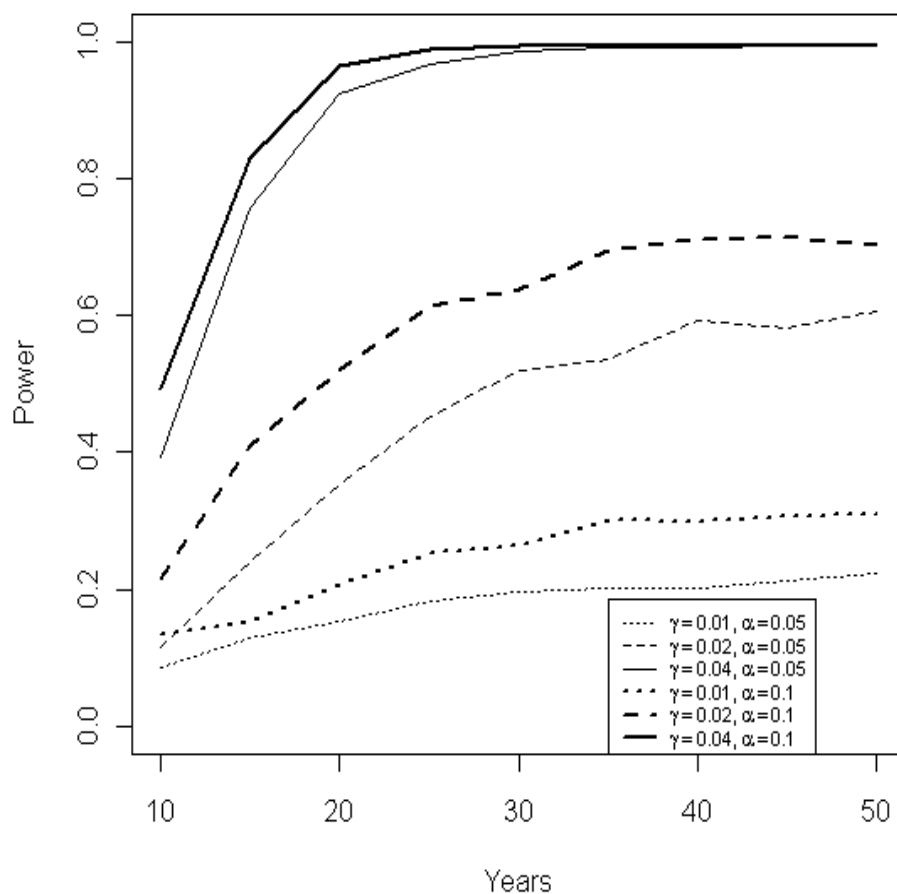




Trend and Power Analysis for National Park Service Marine Data from 2006 to 2010

Pacific Island Network

Natural Resource Technical Report NPS/PACN/NRTR—2013/771



ON THE COVER

Power analysis plots to detect trends in fish density from Kalaupapa National Historical Park at different trend detection levels (γ) and Type I error rates (α). Data used in the analysis were collected from 2006 to 2010.

Trend and Power Analysis for National Park Service Marine Data from 2006 to 2010

Pacific Island Network

Natural Resource Technical Report NPS/PACN/NRTR—2013/771

Leigh Ann Harrod Starceвич

Statistical consultant
PO Box 1032
Corvallis, OR97339
lah@peak.org

June 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Technical Report Series is used to disseminate results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service mission. The series provides contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from the Pacific Islands Network and the Natural Resource Publications Management website (<http://www.nature.nps.gov/publications/nrpm/>). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Starcevich, L. A. H. 2013. Trend and power analysis for National Park Service marine data from 2006 to 2010: Pacific Island Network. Natural Resource Technical Report NPS/PACN/NRTR—2013/771. National Park Service, Fort Collins, Colorado.

Contents

	Page
Contents	iii
Figures.....	v
Tables.....	vii
Executive Summary	ix
Acknowledgments.....	x
Introduction.....	1
Trend analysis	3
Monitoring data	3
Trend analysis methods	5
Power Analysis	9
Simulating trend.....	9
Degrees of freedom for trend testing	10
Results.....	10
Discussion and Conclusions	19
Literature Cited	21
APPENDIX A: Explanation of the linear mixed model	23
APPENDIX B: R code for trend modeling.....	27
Data exploration.....	27
Trend modeling.....	29
Assumption checking.....	33
Trend testing and confidence interval calculation	46
APPENDIX C: Monitoring data used for the analysis	49
APPENDIX D: Power results in tabular format	69

Figures

	Page
Figure 1: Power to detect trends in either direction at $\alpha = 0.10$ for an annual sample of 15 fixed sites and 15 temporary sites for three levels of change.	11
Figure 2: Power to detect trends in either direction at $\alpha = 0.10$ for an annual sample of 15 fixed sites and 15 temporary sites for three levels of change.	12
Figure 3: Power to detect trends in either direction at $\alpha = 0.10$ for an annual sample of 15 fixed sites and 15 temporary sites for three levels of change.	13
Figure 4: Power to detect trends in either direction at $\alpha = 0.10$ for an annual sample of 15 fixed sites and 15 temporary sites for three levels of change.	14
Figure 5: Power to detect trends in either direction at $\alpha = 0.10$ for an annual sample of 15 fixed sites and 15 temporary sites for three levels of change.	15
Figure B.1. Percent cover of turf algae by park and year.	28
Figure B.2. Basic residual diagnostics for the trend model of turf algae percent cover.	30
Figure B.3. Basic residual diagnostics for the trend model of logit-transformed turf algae percent cover.	32
Figure B.4. Quantile-quantile plots to assess the normality of residuals within level of the Year group.	34
Figure B.5. Quantile-quantile plots to assess the normality of residuals within Transects 1 through 5.	35
Figure B.6. Quantile-quantile plots to assess the normality of residuals within Transects 6 through 10.	36
Figure B.7. Quantile-quantile plots to assess the normality of residuals within Transects 11 through 15.	37
Figure B.8. Box plot of residual errors within each year.	38
Figure B.9. Box plot of residual errors within each transect.	39
Figure B.10. Quantile-quantile plots of estimated random effects for site intercepts, site slopes, and years.	41

Figures (continued)

	Page
Figure B.11. Plots of estimated random effects for site intercepts versus site slopes by year.....	42
Figure B.12. Quantile-quantile plots of estimated random site intercepts by year	43
Figure B.13. Quantile-quantile plots of estimated random site slopes by year	44
Figure B.14. Quantile-quantile plots of estimated random site intercepts and slopes for the [1-0] panel.....	45

Tables

	Page
Table 1: Annual means (and SEs) for benthic metrics by park.....	4
Table 2: Annual means (and SEs) for fish metrics by park	4
Table 3: Transformations, fixed effects estimates, trend test results, and variance components estimates by variable (p-values significant at the 0.05 significance level in bold).....	7
Table 4: Net trend over time as a multiplicative factor for several levels of annual trend	9
Table A.1: Correspondence of the R code to the linear mixed model terms	25
Table D.1: Power analysis results for different variables at both parks using two Type-I error levels (α), and three levels of change detection (γ).	69

Executive Summary

Marine monitoring data collected in Kalaupapa National Historical Park (KALA) and Kaloko-Honokohau National Historical Park (KAHO) between 2006 and 2010 provide the basis for a trend analysis and subsequent power analysis. Trends are estimated from the monitoring data with a t-test derived from a linear mixed model which combines fixed effects for status and trend with random effects with variance components to describe year-to-year variation, site-to-site variation, and variation among site-level slopes. Data transformation such as the log, logit, and arc-sine square-root transformation were used to meet linear modeling assumptions. Two-sided trend tests conducted at the 0.10 level indicate significant trends in KAHO turf algae percent cover (p-value = 0.0448) and KALA rugosity (p-value = 0.0199). Future trend modeling may be improved by incorporating covariate information to explain variation and improve the precision of trend estimators.

Power simulations were conducted for Type I error rates of 0.05 and 0.10 and annual increasing trends of 1%, 2%, and 4%. A Monte Carlo power simulation was run for each outcome of interest, park, trend, and Type I error rate. Monte Carlo power simulations incorporate fixed effects estimates of status and estimated variance components to generate similar populations that exhibit a known trend. The power to detect a given trend is calculated as the proportion of times a two-sided trend test is significant at the given Type I error rate for the set of 500 simulated sampled populations. The sampling design used for the simulation is the rotating panel design of 15 annually-visited sites and 15 randomly-selected sites that is used in the monitoring program.

Coral percent cover, rugosity, and fish species richness demonstrate the highest power to detect trend across parks. Annual trends in rugosity and fish species richness of 1%, 2%, or 4% can be detected with at least 80% power in KALA within 10 years. In KAHO, moderate (2%) to large (4%) annual trends in rugosity and turf algae cover can be detected within the same time frame. These indicators may be useful for early detection of trends.

Acknowledgments

The author would like to thank E. Brown for his helpful discussion of the marine data and review comments.

Introduction

The Pacific Island Network (PACN) of the National Park Service (NPS) annually monitors indicators or “Vital Signs” of marine ecosystems. These indicators include benthic substrate cover for macro-algae, coral, coralline algae, turf algae, and macroinvertebrates; coral rugosity coral settlement (number observed per square meter and five-month period); and fish density (number of fish/125 m²), fish biomass (metric tons per hectare), and fish species richness (number of species/125 m²) (Brown et. al. 2011). These indicators are monitored annually at 15 fixed transects and each year at an additional 15 randomly-selected transects with the goal of status estimation and trend detection.

In this report, the monitoring data are examined and status estimates are provided. Trend modeling provides estimates of baseline status, trend over the monitoring period, and components of variance that impact the power to detect trend. The power to detect three levels of trends is examined using a linear mixed model and Monte Carlo power simulation (Heard et al. 2007, Sims et al. 2006). A discussion of the power analysis results followed with recommendations on outcomes of interest for early trend detection.

Trend analysis

Monitoring data

The monitoring data was collected in two parks: Kalaupapa National Historical Park (KALA) on Moloka'i, Hawai'i, and Kaloko-Honokohau National Historical Park (KAHO) on the big island of Hawai'i. The split-panel sampling design consisted of 15 fixed transects visited annually and 15 transects selected randomly each year and only sampled once. Using the notation of McDonald (2003), the revisit design has the form $[(1-0)^{15}, (1-n)^{15}]$. The notation of $[1-0]$ describes a panel which is visited one year and rested zero years, i.e. is visited annually. The $[1-n]$ denotes panels of sites that are visited one year and never visited again. The exponent of "15" for each panel set indicates that 15 sites are included in each panel. This design combines temporal connectedness for trend estimation with increased spatial distribution for robust status estimation. Coral settlement data was collected in KALA only, while the remaining metrics were collected in both KALA and KAHO. KALA survey data are available from 2006 to 2010, and KAHO survey data are available for 2007 to 2010. Means for each metric by park and year are provided in Table 1.

Substrate cover data were collected from 25m X 5m transects located on hard-bottom substrate occurring between depths of 10m to 20m. Photographs representing an area of roughly 40cm by 25cm were taken every 1m along the transect line and analyzed for substrate cover. Substrate analysis consisted of randomly selecting 50 points on each photograph and obtaining the substrate type at each point. The total point count of each substrate type on the transect was divided by the total number of points analyzed on that transect to obtain site-level estimates of substrate percent cover.

Coral settlement data are collected by placing artificial substrates along transects and recording the number of coral individuals that settle on the tile in a particular time period. This metric is expressed as the number of settled larvae per square-meter per time period. This variable is affected by current, precipitation, and wave dynamics during spawning events. Rugosity, which is the ratio of the length of the contour of the substrate to the length of the transect, is a unit-less measure of surface complexity. Since the substrate contour will always be at least as long as the transect, this metric is bounded below by one. Fish species, number, and size were documented within the 25m X 5m transect corridor to derive fish density, biomass, and species richness. Refer to the NPS benthic protocol for more a detailed description of field methodology (Brown et. al. 2011).

Table 1: Annual means (and SEs) for benthic metrics by park

Year	Park	Macro- algae Percent Cover	Coral Percent Cover	Coralline algae Percent Cover	Macro- invert. Percent Cover	Turf Algae Percent Cover	Coral Settlement (number/ m ² /5-month period)	Rugosity*
2007	KAHO	11.49 (0.20)	20.31 (0.54)	0.64 (0.02)	5.07 (0.16)	62.00 (0.58)		1.84 (0.02)
2008	KAHO	3.29 (0.06)	21.13 (0.51)	11.06 (0.20)	2.70 (0.08)	58.85 (0.63)		2.01 (0.03)
2009	KAHO	3.61 (0.08)	22.63 (0.56)	11.23 (0.15)	3.57 (0.14)	54.63 (0.61)		1.86 (0.02)
2010	KAHO	4.26 (0.09)	23.44 (0.55)	9.71 (0.13)	3.94 (0.08)	55.31 (0.60)		
2006	KALA	7.88 (0.28)	9.60 (0.21)	5.23 (0.14)	0.15 (0.01)	75.92 (0.29)	75.41 (6.88)	1.57 (0.01)
2007	KALA	16.66 (0.19)	9.83 (0.26)	3.41 (0.11)	0.27 (0.01)	67.79 (0.44)	128.74 (6.90)	1.58 (0.02)
2008	KALA	26.93 (0.44)	9.74 (0.25)	3.16 (0.11)	0.30 (0.03)	58.86 (0.48)	214.17 (17.21)	1.60 (0.02)
2009	KALA	21.79 (0.66)	6.76 (0.25)	4.21 (0.16)	0.07 (0.00)	65.29 (0.51)	88.40 (7.55)	1.64 (0.02)
2010	KALA	22.42 (0.53)	7.64 (0.19)	4.92 (0.15)	0.13 (0.01)	63.37 (0.45)	75.61 (7.82)	

* See Brown et.al. (2011)

Table 2: Annual means (and SEs) for fish metrics by park

Year	Park	Density (number*1000/ha)	Biomass (metric tons/ha)	Species Richness (No./125 m ²)
2007	KAHO	13.75 (0.25)	8639.72 (160.26)	23.47 (0.16)
2008	KAHO	14.88 (0.21)	10763.93 (346.28)	25.57 (0.16)
2009	KAHO	15.91 (0.25)	7161.54 (121.70)	22.53 (0.17)
2010	KAHO	14.19 (0.20)	9334.53 (221.51)	25.30 (0.16)
2006	KALA	18.12 (0.43)	24657.74 (504.91)	27.00 (0.22)
2007	KALA	15.96 (0.31)	28787.00 (966.92)	28.80 (0.29)
2008	KALA	20.03 (0.41)	26135.31 (1041.58)	26.20 (0.22)
2009	KALA	10.46 (0.25)	24879.59 (920.94)	23.73 (0.23)
2010	KALA	12.87 (0.30)	25997.95 (946.47)	24.37 (0.19)

Trend analysis methods

A linear mixed modeling approach is used for trend estimation and testing (Larsen et al. 2001, Urquhart et al. 1993; VanLeeuwen et al. 1996). This modeling approach combines fixed effects that influence the mean structure with random effects that impact the variance structure. The fixed effects portion of the model ($\beta_0 + w_j\beta_1$) is equivalent to a simple linear regression model. Rather than pooling all error sources into a single residual error term, the linear mixed model partitions the error into different sources of variation (site-to-site variation, year-to-year variation, and the variation among site-level trend slopes). The linear mixed model is used to estimate trend and variance components and is defined as:

$$y_{ij} = \beta_0 + w_j\beta_1 + b_j + a_i + w_jt_i + e_{ij},$$

where $i=1,...,m_a$; $j=1,...,m_b$;

m_a = the number of sites in the sample;

m_b = the number of consecutive years in the sample;

y_{ij} = outcome of interest (possibly transformed),

w_j = constant representing the j^{th} year (covariate);

β_0 and β_1 = fixed intercept and slope of the linear time trend;

b_j = random effect of the j^{th} year, iid $N(0, \sigma_b^2)$, where σ_b^2 is the year-to-year variation;

a_i = random intercept of i^{th} site, iid $N(0, \sigma_a^2)$, where σ_a^2 is the site-to-site variation;

t_i = random slope of i^{th} site, iid $N(0, \sigma_t^2)$, where σ_t^2 is the variation among site-level slopes; and

e_{ij} = unexplained error, iid as $N(0, \sigma_e^2)$, where σ_e^2 is the unexplained residual variation.

The fixed trend effect is estimated with expected generalized least squares estimation (Urquhart et al. 1998, VanLeeuwen et al. 1996). Piepho and Ogotu (2002) model the random site intercept (a_i) and random site slope (t_i) as multivariate normal random variables with covariance σ_{at} so that a trend test that is invariant to shifts in time may be obtained with standard statistical software. Variance estimation is conducted using restricted maximum likelihood (REML), which is recommended when not all sites are visited annually (i.e. the data are "unbalanced") (Spilke et al. 2005). See Appendix A for more on the linear mixed model and its implementation in R programming software (2011).

The use of the linear mixed model requires assumptions of homoscedastic and normally-distributed error terms. To meet these assumptions, data transformations are used. Three data transformations, the logarithmic, logit, and arc-sine square-root transformations, are considered for the PACN marine data. The logarithmic transformation is useful for count data or positive real numbers exhibiting a range exceeding an order of magnitude (Ramsey and Schafer 1997). The logit and arcsine square-root transformations are

appropriate for proportion data falling between 0 and 1, inclusive. The logit transformation is appropriate for any proportional data but the arcsine square-root transformation is most effective in stabilizing variances when proportions fall either below 0.2 or above 0.8 (Mosteller and Youtz 1961). For the analysis of both fixed and temporary transects, the numbering of temporary transects was changed to unique identifiers so that trend analysis would identify these transects as unique rather than replicates of fixed transects with the same identifier.

Exploratory data analysis indicated possible relationships between outcomes and the position along the transect. A model predictor, *Easting*, was obtained by scaling the longitudinal coordinate of the transects for more stable regression parameter estimation. Model selection among potential fixed effects was conducted using the Bayes Information Criterion. For each outcome of interest, residual diagnostics were used to compare linear mixed model fits of the untransformed outcomes and each appropriate data transformation (Pinheiro and Bates 2004). When results from the logit and arc-sine square-root transformations were similar, the logit transformation was preferred due to its easier interpretability. The transformations used, fixed effects estimates, trend test results, and estimated variance components are provided for each outcome and park in Table 3. When a cell for a variance component estimate is left empty, that variance component was estimated as zero and dropped from the model. Note that the trend is test is two-sided, meaning that the alternative hypothesis is preferred when the trend is either significantly more or less than zero. See Appendix B for analysis examples of linear mixed modeling and residual diagnostics implementing code from the R (2011) statistical programming environment.

Table 3: Transformations, fixed effects estimates, trend test results, and variance components estimates by variable (p-values significant at the 0.05 significance level in **bold**).

	Variable	Park	Transformation	$\hat{\beta}_0$ Est. baseline status	$\hat{\beta}_1$ Est. trend (SE)	Two-sided trend test p-value	$\hat{\beta}_2$ Est. effect of Easting	$\hat{\sigma}_b^2$ (year-to-year var.)	$\hat{\sigma}_a^2$ (site-to-site var.)	$\hat{\sigma}_t^2$ (site-level slope var.)	$\hat{\sigma}_{at}$ (site-slope cov.)	$\hat{\sigma}_e^2$ (residual var.)
✓	Coral Percent Cover	KALA	Arcsine square root	0.0125	-0.0098 (0.0040)	0.0940	0.06844	0.000103	0.005208	-	-	0.001041
		KAHO	Arcsine square root	0.4045	0.0038 (0.0047)	0.4820	-	0.000032	0.0333	0.000084	0.000072	0.000843
	Coralline Algae Percent Cover	KALA	Logit	-3.6709	0.0316 (0.1381)	0.8337	0.2992	0.1748	0.5666	-	-	0.3257
		KAHO	Logit	-5.3310	0.9222 (0.5472)	0.2316	-	1.4757	1.5492	0.1312	-0.4322	0.1284
	Algae Percent Cover	KALA	Logit	-2.2889	0.2987 (0.1934)	0.2204	-0.2802	0.3510	0.0634	-	-	0.6552
		KAHO	Logit	-2.3694	0.2957 (0.1738)	0.1880	-	0.2770	0.2777	-	-	0.6373
	Turf Algae Percent Cover	KALA	Logit	0.9800	-0.1397 (0.0710)	0.1256	-	0.03569	0.2454	0.02338	-0.04484	0.2072
		KAHO	Logit	0.6548	-0.0676 (0.0314)	0.0448	-	-	0.5719	0.007876	-0.00920	0.04491
	Macro-invertebrate Percent Cover	KALA	Arcsine square root	0.0398	-0.0036 (0.0024)	0.2384	-	0.000040	0.000630	-	-	0.000404
		KAHO	Logit	-3.7130	-0.0141 (0.1491)	0.9331	-	0.1004	1.8302	0.01235	-0.1113	0.1353
	Rugosity	KALA	Log	0.4358	0.0157 (0.0053)	0.0199	-	0.000016	0.01666	0.000250	0.000035	0.000597
		KAHO	Log	0.6129	0.0086 (0.0442)	0.8769	-	0.003366	0.03933	0.000607	-0.00545	0.006903
Fish Abundance	KALA	Log	2.7288	-0.1200 (0.0589)	0.1220	-	0.02768	0.3202	0.007159	-0.02812	0.08555	
	KAHO	Log	2.3069	0.0182 (0.0435)	0.7179	-	0.003197	0.08034	-	-	0.1548	

Table 3: Transformations, fixed effects estimates, trend test results, and variance components estimates by variable (p-values significant at the 0.05 significance level in **bold**; continued).

Variable	Park	Transformation	$\hat{\beta}_0$ Est. baseline status	$\hat{\beta}_1$ Est. trend (SE)	Two- sided trend test p-value	$\hat{\beta}_2$ Est. effect of Easting	$\hat{\sigma}_b^2$ (year-to- year var.)	$\hat{\sigma}_a^2$ (site-to- site var.)	$\hat{\sigma}_t^2$ (site-level slope var.)	$\hat{\sigma}_{at}$ (site-slope cov.)	$\hat{\sigma}_e^2$ (residual var.)
Fish Biomass	KALA	Log	9.9981	-0.0344 (0.0367)	0.3512	-	-	0.6426	-	-	0.2610
	KAHO	Log	8.8673	0.0081 (0.0613)	0.9073	-	0.008311	0.4582	0.004549	-0.05061	0.2260
Fish Species Richness	KALA	Log	3.2846	-0.0152 (0.0105)	0.1522	-	-	0.06122	-	-	0.02090
	KAHO	Log	3.1207	0.0161 (0.0304)	0.6414	-	0.003536	0.04192	0.002164	-0.00461	0.01332
Coral Settlement	KALA	Log	3.7332	-0.2298 (0.2946)	0.4864	0.2973*	0.6739	0.2415	0.08369	0.04259	2.0715

* The fixed Easting effect in the Coral Settlement model also incorporated a quadratic term with coefficient 0.1876.

Power Analysis

A Monte Carlo power simulation is used to approximate power to detect a trend given the baseline status and variance composition of each marine indicator. The fixed and random effects estimates from the monitoring data are used to simulate the population of interest with a known change over time. A sample of 15 fixed transects and 15 temporary annual transects are randomly selected from the population and the appropriate trend model is applied to the data from the sample. A total of 500 populations are simulated and sampled, and the power to detect trend is computed as the proportion of times the null hypothesis is rejected in favor of the alternative hypothesis for a given trend.

