized and evaluated. Information on the time and cost savings from any reduction, and feasibility of a reduction (e.g., necessity of two diver teams for safety), must be incorporated in the potential protocol changes. The analysis contained herein may be used to support or not support changes in the sampling design, but because of the wide range of conclusions for each species, site, and year combination, it is not possible to use these results without consideration of many other factors.

6.5 Future Work

This report examined precision and power to detect differences in densities for data collected from the 1-m quadrat, 5-m quadrat, band transect, and RPC data collection methods. The power to detect trend over time analysis may be improved by taking the island and biogeographic region associated with each site into account in the model (see Appendix B).

The other data collection methods (Table 1) have not undergone the same intense review as the four core methods. Future power analyses should focus on these other methods. In particular, many specimens are measured for the fish-size frequencies and natural habitat size frequencies. It may be worth revisiting those methods to confirm if an appropriate number of samples are being measured.

Conducting power analyses for zero-inflated data is an ongoing area of interest. Some of the zero counts from the CHIS data can be explained by the overdispersion parameter of a negative binomial model, but for other species, the zeros represent true absences and need to be modeled separately. Although zero-inflation models were not required for the example species from this report, one future direction of study would be to determine which species do need to have the zeros modeled separately and how to detect trends from the zero-inflated data.

Beyond the need for additional power analyses, the CHIS data are a rich time series for an entire ecosystem. This report analyzed species individually, but a community analysis could explicitly

incorporate species interactions and allow for more inference because the model would be fit to more data. Future analyses of the CHIS data should consider a community approach to data analysis.

7. References

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Appendix A

Summary statistics

These tables display summary statistics for each sampling method. For each species with data, the table displays the number of sites with data, the range of years for which the species was sampled, the number of site-years with data, the number of site-years with at least one positive count, the proportion of site-years where the median count per replicate was zero, and the proportion of site-years where the replicate counts passed the Shapiro-Wilk normality test.

Table A-1. 1-m quadrat sampling summary statistics for each species with data for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Num. of Site-Years with Data	Num. of Sites with Data	Num. of Site-Years Ever Detected	Proportion Normal	Proportion with Median = 0	Method	Years
14027	<i>Alloclinus holderi</i>	island kelpfish	609	33	267	0.13	0.63	1-m ² quad	1996–2018
11009	<i>Centrostephanus coronatus</i>	Coronado urchin	609	33	316	0.11	0.66	1-m ² quad	1996–2018
14026	<i>Coryphopterus nicholsi</i>	blackeye goby	609	33	535	0.3	0.46	1-m ² quad	1996–2018
9010 ^A	<i>Crassedoma giganteum</i>	rock scallop	4	2	4	0	1	1-m ² quad	2003–2005
9005	<i>Cypraea spadicea</i>	chestnut cowrie	609	33	461	0.02	0.82	1-m ² quad	1996–2018
2015 ^A	<i>Dictyoneupsis reticulata</i> - <i>Agarum fimbriatum</i>	<i>Dictyoneupsis reticulata</i> / <i>Agarum fimbriatum</i> , adult (>10cm wide)	22	4	21	0.05	0.71	1-m ² quad	2003–2017
2015.5 ^A	<i>Dictyoneupsis reticulata</i> - <i>Agarum fimbriatum</i>	<i>Dictyoneupsis reticulata</i> / <i>Agarum fimbriatum</i> , juvenile (<10cm wide)	16	4	12	0	0.83	1-m ² quad	2003–2018
2004	<i>Eisenia arborea</i>	<i>Southern sea palm</i> , adult	609	33	190	0.07	0.75	1-m ² quad	1996–2018

^A Data for this species were collected at a limited number of sites (<10). Therefore, no density plots of this species were created.

Table A-1 (continued). 1-m quadrat sampling summary statistics for each species with data for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Num. of Site-Years with Data	Num. of Sites with Data	Num. of Site-Years Ever Detected	Proportion Normal	Proportion with Median = 0	Method	Years
2004.5	<i>Eisenia arborea</i>	Southern sea palm, juvenile	609	33	236	0.06	0.78	1-m ² quad	1996–2018
9002 ^A	<i>Haliotis rufescens</i>	red abalone	9	1	9	0	0.56	1-m ² quad	2002–2017
9006 ^A	<i>Kelletia kelletii</i>	Kellett's whelk	15	3	15	0.07	0.4	1-m ² quad	1996–2011
2006	<i>Laminaria farlowii</i>	oar weed, adult (>10cm wide)	609	33	125	0.18	0.51	1-m ² quad	1996–2018
2006.5	<i>Laminaria farlowii</i>	oar weed, juvenile (<10cm wide)	609	33	177	0.1	0.6	1-m ² quad	1996–2018
9008	<i>Lithopoma gibberosa</i>	red turban snail	511	33	117	0.04	0.83	1-m ² quad	1996–2018
11004	<i>Lytechinus anamesus</i>	white sea urchin	117	24	107	0.18	0.59	1-m ² quad	1996–2017
14025	<i>Lythrypnus dalli</i>	blue-banded goby	609	33	99	0.12	0.62	1-m ² quad	1996–2018
2002	<i>Macrocystis pyrifera</i>	giant kelp, adult (>1m)	609	33	314	0.11	0.58	1-m ² quad	1996–2018
2002.5	<i>Macrocystis pyrifera</i>	giant kelp, juvenile (<1m)	609	33	366	0.15	0.47	1-m ² quad	1996–2018
2002.99	<i>Macrocystis pyrifera</i>	giant kelp stipes > 1m	264	33	139	0.12	0.6	1-m ² quad	2007–2014
9007	<i>Megastrea undosa</i>	wavy turban snail	609	33	416	0.15	0.59	1-m ² quad	1996–2018
14030	<i>Oxylebius pictus</i>	painted greenling	33	33	21	0	0.86	1-m ² quad	2007–2007
11007	<i>Parastichopus parvimensis</i>	warty sea cucumber	609	33	511	0.14	0.63	1-m ² quad	1996–2018
11001	<i>Patiria miniata</i>	bat star	609	33	522	0.43	0.31	1-m ² quad	1996–2018
11002	<i>Pisaster giganteus</i>	giant-spined sea star	609	33	358	0.01	0.87	1-m ² quad	1996–2018

^A Data for this species were collected at a limited number of sites (<10). Therefore, no density plots of this species were created.

Table A-1 (continued). 1-m quadrat sampling summary statistics for each species with data for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Num. of Site-Years with Data	Num. of Sites with Data	Num. of Site-Years Ever Detected	Proportion Normal	Proportion with Median = 0	Method	Years
2005	<i>Pterygophora californica</i>	California sea palm, adult	609	33	152	0.07	0.66	1-m ² quad	1996–2018
2005.5	<i>Pterygophora californica</i>	California sea palm, juvenile	609	33	147	0.04	0.71	1-m ² quad	1996–2018
11003 ^A	<i>Pycnopodia helianthoides</i>	sunflower star	1	1	1	0	0	1-m ² quad	2005–2005
2016	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , adult (>50cm or receptacles present)	297	33	63	0.11	0.49	1-m ² quad	2010–2018
2016.5	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , juvenile (<50cm and no receptacles)	297	33	99	0.18	0.37	1-m ² quad	2010–2018
11005	<i>Strongylocentrotus franciscanus</i>	red sea urchin	609	33	600	0.48	0.2	1-m ² quad	1996–2018
11006	<i>Strongylocentrotus purpuratus</i>	purple sea urchin	609	33	594	0.49	0.17	1-m ² quad	1996–2018
12002	<i>Styela montereyensis</i>	stalked tunicate	609	33	139	0.17	0.55	1-m ² quad	1996–2018
9014	<i>Tegula regina</i>	queen tegula	429	33	150	0	0.95	1-m ² quad	2006–2018
2009 ^A	<i>Undaria pinnatifida</i>	Wakame	2	1	1	0	1	1-m ² quad	2016–2018
2009.5 ^A	<i>Undaria pinnatifida</i>	Wakame	3	1	3	0	0.67	1-m ² quad	2016–2018

^A Data for this species were collected at a limited number of sites (<10). Therefore, no density plots of this species were created.

Table A-2. 5-m quadrat sampling summary statistics for each species with data for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Num. of Site-Years with Data	Num. of Sites with Data	Num. of Site-Years Ever Detected	Proportion Normal	Proportion with Median = 0	Method	Years
2002.25	<i>Macrocystis pyrifera</i>	giant kelp, adult (>1m and haptera above the primary dichotomy)	609	33	324	0.01	0.59	5-m ² quad	1996–2018
2002.75	<i>Macrocystis pyrifera</i>	giant kelp, subadult (>1m and no haptera above the primary dichotomy)	609	33	346	0.02	0.64	5-m ² quad	1996–2018
11002	<i>Pisaster giganteus</i>	giant-spined sea star	609	33	476	0	0.8	5-m ² quad	1996–2018
11011	<i>Pisaster ochraceus</i>	ochre sea star	231	33	21	0	1	5-m ² quad	2012–2018
2016	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , adult (>50cm or receptacles present)	297	33	87	0.02	0.54	5-m ² quad	2010–2018
2016.5	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , juvenile (<50cm and no receptacles)	297	33	103	0.02	0.46	5-m ² quad	2010–2018
2009 ^A	<i>Undaria pinnatifida</i>	Wakame	2	1	2	0	1	5-m ² quad	2016–2018
2009.5 ^A	<i>Undaria pinnatifida</i>	Wakame	3	1	3	0	0.67	5-m ² quad	2016–2018

^A Data for this species were collected at a limited number of sites (<10). Therefore, no density plots of this species were created.