Simulating trend

Trends are generated as exponential on the original scale of the metric. Let γ be the annual trend expressed as the proportion by which the metric changes each year. For example, $\gamma = 0.04$ implies that the population increases by 4% each year, while a $\gamma = -0.04$ means that the population mean decreases by 4% annually. The net trend, δ , over m_b years is a function of the annual trend expressed as:

$$\delta = (\gamma + 1)^{m_b - 1}.$$

The net trend over time is provided for different levels of annual change in Table 4. For example, for a positive annual trend of 4%, the net trend after 5 years represents a 22% increase from the original population indicator. After 50 years, the indicator has increased in value by 611%. A negative annual trend of 4% represents a population that is 82% smaller in value after 5 years for an 18% decline. After 50 years, the population indicator has declined 87% overall to 13% of its original value.

Table 4: Net trend over time as a multiplicative factor for several levels of annual trend

Year	Annual trend (γ)					
	0.01	0.02	0.04	-0.01	-0.02	-0.04
5	1.05	1.10	1.22	0.95	0.90	0.82
10	1.10	1.22	1.48	0.90	0.82	0.66
15	1.16	1.35	1.80	0.86	0.74	0.54
20	1.22	1.49	2.19	0.82	0.67	0.44
25	1.28	1.64	2.67	0.78	0.60	0.36
30	1.35	1.81	3.24	0.74	0.55	0.29
35	1.42	2.00	3.95	0.70	0.49	0.24
40	1.49	2.21	4.80	0.67	0.45	0.20
45	1.56	2.44	5.84	0.64	0.40	0.16
50	1.64	2.69	7.11	0.61	0.36	0.13

Note that the power to detect decreasing trends is higher than the power to detect increasing trends for two outcomes with the same net change (Gerrodette 1987). Also note that this power analysis for trend is a univariate approach which generates trends for each outcome independently. In reality, one could not observe increases in all of the percent cover outcomes because cover values for some substrate types would decrease as others increased. However, this approach considers the variance composition of each indicator separately so that the utility of each indicator for long-term monitoring may be assessed.

Degrees of freedom for trend testing

The Wald-type F-test is used for trend testing (Piepho and Ogutu 2002) and Satterthwaite degrees of freedom are recommended for unbalanced data (Spilke et al. 2005). Calculating the degrees of freedom with the Geisbrecht-Burns (1985) approach, as recommended by Piepho and Ogutu (2002) is time-consuming for simulations. The Geisbrecht-Burns (1985) approach was compared to the approximation used by Sims et al. (2006) and the Welch-Satterthwaite approximation (Welch 1947). The degrees of freedom from the Sims et al. (2006) approach are most similar to those from the Geisbrecht-Burns (1985) approach when $\sigma_t^2 > 0$. When $\sigma_t^2 = 0$, the Welch-Satterthwaite approximation (Welch 1947) outperforms the Sims et al. (2006) approximation, which produces degrees of freedom near 0. However, the Welch-Satterthwaite approximation (Welch 1947) often generates degrees of freedom considerably larger than the Geisbrecht-Burns (1985) degrees of freedom. This discrepancy may inflate power approximations for small sample sizes when $\sigma_t^2 = 0$.

Results

Power is computed for two-sided tests of trend by park for three levels of annual trend and Type I error rates (α) of 0.05 and 0.10 (Figures 1 through 5, Appendix D). Power plots may not always increase monotonically with time due to simulation variation rather than a real pattern in the power curve. Note that power is higher when α is 0.10 because the null hypothesis is rejected more frequently for the higher Type I error rate. The power to detect trend is more conservative for population increases than for population declines (Gerrodette 1987). Population increases are simulated for all outcomes of interest with the exception of percent cover of turf algae, which demonstrated high percent cover values and were better simulated under decline.

As expected, the power to detect trend is higher when the trend effect is more extreme. Therefore, power to detect annual trend of 4% is larger than the power to detect an annual trend of 1%. The power to detect trends in the percent cover of coral in KALA (Figure 1a) is reasonably high overall, with even the lowest trend of 1% detected with an 80% probability in about 20 years. Detection of trends in KAHO coral cover (Figure 1b) exhibits slightly lower power than in KALA due to higher site-to-site variation in KAHO.

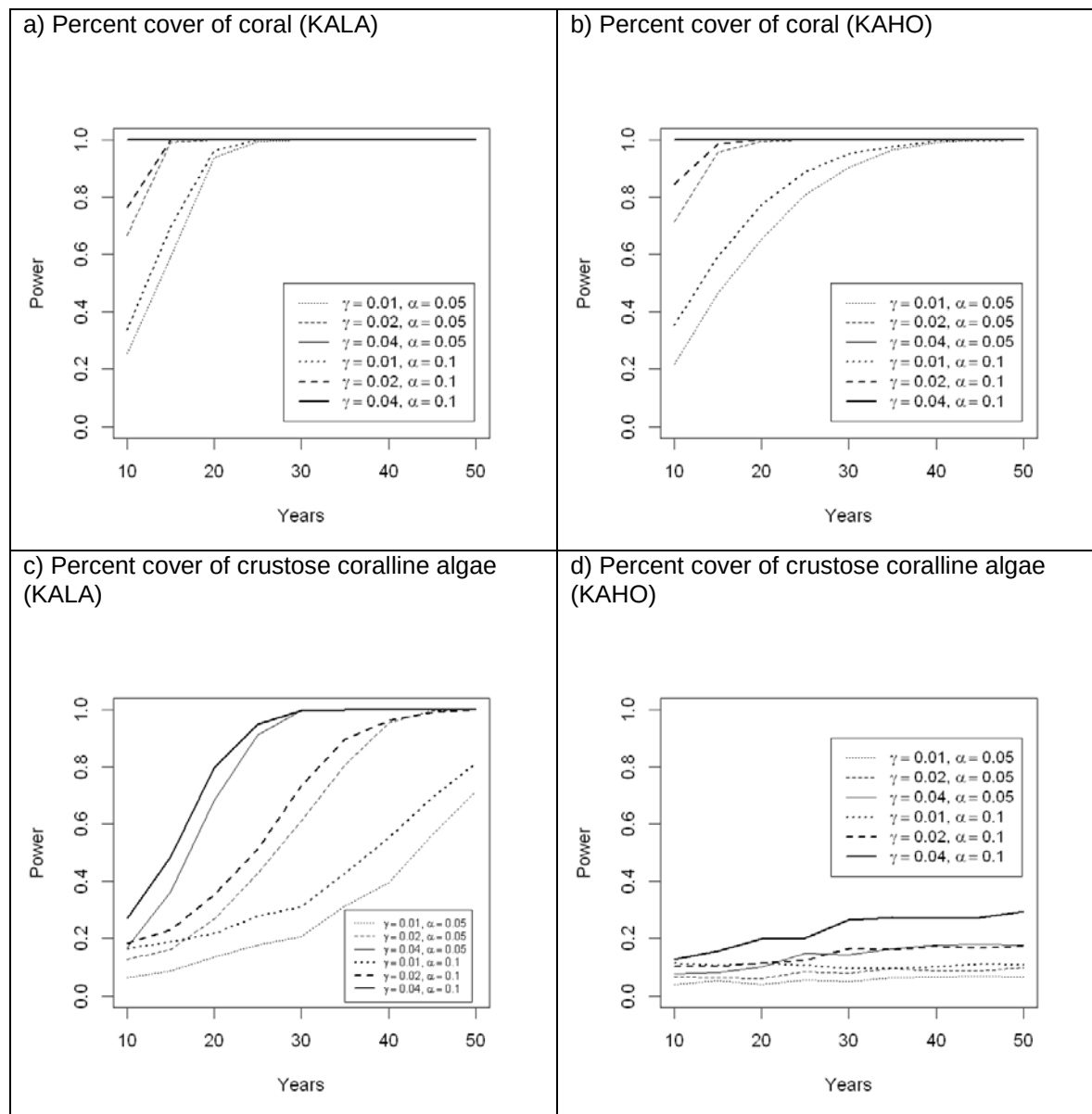


Figure 1: Power to detect trends in either direction at $\alpha = 0.10$ for an annual sample of 15 fixed sites and 15 temporary sites for three levels of change.

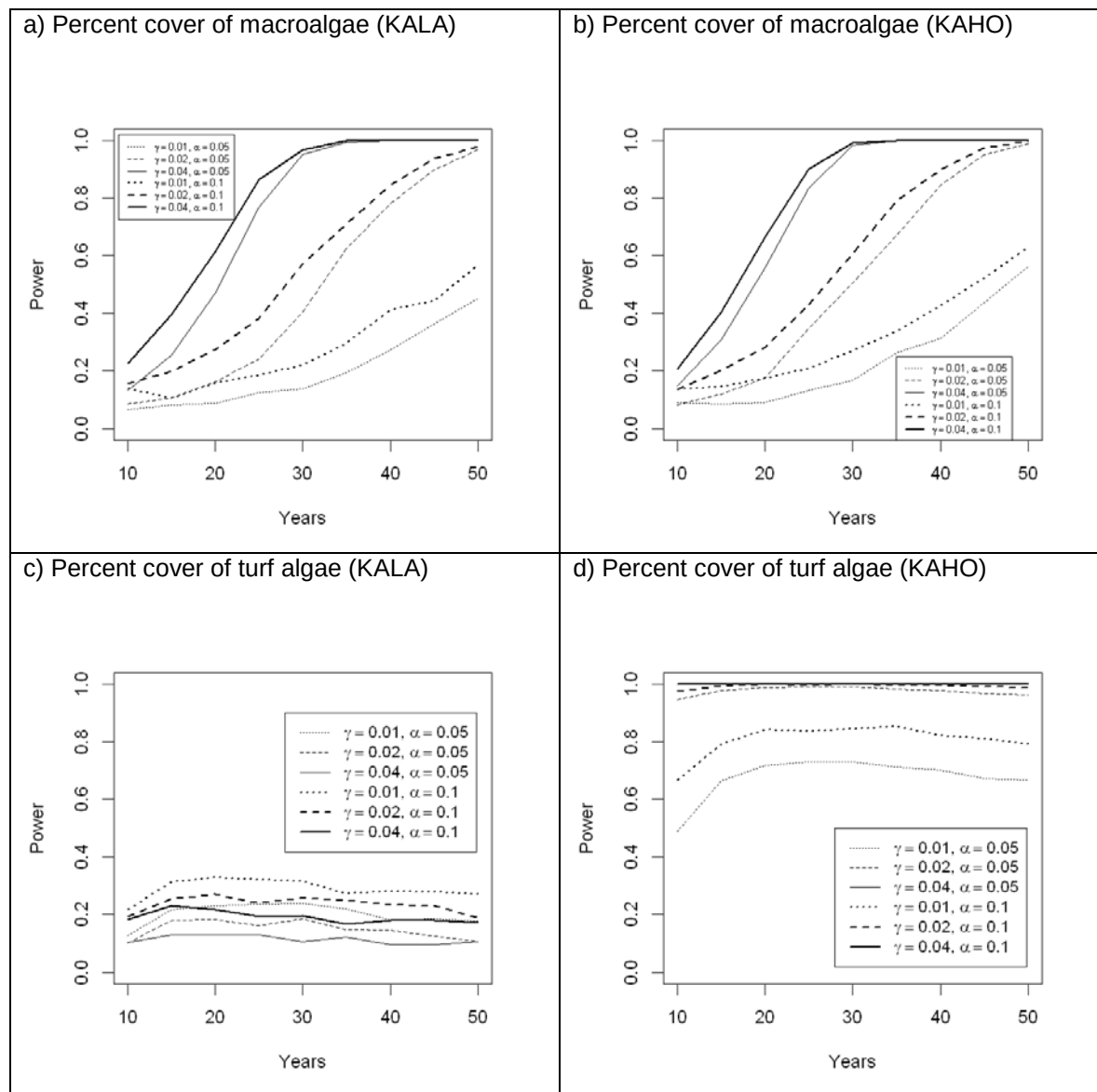


Figure 2: Power to detect trends in either direction at $\alpha = 0.10$ for an annual sample of 15 fixed sites and 15 temporary sites for three levels of change.

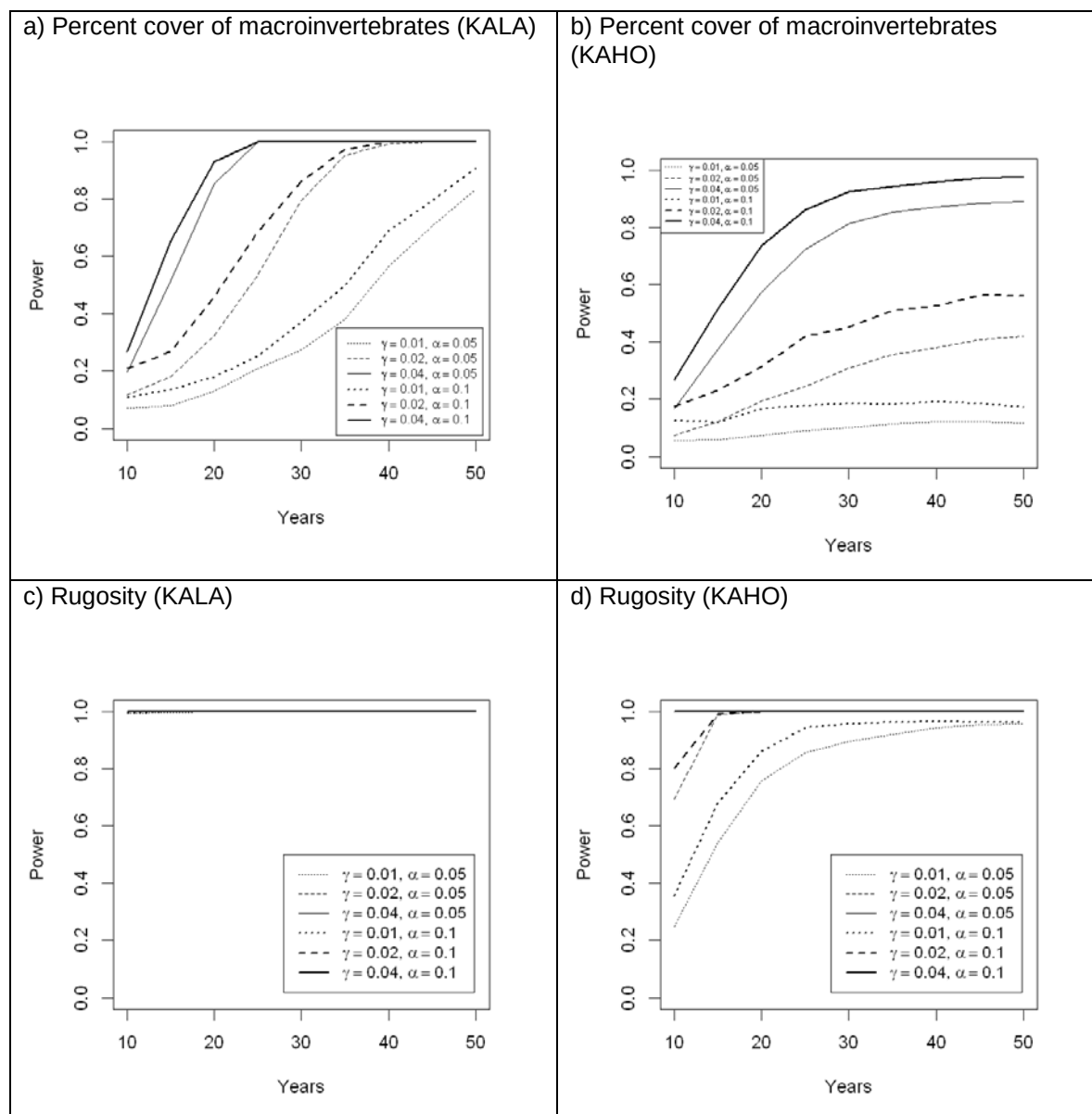


Figure 3: Power to detect trends in either direction at $\alpha = 0.10$ for an annual sample of 15 fixed sites and 15 temporary sites for three levels of change.

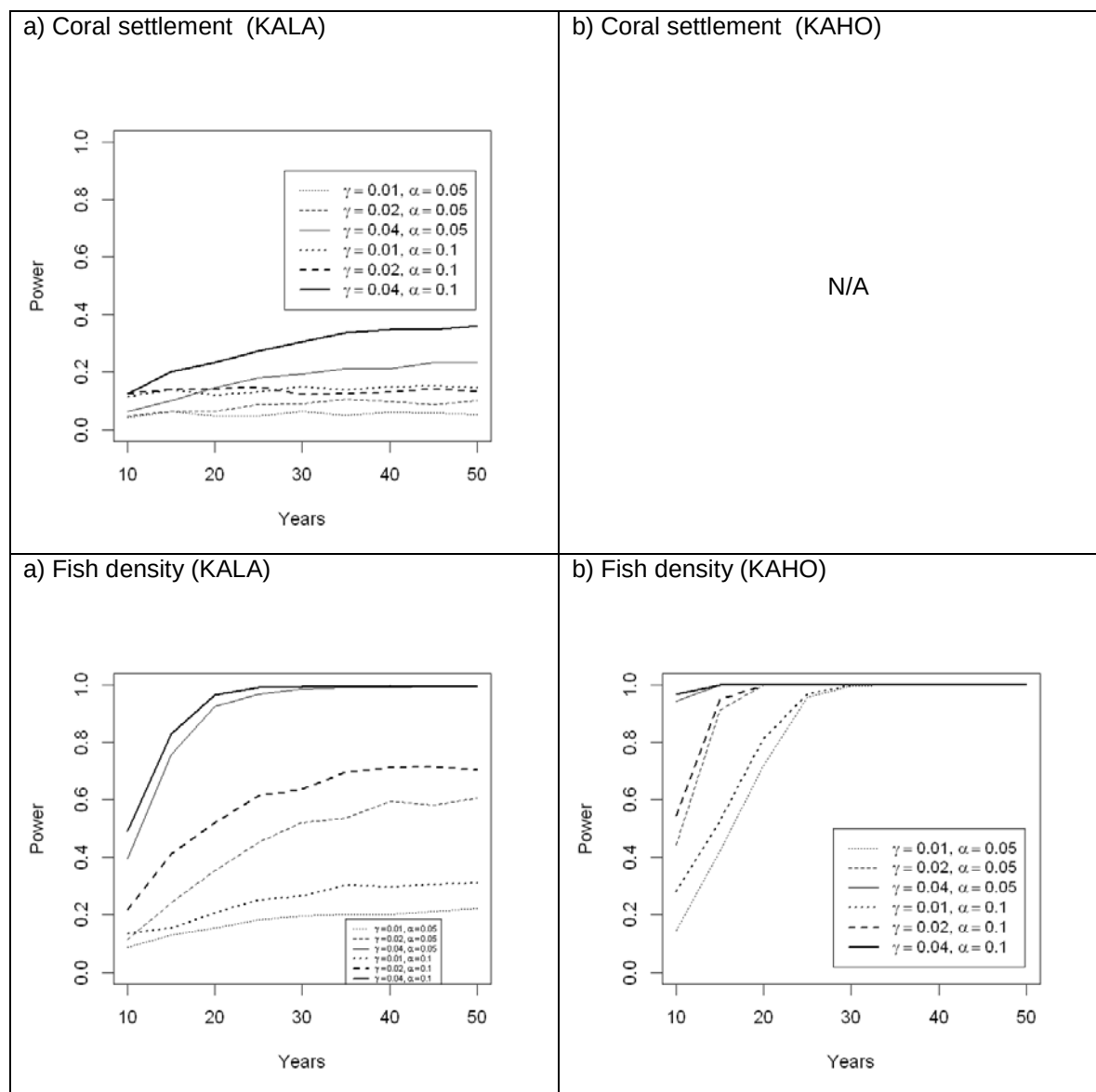


Figure 4: Power to detect trends in either direction at $\alpha = 0.10$ for an annual sample of 15 fixed sites and 15 temporary sites for three levels of change.

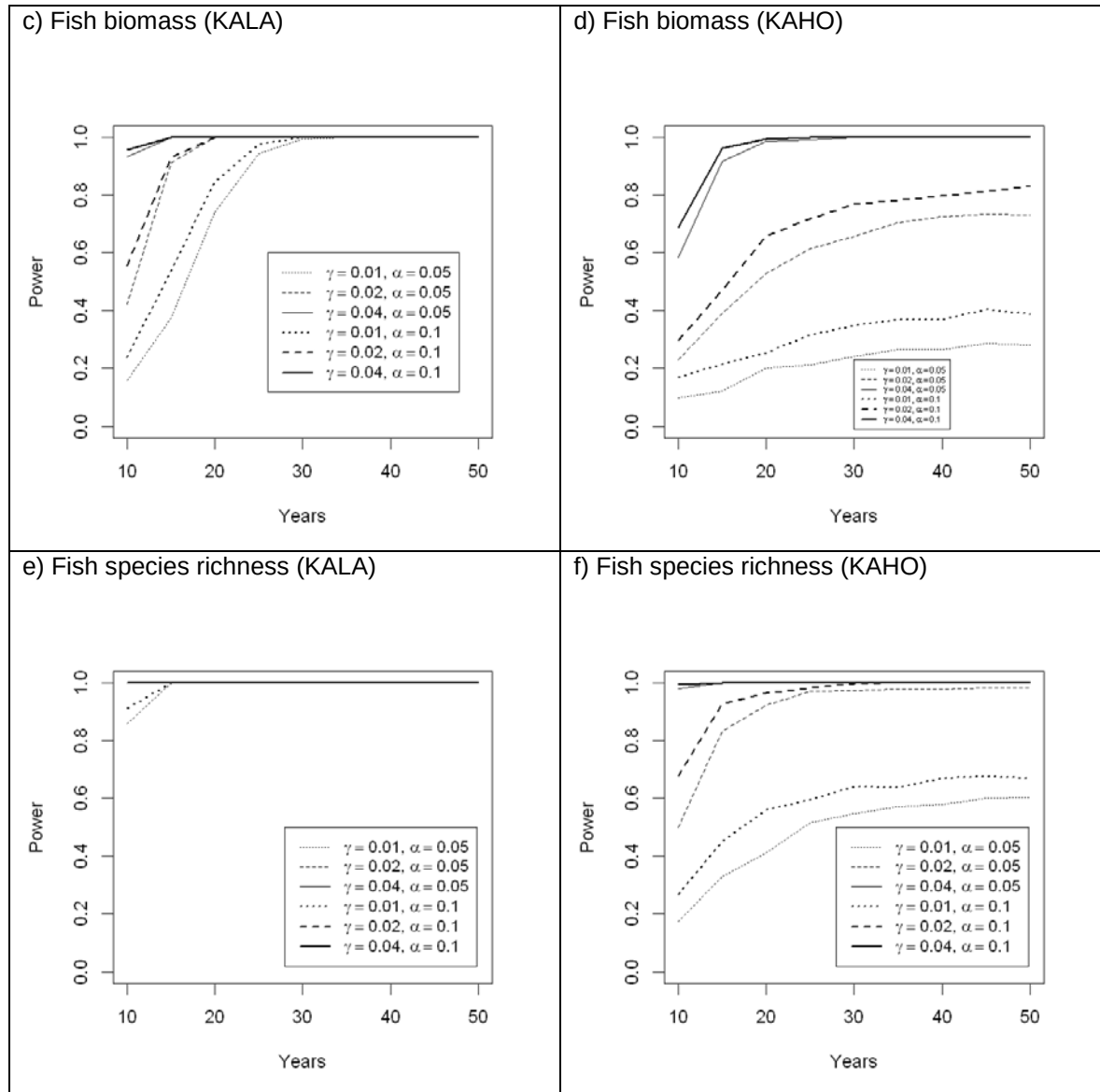


Figure 5: Power to detect trends in either direction at $\alpha = 0.10$ for an annual sample of 15 fixed sites and 15 temporary sites for three levels of change.

The power to detect trends in coralline algae in KALA (Figure 1c) is low for a small annual trend of 1%, with power just reaching 80% when testing with a Type I error rate of 0.10 after 50 consecutive survey years. Power to detect trends of 2% and 4% achieve 80% power after about 35 years and 30 years, respectively, for a Type I error rate of 0.05 and 35 years and 20 years, respectively, for a Type I error rate of 0.10. Power to detect trends in coralline algae in KAHO (Figure 1d) is uniformly low, likely due to the large year-to-year variance component estimated from the monitoring data (see Table 2). Note that increasing the sample size does not help to increase power to detect trend when the year-to-year variation is high; only consistent sampling over time can overcome this variation source (Urquhart and Kincaid 1999). Note that high site-to-site variance and variation among site-level slopes also contribute to low power to detect trend.

Trend detection of percent cover of algae in KALA (Figure 2a) and KAHO (Figure 2b) is uniformly low to detect an annual trend of 1%. At least 40 years of consistent monitoring in KALA are required to achieve 80% power to detect an annual trend of 2%, and 25 to 30 years are needed for an annual trend of 4% depending on the Type I error level. Power to detect trend in the percent cover of algae in KAHO (Figure 2b) is slightly higher, with 80% power reached in 25 years for a 4% trend and 40 years for a 2% trend. The higher power in KAHO is likely due to the lower year-to-year variation estimated in KAHO (0.2770) than in KALA (0.3510) despite the higher site-to-site variation observed in KAHO.

Recall that population declines are generated for turf algae power simulations due to the relatively large cover percentages observed for this metric. Power to detect trend in the percent cover of turf algae in KALA (Figure 2c) is uniformly low for all three trend levels, and this low power is likely due to high year-to-year variation and residual variation. Power to detect trend in turf algae in KAHO (Figure 2d) is very high for annual trends of 2% and 4%, with power to detect a 1% trend reaching 80% after about 20 consecutive survey years when a Type I error of 0.10 is used. However, the high power to detect trend results from an estimate of year-to-year variation of 0. Subsequent monitoring may result in a non-zero estimate of year-to-year variation which will lower the power to detect trend in the percent cover of KAHO turf algae.

Power to detect trends in the percent cover of macroinvertebrates in KALA (Figure 3a) is reasonable, with trends of 4%, 2%, and 1% detected with 80% power in just under 20, 30, and 50 years, respectively. Power to detect trends in the percent cover of macroinvertebrates in KAHO (Figure 3b) was approximated as lower, with only trends of 4% detected with at least 80% power in less than 50 years. The power to detect trends in rugosity in KALA (Figure 3c) is uniformly high, with power near 100% for all three trend levels achieved within 10 years of monitoring. The power to detect trends in rugosity in KAHO (Figure 3d) exceeds 80% for trends of 2% and 4% within 10 to 20 monitoring years depending on the Type I error level and for a 1% annual trend within 20 to 25 years of monitoring. The power to detect trends in coral settlement in KALA (Figure 3e) is uniformly low for all three trend levels in a 50-year monitoring period.

Trend testing for KALA fish density (Figure 4a) is uniformly low for annual trends of 1% and 2%, but 80% power may be attained within 20 years when detecting a 4% annual trend. Trend detection of fish density in KAHO (Figure 4b) and fish biomass in KALA (Figure 4c) achieves 80% for all three trend levels within 25 monitoring years. Trend testing for KAHO fish biomass

(Figure 4d) may be conducted with at least 80% power within 15 years if the trend is large (4%) and within 40 years if the trend is moderate (2%) and testing is conducted at a Type I error rate of 0.10. Trend testing of fish species richness in KALA (Figure 4e) is uniformly high for all three trends with at least 10 monitoring years. Power to detect trends of 2% and 4% in KAHO fish species richness (Figure 4f) reaches 80% in less than 15 years, but power to detect an annual trend of 1% does not attain 80% within a 50-year monitoring period.

Discussion and Conclusions

Many of the PACN marine indicators chosen for monitoring exhibit acceptable levels of power for detecting trends. Coral percent cover, rugosity, and fish species richness demonstrate the highest power to detect trend across parks. Power to detect trends in several indicators differed by park. In KALA, trends in fish biomass and species richness may be detected with power of at least 80% within 10 to 20 years. In KAHO, tests of trend in the percent cover of turf algae and fish density exhibit acceptable power. However, the year-to-year variation of KAHO turf algae cover was estimated as 0. If subsequent monitoring results in a non-zero estimate of year-to-year variation, power may be lower than is indicated in this report. These differences between parks may decrease as more years of monitoring data are developed or may reflect very different sources of variability between the two parks such as ocean conditions or differing effects of stressors.

The power analysis indicates that any of the trends in rugosity and fish species richness examined in this analysis could be detected with at least 80% power in KALA within 10 years. Moderate (2%) to large (4%) annual trends in rugosity and turf algae cover can be detected in KAHO within 10 years. These indicators may provide the basis for early detection of trends.

Future trend modeling may be improved by incorporating covariate information to explain variation and improve the precision of trend estimators. Covariates might include indicators of ocean condition, weather, or other factors that affect the outcomes monitored in this protocol. The use of appropriate data transformations help to meet the assumptions of the linear mixed model, but transformations should be chosen to adequately reflect the attributes of the data (e.g. logit transformation for proportion data, arcsine square-root transformation for very small or very large proportions). If non-constant variance is evident from residual diagnostics, a generalized linear mixed modeling approach may be an effective tool for trend estimation.

Variance composition and trend effect size greatly impact the power to detect trends. For indicators exhibiting high year-to-year variation, increasing the annual sample size of transects will not increase power for trend detection (Urquhart and Kincaid 1999). Only consistent sampling over time can mitigate this variation source, underscoring the importance of trend monitoring of marine indicators.

Literature Cited

- Brown, E., D. Minton, R. Daniel, F. Klasner, L. Basch, A. Snyder, P. Craig, G. Dicus, K. DeVerse, and T. Jones. 2011. Pacific Island Network benthic marine community monitoring protocol: Version 2.0. Natural Resource Report NPS/PACN/NRTR—2011/339. National Park Service, Fort Collins, Colorado.
- Giesbrecht, F. G., and J. C. Burns. 1985. Two-stage analysis based on a mixed model: large sample asymptotic theory and small-sample simulation results. *Biometrics* 41:477-486.
- Gerrodette, T. 1987. A power analysis for detecting trends. *Ecology* 68(5): 1364-1372.
- Heard, A.M., L.A.H. Starcevich, J.O. Sickman, D.W. Schweizer, and M.G. Rose. 2007. Sierra Nevada Network Lake Monitoring Protocol. Sierra Nevada Network. U.S. Department of Interior - National Park Service, Three Rivers, California. 71pp.
- Kenward, M.G. and J.H. Rogers. 1997. Small sample inference for fixed effects from restricted maximum likelihood. *Biometrics* 53, 983-997.
- Kuehl, R.O. 1994. Statistical Principles of Research Design and Analysis. Duxbury Press: California.
- Larsen, D.P., T.M. Kincaid, S.E. Jacobs, N.S. Urquhart. 2001. Designs for evaluation local and regional scale trends. *BioScience* 51(12): 1069-1078.
- McDonald, T.L. 2003. Review of environmental monitoring methods: survey designs. *Environmental Monitoring and Assessment* 85:277-292.
- Mosteller, F. and C. Youtz. 1961. Tables of the Freeman-Tukey transformations for the binomial and Poisson distribution. *Biometrika* 48: 433-439.
- Piepho, H.P. and J.O. Ogutu. 2002. A simple mixed model for trend analysis in wildlife populations. *Journal of Agricultural, Biological, and Environmental Statistics* 7(3): 350-360.
- Pinheiro, J.C. and D.M. Bates. 2004. Mixed-Effects Models in S and S-PLUS. Springer: New York.
- R Development Core Team. 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL <http://www.R-project.org/>.
- Ramsey, F.L. and D.W. Schafer. 1997. The Statistical Sleuth: A Course in Methods of Data Analysis. Duxbury Press: Belmont, CA.
- Satterthwaite, F.E. 1946. An approximate distribution of estimates of variance components. *Biometrics* 2: 110-114.

Sims, M., S. Wanless, M.P. Harris, P.I. Mitchell, and D.A. Elston. 2006. Evaluating the power of monitoring plot designs for detecting long-term trends in the numbers of common guillemots. *Journal of Applied Ecology* 43: 537-546.

Spilke, J., H.P. Piepho, and X. Hu. 2005. Analysis of unbalanced data by mixed linear models using the MIXED procedure of the SAS system. *Journal of Agronomy and Crop Science* 191:47-54.

Urquhart, N.S. W.S. Overton, and D.S. Birkes. 1993. Comparing sampling designs for monitoring ecological status and trends: impact of temporal patterns. *Statistics for the Environment*, V. Barnett and K.F. Turkman, eds. John Wiley and Sons Ltd.

VanLeeuwen, D.M., L.W. Murray, and N.S. Urquhart. 1996. A mixed model with both fixed and random trend components across time. *Journal of Agricultural, Biological, and Environmental Statistics* 1(4): 435-453.

Welch, B.L. 1947. The generalization of "student's" problem when several different population variances are involved. *Biometrika* 34: 28-35.

APPENDIX A: Explanation of the linear mixed model

The effect of a factor describes the change observed in a metric caused by a change in the level of that factor (Kuehl 1994). A linear mixed model incorporates both fixed effects and random effects. Fixed effects are population-level effects that do not change under repeated sampling (Pinheiro and Bates 2004). Random effects are effects associated with sampling units and may vary for repeated sampling. This variability is modeled by defining the effect as a random variable with a known distribution. The linear mixed model proposed by Piepho and Ogutu (2002) is defined as:

$$y_{ij} = \beta_0 + w_j \beta_1 + b_j + a_i + w_j t_i + e_{ij},$$

where $i=1,...,m_a$; $j=1,...,m_b$;

m_a = the number of sites in the sample;

m_b = the number of consecutive years in the sample;

y_{ij} = outcome of interest (possibly transformed),

w_j = constant representing the j^{th} year (covariate);

β_0 and β_1 = fixed intercept and slope of the linear time trend for the linear mixed model;

b_j = random effect of the j^{th} year, iid $N(0, \sigma_b^2)$, where σ_b^2 is the year-to-year variation;

a_i = random intercept of i^{th} site, iid $N(0, \sigma_a^2)$, where σ_a^2 is the site-to-site variation;

t_i = random slope of i^{th} site, iid $N(0, \sigma_t^2)$, where σ_t^2 is the variation among site-level slopes; and

e_{ij} = unexplained error, iid as $N(0, \sigma_e^2)$, where σ_e^2 is the unexplained residual variation.

Each of the random effects (b_j , a_i , t_i , and e_{ij}) is assumed to follow a normal distribution with a mean of 0 and specified variances. The expected value of each random effect is 0, so these effects do not affect the mean structure of the outcome of interest. Note further than Piepho and Ogutu (2002) model a_i and t_i as correlated where $\text{cov}(a_i, t_i) = \sigma_{at}$. Because these effects are assumed to be random variables that represent a larger population, the variance of the random effect impacts the variance of the outcome of interest. However, the definition of sources of variation can be informative and reduces the unexplained variation, which negatively impacts the power to detect trend.

For comparison, the simple linear regression model has the form of a straight line with residual error for each observation and is given by the following notation:

$$y_{ij} = \beta'_0 + \beta'_1 w_j + e'_{ij},$$

β'_0 and β'_1 = fixed intercept and slope of the linear time trend for the simple linear regression model; and

e'_{ij} = unexplained error, iid as $N(0, \sigma^2)$, where σ^2 is the unexplained residual variation.

Note that the regression parameters are augmented by prime notation to distinguish these values from the regression parameters in the linear mixed model. The mean structure is defined by the fixed effects only for both the simple linear regression model (β'_0 and β'_1) and the linear mixed model (β_0 and β_1). These parameters are not assumed to come from some larger population of effects and therefore do not affect the variance structure of the outcome of interest. For the linear mixed model, the error term is broken into a linear combination of random effects and a residual error term. The random effects correspond to components of variance for levels of factors that influence the variance structure but not the mean structure.

Previous work in trend modeling (Piepho and Ogutu 2002, Urquhart et al. 1993) has incorporated variance components for site-to-site variation (σ_a^2), variation in site-level slopes (σ_t^2), and year-to-year variation (σ_b^2). Site-to-site variation had less impact on the power to detect trend than the other components of variation. Highly-variable site-level slopes and high year-to-year variation can negatively impact the power to detect trend. Large variation in these components can be orders of magnitude smaller than the site-to-site variation and still have more impact on the power to detect trend.

Let a "group" be defined by levels of factors for which random effects are modeled (e.g. *Year*, *Transect*, or *Year-by-Transect* groups). Two primary assumptions are required for the linear mixed model (Pinheiro and Bates 2004):

1. Independent and identically-distributed errors within groups with mean 0 and a common group-level variance, which is independent of the random effects
2. Normally-distributed random effects with mean 0 and covariance matrix Ψ , where both the random effects and the covariance matrix are independent of groups

Assumption (1) is assessed with normal quantile-quantile plots and boxplots of estimated residual errors from the linear mixed model fit. Checking assumption (2) requires normal quantile-quantile plots and paired plots of the estimated random effects within groups and comparisons of fits with more general variance structures with analysis of variance. Pinheiro and Bates (2004) provide an excellent discussion of residual diagnostics for S and S-PLUS programming languages. See Appendix B for examples of how these diagnostics were translated to R programming language.

The Piepho-Ogutu (2002) model may be fit in R as follows:

```
fit<-lmer(Y ~ WYear +(1+WYear|Site) +(1|Year), data=dataset).
```

The correspondence of the R code to the terms in the linear mixed model is provided in Table A.1.

Table A.1: Correspondence of the R code to the linear mixed model terms

R code	Linear mixed model notation	Description
Y	y_{ij}	Outcome of interest
lmer	-	R function that specifies a linear mixed model will be used with REML as the default method for variance component estimation
WYear	w_j	Generates the regression coefficient corresponding to the linear trend in Y.
(1+WYear Site)	$a_i + w_j t_i$	Random site intercept effect and random site slope effect. Their covariance, σ_{at} , is generated as non-zero because the random site intercept (obtained by the 1) and the random site slope (obtained by the WYear term) are modeled jointly within levels of Site
(1 Year)	b_j	Random year intercept effect
dataset	-	The data set containing all of the variables listed
-	e_{ij}	The residual error is automatically estimated

Because the t -distribution is assumed for the regression coefficient estimates, appropriate degrees of freedom must be obtained for hypothesis testing of trend and confidence interval construction for trend estimates. When all sites are not visited every year, the data are considered unbalanced. Satterthwaite degrees of freedom are recommended for unbalanced data sets (Spilke et al. 2005). However, due to disagreement by R programming language developers regarding a one-size-fits-all approach to estimating degrees of freedom (see <https://stat.ethz.ch/pipermail/r-help/2006-May/094765.html> for more on this discussion), the degrees of freedom are not provided in *lmer* output. Spilke et al. (2005) recommend the Kenward-Rogers (1997) degrees of freedom approximation to Satterthwaite's (1946) degrees of freedom. These may be obtained from the *doBy* R package. See Appendix B for an example of how to obtain the Kenward-Rogers degrees of freedom in R.

APPENDIX B: R code for trend modeling

An example of the linear mixed modeling approach is given using the percent cover for turf algae from the *Benthic* data set (Appendix C) as the outcome of interest. Copy and paste the data set into an open R workspace. The *lme4* and *doBy* R packages will be used in this example. In R, go to the *Packages* menu and select *Install package(s)*. Then select a local CRAN mirror site and the *lme4* package. Repeat these steps (a CRAN mirror is not needed to install subsequent packages) and install the *doBy* package. Now the packages are available to load and use for analysis. Note that the package must be loaded every time an R session is opened. Load the package by entering the following command at the prompt in the R console:

```
library(lme4)
```

Data exploration

If the data are stored in a tab-delimited text file within the current working directory, the data could be read into R with the *read.table* command.

```
Benthic<-read.table("Benthic_111511.txt", header=TRUE, sep="\t")
```

Examine the names of the data columns:

```
names(Benthic)
```

Examine the first six rows of the data set

```
head(Benthic)
```

Plot the outcome of interest, KALA turf algae percent cover, by year and park (Figure B.1).

```
par(mfrow=c(2,1)) # create two plots on a page
plot(as.numeric(Benthic$Year[Benthic$Park=="KALA"]),
Benthic$TurfAlgae[Benthic$Park=="KALA"], xlab="Year", ylab="KALA Turf
Algae Pct Cover")
plot(as.numeric(Benthic$Year[Benthic$Park=="KAHO"]),
Benthic$TurfAlgae[Benthic$Park=="KAHO"], xlab="Year", ylab="KAHO Turf
Algae Pct Cover")
```

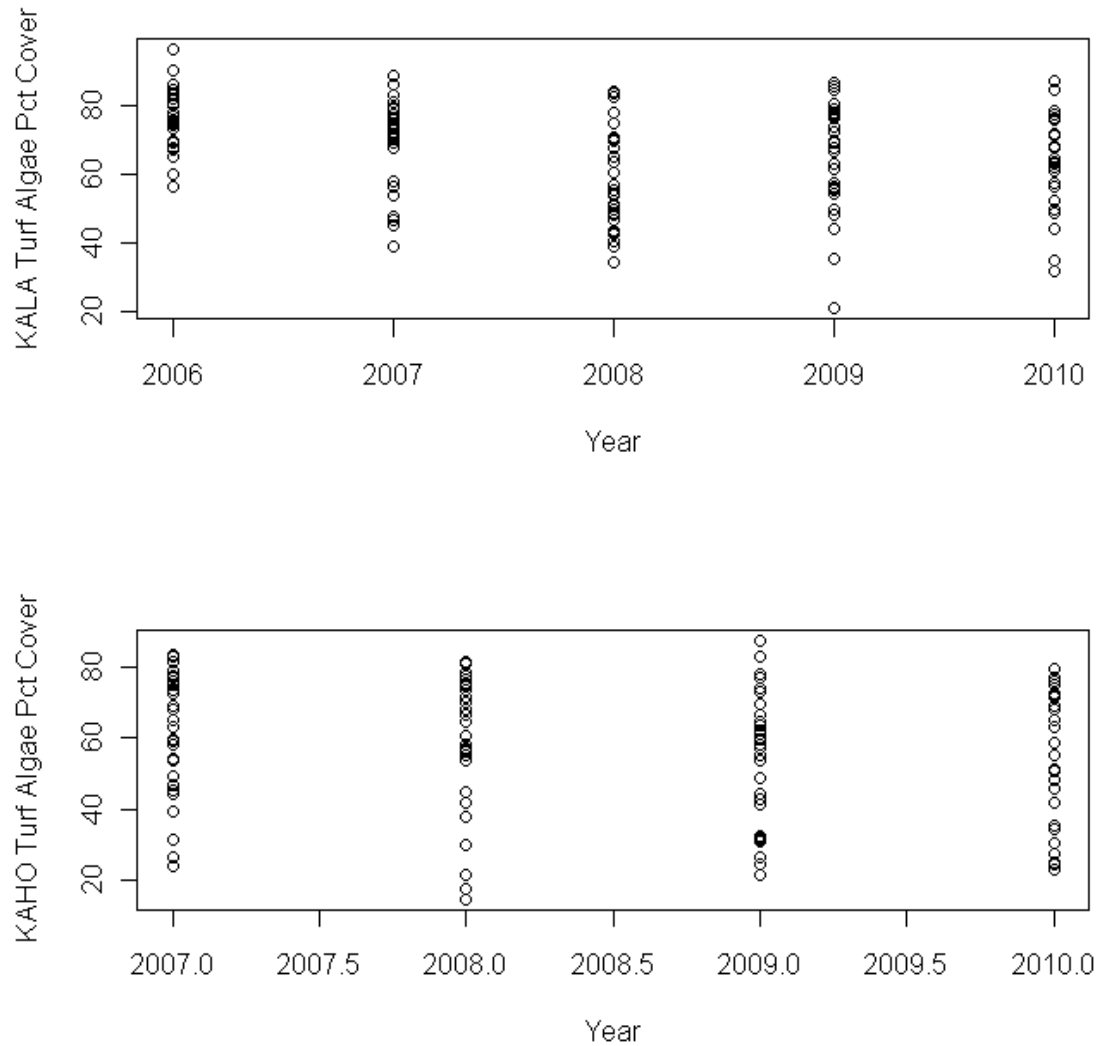


Figure B.1. Percent cover of turf algae by park and year.

Use the following steps to format the data for analysis. Create a time covariate, *WYear*, that begins at year 0. This variable will be more stable than the *Year* covariate for trend estimation.

```
range(Benthic$Year)
Benthic$WYear<-Benthic$Year-2006
```

Change the *Year* and *Transect2* covariates to factors (classification variable) for modeling random year and site effects.

```
Benthic$Year<-as.factor(Benthic$Year)
Benthic$Transect2<-as.factor(Benthic$Transect2)
```

Note the use of a second transect variable, *Transect2*. This variable renames the original transects so that unique identifiers are used. The original transect identifiers, *Transect*, are kept for comparison.