Table A-3. Band transect summary statistics for each species with data for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Num. of Site-Years with Data	Num. of Sites with Data	Num. of Site-Years Ever Detected	Proportion Normal	Proportion with Median = 0	Method	Years
9011	<i>Aplysia californica</i>	California brown sea hare	610	33	413	0.23	0.47	Band	1996–2018
9010	<i>Crassedoma giganteum</i>	rock scallop	610	33	598	0.25	0.33	Band	1996–2018
9015	<i>Cryptochiton stelleri</i>	gumboot chiton	201	33	12	0	1	Band	2012–2018
9012	<i>Haliotis assimilis</i>	threaded abalone	233	33	6	0	1	Band	2011–2018
9003	<i>Haliotis corrugata</i>	pink abalone	610	33	61	0	0.95	Band	1996–2018
9004	<i>Haliotis fulgens</i>	green abalone	610	33	7	0	1	Band	1996–2018
9002	<i>Haliotis rufescens</i>	red abalone	610	33	147	0.26	0.49	Band	1996–2018
9013	<i>Haliotis sorenseni</i>	white abalone	199	33	0	NA	NA	Band	2012–2018
9006	<i>Kelletia kelletii</i>	Kellett's whelk	610	33	457	0.16	0.52	Band	1996–2018
6006	<i>Lophogorgia chilensis</i>	red gorgonian	610	33	425	0.39	0.38	Band	1996–2018
11004	<i>Lytechinus anamesus</i>	white sea urchin	610	33	336	0.26	0.41	Band	1996–2018
9009	<i>Megathura crenulata</i>	giant keyhole limpet	610	33	518	0.29	0.42	Band	1996–2018
6008	<i>Muricea californica</i>	California golden gorgonian	610	33	281	0.16	0.63	Band	1996–2018
6007	<i>Muricea fruticosa</i>	brown gorgonian	610	33	155	0.01	0.94	Band	1996–2018
8001	<i>Panulirus interruptus</i>	California spiny lobster	610	33	270	0.04	0.76	Band	1996–2018
11002	<i>Pisaster giganteus</i>	giant-spined sea star	152	33	90	0.01	0.92	Band	2014–2018
11011	<i>Pisaster ochraceus</i>	ochre sea star	138	33	7	0	1	Band	2014–2018
11003	<i>Pycnopodia helianthoides</i>	sunflower star	610	33	238	0.39	0.37	Band	1996–2018

^A Data for this species were collected at a limited number of sites (<10). Therefore, no density plots of this species were created.

Table A-3 (continued). Band transect summary statistics for each species with data for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Num. of Site-Years with Data	Num. of Sites with Data	Num. of Site-Years Ever Detected	Proportion Normal	Proportion with Median = 0	Method	Years
2016	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , adult (>50cm or receptacles present)	297	33	94	0.29	0.31	Band	2010–2018
2016.5	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , juvenile (<50cm and no receptacles)	165	33	30	0.1	0.5	Band	2010–2014
6001	<i>Stylaster californicus</i>	California hydrocoral	610	33	25	0	0.08	Band	1996–2018
5002	<i>Tethya aurantia</i>	orange puffball sponge	610	33	549	0.53	0.24	Band	1996–2018
2009 ^A	<i>Undaria pinnatifida</i>	Wakame	4	3	2	0	0.5	Band	2016–2018
2009.5 ^A	<i>Undaria pinnatifida</i>	Wakame	4	3	2	0.5	0.5	Band	2016–2018
6002	<i>Urticina lofotensis</i>	white-spotted rose anemone	610	33	217	0.51	0.19	Band	1996–2018

^A Data for this species were collected at a limited number of sites (<10). Therefore, no density plots of this species were created.

Table A-4. Random point contact sampling summary statistics for each species with data for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Num. of Site-Years with Data	Num. of Sites with Data	Num. of Site-Years Ever Detected	Proportion Normal	Proportion with Median = 0	Method	Years
6005	<i>Astrangia lajollaensis</i>	La Jolla cup coral	607	33	501	0.13	0.65	RPCs	1996–2018
6004	<i>Balanophyllia elegans</i>	orange cup coral	607	33	367	0.04	0.76	RPCs	1996–2018
15001	<i>Bare Substrate</i>	Bare Substrate	607	33	606	0.47	0.06	RPCs	1996–2018
10001	<i>Bryozoa</i>	bryozoans (miscellaneous)	607	33	559	0.39	0.33	RPCs	1996–2018
1001	<i>Chlorophyta</i>	green algae	607	33	352	0.04	0.83	RPCs	1996–2018
15003	<i>Cobble</i>	Cobble	607	33	597	0.14	0.37	RPCs	1996–2018
3002	<i>Corallinales</i>	articulated coralline algae	607	33	507	0.21	0.54	RPCs	1996–2018
3003	<i>Corallinales</i>	encrusting coralline algae	607	33	607	0.84	0	RPCs	1996–2018
6003	<i>Corynactis californicus</i>	club-tipped anemone	607	33	480	0.07	0.74	RPCs	1996–2018
2007	<i>Cystoseira</i>	bladder chain kelp	607	33	236	0.03	0.77	RPCs	1996–2018
2003	<i>Desmarestia</i>	acid weed	607	33	146	0.05	0.79	RPCs	1996–2018
10002	<i>Diaperoecia californica</i>	Southern staghorn bryozoan	607	33	316	0.03	0.87	RPCs	1996–2018
7001	<i>Diopatra ornata</i>	ornate tube worm	607	33	390	0.07	0.72	RPCs	1996–2018
2012	<i>Eisenia arborea</i>	Southern sea palm, all	607	33	242	0.08	0.73	RPCs	1996–2018
3004	<i>Gelidium</i>	agar weed	607	33	78	0	0.94	RPCs	1996–2018
3005	<i>Gigartina</i>	sea tongue	607	33	177	0.06	0.73	RPCs	1996–2018
2014	<i>Laminaria farlowii</i>	oar weed, all	607	33	137	0.18	0.5	RPCs	1996–2018
2010	<i>Macrocystis pyrifera</i>	giant kelp, all	607	33	359	0.34	0.32	RPCs	1996–2018

Table A-4 (continued). Random point contact sampling summary statistics for each species with data for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Num. of Site-Years with Data	Num. of Sites with Data	Num. of Site-Years Ever Detected	Proportion Normal	Proportion with Median = 0	Method	Years
13002	Miscellaneous Invertebrates excluding <i>Ophiothrix spiculata</i>	Miscellaneous Invertebrates excluding <i>Ophiothrix spiculata</i>	495	33	495	0.6	0.06	RPCs	2003–2018
13001	Miscellaneous Invertebrates including <i>Ophiothrix spiculata</i>	Miscellaneous Invertebrates including <i>Ophiothrix spiculata</i>	112	16	112	0.67	0.03	RPCs	1996–2002
11010	<i>Ophiothrix spiculata</i>	spiny brittle star	495	33	164	0.14	0.48	RPCs	2003–2018
11008	<i>Pachythyone rubra</i>	aggregated red sea cucumber	607	33	78	0.08	0.77	RPCs	1996–2018
2001	<i>Phaeophyta</i>	brown algae (miscellaneous)	607	33	419	0.13	0.67	RPCs	1996–2018
7002	<i>Phragmatopoma californica</i>	colonial sand-tube worm	607	33	189	0.06	0.67	RPCs	1996–2018
4001	<i>Plantae</i>	miscellaneous plants (i.e., diatoms)	607	33	425	0.21	0.52	RPCs	1996–2018
5001	<i>Porifera</i>	sponges	607	33	445	0.04	0.77	RPCs	1996–2018
2013	<i>Pterygophora californica</i>	California sea palm, all	607	33	169	0.07	0.62	RPCs	1996–2018
3001	<i>Rhodophyta</i>	red algae (miscellaneous)	607	33	599	0.5	0.13	RPCs	1996–2018
15002	<i>Rock</i>	Rock	607	33	607	0.27	0	RPCs	1996–2018
15004	<i>Sand</i>	Sand	607	33	596	0.12	0.4	RPCs	1996–2018

Table A-4 (continued). Random point contact sampling summary statistics for each species with data for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Num. of Site-Years with Data	Num. of Sites with Data	Num. of Site-Years Ever Detected	Proportion Normal	Proportion with Median = 0	Method	Years
2017	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , all	297	33	91	0.18	0.47	RPCs	2010–2018
9001	<i>Serpulorbis squamigerus</i>	scaled wormsnaill	607	33	251	0	0.93	RPCs	1996–2018
12001	<i>Tunicata</i>	tunicates	607	33	514	0.2	0.53	RPCs	1996–2018

Precision tables

These tables display the average mean and estimated standard error of the replicate counts for each species and sampling method. It also displays the estimated standard errors if 5, 10, 20, 30, or 40 replicates were taken at each site instead of the current sample size associated with each method.