Create separate data sets for each park

```
Benthic_KALA<-Benthic[Benthic$Park=="KALA",]  
Benthic_KAHO<-Benthic[Benthic$Park=="KAHO",]
```

Trend modeling

Now the Piepho-Ogutu (2002) linear mixed model is fit to the turf algae percent cover data in KALA. Load the *lme4* library and fit the model on the outcome of interest.

```
library(lme4)  
fit1<-lmer(TurfAlgae ~ WYear + (1+WYear|Transect2) +(1|Year),  
data=Benthic_KALA)  
summary(fit1)
```

Output:

```
Formula: TurfAlgae ~ WYear + (1 + WYear | Transect2) + (1 | Year)  
Data: Benthic_KALA  
AIC   BIC logLik deviance REMLdev  
1201 1222 -593.4    1193    1187  
Random effects:  
Groups      Name      Variance Std.Dev. Corr  
Transect2 (Intercept)  50.3450  7.0954  
WYear      6.6392  2.5767  -0.191  
Year      (Intercept)  15.6338  3.9540  
Residual      101.9191 10.0955  
Number of obs: 150, groups: Transect2, 90; Year, 5  
  
Fixed effects:  
              Estimate Std. Error t value  
(Intercept)    71.590      3.552   20.156  
WYear          -3.049      1.464   -2.082
```

Examine the residuals from the linear mixed model fit by copying and pasting the following function into the R console (Figure B.2):

```
ResidDiagnostic<-function(fit) {  
  par(mfrow=c(2,2))  
  plot(fitted(fit), resid(fit))  
  qqnorm(resid(fit))  
  hist(resid(fit))}  
  
ResidDiagnostic(fit1)
```

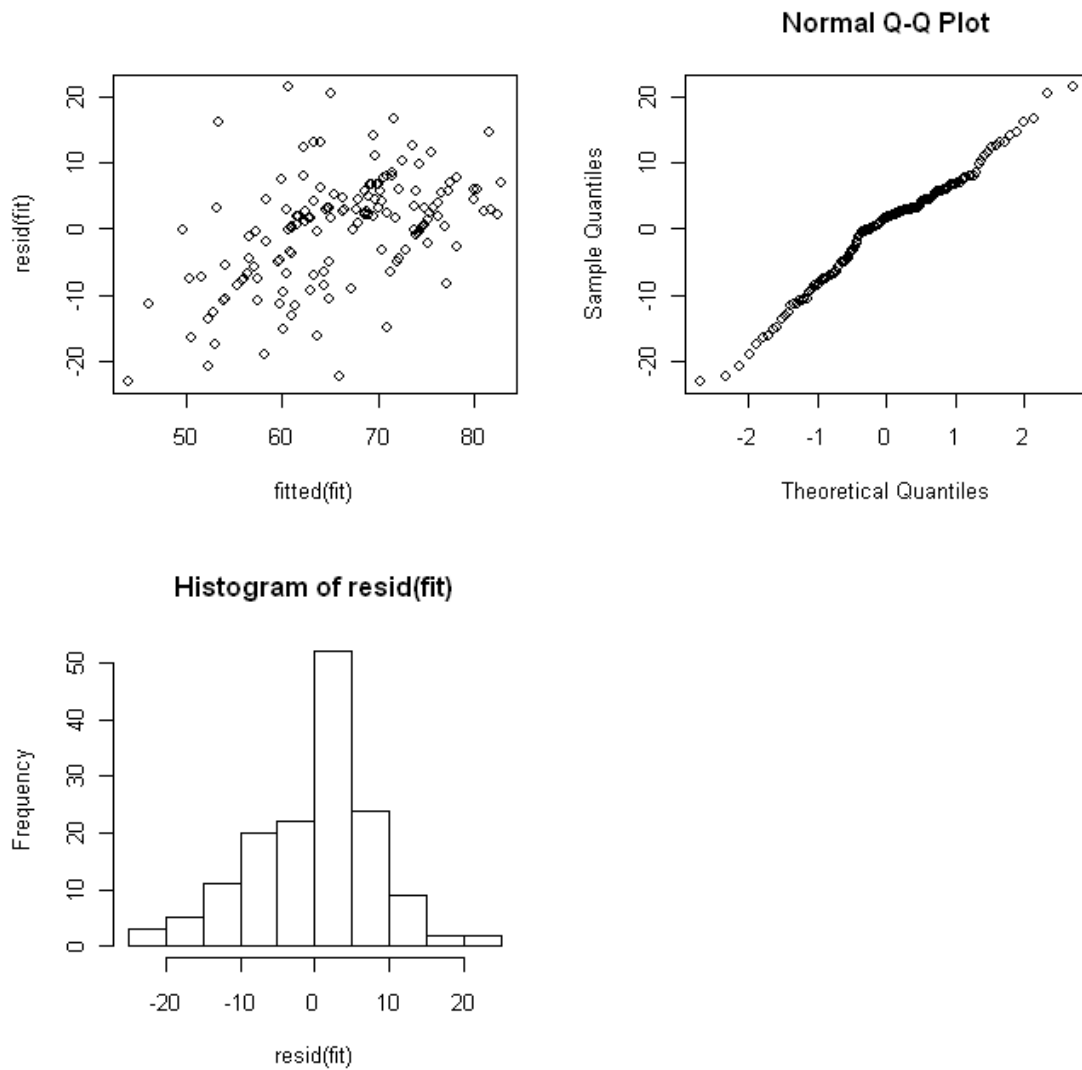


Figure B.2. Basic residual diagnostics for the trend model of turf algae percent cover.

Slight left skewness in the histogram of the residuals indicates a possible need for a data transformation. The range of the turf algae percent cover outcome is examined to determine the appropriate transformation.

```
tapply(Benthic_KALA$TurfAlgae, Benthic_KALA$Year, range)
```

Output:

```
$`2006`  
[1] 56.15385 96.07692  
  
$`2007`  
[1] 39.07692 88.38462  
  
$`2008`  
[1] 34.23077 84.07692  
  
$`2009`  
[1] 20.98386 86.31822  
  
$`2010`  
[1] 31.61538 87.15385
```

If the percent cover measurements were either less than 20% or greater than 80%, the arc-sine square-root transformation would be considered. Instead, a logit transformation, which is appropriate for proportion data greater than zero, is applied. The logit function is created and applied to the turf algae percent cover data as follows (with the arc-sine square-root transformation provided for reference):

```
arcsinsqrt<-function(x) return(asin(sqrt(x)))  
logit<-function(x) return(log(x/(1-x)))  
Benthic_KALA$LogitTurfAlgae<- arcsinsqrt((Benthic_KALA$TurfAlgae)/100)  
Benthic_KALA$LogitTurfAlgae<- logit((Benthic_KALA$TurfAlgae)/100)
```

Obtain linear mixed model fits for the arc-sine square-root and logit transformations as follows:

```
fit2<-lmer(LogitTurfAlgae ~ WYear +(1+WYear|Transect2) +(1|Year),  
data=Benthic_KALA)  
summary(fit2)
```

Output:

```
Linear mixed model fit by REML  
Formula: LogitTurfAlgae ~ WYear + (1 + WYear | Transect2) + (1 | Year)  
Data: Benthic_KALA  
AIC      BIC logLik deviance REMLdev  
301.3 322.3 -143.6    281.1    287.3  
Random effects:  
Groups      Name              Variance Std.Dev. Corr  
Transect2 (Intercept) 0.245441 0.49542  
WYear      0.023381 0.15291 -0.592  
Year       (Intercept) 0.035692 0.18892  
Residual   0.207217 0.45521  
Number of obs: 150, groups: Transect2, 90; Year, 5
```

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	0.98002	0.17624	5.561
WYear	-0.13972	0.07103	-1.967

Examine the residuals:

ResidDiagnostic(fit2)

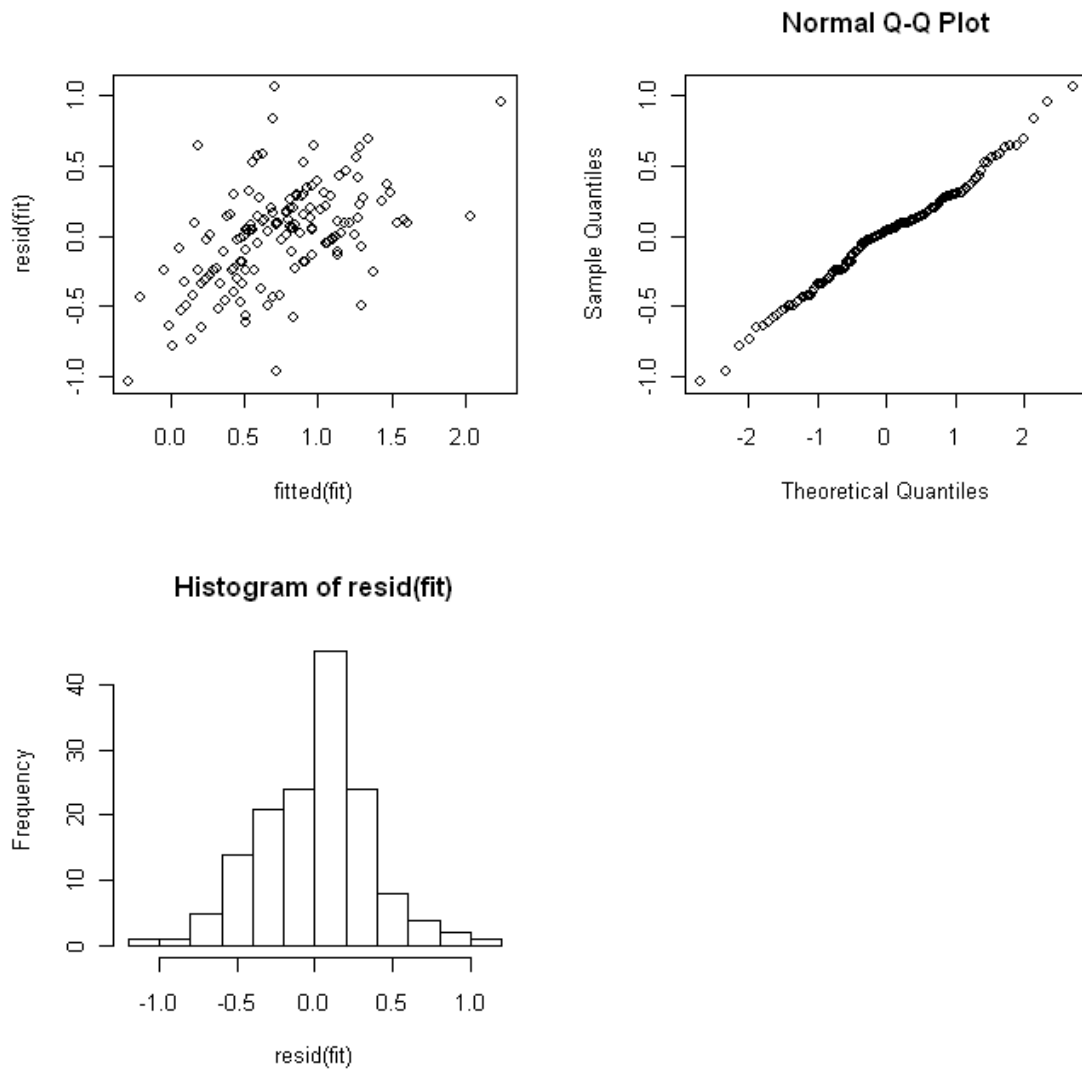


Figure B.3. Basic residual diagnostics for the trend model of logit-transformed turf algae percent cover.

Assumption checking

The left skewness observed in Figure B.2 is corrected by the logit transformation (Figure B.3). More extensive graphical residual diagnostics are used to examine the assumptions of the linear mixed model (Pinheiro and Bates 2004). Two main assumptions are addressed:

1. Independent and identically-distributed errors within groups with mean 0 and a common group-level variance, which is independent of the random effects
2. Normally-distributed random effects with mean 0 and covariance matrix Ψ , where both the random effects and the covariance matrix are independent of groups

Groups are defined by levels of variables for which random effects are modeled. To assess the first assumption, plots of residuals are examined. A quantile-quantile plot of the residuals compared to a normal distribution is used to determine if the within-group errors are approximately normally distributed. There is no within-transect replication within a given year, so we cannot examine residuals within a single transect and year. Therefore, we will examine residuals across transects within each year and across years within each transect. The quantile-quantile plots of residual errors within groups formed by years (Figure B.4) are obtained with the following code and do not demonstrate exceptional departures from normality:

```
par(mfrow=c(3,2))
for (w in 0:4) qqnorm(resid(fit2)[Benthic_KALA$WYear==w], main=
w+2005)
```

Quantile-quantile plots of residual errors within transects in the [1-0] panel are provided in sets of five for transects 1 through 15 (Figures 5 to 7). Assessing normality is difficult with only five years of data, but the general pattern is encouraging.

```
par(mfrow=c(3,2))
for (w in 1:5) qqnorm(resid(fit2)[Benthic_KALA$Transect2==w],
main=c("Transect",w))
```

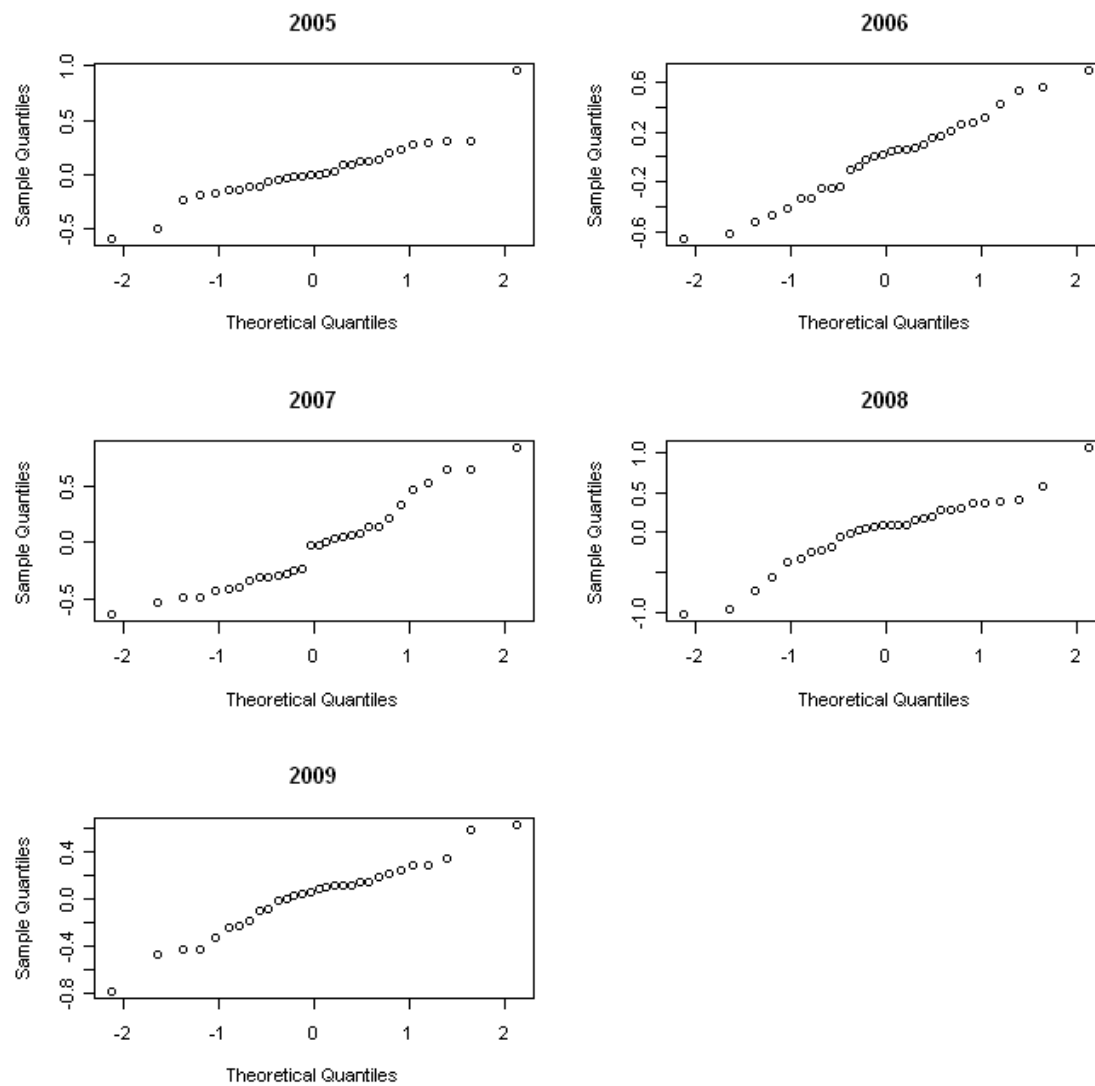


Figure B.4. Quantile-quantile plots to assess the normality of residuals within level of the Year group.

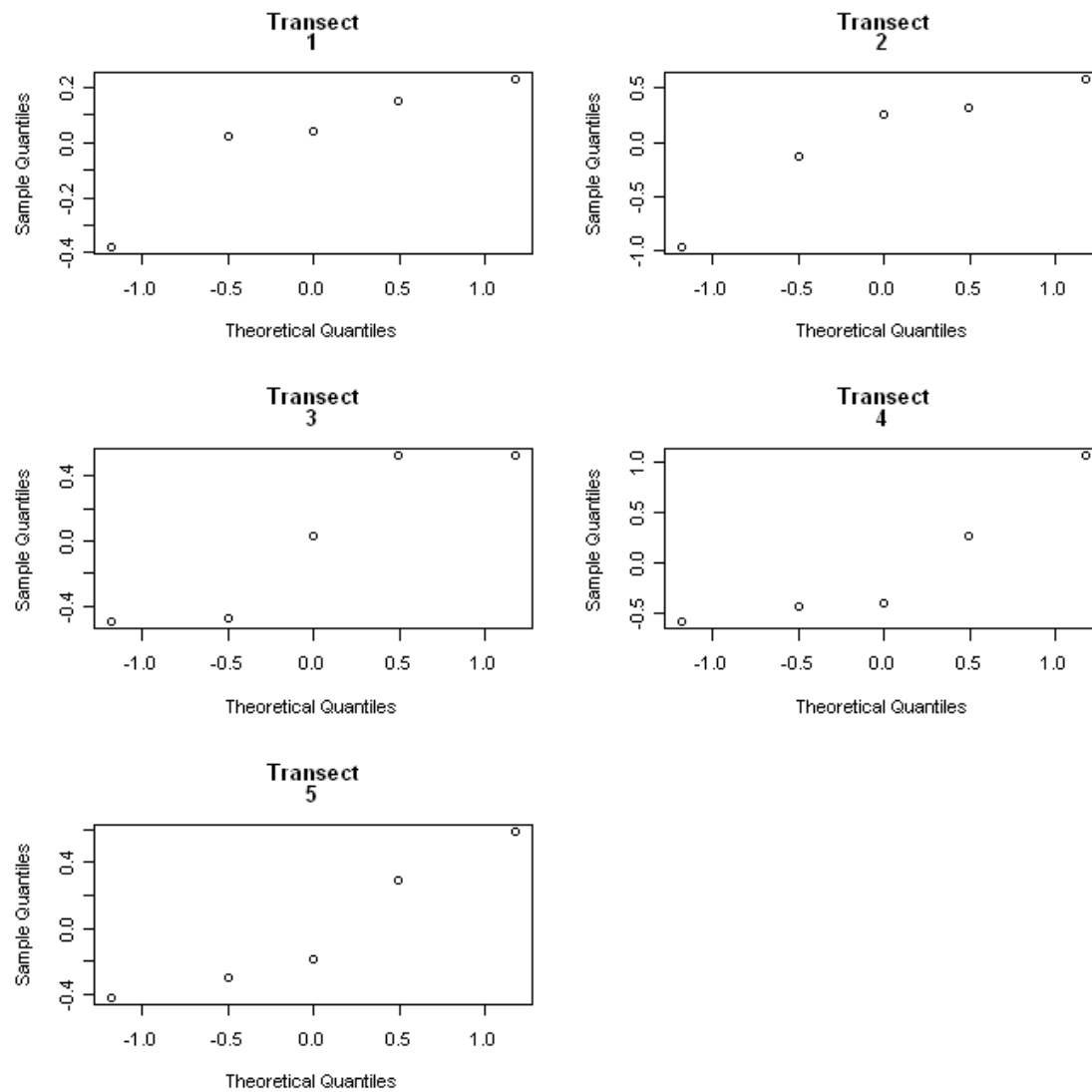


Figure B.5. Quantile-quantile plots to assess the normality of residuals within Transects 1 through 5.

```

par(mfrow=c(3,2))
for (w in 6:10) qqnorm(resid(fit2)[Benthic_KALA$Transect2==w],
main=c("Transect",w))

```

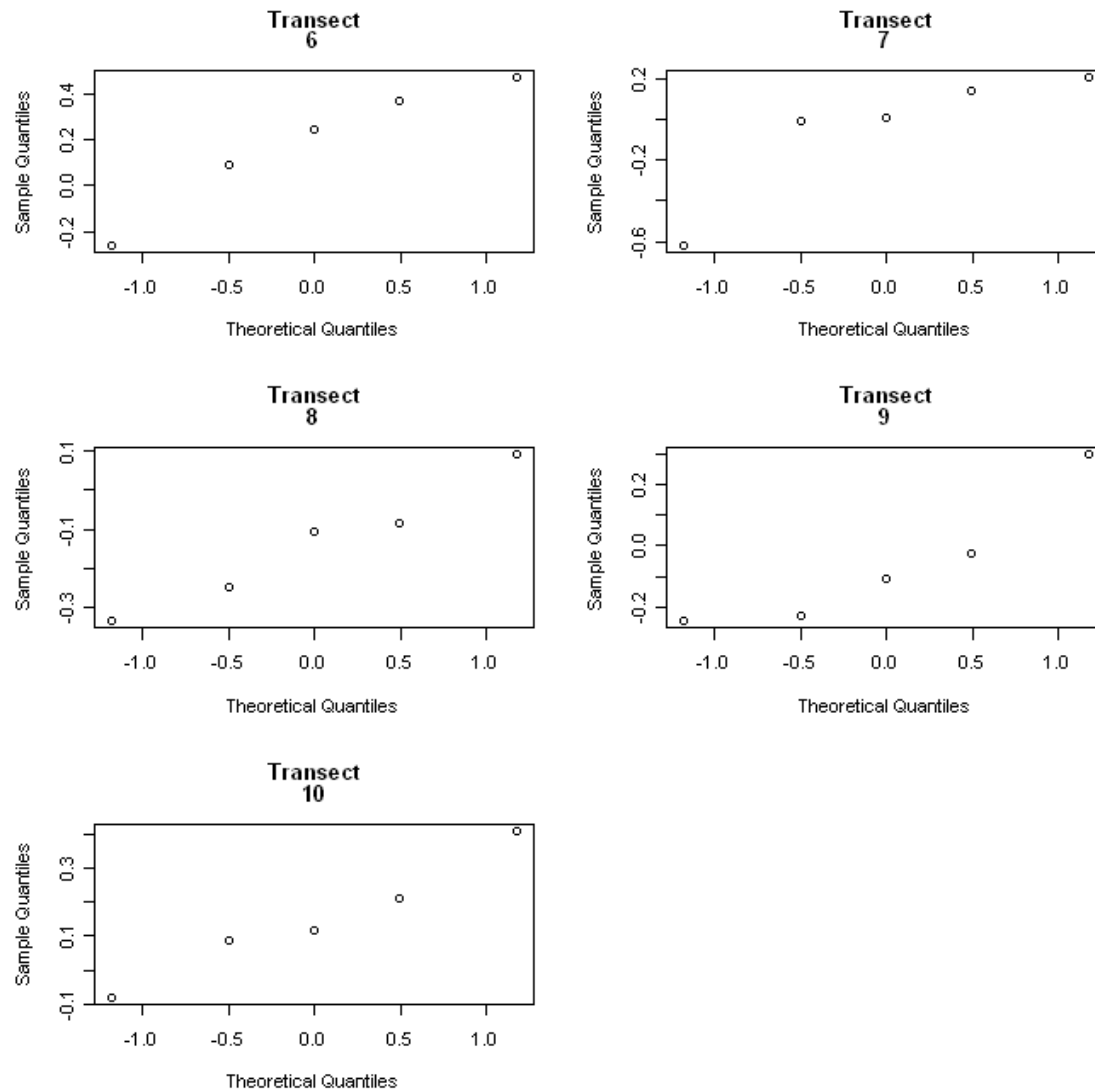


Figure B.6. Quantile-quantile plots to assess the normality of residuals within Transects 6 through 10.

```

par(mfrow=c(3,2))
for (w in 11:15)
qqnorm(resid(fit2)[Benthic_KALA$Transect2==w], main=c("Transect",w))

```

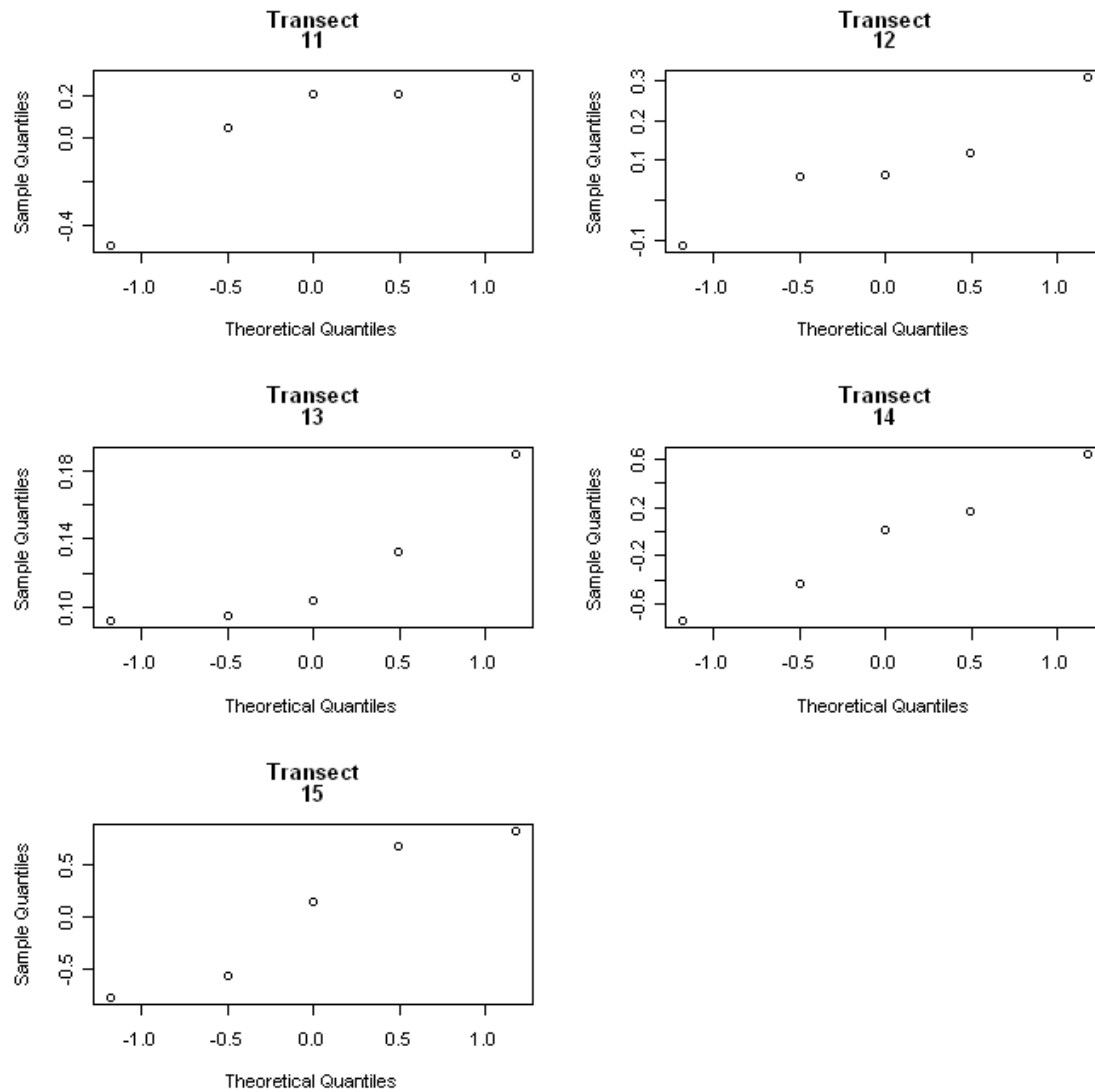


Figure B.7. Quantile-quantile plots to assess the normality of residuals within Transects 11 through 15.

Box plots of residual errors are used to assess whether or not the within-group mean of the errors is 0 with equal variance. The boxplot of residuals across transects within each year is obtained with the following code:

```
par(mfrow=c(1,1))          # one plot per page
boxplot(fit2@ resid~Year, data= Benthic_KALA, xlab="Year",
        ylab="Residuals")
abline(0,0, col=2)
```

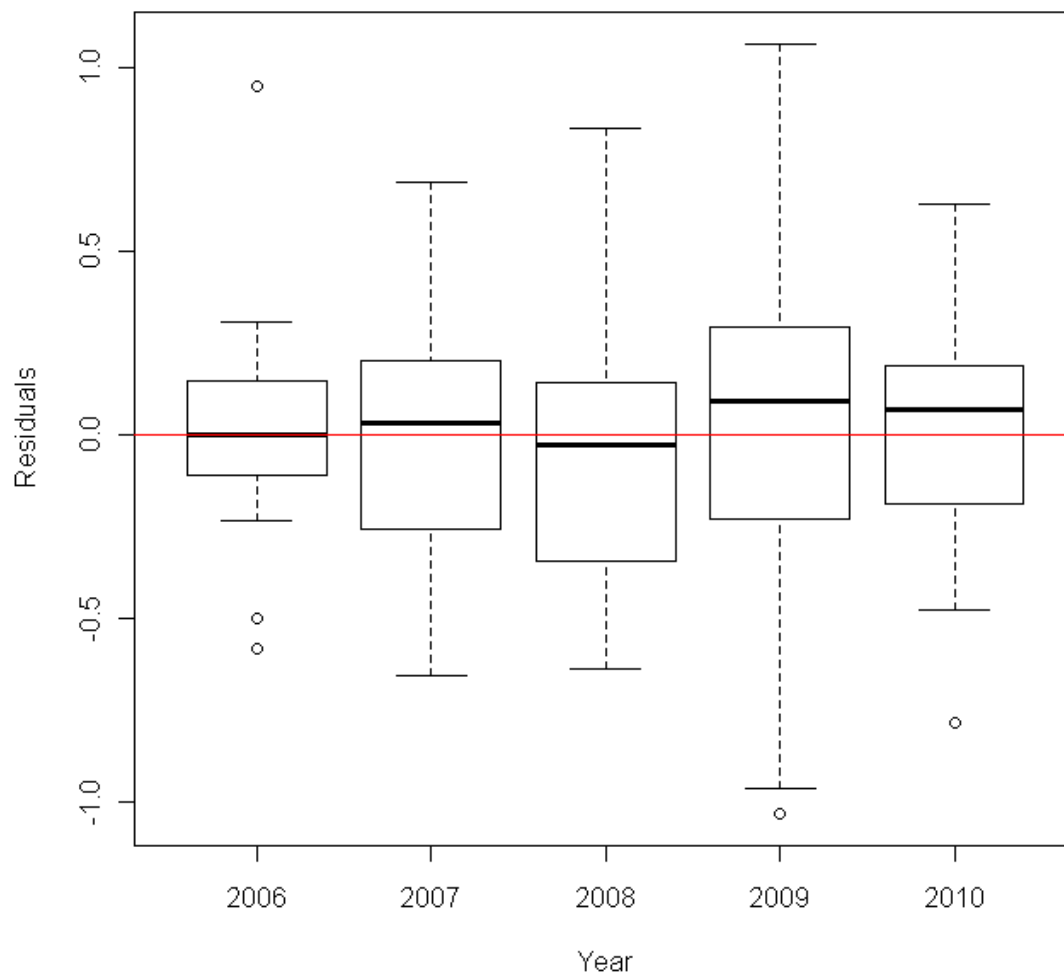


Figure B.8. Box plot of residual errors within each year.

The errors in 2009 are more variable than in other years. With only five years of data, it is difficult to determine if the variation is substantially larger than the other years. The box plot of residual errors by transect for the 15 transects with replication in the [1-0] panel (Figure B.9) is obtained as follows:

```

par(mfrow=c(1,1))          # one plot per page
boxplot(fit2@ resid~as.numeric(Transect2), data= Benthic_KALA, subset=
Benthic_KALA$Transect2%in%(1:15), xlab="Transect", ylab="Residuals")
abline(0,0, col=2)

```

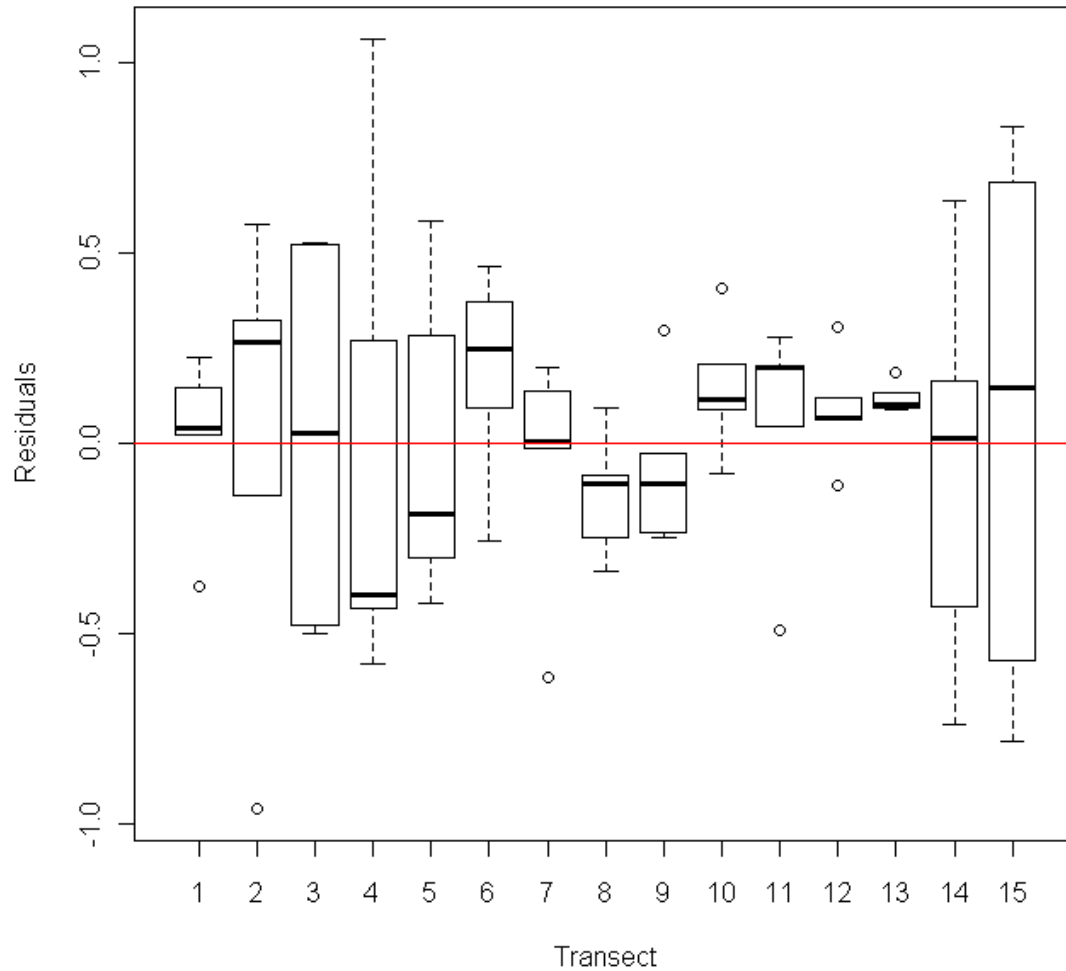


Figure B.9. Box plot of residual errors within each transect.

Figure B.9 indicates that residuals exhibit an overall mean of 0 but variation within transects is inconsistent. However, note that only 5 years of data are available for each transect. As more years of monitoring data accumulate, this assumption will be more reasonably assessed. If a similar pattern persists, it may indicate subpopulations of transects based on some transect-level covariate (e.g. depth) within which random effect may be modeled. The paucity of temporal replication at a given site does not warrant the use of a more complex model. The variance of the residual errors within each transect are examined with the following commands:

```

tapply(resid(fit2), Benthic_KALA$Transect2, var)
round(range(tapply(resid(fit2), Benthic_KALA$Transect2, var)[1:15]),4)
# 0.0016 0.5274
round(mean(tapply(resid(fit2), Benthic_KALA$Transect2, var)[1:15]),4)
#0.1707
round(quantile(tapply(resid(fit2), Benthic_KALA$Transect2, var)[1:15],
prob=seq(0,10,2)/10),4)
#    0%    20%    40%    60%    80%   100%
# 0.0016 0.0314 0.0700 0.1362 0.3014 0.5274

```

The estimated transect-to-transect variance component from `fit2` is 0.2454, which is higher than the mean of the observed within-transect variation estimates. This result suggests that the estimated transect-to-transect variance may be conservative. As more years of monitoring data accumulate, this variance component will be estimated more accurately. Site-to-site variance does not impact the power to detect trends as severely as year-to-year variation (Urquhart and Kincaid 1999), so the power analysis based on only five years of monitoring may not be greatly impacted if the transect-to-transect variance is slightly underestimated.

Now the assumptions on random effects are assessed. Quantile-quantile plots are produced for each of the random effects: the random site-level intercepts, random site-level slopes, and random year effects (Figure B.10) with the following code:

```

par(mfrow=c(2,2))      # Create a 2x2 matrix of plots
# Site effect
qqnorm(ranef(fit2)$Transect2[,1], main="Random site-intercept effects")

# Slope effect
qqnorm(ranef(fit2)$Transect2[,2], main="Random site-slope effects")

# Year effect
qqnorm(ranef(fit2)$Year[,1], main="Random year effects")

```

All three of the random effects exhibit slight but not excessive skewness. The random effects for site slope were most skewed to the left.

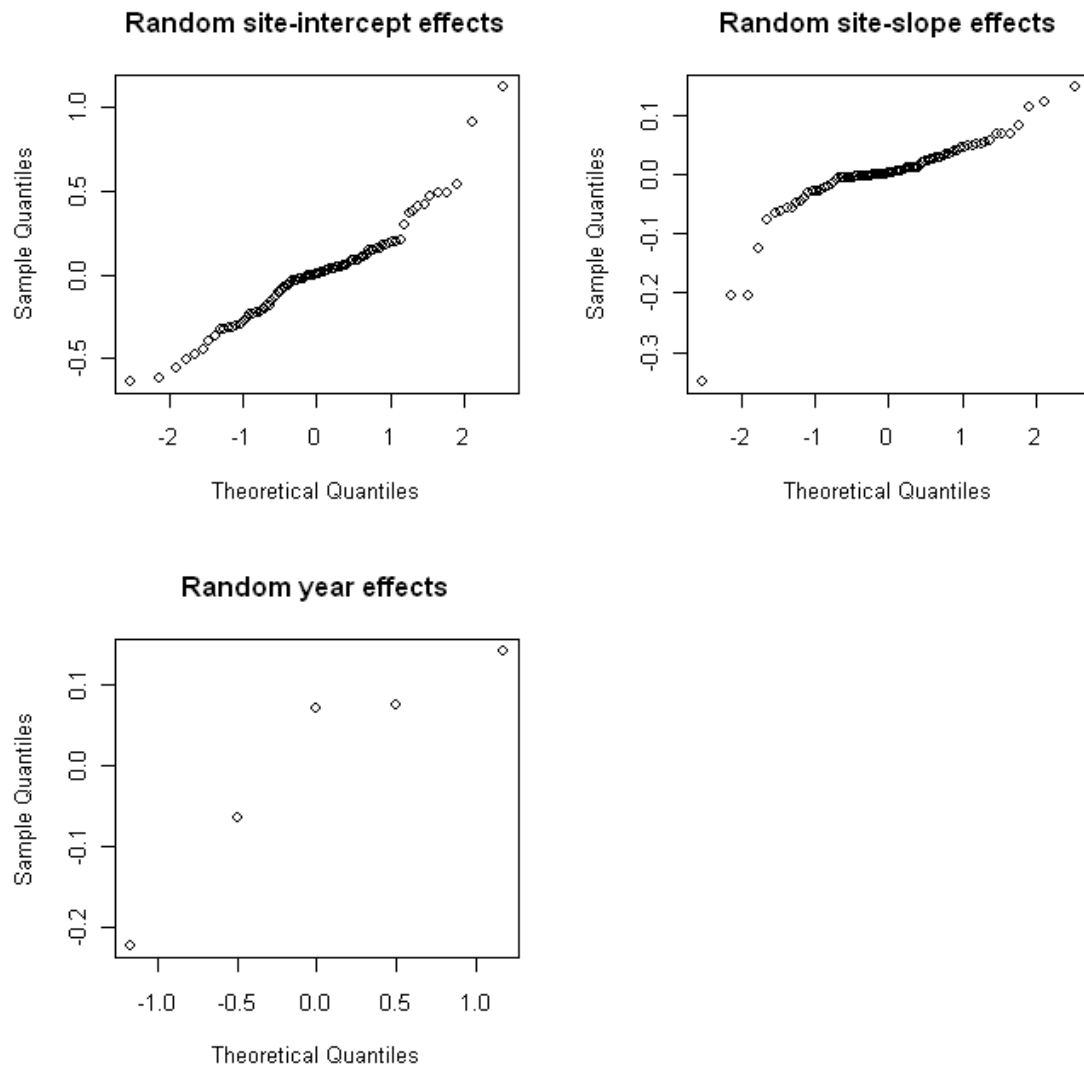


Figure B.10. Quantile-quantile plots of estimated random effects for site intercepts, site slopes, and years

The relationships among groups defining random effects are examined to assess the homogeneity of random effects groups. This assumption is assessed with paired plots of the site effects for each year. Figure B.11 is obtained with the following R code:

```
TransectByYear<-list(c(1:15, 16:30), c(1:15, 31:45), c(1:15, 46:60),
c(1:15, 61:75), c(1:15, 76:90))
TransectVec<-1:90
par(mfrow=c(3,2))          # 3 rows and 2 columns of plots
for (w in 1:5)
plot(ranef(fit2)$Transect2[TransectVec%in%TransectByYear[[w]],1],
ranef(fit2)$Transect2[TransectVec%in%TransectByYear[[w]],2],
main=w+2005,xlab=" Est. random site intercept", ylab="Est. random site
slope")
```

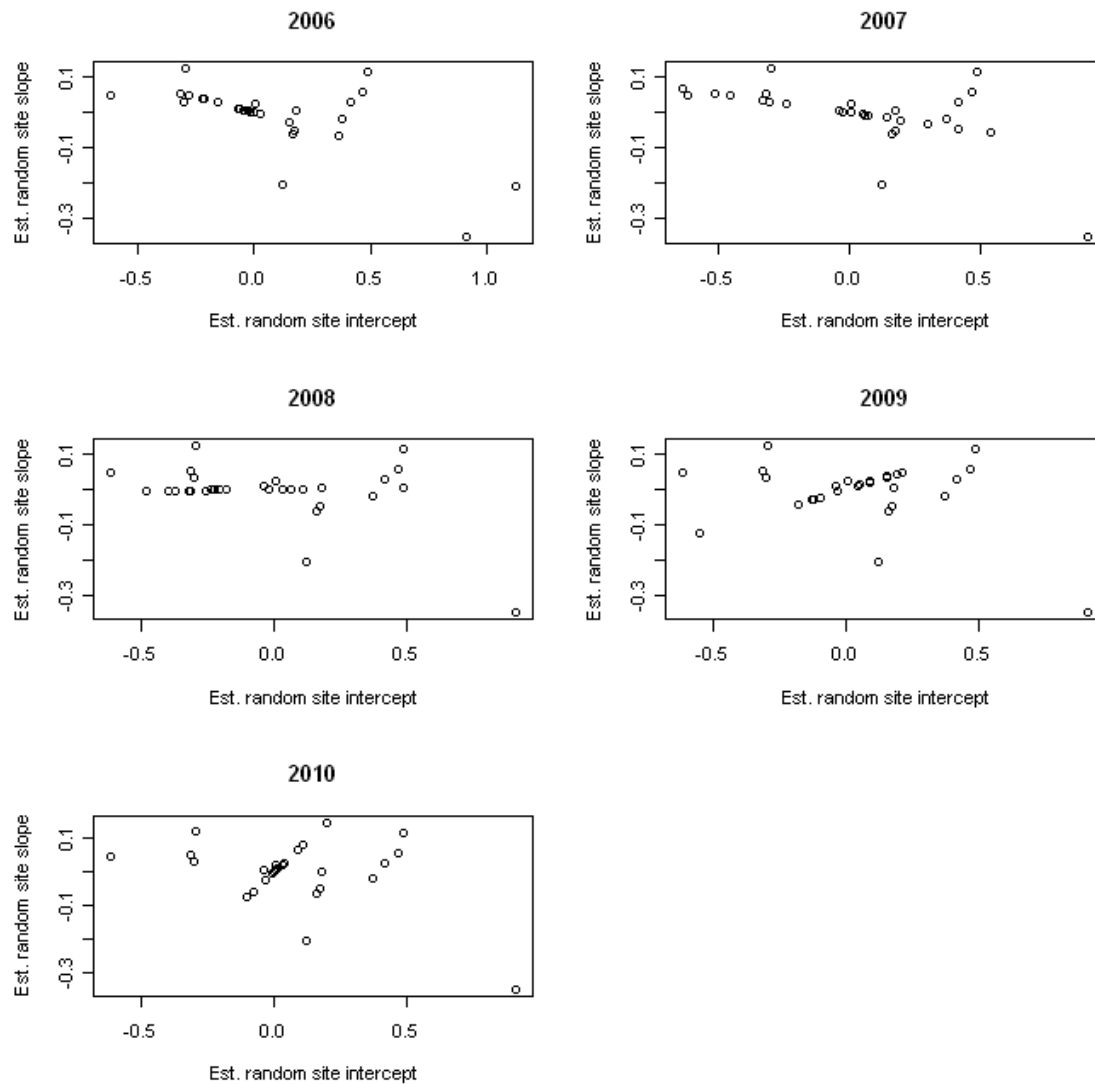


Figure B.11. Plots of estimated random effects for site intercepts versus site slopes by year

The plots of random sites slopes against random site intercepts by year (Figure B.11) represent two sets of panels. Sites from the [1-0] panel are visited every year, and the corresponding site effects do not vary with year. The sites in the [1-n] panels are estimated for only a single year and demonstrate a linear relationship. The observed linear pattern between the two sets of estimated site effects may simply be an artifact of estimation without replication. Note that similar analysis in SAS results in inestimable site effects for the [1-n] panel. Since transects are visited only once each year, replication does not exist to model the site-level effects within levels of years.