Table A-5. Current and potential precisions for the 1-m quadrat method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Avg Count	Avg SE (12 surveys; current)	Avg SE (5 surveys)	Avg SE (10 surveys)	Avg SE (20 surveys)	Avg SE (30 surveys)	Avg SE (40 surveys)
14027	<i>Alloclinus holderi</i>	island kelpfish	0.37	0.11	0.17	0.12	0.08	0.07	0.06
11009	<i>Centrostephanus coronatus</i>	Coronado urchin	0.55	0.19	0.29	0.21	0.15	0.12	0.10
14026	<i>Coryphopterus nicholsi</i>	blackeye goby	0.97	0.22	0.34	0.24	0.17	0.14	0.12
9010	<i>Crassedoma giganteum</i>	rock scallop	0.59	0.29	0.45	0.32	0.22	0.18	0.16
9005	<i>Cypraea spadicea</i>	chestnut cowrie	0.27	0.13	0.20	0.14	0.10	0.08	0.07
2015	<i>Dictyoneuropsis reticulata</i> - <i>Agarum fimbriatum</i>	<i>Dictyoneuropsis reticulata</i> / <i>Agarum fimbriatum</i> , adult (>10cm wide)	0.89	0.42	0.65	0.46	0.33	0.27	0.23
2015.5	<i>Dictyoneuropsis reticulata</i> - <i>Agarum fimbriatum</i>	<i>Dictyoneuropsis reticulata</i> / <i>Agarum fimbriatum</i> , juvenile (<10cm wide)	0.49	0.30	0.47	0.33	0.24	0.19	0.17
2004	<i>Eisenia arborea</i>	Southern sea palm, adult	0.52	0.20	0.31	0.22	0.15	0.12	0.11
2004.5	<i>Eisenia arborea</i>	Southern sea palm, juvenile	0.59	0.22	0.34	0.24	0.17	0.14	0.12
9002	<i>Haliotis rufescens</i>	red abalone	0.50	0.20	0.31	0.22	0.16	0.13	0.11
9006	<i>Kelletia kelletii</i>	Kellet's whelk	0.55	0.19	0.29	0.20	0.14	0.12	0.10

Table A-5 (continued). Current and potential precisions for the 1-m quadrat method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Avg Count	Avg SE (12 surveys; current)	Avg SE (5 surveys)	Avg SE (10 surveys)	Avg SE (20 surveys)	Avg SE (30 surveys)	Avg SE (40 surveys)
2006	<i>Laminaria farlowii</i>	oar weed, adult (>10cm wide)	1.45	0.40	0.63	0.44	0.31	0.26	0.22
2006.5	<i>Laminaria farlowii</i>	oar weed, juvenile (<10cm wide)	5.26	1.67	2.58	1.83	1.29	1.05	0.91
9008	<i>Lithopoma gibberosa</i>	red turban snail	0.28	0.13	0.20	0.14	0.10	0.08	0.07
11004	<i>Lytechinus anamesus</i>	white sea urchin	2.62	0.59	0.91	0.64	0.45	0.37	0.32
14025	<i>Lythrypnus dalli</i>	blue-banded goby	1.14	0.35	0.55	0.39	0.27	0.22	0.19
2002	<i>Macrocystis pyrifera</i>	giant kelp, adult (>1m)	0.56	0.20	0.31	0.22	0.16	0.13	0.11
2002.5	<i>Macrocystis pyrifera</i>	giant kelp, juvenile (<1m)	3.75	1.22	1.89	1.34	0.95	0.77	0.67
2002.99	<i>Macrocystis pyrifera</i>	giant kelp stipes > 1m	3.39	1.41	2.18	1.54	1.09	0.89	0.77
9007	<i>Megastrea undosa</i>	wavy turban snail	0.89	0.25	0.39	0.27	0.19	0.16	0.14
14030	<i>Oxylebius pictus</i>	painted greenling	0.16	0.08	0.12	0.08	0.06	0.05	0.04
11007	<i>Parastichopus parvimensis</i>	warty sea cucumber	0.40	0.14	0.21	0.15	0.11	0.09	0.07
11001	<i>Patiria miniata</i>	bat star	1.41	0.30	0.46	0.33	0.23	0.19	0.16
11002	<i>Pisaster giganteus</i>	giant-spined sea star	0.20	0.10	0.15	0.11	0.08	0.06	0.05
2005	<i>Pterygophora californica</i>	California sea palm, adult	0.57	0.23	0.35	0.25	0.18	0.14	0.12
2005.5	<i>Pterygophora californica</i>	California sea palm, juvenile	1.13	0.56	0.87	0.61	0.43	0.35	0.31

Table A-5 (continued). Current and potential precisions for the 1-m quadrat method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Avg Count	Avg SE (12 surveys; current)	Avg SE (5 surveys)	Avg SE (10 surveys)	Avg SE (20 surveys)	Avg SE (30 surveys)	Avg SE (40 surveys)
11003	<i>Pycnopodia helianthoides</i>	sunflower star	0.33	0.09	0.15	0.10	0.07	0.06	0.05
2016	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , adult (>50cm or receptacles present)	4.07	1.24	1.91	1.35	0.96	0.78	0.68
2016.5	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , juvenile (<50cm and no receptacles)	16.15	4.70	7.29	5.15	3.64	2.97	2.58
11005	<i>Strongylocentrotus franciscanus</i>	red sea urchin	5.00	1.08	1.67	1.18	0.84	0.68	0.59
11006	<i>Strongylocentrotus purpuratus</i>	purple sea urchin	21.45	3.57	5.53	3.91	2.76	2.26	1.95
12002	<i>Styela montereyensis</i>	stalked tunicate	0.79	0.22	0.34	0.24	0.17	0.14	0.12
9014	<i>Tegula regina</i>	queen tegula	0.17	0.11	0.17	0.12	0.08	0.07	0.06
2009	<i>Undaria pinnatifida</i>	Wakame	0.04	0.04	0.06	0.05	0.03	0.03	0.02
2009.5	<i>Undaria pinnatifida</i>	Wakame	0.28	0.11	0.18	0.12	0.09	0.07	0.06

Table A-6. Current and potential precisions for the 5-m quadrat method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Avg Count	Avg SE (40 surveys; current)	Avg SE (5 surveys)	Avg SE (10 surveys)	Avg SE (20 surveys)	Avg SE (30 surveys)	Avg SE (40 surveys)
2002.25	<i>Macrocystis pyrifera</i>	giant kelp, adult (>1m and haptera above the primary dichotomy)	0.89	0.17	0.48	0.34	0.24	0.20	0.17
2002.75	<i>Macrocystis pyrifera</i>	giant kelp, subadult (>1m and no haptera above the primary dichotomy)	1.83	0.33	0.95	0.67	0.47	0.39	0.33
11002	<i>Pisaster giganteus</i>	giant-spined sea star	0.60	0.14	0.39	0.27	0.19	0.16	0.14
11011	<i>Pisaster ochraceus</i>	ochre sea star	0.08	0.04	0.12	0.08	0.06	0.05	0.04
2016	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , adult (>50cm or receptacles present)	11.35	1.70	4.82	3.41	2.41	1.97	1.70
2016.5	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , juvenile (<50cm and no receptacles)	60.89	8.28	23.43	16.57	11.72	9.57	8.28
2009	<i>Undaria pinnatifida</i>	Wakame	0.43	0.11	0.30	0.21	0.15	0.12	0.11
2009.5	<i>Undaria pinnatifida</i>	Wakame	0.84	0.18	0.51	0.36	0.26	0.21	0.18

Table A-7. Current and potential precisions for the random point contact (RPC) method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Avg Count	Avg SE (15 surveys; current)	Avg SE (5 surveys)	Avg SE (10 surveys)	Avg SE (20 surveys)	Avg SE (30 surveys)	Avg SE (40 surveys)
6005	<i>Astrangia lajollaensis</i>	La Jolla cup coral	0.30	0.08	0.13	0.09	0.07	0.05	0.05
6004	<i>Balanophyllia elegans</i>	orange cup coral	0.14	0.05	0.08	0.06	0.04	0.03	0.03
15001	<i>Bare Substrate</i>	Bare Substrate	1.97	0.35	0.61	0.43	0.31	0.25	0.22
10001	<i>Bryozoa</i>	bryozoans (miscellaneous)	1.03	0.17	0.29	0.20	0.14	0.12	0.10
1001	<i>Chlorophyta</i>	green algae	0.18	0.06	0.11	0.08	0.05	0.04	0.04
15003	<i>Cobble</i>	Cobble	0.81	0.25	0.43	0.30	0.21	0.17	0.15
3002	<i>Corallinales</i>	articulated coralline algae	0.60	0.13	0.23	0.16	0.12	0.09	0.08
3003	<i>Corallinales</i>	encrusting coralline algae	4.14	0.35	0.61	0.43	0.31	0.25	0.22
6003	<i>Corynactis californicus</i>	club-tipped anemone	0.29	0.10	0.17	0.12	0.09	0.07	0.06
2007	<i>Cystoseira</i>	bladder chain kelp	0.38	0.14	0.24	0.17	0.12	0.10	0.09
2003	<i>Desmarestia</i>	acid weed	0.50	0.18	0.31	0.22	0.16	0.13	0.11
10002	<i>Diaperoecia californica</i>	Southern staghorn bryozoan	0.16	0.07	0.11	0.08	0.06	0.05	0.04
7001	<i>Diopatra ornata</i>	ornate tube worm	0.34	0.11	0.20	0.14	0.10	0.08	0.07
2012	<i>Eisenia arborea</i>	Southern sea palm, all	0.65	0.20	0.35	0.25	0.18	0.14	0.13
3004	<i>Gelidium</i>	agar weed	0.60	0.25	0.44	0.31	0.22	0.18	0.16
3005	<i>Gigartina</i>	sea tongue	0.31	0.11	0.19	0.13	0.09	0.08	0.07
2014	<i>Laminaria farlowii</i>	oar weed, all	1.00	0.25	0.42	0.30	0.21	0.17	0.15

Table A-7 (continued). Current and potential precisions for the random point contact (RPC) method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Avg Count	Avg SE (15 surveys; current)	Avg SE (5 surveys)	Avg SE (10 surveys)	Avg SE (20 surveys)	Avg SE (30 surveys)	Avg SE (40 surveys)
2010	<i>Macrocystis pyrifera</i>	giant kelp, all	1.48	0.33	0.57	0.40	0.28	0.23	0.20
13002	Miscellaneous Invertebrates excluding <i>Ophiothrix spiculata</i>	Miscellaneous Invertebrates excluding <i>Ophiothrix spiculata</i>	1.23	0.20	0.34	0.24	0.17	0.14	0.12
13001	Miscellaneous Invertebrates including <i>Ophiothrix spiculata</i>	Miscellaneous Invertebrates including <i>Ophiothrix spiculata</i>	1.62	0.25	0.43	0.30	0.22	0.18	0.15
11010	<i>Ophiothrix spiculata</i>	spiny brittle star	1.99	0.33	0.58	0.41	0.29	0.24	0.20
11008	<i>Pachythyone rubra</i>	aggregated red sea cucumber	0.53	0.18	0.31	0.22	0.15	0.12	0.11
2001	<i>Phaeophyta</i>	brown algae (miscellaneous)	0.52	0.14	0.24	0.17	0.12	0.10	0.08
7002	<i>Phragmatopoma californica</i>	colonial sand-tube worm	0.32	0.11	0.18	0.13	0.09	0.07	0.06
4001	<i>Plantae</i>	miscellaneous plants (i.e., diatoms)	0.58	0.13	0.23	0.16	0.11	0.09	0.08
5001	<i>Porifera</i>	sponges	0.17	0.06	0.10	0.07	0.05	0.04	0.03
2013	<i>Pterygophora californica</i>	California sea palm, all	0.69	0.23	0.40	0.28	0.20	0.16	0.14
3001	<i>Rhodophyta</i>	red algae (miscellaneous)	1.97	0.26	0.45	0.32	0.22	0.18	0.16