Normal quantile-quantile plots are used to assess the assumption of normality for each of the site-level effects within levels of the year effects. The site-level random intercepts appear roughly normal (Figure B.12) but the site-level random slopes exhibit left-skewness (Figure

B.13). The overall patterns are similar across years, suggesting that the assumption of homogeneity within groups is met. The plots are obtained with the following R code:

```
par(mfrow=c(3,2))
for (w in 1:5) {
  qqnorm(ranef(fit2)$Transect2[TransectVec%in%TransectByYear[[w]],1],
  main=w+2005,xlab="Est. random site intercept",)
}
```

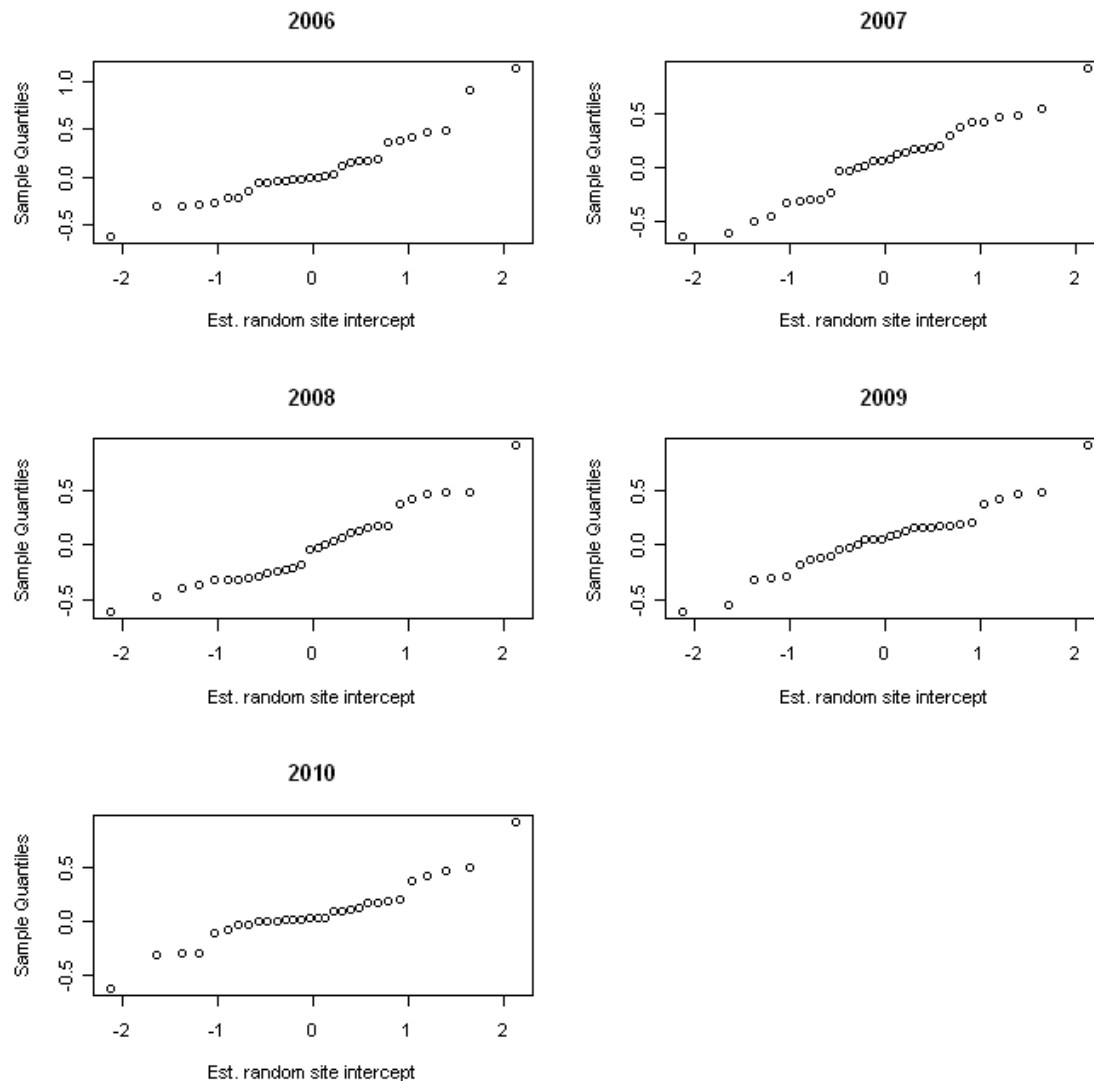


Figure B.12. Quantile-quantile plots of estimated random site intercepts by year

```
par(mfrow=c(3,2))
for (w in 1:5) {
  qqnorm(ranef(fit2)$Transect2[TransectVec%in%TransectByYear[[w]],2],
  main=w+2005,xlab="Est. random site slope",)
}
```

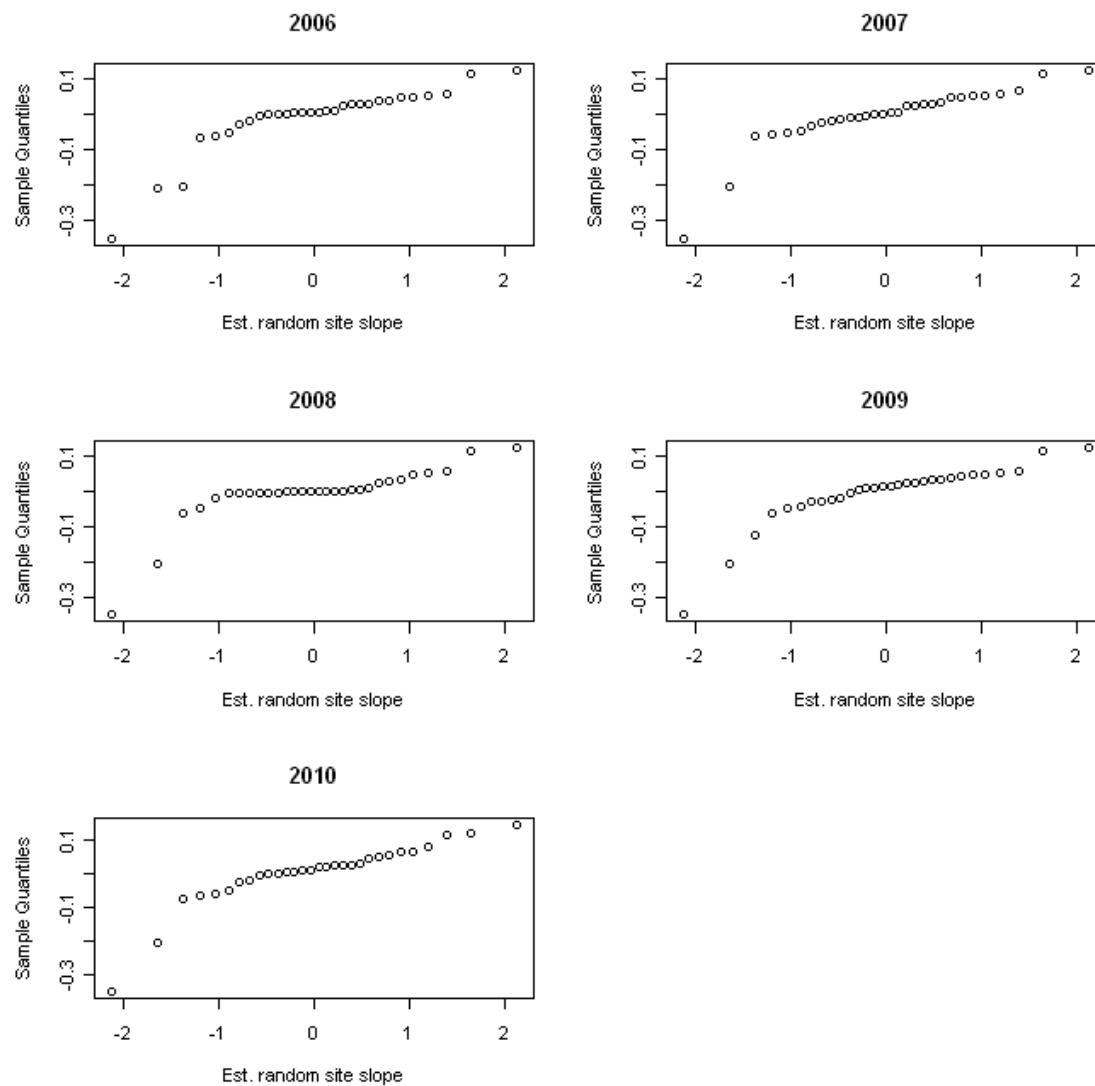


Figure B.13. Quantile-quantile plots of estimated random site slopes by year

As previously noted, the site-level random effects for the [1-0] panel do not vary by year, but the random site effects in the [1-n] panels are specific to a single year. Quantile-quantile plots for only the random site effects in the [1-0] panel (Figure B.14) are obtained with the following R code:

```

par(mfrow=c(2,1))
qqnorm(ranef(fit2)$Transect2[TransectVec%in%(1:15),1],
main="Intercept",xlab="Est. random site intercept",)
qqnorm(ranef(fit2)$Transect2[TransectVec%in%(1:15),2],
main="Slope",xlab="Est. random site slope",)

```

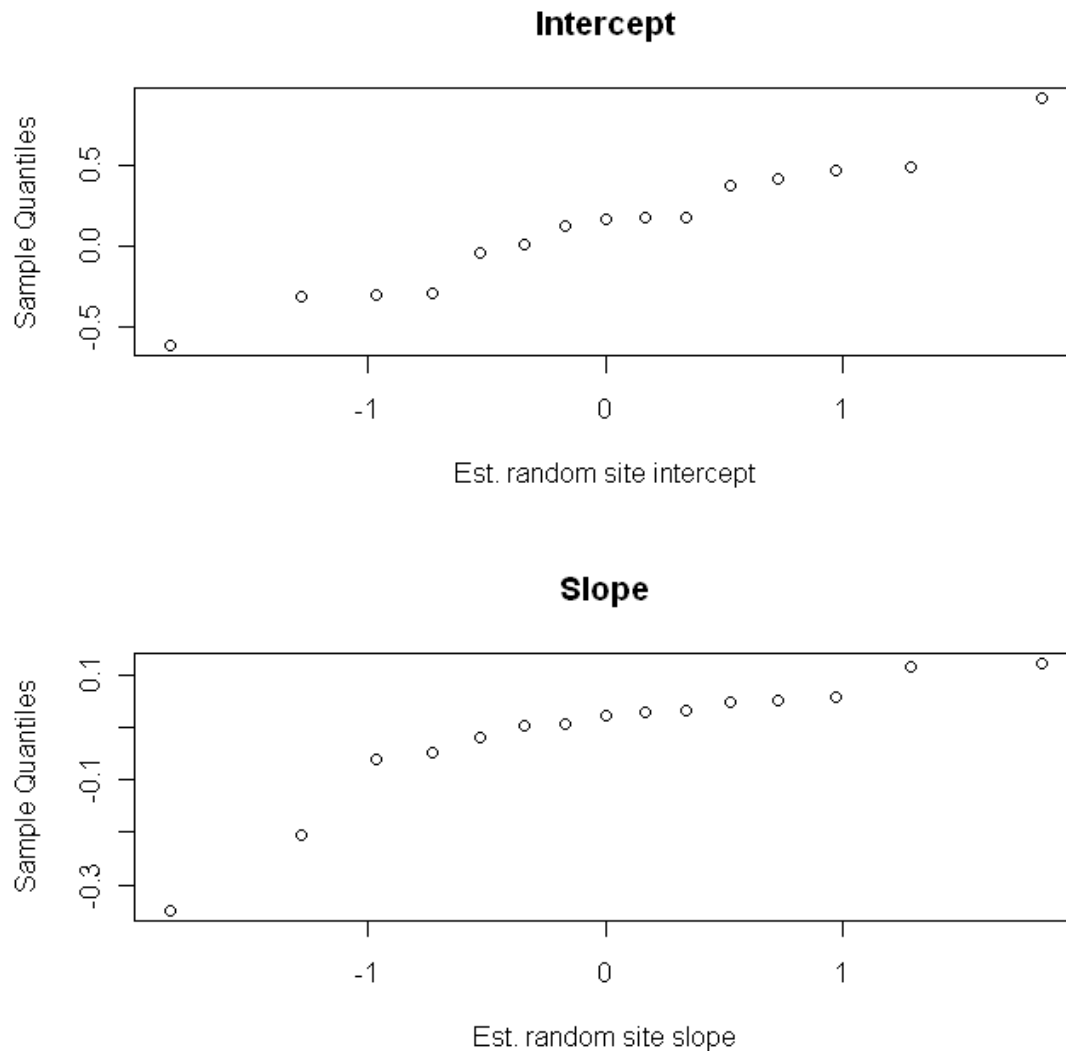


Figure B.14. Quantile-quantile plots of estimated random site intercepts and slopes for the [1-0] panel

The left-skewness in the random site-slope effects may represent a violation of the assumption of normality. Information criteria did not provide evidence for omitting the random site-slope effect or the covariance between the random site intercept and random site slope from the model. Because the hypothesis test of the random site-slope variance based on the normal distribution is significant at the 0.10 level (output from SAS: $\hat{\sigma}_t^2 = 0.0234$, SE = 0.0144, p-value = 0.0525), this random effect is retained in the trend model.

The random site intercepts and random site slopes are assumed to be correlated in the Piepho-Ogutu (2002) model, but the assumption of independence is required between each of the two site-level random effects and the random effect for year. Figures B.12 and B.13 indicate homogeneity of site-level variance components among years. The linear pattern between site-level effects may indicate that the covariance of the site effects within a given site (σ_{at}) may not be homogeneous across years. This pattern would also indicate a violation of the assumption of independence between random site effects and random year effects. However, if this pattern results solely from the lack of replication for the [1-n] panel, then the assumption of independence may be reasonable to make. Pinheiro and Bates (2004) also recommend assessing independence by generating a more general correlation structure and comparing the two models with analysis of variance. Random effects are not estimable for this fuller model without within-year replication at a site, so the model defined by *fit2* is used for the trend analysis.

Trend testing and confidence interval calculation

Both the trend test and the confidence interval of the trend estimate rely on obtaining the appropriate degrees of freedom. Approximate Satterthwaite (1946) degrees of freedom are obtained for confidence interval calculation and for the trend test (Kenward and Rogers 1997):

```
Beta<-fixef(fit2)[2]
VarBeta<-vcov(fit2)[2,2]          # Est. variance of fixed trend est.
c(Beta, VarBeta)
# -0.13972441  0.00504458
```

Fit a reduced model without the fixed effect for year, Wyear.

```
fit2.red<-lmer(LogitTurfAlgae ~ 1 +(1+WYear|Transect2) +(1|Year),
data=Benthic_KALA)
```

Load the *doBy* library to obtain the Kenward-Roger (1997) approximation to Satterthwaite's degrees of freedom.

```
library(doBy)
df<-KRmodcomp(fit2, fit2.red)
eta<-df$stats[2]
eta
# 3.77488
```

Conduct the two-sided trend test.

```
t.stat<-Beta/sqrt(VarBeta)
p.value<-2*pt(abs(t.stat), eta, lower=FALSE)
c(t.stat=t.stat, p.value =p.value)
```

The two-sided trend test indicates an inconclusive test of trend at the 0.10 level ($t = -1.9673$, $df = 3.7749$, $p = 0.1248$). The Satterthwaite degrees of freedom may also be used to obtain the appropriate critical t -value for the confidence interval on the mean as follows:

```
alpha<-0.10  
c(Beta-qt((1-alpha/2), eta)*sqrt(VarBeta), Beta+qt((1-alpha/2),  
eta)*sqrt(VarBeta))
```

The 90%-confidence interval on the estimated trend in the logit-transformed turf algae percent cover is (-0.2938, 0.0143). Therefore, the estimated trend in the log-odds ratio of the proportion of turf algae cover in KALA (-0.1397) is not significantly different from 0 at the 0.10 level.

[illegible]

[illegible]

```

42L, 43L, 44L, 45L, 1L, 2L, 3L, 4L, 5L, 6L, 7L, 8L, 9L, 10L,
11L, 12L, 13L, 14L, 15L, 46L, 47L, 48L, 49L, 50L, 51L, 52L,
53L, 54L, 55L, 56L, 57L, 58L, 59L, 60L, 1L, 2L, 3L, 4L, 5L,
6L, 7L, 8L, 9L, 10L, 11L, 12L, 13L, 14L, 15L, 61L, 62L, 63L,
64L, 65L, 66L, 67L, 68L, 69L, 70L, 71L, 72L, 73L, 74L, 75L,
1L, 2L, 3L, 4L, 5L, 6L, 7L, 8L, 9L, 10L, 11L, 12L, 13L, 14L,
15L, 16L, 17L, 18L, 19L, 20L, 21L, 22L, 23L, 24L, 25L, 26L,
27L, 28L, 29L, 30L, 1L, 2L, 3L, 4L, 5L, 6L, 7L, 8L, 9L, 10L,
11L, 12L, 13L, 14L, 15L, 31L, 32L, 33L, 34L, 35L, 36L, 37L,
38L, 39L, 40L, 41L, 42L, 43L, 44L, 45L, 1L, 2L, 3L, 4L, 5L,
6L, 7L, 8L, 9L, 10L, 11L, 12L, 13L, 14L, 15L, 46L, 47L, 48L,
49L, 50L, 51L, 52L, 53L, 54L, 55L, 56L, 57L, 58L, 59L, 60L,
1L, 2L, 3L, 4L, 5L, 6L, 7L, 8L, 9L, 10L, 11L, 12L, 13L, 14L,
15L, 61L, 62L, 63L, 64L, 65L, 66L, 67L, 68L, 69L, 70L, 71L,
72L, 73L, 74L, 75L, 1L, 2L, 3L, 4L, 5L, 6L, 7L, 8L, 9L, 10L,
11L, 12L, 13L, 14L, 15L, 76L, 77L, 78L, 79L, 80L, 81L, 82L,
83L, 84L, 85L, 86L, 87L, 88L, 89L, 90L, 1L, 2L, 3L, 4L, 5L,
6L, 7L, 8L, 9L, 10L, 11L, 12L, 13L, 14L, 15L, 16L, 17L, 18L,
19L, 20L, 21L, 22L, 23L, 24L, 25L, 26L, 27L, 28L, 29L, 30L,
1L, 2L, 3L, 4L, 5L, 6L, 7L, 8L, 9L, 10L, 11L, 12L, 13L, 14L,
15L, 31L, 32L, 33L, 34L, 35L, 36L, 37L, 38L, 39L, 40L, 41L,
42L, 43L, 44L, 45L, 1L, 2L, 3L, 4L, 5L, 6L, 7L, 8L, 9L, 10L,
11L, 12L, 13L, 14L, 15L, 16L, 17L, 18L, 19L, 20L, 21L, 22L,
23L, 24L, 25L, 26L, 27L, 28L, 29L, 30L, 1L, 2L, 3L, 4L, 5L,
6L, 7L, 8L, 9L, 10L, 11L, 12L, 13L, 14L, 15L, 31L, 32L, 33L,
34L, 35L, 36L, 37L, 38L, 39L, 40L, 41L, 42L, 43L, 44L, 45L
), .Label = c("1", "2", "3", "4", "5", "6", "7", "8", "9",
"10", "11", "12", "13", "14", "15", "16", "17", "18", "19",
"20", "21", "22", "23", "24", "25", "26", "27", "28", "29",
"30", "31", "32", "33", "34", "35", "36", "37", "38", "39",
"40", "41", "42", "43", "44", "45", "46", "47", "48", "49",
"50", "51", "52", "53", "54", "55", "56", "57", "58", "59",
"60", "61", "62", "63", "64", "65", "66", "67", "68", "69",
"70", "71", "72", "73", "74", "75", "76", "77", "78", "79",
"80", "81", "82", "83", "84", "85", "86", "87", "88", "89",
"90"), class = "factor"), X_Coord_Start = c(809970, 810276,
810649, 810770, 810836, 810775, 810732, 810822, 810900, 811314,
811500, 811539, 811385, 811267, 811242, 810005, 810402, 810368,
810670, 810835, 810713, 810685, 810783, 810812, 810725, 810884,
810976, 811095, 811179, 811276, 809970, 810276, 810649, 810770,
810836, 810775, 810732, 810822, 810900, 811314, 811500, 811539,
811385, 811267, 811242, 182130.3687, 181634.3589, 181751.7594,
182296.6801, 181926.7283, 180844.5929, 181719.9924, 182343.5257,
181002.0544, 182275.8243, 182200.6947, 182343.713, 181609.0109,
181771.8367, 181612.2204, 809970, 810276, 810649, 810770,
810836, 810775, 810732, 810822, 810900, 811314, 811500, 811539,
811385, 811267, 811242, 181602, 181622, 181691, 181651, 181617,
181685, 181701, 181672, 181726, 181769, 181889, 181929, 182295,
182281, 182074, 809970, 810276, 810649, 810770, 810836, 810775,
810732, 810822, 810900, 811314, 811500, 811539, 811385, 811267,
811242, 810150, 810733, 811315, 810999, 810806, 809849, 811496,
811207, 809996, 810609, 810855, 810245, 810994, 811489, 810749,
706010, 706258, 708983, 708894, 709266, 709377, 709481, 710816,
711136, 712308, 712922, 713052, 713059, 715830, 716364, 709056,
708877, 710320, 711820, 712068, 712211, 712235, 712616, 712739,
713007, 713154, 713495, 714244, 715376, 715452, 706010, 706258,
708983, 708894, 709266, 709377, 709481, 710816, 711136, 712308,
712922, 713052, 713059, 715830, 716364, 705818, 706243, 708987,
709475, 709586, 710071, 710073, 711814, 711815, 712042, 712046,
713142, 713514, 715909, 716680, 706010, 706258, 708983, 708894,
709266, 709377, 709481, 710816, 711136, 712308, 712922, 713052,
713059, 715830, 716364, 705033, 705851, 706212, 709070, 709502,
710135, 710344, 711587, 712088, 712302, 712590, 712710, 713167,