Table A-7 (continued). Current and potential precisions for the random point contact (RPC) method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Avg Count	Avg SE (15 surveys; current)	Avg SE (5 surveys)	Avg SE (10 surveys)	Avg SE (20 surveys)	Avg SE (30 surveys)	Avg SE (40 surveys)
15002	<i>Rock</i>	Rock	8.18	0.46	0.80	0.56	0.40	0.33	0.28
15004	<i>Sand</i>	Sand	1.04	0.31	0.54	0.39	0.27	0.22	0.19
2017	<i>Sargassum horneri</i>	Sargassum horneri, all	0.91	0.22	0.37	0.26	0.19	0.15	0.13
9001	<i>Serpulorbis squamigerus</i>	scaled wormsnail	0.07	0.03	0.06	0.04	0.03	0.02	0.02
12001	<i>Tunicata</i>	tunicates	0.44	0.10	0.17	0.12	0.09	0.07	0.06

Table A-8. Current and potential precisions for the band transects method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Avg Count	Avg SE (12 surveys; current)	Avg SE (5 surveys)	Avg SE (10 surveys)	Avg SE (20 surveys)	Avg SE (30 surveys)	Avg SE (40 surveys)
9011	<i>Aplysia californica</i>	California brown sea hare	1.47	0.35	0.55	0.39	0.27	0.22	0.19
9010	<i>Crassidoma giganteum</i>	rock scallop	1.83	0.48	0.74	0.52	0.37	0.30	0.26
9015	<i>Cryptochiton stelleri</i>	gumboot chiton	0.07	0.05	0.08	0.06	0.04	0.03	0.03
9012	<i>Haliotis assimilis</i>	threaded abalone	0.05	0.05	0.08	0.05	0.04	0.03	0.03
9003	<i>Haliotis corrugata</i>	pink abalone	0.11	0.07	0.11	0.08	0.06	0.05	0.04
9004	<i>Haliotis fulgens</i>	green abalone	0.14	0.09	0.15	0.10	0.07	0.06	0.05
9002	<i>Haliotis rufescens</i>	red abalone	3.46	0.75	1.16	0.82	0.58	0.47	0.41
9013	<i>Haliotis sorenseni</i>	white abalone	—	—	—	—	—	—	—
9006	<i>Kelletia kelletii</i>	Kellet's whelk	1.28	0.32	0.50	0.36	0.25	0.21	0.18
6006	<i>Lophogorgia chilensis</i>	red gorgonian	2.44	0.57	0.88	0.62	0.44	0.36	0.31
11004	<i>Lytechinus anamesus</i>	white sea urchin	26.48	4.15	6.43	4.55	3.21	2.62	2.27
9009	<i>Megathura crenulata</i>	giant keyhole limpet	1.54	0.31	0.48	0.34	0.24	0.19	0.17
6008	<i>Muricea californica</i>	California golden gorgonian	0.76	0.16	0.25	0.17	0.12	0.10	0.09
6007	<i>Muricea fruticosa</i>	brown gorgonian	0.14	0.08	0.12	0.09	0.06	0.05	0.04
8001	<i>Panulirus interruptus</i>	California spiny lobster	0.49	0.21	0.33	0.23	0.16	0.13	0.12
11002	<i>Pisaster giganteus</i>	giant-spined sea star	0.15	0.08	0.12	0.09	0.06	0.05	0.04
11011	<i>Pisaster ochraceus</i>	ochre sea star	0.05	0.05	0.07	0.05	0.03	0.03	0.02

Table A-8 (continued). Current and potential precisions for the band transects method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	Avg Count	Avg SE (12 surveys; current)	Avg SE (5 surveys)	Avg SE (10 surveys)	Avg SE (20 surveys)	Avg SE (30 surveys)	Avg SE (40 surveys)
11003	<i>Pycnopodia helianthoides</i>	sunflower star	1.35	0.26	0.40	0.28	0.20	0.16	0.14
2016	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , adult (>50cm or receptacles present)	57.55	10.92	16.92	11.96	8.46	6.91	5.98
2016.5	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , juvenile (<50cm and no receptacles)	41.42	16.92	26.21	18.53	13.10	10.70	9.27
6001	<i>Stylaster californicus</i>	California hydrocoral	3.13	1.24	1.92	1.36	0.96	0.78	0.68
5002	<i>Tethya aurantia</i>	orange puffball sponge	2.85	0.46	0.71	0.50	0.36	0.29	0.25
2009	<i>Undaria pinnatifida</i>	Wakame	2.35	0.45	0.69	0.49	0.34	0.28	0.24
2009.5	<i>Undaria pinnatifida</i>	Wakame	5.25	0.99	1.53	1.08	0.77	0.63	0.54
6002	<i>Urticina lofotensis</i>	white-spotted rose anemone	3.00	0.58	0.89	0.63	0.45	0.36	0.32

Power to detect year-to-year change at a given site

These tables display the required sample sizes to detect a 40% difference in abundances with 80% power for each species and data collection method.

Table A-9. Sample size calculations for the 1-m quadrat data collection method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	All Site-Year Combinations		Only Site-Year Combinations Passing Normality Test	
			Num. of Site-Year Combinations	Median Req. Sample Size	Num. of Site-Years That Are Normal	Median Req. Sample Size
2002	<i>Macrocystis pyrifera</i>	giant kelp, adult (>1m)	2052	85	63	35
2002.5	<i>Macrocystis pyrifera</i>	giant kelp, juvenile (<1m)	2462	75	62	30
2002.99	<i>Macrocystis pyrifera</i>	giant kelp stipes >1m	400	117	22	39
2004	<i>Eisenia arborea</i>	Southern sea palm, adult	963	125	16	32
2004.5	<i>Eisenia arborea</i>	Southern sea palm, juvenile	1196	129	8	34
2005	<i>Pterygophora californica</i>	California sea palm, adult	1036	109	6	54
2005.5	<i>Pterygophora californica</i>	California sea palm, juvenile	897	142	1	52
2006	<i>Laminaria farlowii</i>	oar weed, adult (>10cm wide)	846	63	64	30
2006.5	<i>Laminaria farlowii</i>	oar weed, juvenile (<10cm wide)	1079	89	31	34
2009.5	<i>Undaria pinnatifida</i>	Wakame	3	53	–	–
2015	<i>Dictyoneuropsis reticulata</i> - <i>Agarum fimbriatum</i>	<i>Dictyoneuropsis reticulata</i> / <i>Agarum fimbriatum</i> , adult (>10cm wide)	66	138	–	–
2015.5	<i>Dictyoneuropsis reticulata</i> - <i>Agarum fimbriatum</i>	<i>Dictyoneuropsis reticulata</i> / <i>Agarum fimbriatum</i> , juvenile (<10cm wide)	21	225	–	–
2016	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , adult (>50cm or receptacles present)	93	81	1	12
2016.5	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , juvenile (<50cm and no receptacles)	204	88	15	22
9002	<i>Haliotis rufescens</i>	red abalone	36	109	–	–

Table A-9 (continued). Sample size calculations for the 1-m quadrat data collection method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	All Site-Year Combinations		Only Site-Year Combinations Passing Normality Test	
			Num. of Site-Year Combinations	Median Req. Sample Size	Num. of Site-Years That Are Normal	Median Req. Sample Size
9005	<i>Cypraea spadicea</i>	chestnut cowrie	3428	154	10	52
9006	<i>Kelletia kelletii</i>	Kellet's whelk	78	78	–	–
9007	<i>Megastrea undosa</i>	wavy turban snail	3149	67	170	25
9008	<i>Lithopoma gibberosa</i>	red turban snail	568	144	1	21
9010	<i>Crassedoma giganteum</i>	rock scallop	3	151	–	–
9014	<i>Tegula regina</i>	queen tegula	595	291	–	–
11001	<i>Patiria miniata</i>	bat star	4363	31	1171	22
11002	<i>Pisaster giganteus</i>	giant-spined sea star	2072	165	–	–
11004	<i>Lytechinus anamesus</i>	white sea urchin	289	56	25	17
11005	<i>Strongylocentrotus franciscanus</i>	red sea urchin	5503	35	1512	19
11006	<i>Strongylocentrotus purpuratus</i>	purple sea urchin	5357	28	1588	15
11007	<i>Parastichopus parvimensis</i>	warty sea cucumber	4091	101	242	33
11009	<i>Centrostephanus coronatus</i>	Coronado urchin	2066	95	47	37
12002	<i>Styela montereyensis</i>	stalked tunicate	971	81	87	22
14025	<i>Lythrypnus dalli</i>	blue-banded goby	368	78	8	24
14026	<i>Coryphopterus nicholsi</i>	blackeye goby	4422	51	765	21
14027	<i>Alloclinus holderi</i>	island kelpfish	1626	60	62	25
Overall avg:			–	103	–	29

Table A-10. Sample size calculations for the 5-m quadrat data collection method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	All Site-Year Combinations		Only Site-Year Combinations Passing Normality Test	
			Num. of Site-Year Combinations	Median Req. Sample Size	Num. of Site-Years That Are Normal	Median Req. Sample Size
2002.25	<i>Macrocystis pyrifera</i>	giant kelp, adult (>1m and haptera above the primary dichotomy)	2179	76	3	17
2002.75	<i>Macrocystis pyrifera</i>	giant kelp, subadult (>1m and no haptera above the primary dichotomy)	2288	91	0	–
2009	<i>Undaria pinnatifida</i>	Wakame	1	84	0	–
2009.5	<i>Undaria pinnatifida</i>	Wakame	3	53	0	–
2016	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , adult (>50cm or receptacles present)	166	78	0	–
2016.5	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , juvenile (<50cm and no receptacles)	217	80	0	–
11002	<i>Pisaster giganteus</i>	giant-spined sea star	3541	134	0	–
11011	<i>Pisaster ochraceus</i>	ochre sea star	10	647	0	–
Overall avg:			–	155	–	17

Table A-11. Sample size calculations for the band transects data collection method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	All Site-Year Combinations		Only Site-Year Combinations Passing Normality Test	
			Num. of Site-Year Combinations	Median Req. Sample Size	Num. of Site-Years That Are Normal	Median Req. Sample Size
2009	<i>Undaria pinnatifida</i>	Wakame	1	17	0	–
2009.5	<i>Undaria pinnatifida</i>	Wakame	1	15	0	–
2016	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , adult (>50cm or receptacles present)	184	38	22	12
2016.5	<i>Sargassum horneri</i>	<i>Sargassum horneri</i> , juvenile (<50cm and no receptacles)	29	112	3	30
5002	<i>Tethya aurantia</i>	orange puffball sponge	4784	25	1894	14
6001	<i>Stylaster californicus</i>	California hydrocoral	254	101	0	–
6002	<i>Urticina lofotensis</i>	white-spotted rose anemone	1823	32	748	22
6006	<i>Lophogorgia chilensis</i>	red gorgonian	3551	44	1064	20
6007	<i>Muricea fruticosa</i>	brown gorgonian	872	227	1	29
6008	<i>Muricea californica</i>	California golden gorgonian	2009	97	177	33
8001	<i>Panulirus interruptus</i>	California spiny lobster	1747	138	4	35
9002	<i>Haliotis rufescens</i>	red abalone	1086	66	184	41
9003	<i>Haliotis corrugata</i>	pink abalone	267	296	0	–
9004	<i>Haliotis fulgens</i>	green abalone	3	185	0	–
9006	<i>Kelletia kelletii</i>	Kellet's whelk	3751	81	270	14
9009	<i>Megathura crenulata</i>	giant keyhole limpet	4144	59	554	18
9010	<i>Crassidoma giganteum</i>	rock scallop	5444	57	442	24
9011	<i>Aplysia californica</i>	California brown sea hare	2917	64	389	18
9012	<i>Haliotis assimilis</i>	threaded abalone	3	581	0	–
9015	<i>Cryptochiton stelleri</i>	gumboot chiton	13	327	0	–

Table A-11 (continued). Sample size calculations for the band transects data collection method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	All Site-Year Combinations		Only Site-Year Combinations Passing Normality Test	
			Num. of Site-Year Combinations	Median Req. Sample Size	Num. of Site-Years That Are Normal	Median Req. Sample Size
11002	<i>Pisaster giganteus</i>	giant-spined sea star	120	179	0	–
11003	<i>Pycnopodia helianthoides</i>	sunflower star	1385	29	411	15
11004	<i>Lytechinus anamesus</i>	white sea urchin	2149	44	289	15
11011	<i>Pisaster ochraceus</i>	ochre sea star	3	179	0	–
Overall avg:			–	125	–	23

Table A-12. Sample size calculations for the random point contact (RPC) data collection method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	All Site-Year Combinations		Only Site-Year Combinations Passing Normality Test	
			Num. of Site-Year Combinations	Median Req. Sample Size	Num. of Site-Years That Are Normal	Median Req. Sample Size
1001	<i>Chlorophyta</i>	green algae	2169	156	4	25
2001	<i>Phaeophyta</i>	brown algae (miscellaneous)	2856	110	69	21
2003	<i>Desmarestia</i>	acid weed	564	138	4	30
2007	<i>Cystoseira</i>	bladder chain kelp	1477	137	7	33
2010	<i>Macrocystis pyrifera</i>	giant kelp, all	2425	41	469	20
2012	<i>Eisenia arborea</i>	Southern sea palm, all	1360	122	39	44
2013	<i>Pterygophora californica</i>	California sea palm, all	1209	105	9	40
2014	<i>Laminaria farlowii</i>	oar weed, all	874	50	93	23
2017	<i>Sargassum homeri</i>	<i>Sargassum homeri</i> , all	170	57	11	16
3001	<i>Rhodophyta</i>	red algae (miscellaneous)	5444	–	1571	–
3002	<i>Corallinales</i>	articulated coralline algae	4228	74	559	21
3003	<i>Corallinales</i>	encrusting coralline algae	5609	–	4004	–
3004	<i>Gelidium</i>	agar weed	308	167	–	–
3005	<i>Gigartina</i>	sea tongue	1049	112	8	16
4001	<i>Plantae</i>	miscellaneous plants (i.e., diatoms)	2879	54	168	23
5001	<i>Porifera</i>	sponges	3262	119	27	31
6003	<i>Corynactis californicus</i>	club-tipped anemone	3711	136	67	38
6004	<i>Balanophyllia elegans</i>	orange cup coral	2773	110	16	37
6005	<i>Astrangia lajollaensis</i>	La Jolla cup coral	4250	98	368	20
7001	<i>Diopatra ornata</i>	ornate tube worm	2664	130	86	37
7002	<i>Phragmatopoma californica</i>	colonial sand-tube worm	947	89	9	25

Table A-12 (continued). Sample size calculations for the random point contact (RPC) data collection method for the kelp forest monitoring program at Channel Islands National Park.

Species	Scientific Name	Common Name	All Site-Year Combinations		Only Site-Year Combinations Passing Normality Test	
			Num. of Site-Year Combinations	Median Req. Sample Size	Num. of Site-Years That Are Normal	Median Req. Sample Size
9001	<i>Serpulorbis squamigerus</i>	scaled wormsnaill	1173	229	–	–
10001	<i>Bryozoa</i>	bryozoans (miscellaneous)	4791	25	1060	13
10002	<i>Diaperoecia californica</i>	Southern staghorn bryozoan	2127	158	9	42
11008	<i>Pachythyone rubra</i>	aggregated red sea cucumber	266	164	4	24
11010	<i>Ophiothrix spiculata</i>	spiny brittle star	683	37	36	13
12001	<i>Tunicata</i>	tunicates	4182	62	320	24
13001	Miscellaneous Invertebrates including <i>Ophiothrix spiculata</i>	Miscellaneous Invertebrates including <i>Ophiothrix spiculata</i>	336	20	153	15
13002	Miscellaneous Invertebrates excluding <i>Ophiothrix spiculata</i>	Miscellaneous Invertebrates excluding <i>Ophiothrix spiculata</i>	3481	23	1328	17
15001	Bare Substrate	Bare Substrate	5596	29	1561	16
15002	Rock	Rock	5609	–	803	–
15003	Cobble	Cobble	5453	87	284	31
15004	Sand	Sand	5454	97	333	32
Overall avg:			–	98	–	26

Appendix B

Appendix B shows the results of our power analysis to detect trends in abundance by island for four key species. This analysis fits the linear mixed effects models from section 5 (Eq. 4), but with a separate model fit to each island. The models for some species and islands had convergence errors; for those data sets, more parsimonious models were fit as noted. A summary of the model fits and plots of the power analysis are shown for four species: the purple sea urchin (*Strongylocentrotus purpuratus*), red sea urchin (*Strongylocentrotus franciscanus*), California spiny lobster (*Panulirus interruptus*), and the warty sea cucumber (*Parastichopus parvimensis*).

Purple sea urchin (*Strongylocentrotus purpuratus*)

Power analysis results

Fitted model: $\text{lmer}(\log(\text{SumCt} + 0.25) \sim \text{yr0} + \text{MPA} + (\text{yr0}|\text{SiteName}) + (1|\text{yr0}))$