```

714958, 715751, 706010, 706258, 708983, 708894, 709266, 709377,
 709481, 710816, 711136, 712308, 712922, 713052, 713059, 715830,
 716364, 706883, 706919, 706933, 707233, 708890, 709013, 709500,
 710903, 711816, 712116, 713028, 713102, 715193, 715769, 716181,
 706010, 706258, 708983, 708894, 709266, 709377, 709481, 710816,
 711136, 712308, 712922, 713052, 713059, 715830, 716364, 705097,
 706218, 706438, 707253, 708974, 708957, 709406, 711154, 711841,
 712245, 712490, 712514, 713153, 713261, 715770, 529758, 529930,
 530408, 531597, 531894, 532034, 532906, 533517, 533758, 535411,
 535575, 535629, 535731, 536734, 537453, 530113, 535610, 534039,
 536723, 535639, 535525, 532302, 533030, 532190, 532031, 530942,
 531779, 529808, 534788, 530918, 529758, 529930, 530408, 531597,
 531894, 532034, 532906, 533517, 533758, 535411, 535575, 535629,
 535731, 536734, 537453, 533420, 535444, 535689, 531945, 529747,
 533359, 530787, 532726, 529790, 537030, 537136, 534671, 530991,
 533529, 529748, 254153, 253560, 252952, 252677, 252270, 251809,
 251604, 246284, 245948, 245931, 245687, 245209, 245051, 244803,
 244852, 252792, 253380, 252231, 252530, 252879, 253843, 251952,
 253245, 246323, 245792, 245852, 245779, 246135, 244688, 245479,
 254153, 253560, 252952, 252677, 252270, 251809, 251604, 246284,
 245948, 245931, 245687, 245209, 245051, 244803, 244852, 254153,
 254332, 253842, 253435, 253382, 253313, 251456, 251681, 246186,
 246241, 245917, 245859, 245642, 245352, 245585), Y_Coord_Start = c(2180012,
 2179937, 2179739, 2179652, 2179435, 2179296, 2179147, 2178695,
 2178297, 2177891, 2177631, 2177488, 2177405, 2177310, 2177163,
 2179971, 2179942, 2179906, 2179708, 2179326, 2179118, 2178930,
 2178879, 2178764, 2178604, 2178321, 2178262, 2178030, 2177961,
 2177872, 2180012, 2179937, 2179739, 2179652, 2179435, 2179296,
 2179147, 2178695, 2178297, 2177891, 2177631, 2177488, 2177405,
 2177310, 2177163, 2177985.409, 2178863.184, 2179461.562,
 2177875.279, 2178203.938, 2180182.526, 2178541.704, 2177791.415,
 2180160.982, 2177563.138, 2177907.996, 2177604.189, 2178779.021,
 2178368.671, 2179196.869, 2180012, 2179937, 2179739, 2179652,
 2179435, 2179296, 2179147, 2178695, 2178297, 2177891, 2177631,
 2177488, 2177405, 2177310, 2177163, 2179817, 2179750, 2179504,
 2179428, 2179353, 2179282, 2179086, 2178693, 2178602, 2178373,
 2178295, 2178150, 2177845, 2177547, 2177336, 2180012, 2179937,
 2179739, 2179652, 2179435, 2179296, 2179147, 2178695, 2178297,
 2177891, 2177631, 2177488, 2177405, 2177310, 2177163, 2179998,
 2179603, 2177856, 2178103, 2179530, 2180053, 2177707, 2177964,
 2179979, 2179746, 2178575, 2179974, 2178275, 2177579, 2179043,
 2344139, 2344036, 2344924, 2345511, 2346429, 2346496, 2346801,
 2347337, 2347201, 2345598, 2344752, 2344465, 2343922, 2342575,
 2342586, 2344531, 2345415, 2347352, 2346585, 2346317, 2346008,
 2345715, 2345182, 2345067, 2344447, 2344167, 2343029, 2342804,
 2342570, 2342726, 2344139, 2344036, 2344924, 2345511, 2346429,
 2346496, 2346801, 2347337, 2347201, 2345598, 2344752, 2344465,
 2343922, 2342575, 2342586, 2344101, 2344042, 2345527, 2346632,
 2346825, 2347179, 2347287, 2346650, 2346609, 2346421, 2346380,
 2344298, 2342909, 2342507, 2342155, 2344139, 2344036, 2344924,
 2345511, 2346429, 2346496, 2346801, 2347337, 2347201, 2345598,
 2344752, 2344465, 2343922, 2342575, 2342586, 2344186, 2344092,
 2344125, 2346188, 2346743, 2347282, 2347265, 2346816, 2346409,
 2345677, 2345211, 2344981, 2343737, 2342936, 2342734, 2344139,
 2344036, 2344924, 2345511, 2346429, 2346496, 2346801, 2347337,
 2347201, 2345598, 2344752, 2344465, 2343922, 2342575, 2342586,
 2343870, 2343735, 2343722, 2343701, 2345174, 2345977, 2346806,
 2347243, 2346599, 2346040, 2344364, 2343730, 2342722, 2342583,
 2342574, 2344139, 2344036, 2344924, 2345511, 2346429, 2346496,
 2346801, 2347337, 2347201, 2345598, 2344752, 2344465, 2343922,
 2342575, 2342586, 2344134, 2344173, 2343978, 2343686, 2346131,
 2346285, 2346539, 2347232, 2346540, 2345764, 2345295, 2345307,
 2343789, 2343363, 2342692, 8421724, 8422159, 8422546, 8423382,

8423508, 8424005, 8424591, 8424434, 8424999, 8426167, 8426664,
 8425213, 8426150, 8425245, 8424817, 8422270, 8426208, 8425056,
 8424962, 8425901, 8425178, 8424393, 8424534, 8424321, 8423932,
 8423222, 8423381, 8422190, 8425590, 8423042, 8421724, 8422159,
 8422546, 8423382, 8423508, 8424005, 8424591, 8424434, 8424999,
 8426167, 8426664, 8425213, 8426150, 8425245, 8424817, 8424275,
 8426696, 8425675, 8423686, 8421338, 8424821, 8422858, 8424424,
 8421916, 8424601, 8424605, 8425638, 8423350, 8424862, 8421147,
 1491706, 1491610, 1491402, 1490962, 1491173, 1491375, 1491468,
 1482892, 1482393, 1481962, 1481358, 1481014, 1480571, 1480316,
 1480024, 1491071, 1491566, 1491172, 1491064, 1491177, 1491606,
 1491281, 1491596, 1483037, 1481872, 1482566, 1482706, 1482662,
 1480070, 1481162, 1491706, 1491610, 1491402, 1490962, 1491173,
 1491375, 1491468, 1482892, 1482393, 1481962, 1481358, 1481014,
 1480571, 1480316, 1480024, 1491706, 1491770, 1491602, 1491594,
 1491556, 1491575, 1491586, 1491513, 1482999, 1482858, 1481751,
 1481589, 1481293, 1481041, 1481036), Algae = c(6.3076923077,
 21.12, 5.7692307692, 9.4980694981, 9.1538461538, 5.4615384615,
 9.0769230769, 11, 24.5384615385, 8.1538461538, 4.0769230769,
 16.1538461538, 15.8461538462, 20.3076923077, 13.3846153846,
 11.5384615385, 12.0769230769, 9.04, 6, 3.4615384615, 7.6153846154,
 7.0769230769, 24.1538461538, 18.4615384615, 17.6153846154,
 16.6923076923, 7.9230769231, 9.8461538462, 6.6923076923,
 6.6153846154, 5.3076923077, 3.3076923077, 3.2307692308, 1.4615384615,
 2.6153846154, 4.3846153846, 4, 3.3846153846, 3.5905271199,
 5, 2.7692307692, 4.9230769231, 5.5384615385, 3.1538461538,
 2, 2.4615384615, 2.9230769231, 4.9230769231, 3.0769230769,
 3, 1, 0.7692307692, 3.9230769231, 0.6153846154, 2.6153846154,
 2.9230769231, 0.9230769231, 2.5384615385, 3.1538461538, 9.2307692308,
 3.2307692308, 6.4615384615, 3.9230769231, 4.5384615385, 1.8461538462,
 2.7692307692, 3.0769230769, 1.3076923077, 2.0769230769, 0.4615384615,
 0.6923076923, 2, 6.6923076923, 8.3846153846, 5.0769230769,
 1.3076923077, 1.3076923077, 1.5384615385, 1.6153846154, 3.0769230769,
 3.8461538462, 2, 3.8461538462, 3.0769230769, 5.5384615385,
 2.6153846154, 6.6153846154, 3.0769230769, 8.6923076923, 7.6923076923,
 4.0769230769, 3.5384615385, 1.7692307692, 2.8461538462, 2.3846153846,
 4.6153846154, 4, 2.5384615385, 3.6923076923, 1.8461538462,
 1.2307692308, 2.9230769231, 5.0769230769, 5.8326937836, 13.9230769231,
 5.6153846154, 7.5384615385, 3.6153846154, 7.981580967, 4.2307692308,
 7.2307692308, 0.5384615385, 1.6923076923, 6.2307692308, 4.7692307692,
 3.2307692308, 5.6153846154, 6.3846153846, 0.7692307692, 1.9230769231,
 11.3076923077, 16.6153846154, 20.6153846154, 36.6153846154,
 4.4615384615, 4.6923076923, 4.56, 2.6923076923, 3.3076923077,
 3.7692307692, 1.7692307692, 3.6923076923, 6, 15.0769230769,
 7.8461538462, 22.5384615385, 8.3846153846, 0.9230769231,
 1.0769230769, 0.6923076923, 2.2307692308, 2.6923076923, 2.8888888889,
 1.36, 3.4615384615, 5.3076923077, 1, 11.3846153846, 18.6923076923,
 10.8461538462, 17, 17.7692307692, 12.6153846154, 19.3076923077,
 24.8461538462, 14.8461538462, 25.3846153846, 18.1538461538,
 19.6153846154, 14.6923076923, 11.7692307692, 15.5384615385,
 12.3076923077, 23.7692307692, 5.6153846154, 12.5384615385,
 9.0769230769, 23.0769230769, 14.7692307692, 15.1538461538,
 17, 21.9230769231, 27.1538461538, 16.3076923077, 16.3076923077,
 26.8461538462, 4.9230769231, 11.6153846154, 14.6153846154,
 15.3076923077, 28.6153846154, 21.8461538462, 18.9230769231,
 41.84, 32.3076923077, 6.6923076923, 20.0769230769, 20.3846153846,
 19.0769230769, 15.5384615385, 27.5384615385, 19.4615384615,
 16.3076923077, 25.7692307692, 14.56, 40.7692307692, 57.1538461538,
 47.2307692308, 15.1538461538, 15.9230769231, 18.9230769231,
 3.7692307692, 28.7692307692, 36.8461538462, 44.7692307692,
 31.7692307692, 21.8461538462, 39.1538461538, 24.6923076923,
 52.0769230769, 36.6923076923, 50.3846153846, 25.3076923077,
 6, 5.6923076923, 6.764027671, 3.1851851852, 5.3076923077,

3.7692307692, 7.1538461538, 12.1538461538, 14.0769230769,
 10.6923076923, 55.5384615385, 50.9230769231, 42.8461538462,
 40.7236335643, 27.7692307692, 31.9230769231, 13.6153846154,
 7.7692307692, 6.9230769231, 2.3846153846, 10.3846153846,
 7.5384615385, 5.6153846154, 13.9230769231, 25.5384615385,
 75.4803996925, 47.6153846154, 24, 14.3076923077, 44.8461538462,
 35.9230769231, 20.4615384615, 8.6923076923, 11.5384615385,
 14.8461538462, 19.8461538462, 14.1538461538, 14.5272867025,
 15.6923076923, 11.4615384615, 60, 65.6153846154, 24.5384615385,
 44.7692307692, 21.6923076923, 30.7692307692, 14.0769230769,
 15.2307692308, 5.8461538462, 11.6923076923, 6.2307692308,
 14.3846153846, 19.0769230769, 23.3846153846, 11.6153846154,
 4.5384615385, 48.9230769231, 20.9230769231, 9.4615384615,
 4.8461538462, 16.5384615385, 3.2, 6.8461538462, 27.36, 4.96,
 12.0769230769, 3.4615384615, 21.4615384615, 19.0769230769,
 9, 3.28, 9.12, 33.037037037, 21.2307692308, 26.3076923077,
 19.8461538462, 30.0833333333, 27.5596612779, 71.04, 80.5384615385,
 31.92, 17.7059276366, 45.5384615385, 26, 26, 26.3846153846,
 33.6153846154, 30.5384615385, 20.0769230769, 10, 16.6923076923,
 9.2307692308, 30.6923076923, 37.5384615385, 12.0740740741,
 32.4615384615, 66.0769230769, 17.4615384615, 28.4615384615,
 12.7692307692, 21.6923076923, 36.4615384615, 40.5384615385,
 44.1538461538, 15.5384615385, 20.9230769231, 33.1538461538,
 12.7692307692, 18.9230769231, 17.1538461538, 13.6923076923,
 21.7692307692, 14.2307692308, 23.5384615385, 17.2307692308,
 17.2307692308, 24.7692307692, 2.9230769231, 4, 35.7692307692,
 33.3076923077, 29.2307692308, 29.0769230769, 24.08, 43.9230769231,
 43.6923076923, 29.1538461538, 21.28, 41.6153846154, 33.6153846154,
 34.2307692308, 39.0769230769, 7.52, 23.3076923077, 39.6923076923,
 36.0769230769, 20.2307692308, 16.6153846154, 23.92, 24.6923076923,
 36.8461538462, 56.16, 28, 36.1538461538, 68.3846153846, 56.3846153846,
 40, 0.8461538462, 2.3846153846, 30.6153846154, 35.7692307692,
 12.6923076923, 27.3846153846, 26.08, 49.6923076923, 42.4615384615,
 31.6153846154, 24.7692307692, 32.6923076923, 42.5057647963,
 25.5384615385, 31.5384615385, 4.3076923077, 8.7692307692,
 5.2307692308, 14.8461538462, 16.2307692308, 23.4615384615,
 18.4615384615, 25.3846153846, 38.3846153846, 40.0769230769,
 31.7692307692, 22.3846153846, 15.2307692308, 38.1538461538,
 24.6923076923), Coral = c(24.7692307692, 10.88, 44.9230769231,
 27.722007722, 40.5384615385, 27.3846153846, 20, 8.1538461538,
 3.3076923077, 43.9230769231, 49.8461538462, 53.3076923077,
 19.9230769231, 4.4615384615, 36.2307692308, 1.9230769231,
 7.5384615385, 23.52, 17.0769230769, 32.5384615385, 7, 9.3076923077,
 15.2307692308, 10, 2, 4.9230769231, 7.7692307692, 5.3846153846,
 5.1538461538, 44.6923076923, 17, 10.0769230769, 46.6153846154,
 27.3076923077, 42.7692307692, 26.0769230769, 11.1538461538,
 6.9230769231, 5.2711993888, 48.6153846154, 49.9230769231,
 55.6923076923, 19.9230769231, 3.7692307692, 32.9230769231,
 9.6153846154, 5.1538461538, 13.0769230769, 26.3076923077,
 25.3076923077, 17.3846153846, 19.0769230769, 6.8461538462,
 21.3076923077, 6.9230769231, 18.4615384615, 6.6923076923,
 4.9230769231, 11.6923076923, 37.1538461538, 19.4615384615,
 11.3076923077, 51.0769230769, 26.5384615385, 45.0769230769,
 27.9230769231, 21.4615384615, 8.1538461538, 5, 53.1538461538,
 43, 52.8461538462, 21.0769230769, 5, 38.0769230769, 2.5384615385,
 45.6923076923, 35.9230769231, 17.3846153846, 22.1538461538,
 17.1538461538, 1.3076923077, 0.6923076923, 4.9230769231,
 11.6923076923, 7.9230769231, 18.8461538462, 40, 16, 7.4615384615,
 19.9230769231, 9.7692307692, 49.6923076923, 28.3076923077,
 44.6923076923, 29.6153846154, 23.5384615385, 9.9230769231,
 4.1538461538, 54.6153846154, 44.8461538462, 52.6923076923,
 18.1538461538, 3.5303146585, 30.9230769231, 8.4615384615,
 16.9230769231, 47.0769230769, 6.9071373753, 52.6153846154,

20.9230769231, 27.5384615385, 4.7692307692, 5.6153846154,
 13.6923076923, 10.8461538462, 21.7692307692, 16.6153846154,
 5.5384615385, 19.5384615385, 0.6153846154, 5.0769230769,
 5.3076923077, 4.6923076923, 9.8461538462, 8, 12.8, 19.2307692308,
 19, 6.7692307692, 12.0769230769, 8.0769230769, 6.9230769231,
 1.4615384615, 0.6923076923, 8.5384615385, 10.9230769231,
 17.8461538462, 15.8461538462, 17.0769230769, 16.6923076923,
 20.6153846154, 17.4074074074, 14.88, 8.5384615385, 1.8461538462,
 0.4615384615, 8.6153846154, 0.6923076923, 7.3076923077, 1,
 5.2307692308, 4.5384615385, 8.1538461538, 9.9230769231, 8.6923076923,
 25.3076923077, 25.4615384615, 16.5384615385, 3.8461538462,
 11.6923076923, 9, 5.6923076923, 1.3846153846, 1, 4.1538461538,
 3.6153846154, 7.7692307692, 9, 8.8461538462, 8.9230769231,
 20.7692307692, 21.6153846154, 24, 16.1538461538, 19.6923076923,
 5.2307692308, 3.6923076923, 0.5384615385, 3.4615384615, 0.3076923077,
 4.4615384615, 4.2307692308, 6.48, 9.5384615385, 8.2307692308,
 18.5384615385, 27.6923076923, 18.1538461538, 4.3076923077,
 15, 6.3846153846, 8, 1.3846153846, 0.64, 5.6923076923, 0.9230769231,
 1.0769230769, 16.3076923077, 19.7692307692, 11.6153846154,
 11.9230769231, 19.0769230769, 19.9230769231, 4.4615384615,
 14.9230769231, 18.6923076923, 6.5384615385, 2.2307692308,
 5.8461538462, 0.0769230769, 2.4615384615, 4.3076923077, 6.3846153846,
 7.3076923077, 3.7663335895, 23.9259259259, 23.5384615385,
 19.6923076923, 3.1538461538, 7.6923076923, 6.0769230769,
 4.6923076923, 2, 0, 0.6153846154, 0.7698229407, 0.2307692308,
 0, 5.6923076923, 9.3846153846, 19.5384615385, 18.3846153846,
 10.6923076923, 13.4615384615, 4.3076923077, 3.1538461538,
 0.3076923077, 0.7686395081, 0.3076923077, 0.3846153846, 3.6923076923,
 3.1538461538, 5.6923076923, 8.0769230769, 4.9230769231, 16.3076923077,
 22.1538461538, 15.6923076923, 3.7692307692, 6.5334358186,
 5.6153846154, 6.1538461538, 1.3846153846, 0.8461538462, 5.6923076923,
 2.7692307692, 10.8461538462, 2.0769230769, 12.6153846154,
 12.9230769231, 11.1538461538, 18.0769230769, 16.9230769231,
 7.0769230769, 4.1538461538, 7.6153846154, 7.5384615385, 3.6153846154,
 1.7692307692, 9.0769230769, 15.7692307692, 31, 39, 45.92,
 33.9230769231, 18, 55.2, 30.0769230769, 0.2307692308, 3.0769230769,
 14, 50.2307692308, 7.92, 1.36, 30.0740740741, 19.9230769231,
 13.4615384615, 29.3846153846, 28.0833333333, 33.9491916859,
 13.6, 4.4615384615, 14.8, 2.9253271747, 14.5384615385, 39.6153846154,
 3.6923076923, 24.3076923077, 17.5384615385, 15.1538461538,
 19.1538461538, 40.1538461538, 39.3846153846, 53, 34.6153846154,
 25.3076923077, 66.8888888889, 32, 1, 9.4615384615, 16.3076923077,
 53.7692307692, 12.0769230769, 4.4615384615, 25.3076923077,
 2.6923076923, 31.6153846154, 51.2307692308, 12.7692307692,
 10.2307692308, 3.2307692308, 16.8461538462, 37.6153846154,
 29, 40.9230769231, 15.9230769231, 4, 4.6923076923, 8.9230769231,
 66.1538461538, 62.3076923077, 3.6153846154, 2.9230769231,
 13, 2.4615384615, 2, 4.4615384615, 4, 5.0769230769, 3.2,
 4.4615384615, 1.8461538462, 0.3846153846, 0.8461538462, 42.96,
 13.1538461538, 2.5384615385, 3.3846153846, 3.6923076923,
 18.8461538462, 9.68, 5.9230769231, 3.2307692308, 2.48, 7.8461538462,
 4.0769230769, 7.6153846154, 2.3076923077, 1.6923076923, 80.2307692308,
 68.8461538462, 5.3076923077, 5.1538461538, 17, 3.7692307692,
 1.84, 3.6923076923, 5.3846153846, 5.4615384615, 4.1538461538,
 6.1538461538, 1.4604150653, 1.5384615385, 1.6153846154, 64.2307692308,
 49.0769230769, 64.9230769231, 19.6923076923, 14.6153846154,
 8.2307692308, 0.6153846154, 0.6153846154, 6.5384615385, 5.3846153846,
 2.2307692308, 8.5384615385, 23.2307692308, 1.6153846154,
 9.7692307692), CorallineAlgae = c(0.6153846154, 1.6, 0.4615384615,
 0.4633204633, 0.1538461538, 0.9230769231, 0.3846153846, 0.3846153846,
 0.0769230769, 1.3846153846, 0.8461538462, 0.4615384615, 0.5384615385,
 0.6153846154, 0.6923076923, 3.1538461538, 2.1538461538, 1.12,
 0.3076923077, 0.2307692308, 0.3076923077, 0.0769230769, 0.0769230769,

0.0769230769, 0, 0.3076923077, 0.6923076923, 0.4615384615,
0.0769230769, 0.5384615385, 5.6153846154, 15.6153846154,
8.6153846154, 4.7692307692, 5.5384615385, 21.3846153846,
13.4615384615, 10.0769230769, 7.1810542399, 10.3846153846,
12.1538461538, 20.9230769231, 14, 9.3846153846, 7.3846153846,
4.7692307692, 8.6923076923, 6.7692307692, 8.0769230769, 9,
2.3076923077, 8.3846153846, 6, 18.1538461538, 6.6153846154,
16.8461538462, 13.2307692308, 13, 12.7692307692, 30.6923076923,
10.2307692308, 15.6923076923, 11.0769230769, 7.5384615385,
7, 22.3846153846, 11.3076923077, 10, 10.2307692308, 10.3076923077,
5.5384615385, 13.3846153846, 6.9230769231, 7.8461538462,
6, 10.7692307692, 5.8461538462, 10.4615384615, 10.3076923077,
12, 10.8461538462, 5.0769230769, 8.3076923077, 14.4615384615,
15.3076923077, 12.5384615385, 18.6153846154, 16.9230769231,
20.1538461538, 9.7692307692, 8.3076923077, 14.5384615385,
9, 9.7692307692, 10.0769230769, 20.2307692308, 15.3076923077,
11.5384615385, 11.6153846154, 13.3076923077, 12.8461538462,
14.9230769231, 11.4615384615, 6.8303914045, 6.5384615385,
7.5384615385, 10.4615384615, 8.6153846154, 8.2885648503,
9.9230769231, 12.5384615385, 5.4615384615, 8, 10.0769230769,
8.3076923077, 7.3846153846, 5.8461538462, 8.7692307692, 2.3076923077,
1.5384615385, 1.2307692308, 2.7692307692, 4, 2, 5.3846153846,
2.3846153846, 8.56, 16.4615384615, 10.0769230769, 4.3076923077,
2.3846153846, 2, 3.1538461538, 3.3846153846, 0.4615384615,
0.5384615385, 3.3076923077, 4.9230769231, 17.7692307692,
12.5384615385, 4.6923076923, 6.5384615385, 5.5555555556,
5.52, 6.9230769231, 4.8461538462, 0.6923076923, 4.9230769231,
3.2307692308, 6.3076923077, 0.0769230769, 0.8461538462, 0.3846153846,
0.0769230769, 6.2307692308, 0.6923076923, 1.6153846154, 8.8461538462,
6.7692307692, 3.6153846154, 1.1538461538, 1.3076923077, 2.1538461538,
2.3076923077, 0.5384615385, 1.3076923077, 1.4615384615, 1.6923076923,
2, 4.0769230769, 1.4615384615, 3.6923076923, 6, 9.6923076923,
9, 14.3846153846, 1.2307692308, 3.1538461538, 1.6923076923,
4.8461538462, 0.7692307692, 1.4615384615, 1.7692307692, 0.64,
4.1538461538, 1, 3.6153846154, 9.0769230769, 7.3846153846,
1.7692307692, 1.3846153846, 2.1538461538, 0.7692307692, 1.2307692308,
0.4, 2, 0.5384615385, 1.4615384615, 1, 0.7692307692, 4.2307692308,
0.7692307692, 8.6923076923, 2.7692307692, 1.0769230769, 3.3846153846,
14.9230769231, 6.0769230769, 7.9230769231, 1.6923076923,
0.3076923077, 0.6923076923, 1.3076923077, 0.8461538462, 9.7692307692,
1.2298232129, 11.1111111111, 14.5384615385, 8.4615384615,
4, 5.4615384615, 3.5384615385, 4.0769230769, 5.0769230769,
0.2307692308, 0.5384615385, 1.3086989992, 0.5384615385, 0.9230769231,
4.0769230769, 5.7692307692, 3.7692307692, 6.7692307692, 21.5384615385,
3.4615384615, 1.6923076923, 1.7692307692, 0.5384615385, 1.8447348194,
1.1538461538, 1.2307692308, 1.5384615385, 1.8461538462, 1.3846153846,
14.0769230769, 1.6153846154, 9.0769230769, 13.4615384615,
11.6923076923, 3.6153846154, 6.3028439662, 4.6153846154,
4.1538461538, 1.2307692308, 0.3076923077, 3.6923076923, 1.3076923077,
2.8461538462, 0.6153846154, 3.7692307692, 2.9230769231, 3.5384615385,
6.0769230769, 14.7692307692, 2.0769230769, 8.6153846154,
12.6153846154, 3.7692307692, 2.2307692308, 2.6923076923,
24.6153846154, 13.4615384615, 44.4615384615, 7.1538461538,
9.28, 17.5384615385, 22.4, 13.68, 13.8461538462, 6, 22.1538461538,
32.3846153846, 39.6923076923, 86.48, 20.8, 18.1481481481,
15.5384615385, 6.7692307692, 23.2307692308, 15.25, 30.4849884527,
2.8, 4, 16.56, 6.2355658199, 12.5384615385, 8.5384615385,
18, 5, 7.3846153846, 17.3846153846, 11.7692307692, 34.2307692308,
3.7692307692, 10.3846153846, 7.7692307692, 17, 6.2962962963,
8.9230769231, 12.2307692308, 15.6923076923, 32.1538461538,
28.8461538462, 61.3076923077, 17.0769230769, 8.6153846154,
11.0769230769, 45.7692307692, 5.7692307692, 17.6923076923,
4.7692307692, 9.2307692308, 14.0769230769, 20.6153846154,