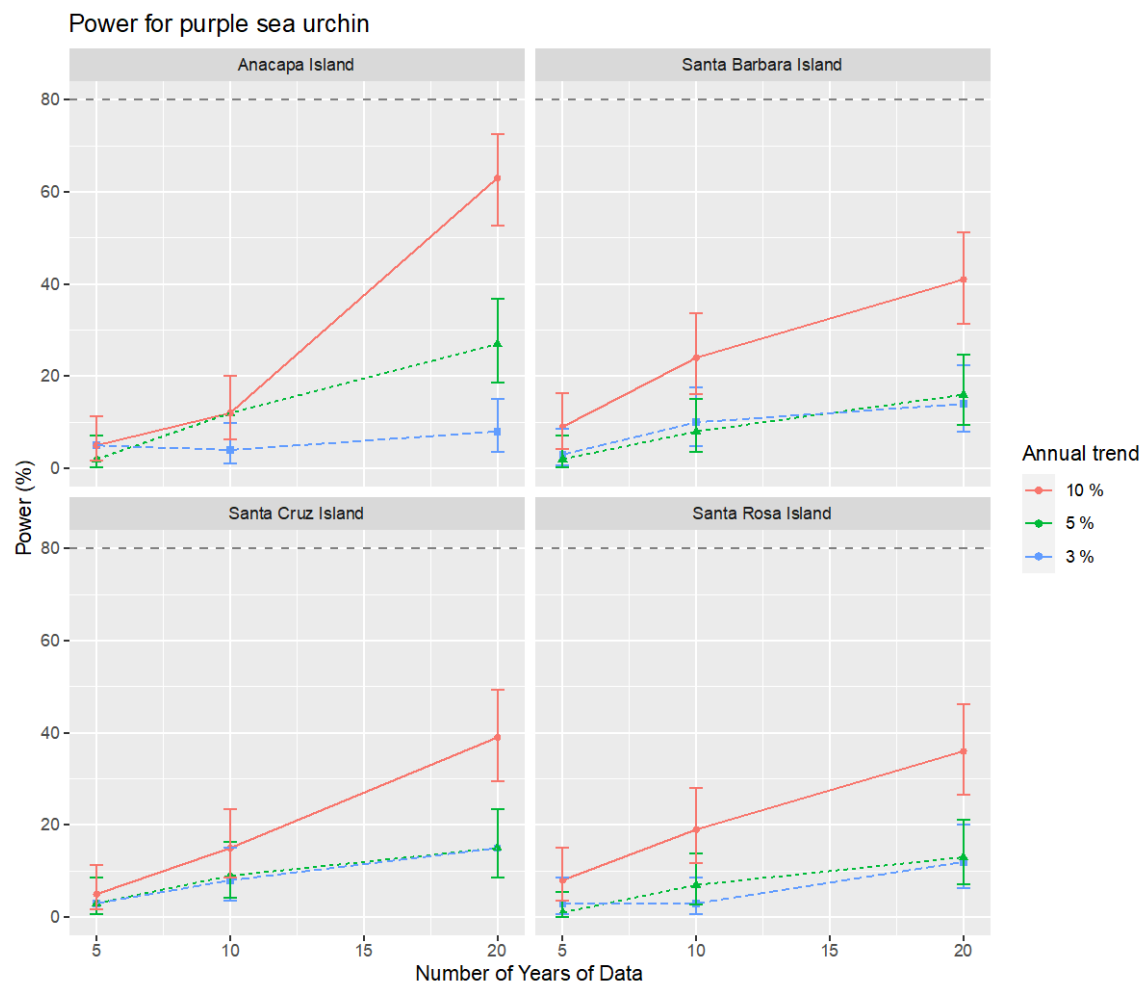


Figure B-1. Purple sea urchin trend over time by island—power analysis results for the kelp forest monitoring program at Channel Islands National Park. The 10% annual trend line is the solid, top line, the 5% annual trend line is the line with shorter broken segments, and the 3% annual trend line is the line with longer broken segments.

Fitted models

Santa Rosa Island

Linear mixed model fit by REML ['lmerMod']

Formula: $\log(\text{SumCt} + 0.25) \sim \text{yr0} + \text{MPA} + (\text{yr0} \mid \text{SiteName}) + (1 \mid \text{yr0})$

Data: dat

REML criterion at convergence: 3710.8

Scaled residuals:

Min	1Q	Median	3Q	Max
-3.4499	-0.6471	0.0667	0.6358	2.9115

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
yr0	(Intercept)	0.46382	0.6810	
SiteName	(Intercept)	2.24772	1.4992	
	yr0	0.01332	0.1154	-0.97
Residual		2.16966	1.4730	

Number of obs: 1008, groups: yr0, 14; SiteName, 6

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-1.66534	0.72724	-2.290
yr0	0.38275	0.06626	5.776
MPAoutside	1.07210	0.33006	3.248

Correlation of Fixed Effects:

	(Intr) yr0
yr0	-0.875
MPAoutside	-0.227 0.000

Santa Cruz Island

Linear mixed model fit by REML ['lmerMod']

Formula: $\log(\text{SumCt} + 0.25) \sim \text{yr0} + \text{MPA} + (\text{yr0} \mid \text{SiteName}) + (1 \mid \text{yr0})$

Data: dat

REML criterion at convergence: 3048.8

Scaled residuals:

Min	1Q	Median	3Q	Max
-4.9971	-0.4701	0.1414	0.6082	2.5872

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
yr0	(Intercept)	0.55420	0.7444	
SiteName	(Intercept)	0.43848	0.6622	
	yr0	0.01314	0.1146	0.22
Residual		1.10101	1.0493	

Number of obs: 1008, groups: yr0, 14; SiteName, 6

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	4.9135	0.5422	9.062
yr0	-0.1934	0.0685	-2.823
MPAoutside	-0.9825	0.5457	-1.800

Correlation of Fixed Effects:

	(Intr)	yr0
yr0	-0.362	
MPAoutside	-0.503	0.000

Anacapa Island

Linear mixed model fit by REML ['lmerMod']

Formula: $\log(\text{SumCt} + 0.25) \sim \text{yr0} + \text{MPA} + (\text{yr0} \mid \text{SiteName}) + (1 \mid \text{yr0})$

Data: dat

REML criterion at convergence: 3479.8

Scaled residuals:

Min	1Q	Median	3Q	Max
-3.0595	-0.5851	-0.0240	0.6421	3.3442

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
yr0	(Intercept)	0.534665	0.7312	
SiteName	(Intercept)	1.584895	1.2589	
	yr0	0.004557	0.0675	-0.16
Residual		1.706210	1.3062	

Number of obs: 1008, groups: yr0, 14; SiteName, 6

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	1.28544	0.81720	1.573
yr0	-0.13992	0.05669	-2.468
MPAoutside	2.85422	1.01998	2.798

Correlation of Fixed Effects:

	(Intr)	yr0
yr0	-0.394	
MPAoutside	-0.624	0.000

Santa Barbara Island

Linear mixed model fit by REML ['lmerMod']

Formula: $\log(\text{SumCt} + 0.25) \sim \text{yr0} + \text{MPA} + (\text{yr0} \mid \text{SiteName}) + (1 \mid \text{yr0})$

Data: dat

REML criterion at convergence: 3747.3

Scaled residuals:

Min	1Q	Median	3Q	Max
-3.7629	-0.4011	0.1557	0.6716	2.3953

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
yr0	(Intercept)	0.51930	0.7206	
SiteName	(Intercept)	0.18077	0.4252	
	yr0	0.01156	0.1075	-0.70
Residual		2.25340	1.5011	

Number of obs: 1008, groups: yr0, 14; SiteName, 6

Fixed effects:

	<i>Estimate</i>	<i>Std. Error</i>	<i>t value</i>
<i>(Intercept)</i>	2.94626	0.43714	6.740
<i>yr0</i>	-0.20062	0.06593	-3.043
<i>MPAoutside</i>	2.42846	0.27844	8.722

Correlation of Fixed Effects:

	<i>(Intr)</i>	<i>yr0</i>
<i>yr0</i>	-0.731	
<i>MPAoutside</i>	-0.318	0.000

Red sea urchin (*Strongylocentrotus franciscanus*)

Power analysis results

Fitted model: $\text{lmer}(\log(\text{SumCt} + 0.25) \sim \text{yr0} + \text{MPA} + (\text{yr0}|\text{SiteName}) + (1|\text{yr0}))$

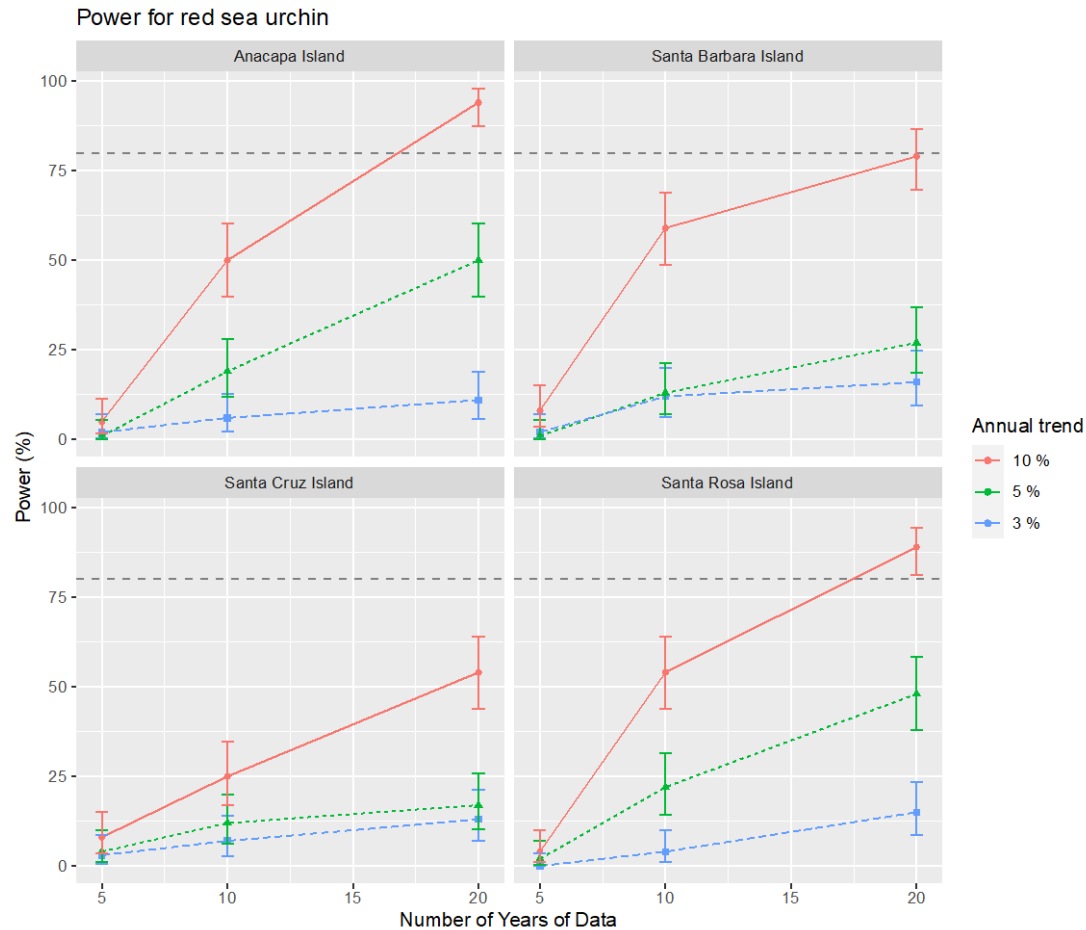


Figure B-2. Red sea urchin trend over time by island—power analysis results for the kelp forest monitoring program at Channel Islands National Park. The 10% annual trend line is the solid, top line, the 5% annual trend line is the line with shorter broken segments, and the 3% annual trend line is the line with longer broken segments.

Fitted models

Santa Rosa Island

Linear mixed model fit by REML [*'lmerMod'*]

Formula: $\log(\text{SumCt} + 0.25) \sim \text{yr0} + \text{MPA} + (\text{yr0} | \text{SiteName}) + (1 | \text{yr0})$

Data: dat

REML criterion at convergence: 3625.1

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.42517	-0.72695	-0.08722	0.68944	3.10867

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
yr0	(Intercept)	0.066324	0.25753	
SiteName	(Intercept)	1.182162	1.08727	
	yr0	0.003545	0.05954	0.10
Residual		2.024905	1.42299	

Number of obs: 1008, groups: yr0, 14; SiteName, 6

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-0.12728	0.65227	-0.195
yr0	0.19750	0.03172	6.227
MPAoutside	-0.96307	0.90366	-1.066

Correlation of Fixed Effects:

	(Intr)	yr0
yr0	-0.078	
MPAoutside	-0.693	0.000

Santa Cruz Island

Linear mixed model fit by REML ['lmerMod']

Formula: log(SumCt + 0.25) ~ yr0 + MPA + (yr0 | SiteName) + (1 | yr0)

Data: dat

REML criterion at convergence: 3003

Scaled residuals:

Min	1Q	Median	3Q	Max
-4.5275	-0.5231	0.1336	0.6363	2.9308

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
yr0	(Intercept)	0.25763	0.5076	
SiteName	(Intercept)	0.77299	0.8792	

yr0	0.01003	0.1001	-0.83
Residual	1.06457	1.0318	

Number of obs: 1008, groups: yr0, 14; SiteName, 6

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	1.75267	0.48897	3.584
yr0	-0.11811	0.05356	-2.205
MPAoutside	1.29118	0.40102	3.220

Correlation of Fixed Effects:

	(Intr)	yr0
yr0	-0.765	
MPAoutside	-0.410	0.000

Anacapa Island

Linear mixed model fit by REML ['lmerMod']

Formula: log(SumCt + 0.25) ~ yr0 + MPA + (yr0 | SiteName) + (1 | yr0)

Data: dat

REML criterion at convergence: 3291.1

Scaled residuals:

Min	1Q	Median	3Q	Max
-3.4489	-0.5704	0.1766	0.6645	2.3707

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
yr0	(Intercept)	0.122127	0.34947	
SiteName	(Intercept)	0.112341	0.33517	
	yr0	0.002898	0.05383	-0.29
Residual		1.450110	1.20421	

Number of obs: 1008, groups: yr0, 14; SiteName, 6

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	1.79361	0.27492	6.524
yr0	-0.19361	0.03329	-5.815

MPAoutside 1.55313 0.28479 5.454

Correlation of Fixed Effects:

(Intr) yr0
yr0 -0.539
MPAoutside -0.518 0.000

Santa Barbara Island

Linear mixed model fit by REML ['lmerMod']

Formula: log(SumCt + 0.25) ~ yr0 + MPA + (yr0 | SiteName) + (1 | yr0)

Data: dat

REML criterion at convergence: 3191.1

Scaled residuals:

Min	1Q	Median	3Q	Max
-3.6241	-0.4754	0.1122	0.6596	2.7757

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
yr0	(Intercept)	0.056708	0.23814	
SiteName	(Intercept)	0.264520	0.51431	
	yr0	0.005385	0.07338	-0.29
Residual		1.312727	1.14574	

Number of obs: 1008, groups: yr0, 14; SiteName, 6

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	2.92132	0.32614	8.957
yr0	-0.28289	0.03503	-8.076
MPAoutside	0.79708	0.41477	1.922

Correlation of Fixed Effects:

(Intr) yr0
yr0 -0.350
MPAoutside -0.636 0.000

California spiny lobster (*Panulirus interruptus*)

Power analysis results

Fitted model for Santa Rosa and Santa Cruz islands:

```
lmer( log(SumCt + 0.25) ~ yr0 + (1|SiteName) )
```

Fitted model for Anacapa and Santa Barbara islands:

```
lmer( log(SumCt + 0.25) ~ yr0 + (1|SiteName) + (1|yr0) )
```

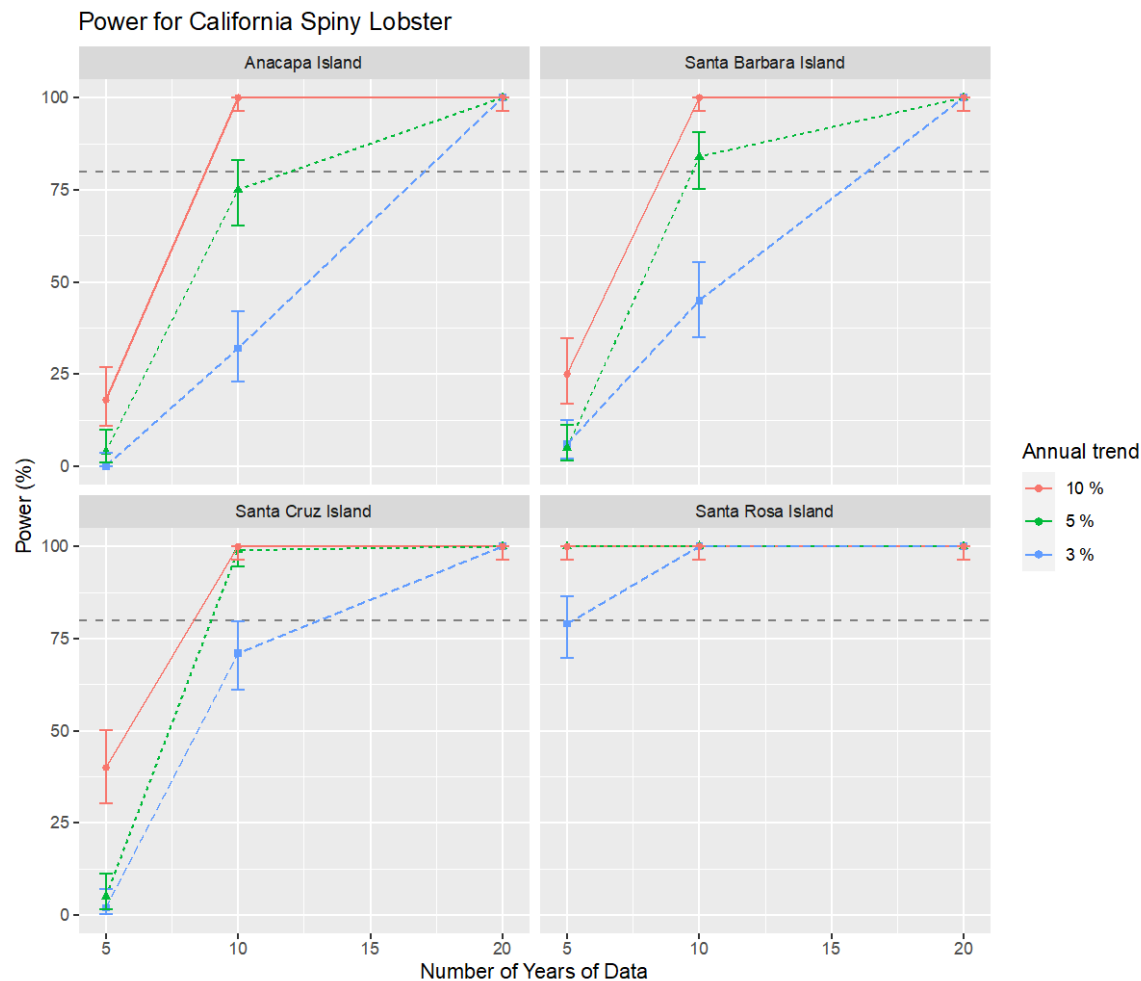


Figure B-3. California spiny lobster trend over time by island—power analysis results for the kelp forest monitoring program at Channel Islands National Park. The 10% annual trend line is the solid, top line, the 5% annual trend line is the line with shorter broken segments, and the 3% annual trend line is the line with longer broken segments.

Fitted models

Santa Rosa Island

Linear mixed model fit by REML [*'lmerMod'*]

Formula: $\log(\text{SumCt} + 0.25) \sim \text{yr0} + (1 \mid \text{SiteName})$
Data: dat

REML criterion at convergence: 240.1

Scaled residuals:

Min	1Q	Median	3Q	Max
-0.8409	-0.2865	-0.1185	0.0486	10.4816

Random effects:

Groups	Name	Variance	Std.Dev.
SiteName	(Intercept)	0.003614	0.06012
	Residual	0.072302	0.26889

Number of obs: 1008, groups: SiteName, 6

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-1.414947	0.029335	-48.234
yr0	0.010937	0.002101	5.206

Correlation of Fixed Effects:

(Intr)
yr0 -0.466

Santa Cruz Island

Linear mixed model fit by REML ['lmerMod']

Formula: $\log(\text{SumCt} + 0.25) \sim \text{yr0} + (1 \mid \text{SiteName})$
Data: dat

REML criterion at convergence: 2455.1

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.1390	-0.5783	-0.1273	0.3721	3.5215

Random effects:

Groups	Name	Variance	Std.Dev.
--------	------	----------	----------

```

SiteName (Intercept) 0.2883    0.5369
Residual              0.6470    0.8043
Number of obs: 1008, groups:  SiteName, 6

```

Fixed effects:

```

                Estimate Std. Error t value
(Intercept) -1.226914    0.224406  -5.467
yr0          0.057302    0.006285   9.118

```

Correlation of Fixed Effects:

```

(Intr)
yr0 -0.182

```

Anacapa Island

Linear mixed model fit by REML ['lmerMod']

Formula: $\log(\text{SumCt} + 0.25) \sim \text{yr0} + (1 \mid \text{SiteName}) + (1 \mid \text{yr0})$

Data: dat

REML criterion at convergence: 3006.2

Scaled residuals:

```

      Min       1Q   Median       3Q      Max
-2.4102 -0.5045 -0.0555   0.3892   3.4166

```

Random effects:

```

Groups   Name             Variance Std.Dev.
yr0      (Intercept) 0.007392 0.08598
SiteName (Intercept) 0.682977 0.82642
Residual                  1.111907 1.05447
Number of obs: 1008, groups:  yr0, 14; SiteName, 6

```

Fixed effects:

```

                Estimate Std. Error t value
(Intercept) -0.94537    0.34598  -2.732
yr0          0.06756    0.01002   6.744

```

Correlation of Fixed Effects:

```

(Intr)

```

yr0 -0.188

Santa Barbara Island

Linear mixed model fit by REML ['lmerMod']

Formula: $\log(\text{SumCt} + 0.25) \sim \text{yr0} + (1 \mid \text{SiteName}) + (1 \mid \text{yr0})$

Data: dat

REML criterion at convergence: 2112.6

Scaled residuals:

Min	1Q	Median	3Q	Max
-1.3907	-0.5925	-0.2362	-0.0446	4.4086

Random effects:

Groups	Name	Variance	Std.Dev.
yr0	(Intercept)	0.01087	0.1043
SiteName	(Intercept)	0.02752	0.1659
Residual		0.45922	0.6777

Number of obs: 1008, groups: yr0, 14; SiteName, 6

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-1.375971	0.094991	-14.485
yr0	0.040528	0.008708	4.654

Correlation of Fixed Effects:

(Intr)
yr0 -0.596

Warty sea cucumber (*Parastichopus parvimensis*)

Power analysis results

Fitted model for Santa Rosa Island:

```
lmer( log(SumCt + 0.25) ~ yr0 + (1|SiteName) )
```

Fitted model for all other islands:

```
lmer( log(SumCt + 0.25) ~ yr0 + MPA + (1|SiteName) + (1|yr0) )
```

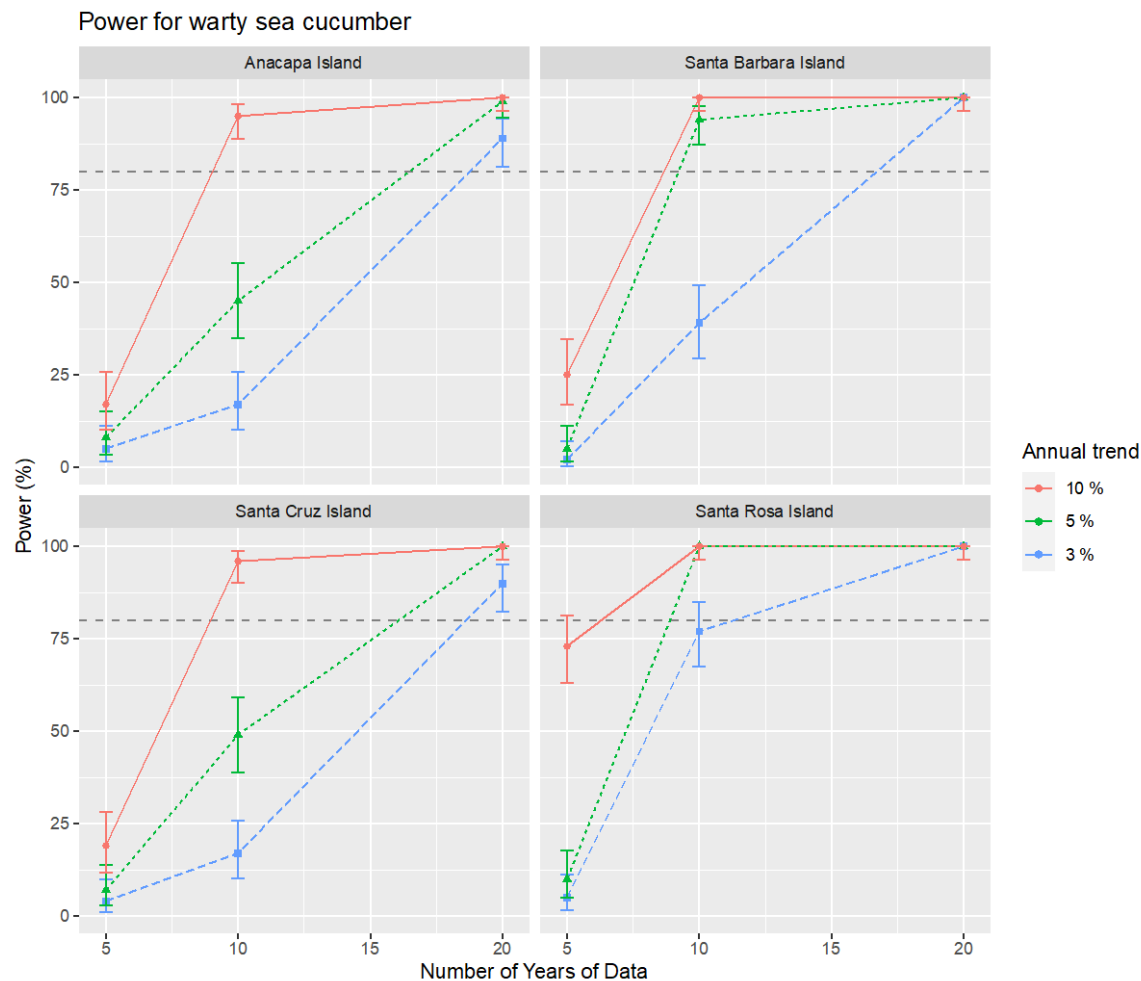


Figure B-4. Warty sea cucumber trend over time by island—power analysis results for the kelp forest monitoring program at Channel Islands National Park. The 10% annual trend line is the solid, top line, the 5% annual trend line is the line with shorter broken segments, and the 3% annual trend line is the line with longer broken segments.

Fitted models

Santa Rosa Island

Linear mixed model fit by REML [*'lmerMod'*]

Formula: $\log(\text{SumCt} + 0.25) \sim \text{yr0} + (1 \mid \text{SiteName})$

Data: dat

REML criterion at convergence: 2025.5

Scaled residuals:

Min	1Q	Median	3Q	Max
-1.0093	-0.4775	-0.2378	-0.1738	4.0640

Random effects:

Groups	Name	Variance	Std.Dev.
SiteName	(Intercept)	0.04487	0.2118
Residual		0.42505	0.6520

Number of obs: 1008, groups: SiteName, 6

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-1.056245	0.094847	-11.136
yr0	-0.004772	0.005094	-0.937

Correlation of Fixed Effects:

	(Intr)
yr0	-0.349

Santa Cruz Island

Linear mixed model fit by REML ['lmerMod']

Formula: $\log(\text{SumCt} + 0.25) \sim \text{yr0} + \text{MPA} + (1 \mid \text{SiteName}) + (1 \mid \text{yr0})$

Data: dat

REML criterion at convergence: 2715.1

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.5555	-0.7161	-0.1593	0.8887	2.9156

Random effects:

Groups	Name	Variance	Std.Dev.
yr0	(Intercept)	0.03818	0.1954
SiteName	(Intercept)	0.13636	0.3693
Residual		0.82763	0.9097

Number of obs: 1008, groups: yr0, 14; SiteName, 6

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	0.38853	0.24300	1.599
yr0	-0.03584	0.01478	-2.425
MPAoutside	-1.02266	0.30690	-3.332

Correlation of Fixed Effects:

	(Intr)	yr0
yr0	-0.395	
MPAoutside	-0.632	0.000

Anacapa Island

Linear mixed model fit by REML ['lmerMod']

Formula: $\log(\text{SumCt} + 0.25) \sim \text{yr0} + \text{MPA} + (1 \mid \text{SiteName}) + (1 \mid \text{yr0})$

Data: dat

REML criterion at convergence: 2932.3

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.1040	-0.8279	-0.2901	0.8196	2.4769

Random effects:

Groups	Name	Variance	Std.Dev.
yr0	(Intercept)	0.03979	0.1995
SiteName	(Intercept)	0.13086	0.3617
Residual		1.02994	1.0149

Number of obs: 1008, groups: yr0, 14; SiteName, 6

Fixed effects:

Estimate	Std. Error	t value
----------	------------	---------

(Intercept)	0.33310	0.24197	1.377
yr0	-0.04958	0.01542	-3.215
MPAoutside	-0.67512	0.30220	-2.234

Correlation of Fixed Effects:

	(Intr)	yr0
yr0	-0.414	
MPAoutside	-0.624	0.000

Santa Barbara Island

Linear mixed model fit by REML ['lmerMod']

Formula: $\log(\text{SumCt} + 0.25) \sim \text{yr0} + \text{MPA} + (1 \mid \text{SiteName}) + (1 \mid \text{yr0})$

Data: dat

REML criterion at convergence: 2595.2

Scaled residuals:

Min	1Q	Median	3Q	Max
-1.9917	-0.6795	-0.2856	0.7388	3.1727

Random effects:

Groups	Name	Variance	Std.Dev.
yr0	(Intercept)	0.004208	0.06487
SiteName	(Intercept)	0.179945	0.42420
Residual		0.743352	0.86218

Number of obs: 1008, groups: yr0, 14; SiteName, 6

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-0.252286	0.253882	-0.994
yr0	-0.061295	0.007992	-7.669
MPAoutside	-0.253752	0.350590	-0.724

Correlation of Fixed Effects:

	(Intr)	yr0
yr0	-0.205	
MPAoutside	-0.690	0.000

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 159/186969, December 2022

National Park Service
U.S. Department of the Interior



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