37.7692307692, 12.6153846154, 6.9230769231, 3.3846153846,
 8.5384615385, 14.2307692308, 2.1538461538, 3.4615384615,
 1.5384615385, 8.9230769231, 2.8461538462, 1.1538461538, 1.84,
 0.9230769231, 0.6153846154, 1.6153846154, 0.96, 3.6923076923,
 2.6923076923, 1.1538461538, 2.4615384615, 9.76, 3.5384615385,
 1.5384615385, 1.0769230769, 6.3076923077, 4.7692307692, 7.44,
 4.4615384615, 2.0769230769, 0.56, 8.5384615385, 4.2307692308,
 2.5384615385, 2.2307692308, 4, 3, 6.3846153846, 4.9230769231,
 13.0769230769, 3.3846153846, 3.1538461538, 3.36, 2.5384615385,
 3.5384615385, 2.7692307692, 5, 5.2307692308, 5.3036126057,
 7, 7, 5.9230769231, 4.5384615385, 2.6923076923, 3.7692307692,
 3.6923076923, 4.0769230769, 4.1538461538, 4.8461538462, 2.4615384615,
 2.8461538462, 4.3846153846, 5.1538461538, 3.8461538462, 6.2307692308,
 12.3846153846), Invert = c(2.9230769231, 12.16, 3.1538461538,
 2.3938223938, 4.6923076923, 3.1538461538, 2.6153846154, 1.6153846154,
 3.8461538462, 6.3846153846, 12.6153846154, 6.1538461538,
 5.4615384615, 1.0769230769, 3.1538461538, 7.7692307692, 5.3846153846,
 15.6, 1.9230769231, 8.6153846154, 1.2307692308, 0.0769230769,
 0.5384615385, 1.9230769231, 0.1538461538, 2.1538461538, 6.0769230769,
 1.5384615385, 6.1538461538, 21.6923076923, 0.6923076923,
 9.0769230769, 2.1538461538, 1, 3.3846153846, 2.2307692308,
 0.7692307692, 0.9230769231, 2.5210084034, 4.6153846154, 11.3076923077,
 3.6153846154, 3.4615384615, 1.6923076923, 3.3076923077, 0.3076923077,
 3.3076923077, 1.6923076923, 3.5384615385, 3.5384615385, 0.3846153846,
 1.3846153846, 0.4615384615, 2.1538461538, 0.7692307692, 2.3846153846,
 1.3846153846, 3, 4.6153846154, 1.3846153846, 0.4615384615,
 4.8461538462, 2.1538461538, 2, 2.4615384615, 2.2307692308,
 0.9230769231, 1, 3.2307692308, 3, 7.4615384615, 3.9230769231,
 3.6153846154, 1.3846153846, 2, 0, 21.3076923077, 7.3846153846,
 3.7692307692, 3.7692307692, 1.8461538462, 0.0769230769, 0.3846153846,
 1.0769230769, 3.2307692308, 2.6923076923, 12.5384615385,
 5.4615384615, 1, 1.9230769231, 1.2307692308, 5.3846153846,
 4.3846153846, 0.8461538462, 5.9230769231, 3.7692307692, 4.4615384615,
 4, 2.1538461538, 4.8461538462, 9.9230769231, 6.2307692308,
 6.3076923077, 2.2256331543, 2.4615384615, 4.1538461538, 5.8461538462,
 7.7692307692, 1.0744435917, 4.6923076923, 4.2307692308, 5.7692307692,
 3.6923076923, 0.9230769231, 1.7692307692, 1.6153846154, 7.6923076923,
 4.1538461538, 0.6153846154, 0.0769230769, 0.0769230769, 0.3076923077,
 0.1538461538, 0.1538461538, 0, 0, 0.08, 0.6923076923, 0,
 0.1538461538, 0.0769230769, 0, 0, 0.0769230769, 0.0769230769,
 0, 0.5384615385, 0.0769230769, 0.1538461538, 0.1538461538,
 0.1538461538, 0, 0.3703703704, 0, 0.4615384615, 0.1538461538,
 0, 0.1538461538, 0, 0.4615384615, 0.3076923077, 0.1538461538,
 0, 0.3076923077, 0.9230769231, 0.0769230769, 0.2307692308,
 0.7692307692, 0.6153846154, 0.2307692308, 0.2307692308, 0,
 0, 0, 0.1538461538, 0.4615384615, 0.0769230769, 0.0769230769,
 0.4615384615, 0.3846153846, 0.0769230769, 0.1538461538, 0.4615384615,
 0.3846153846, 0, 0.0769230769, 0.1538461538, 0.2307692308,
 1.1538461538, 0.3076923077, 0, 0.0769230769, 0.16, 0.1538461538,
 0, 0.9230769231, 0.1538461538, 0.0769230769, 0, 0.1538461538,
 0, 0, 0, 0.2307692308, 0, 0.0769230769, 0.0769230769,
 0, 0.0769230769, 0, 0.4615384615, 0.0769230769, 0.1538461538,
 0.0769230769, 1.0769230769, 0, 4.6153846154, 0.0769230769,
 0.0769230769, 0.2307692308, 0.0769230769, 0.0769230769, 0,
 0, 0.2222222222, 0.1538461538, 0.1538461538, 0.1538461538,
 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.1538461538, 0.3846153846,
 0.2307692308, 0, 0.0769230769, 0, 0, 0.0769230769, 0.1537279016,
 0, 0.1538461538, 0.0769230769, 0.0769230769, 0.1538461538,
 0, 0, 0.1538461538, 0.0769230769, 0.2307692308, 0, 0, 0,
 0, 0, 0, 0.5384615385, 0.2307692308, 0.2307692308, 0.1538461538,
 0.3076923077, 0.2307692308, 0.8461538462, 0, 0.3076923077,
 0, 0, 0.0769230769, 0.0769230769, 0, 0, 1.3076923077, 2.9230769231,
 0.0769230769, 0.7692307692, 0.96, 0.2307692308, 3.84, 3.44,

0.3076923077, 0.2307692308, 0.3846153846, 0.9230769231, 0.6923076923,
 0.4, 5.76, 0.7407407407, 1.6153846154, 0.4615384615, 0.1538461538,
 0.5833333333, 0, 0.48, 0.6923076923, 3.04, 0, 1.6923076923,
 0.2307692308, 7.0769230769, 0.4615384615, 0.3076923077, 0.8461538462,
 2.7692307692, 0.3846153846, 0.6153846154, 0.2307692308, 0.3846153846,
 4.3846153846, 0.6666666667, 0.1538461538, 0.1538461538, 3,
 0, 0.1538461538, 0.0769230769, 3.3846153846, 4, 5, 0, 1,
 1.3076923077, 1.6923076923, 0.0769230769, 1.6923076923, 1.1538461538,
 0, 0.1538461538, 0.2307692308, 0.8461538462, 1.3846153846,
 0.9230769231, 0.6153846154, 3.1538461538, 1.3846153846, 2.3076923077,
 0.5384615385, 0.5384615385, 0.8, 0.8461538462, 1.4615384615,
 0.6153846154, 0.56, 0, 0.9230769231, 0.2307692308, 2.4615384615,
 0.4, 0.7692307692, 0.9230769231, 1.7692307692, 4.5384615385,
 0.0769230769, 1.6, 2.2307692308, 1, 0.88, 2.1538461538, 0.6153846154,
 0.0769230769, 0.3076923077, 0.5384615385, 0.9230769231, 0.6153846154,
 0.6923076923, 3.7692307692, 2.9230769231, 1.3846153846, 1.12,
 3.1538461538, 1.6153846154, 1.2307692308, 1.5384615385, 4.0769230769,
 1.4604150653, 1.6923076923, 1.6153846154, 1.1538461538, 3.0769230769,
 1, 0.3076923077, 1.5384615385, 0.3846153846, 1.7692307692,
 2.8461538462, 1.0769230769, 0.7692307692, 0.3846153846, 0.7692307692,
 0.3846153846, 0.8461538462, 6.1538461538), Substrate = c(0.1538461538,
 0.16, 0.4615384615, 0.2316602317, 1.0769230769, 0.1538461538,
 0, 0.0769230769, 0.1538461538, 0.6923076923, 0.9230769231,
 0.0769230769, 0.1538461538, 0.2307692308, 0, 0, 0.3076923077,
 1.36, 0, 1.6923076923, 0.3846153846, 0, 0.8461538462, 0.6153846154,
 3.6153846154, 0.1538461538, 0, 0, 0.5384615385, 0.0769230769,
 1.3846153846, 1.3846153846, 1.3846153846, 8.4615384615, 4.1538461538,
 1.3076923077, 6.2307692308, 7.0769230769, 2.3682200153, 1.1538461538,
 6.3076923077, 0.0769230769, 0.5384615385, 0.8461538462, 0.6153846154,
 5.4615384615, 5.3076923077, 2, 1.1538461538, 3, 4.4615384615,
 2.2307692308, 6.3076923077, 1.1538461538, 2.2307692308, 4.3076923077,
 4.2307692308, 1.3076923077, 1.3846153846, 0.0769230769, 2.2307692308,
 2.0769230769, 0.0769230769, 4.3076923077, 2.1538461538, 0.6923076923,
 6, 5.5384615385, 1.5384615385, 0.8461538462, 10.7692307692,
 1.2307692308, 0.4615384615, 0.6153846154, 0.2307692308, 2.8461538462,
 4.3846153846, 13.5384615385, 3.4615384615, 0.6923076923,
 1.6153846154, 4.1538461538, 31.5384615385, 10, 2.2307692308,
 4.6153846154, 0.3846153846, 10.0769230769, 0.4615384615,
 0.3846153846, 1.6153846154, 3.6153846154, 1, 7.4615384615,
 1.6153846154, 0.2307692308, 1.7692307692, 6.8461538462, 1.4615384615,
 0.6153846154, 3.8461538462, 0.4615384615, 0.2307692308, 1.9186492709,
 0.3846153846, 5.5384615385, 0.5384615385, 2.5384615385, 3.6838066002,
 3.8461538462, 0, 12.5384615385, 2.6153846154, 1.2307692308,
 3.3076923077, 4.5384615385, 3.7692307692, 1.1538461538, 19.4615384615,
 2, 4.7692307692, 2.0769230769, 0.6153846154, 0.2307692308,
 0, 0, 0, 0.0769230769, 0, 0, 0.1538461538, 0, 0, 1.7692307692,
 0.6153846154, 0.9230769231, 0.3846153846, 0.7692307692, 0,
 1.6923076923, 1.5384615385, 0, 0.2222222222, 1.2, 0.2307692308,
 1.5384615385, 1.3846153846, 0.3846153846, 1.7692307692, 1.2307692308,
 10.5384615385, 1.5384615385, 1.7692307692, 1.5384615385,
 0, 0.2307692308, 0, 0, 0.4615384615, 1.9230769231, 0.6153846154,
 1, 2.3076923077, 4.4615384615, 11, 5.9230769231, 0, 0, 0,
 1.4615384615, 0, 0, 1.7692307692, 0.2307692308, 0, 2.4615384615,
 5.3846153846, 0.0769230769, 6.3846153846, 6.4615384615, 2.0769230769,
 0.3846153846, 0.16, 0, 0, 0, 0, 0.3846153846, 1.6153846154,
 1.3076923077, 0.2307692308, 2, 2.24, 0, 7.1538461538, 3.3846153846,
 0, 0, 0, 0, 0.0769230769, 0.9230769231, 0.1538461538,
 0, 0.0769230769, 0, 1.4615384615, 6.9230769231, 2.1538461538,
 2.3076923077, 1.0769230769, 0.2307692308, 1.9215987702, 0,
 0.0769230769, 0.5384615385, 0.9230769231, 1, 2.8461538462,
 2.9230769231, 1.8461538462, 0.4615384615, 1.5384615385, 2.155504234,
 2.5384615385, 4.0769230769, 0.1538461538, 0.1538461538, 0,
 0, 0.0769230769, 3.0769230769, 8.3076923077, 2.2307692308,

4.0769230769, 0.7686395081, 1, 10.6923076923, 4.0769230769,
 0.2307692308, 0.4615384615, 0, 0.3846153846, 0, 0, 0.4615384615,
 0.3846153846, 1.6910069178, 2.6923076923, 1.1538461538, 2.7692307692,
 1.6153846154, 0.8461538462, 2.2307692308, 0, 4.3076923077,
 1.2307692308, 0.4615384615, 0, 0.5384615385, 0.3076923077,
 0.5384615385, 0.6923076923, 0, 1.0769230769, 2.4615384615,
 2.4615384615, 0.0769230769, 0, 0, 2.9230769231, 2.16, 2.8461538462,
 0, 0, 0, 0.6923076923, 0.7692307692, 0, 0, 0, 0.8, 0.2222222222,
 1.2307692308, 3.4615384615, 0, 0.3333333333, 0, 0.08, 0,
 0, 3.0792917629, 2, 3.3076923077, 0, 0, 4.4615384615, 0,
 0, 0.3846153846, 7.8461538462, 2.6153846154, 1.9230769231,
 0, 0, 0, 0, 0, 0, 0.5384615385, 2.5384615385, 0,
 1.2307692308, 0.3076923077, 0.3846153846, 0.6153846154, 1.0769230769,
 0.6923076923, 0, 2.2307692308, 1.2307692308, 0.3846153846,
 0, 1, 0, 0, 1.4615384615, 0.2307692308, 0.2307692308, 1.7692307692,
 0.4, 4.3076923077, 4.1538461538, 10.3076923077, 0.4, 3.9230769231,
 0.0769230769, 12, 0.0769230769, 1.84, 0.6923076923, 2.3846153846,
 14.1538461538, 3.6153846154, 3.3846153846, 0.72, 0.2307692308,
 2.0769230769, 4.24, 2.5384615385, 8.7692307692, 1.3846153846,
 4.4615384615, 7.5384615385, 0, 0, 3.4615384615, 0.2307692308,
 0.4615384615, 2.2307692308, 0.4, 5.6153846154, 3.2307692308,
 8.6153846154, 6.9230769231, 3.9230769231, 2.2290545734, 16.2307692308,
 1.0769230769, 0, 2.2307692308, 0.0769230769, 0.9230769231,
 0, 2.1538461538, 5.4615384615, 5.3846153846, 8.5384615385,
 7.3846153846, 4.6923076923, 6.5384615385, 4.2307692308, 8,
 5.6153846154), TurfAlgae = c(65, 54.08, 45.2307692308, 59.6911196911,
 44.3846153846, 62.9230769231, 67.9230769231, 78.7692307692,
 68.0769230769, 39.4615384615, 31.6153846154, 23.8461538462,
 58.0769230769, 73.2307692308, 46.5384615385, 75.6153846154,
 72.5384615385, 49.36, 74.6923076923, 53.4615384615, 83.4615384615,
 83.4615384615, 59.1538461538, 68.9230769231, 76.6153846154,
 75.7692307692, 77.5384615385, 82.7692307692, 81.3846153846,
 26.3846153846, 70, 60.3846153846, 37.8461538462, 57, 41.5384615385,
 44.6153846154, 64.3846153846, 71.5384615385, 78.5332314744,
 30.1538461538, 17.4615384615, 14.7692307692, 56.4615384615,
 81.1538461538, 53.7692307692, 77.3846153846, 74.6153846154,
 71.5384615385, 57.8461538462, 56.1538461538, 74.4615384615,
 68.1538461538, 76.4615384615, 56.6153846154, 80.8461538462,
 55.0769230769, 73.5384615385, 75.2307692308, 66.3846153846,
 21.4615384615, 64.3846153846, 59.6153846154, 31.6153846154,
 55.0769230769, 41.4615384615, 44, 57.1538461538, 74, 77.9230769231,
 32, 32.5384615385, 26.6153846154, 61.2307692308, 76.7692307692,
 48.5384615385, 82.5384615385, 21.4615384615, 31.1538461538,
 63.4615384615, 58.3076923077, 64.6923076923, 87.3846153846,
 55.2307692308, 66.4615384615, 61.8461538462, 69.5384615385,
 43, 24.4615384615, 53.6923076923, 72.7692307692, 64.8461538462,
 63.1538461538, 34.1538461538, 50.7692307692, 35.2307692308,
 41.5384615385, 50.9230769231, 65.1538461538, 76.9230769231,
 24.7692307692, 27.3076923077, 22.7692307692, 58.7692307692,
 79.5088257866, 45.7692307692, 68.6923076923, 58.6923076923,
 30.3846153846, 71.834228703, 24.6923076923, 55.0769230769,
 48.1538461538, 79.2307692308, 75.9230769231, 68.1538461538,
 72.3846153846, 55.3076923077, 62.9230769231, 71.3076923077,
 74.9230769231, 81.9230769231, 72.9230769231, 68.9230769231,
 56.1538461538, 79.7692307692, 84.6153846154, 73.28, 59.9230769231,
 67.1538461538, 84.6153846154, 82.9230769231, 85.8461538462,
 83.6153846154, 77.8461538462, 89.8461538462, 67.0769230769,
 75.3846153846, 74.8461538462, 64.8461538462, 67.5384615385,
 74.5384615385, 69.6923076923, 73.037037037, 76.48, 80.1538461538,
 85.7692307692, 96.0769230769, 73.9230769231, 75.4615384615,
 73.3076923077, 71.0769230769, 74.4615384615, 80.6923076923,
 70.6153846154, 58.0769230769, 75.4615384615, 47.4615384615,
 46.7692307692, 56.4615384615, 77.1538461538, 73.2307692308,

73.5384615385, 78.8461538462, 70.2307692308, 88.3846153846,
70.8461538462, 79.4615384615, 67.3846153846, 74.1538461538,
71.4615384615, 70.7692307692, 53.5384615385, 45, 47.7692307692,
57.9230769231, 39.0769230769, 86.0769230769, 76, 82.8461538462,
68.8461538462, 63.5384615385, 70.1538461538, 74.6153846154,
50.72, 53.8461538462, 84.0769230769, 56.7692307692, 42.6923076923,
55.3076923077, 78, 54.3076923077, 70.6923076923, 74.6923076923,
69.6153846154, 82.16, 51.3076923077, 34.2307692308, 46.7692307692,
67.4615384615, 63.5384615385, 65.0769230769, 83.5384615385,
43, 40.3076923077, 48.6153846154, 49.6923076923, 43.4615384615,
48.1538461538, 60.5384615385, 38.7692307692, 55.9230769231,
43.8461538462, 66.6153846154, 85.5384615385, 77, 86.3182167563,
61.4814814815, 56.3076923077, 67.3846153846, 84.3076923077,
73.6923076923, 73.4615384615, 77.6153846154, 35.5384615385,
48.3846153846, 54.4615384615, 55.0423402617, 68.9230769231,
63.0769230769, 76.4615384615, 76.7692307692, 69.3076923077,
72.2307692308, 57.3076923077, 72.3846153846, 80.0769230769,
78.9230769231, 69.4615384615, 20.9838585703, 49.9230769231,
63.5384615385, 76.3076923077, 49.8461538462, 56.3846153846,
57.3846153846, 84.3846153846, 62.8461538462, 49.4615384615,
52.0769230769, 78.0769230769, 70.9454265949, 71.3846153846,
77.0769230769, 34.6153846154, 31.6153846154, 64.6923076923,
48.6923076923, 64.3846153846, 62.0769230769, 68, 67.9230769231,
78.2307692308, 63.6153846154, 61.0769230769, 75.7692307692,
67.3076923077, 56.2307692308, 75.9230769231, 87.1538461538,
44.1538461538, 43.6923076923, 58.3846153846, 19.5384615385,
33.5384615385, 38.48, 38.4615384615, 28.16, 22.56, 43.3846153846,
89.3076923077, 51.7692307692, 33.1538461538, 0.3076923077,
1.6, 62, 17.3333333333, 40.3076923077, 49.5384615385, 27.3076923077,
25.5, 7.6982294072, 12, 10.3076923077, 33.52, 70.0538876059,
23.5384615385, 22.1538461538, 45.1538461538, 43.7692307692,
36.6923076923, 36.0769230769, 46.2307692308, 14.8461538462,
31.6923076923, 24.5384615385, 24.5384615385, 15.7692307692,
14.0740740741, 26.4615384615, 20.5384615385, 54.3846153846,
23.0769230769, 4.4615384615, 4.8461538462, 38.6153846154,
21, 34.5384615385, 7.0769230769, 19.8461538462, 34.7692307692,
70.1538461538, 67.9230769231, 49.1538461538, 26.2307692308,
11.4615384615, 29.8461538462, 52.1538461538, 74.1538461538,
68.1538461538, 50.1538461538, 28.1538461538, 27.0769230769,
56.2307692308, 52.3076923077, 54.1538461538, 65, 70.88, 45.5384615385,
46.0769230769, 53.2307692308, 73.6, 46.3076923077, 60.8461538462,
52, 55.0769230769, 37.52, 58.5384615385, 52.9230769231, 43.5384615385,
61.6153846154, 56.3076923077, 56.64, 62.4615384615, 54.7692307692,
35.68, 50.9230769231, 46.1538461538, 20, 34.3076923077, 46.2307692308,
15, 21.7692307692, 55, 42, 63.5384615385, 62.0769230769,
67.2, 35.3076923077, 43.7692307692, 50.3076923077, 57.6153846154,
47.9230769231, 47.0407378939, 48, 57.1538461538, 24.3846153846,
32.3076923077, 26.0769230769, 60.4615384615, 63.9230769231,
61.6923076923, 69.5384615385, 60.9230769231, 43, 43.5384615385,
56.5384615385, 56.6153846154, 53.0769230769, 45.1538461538,
41.3846153846), Other = c(0.2307692308, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0.0769230769, 0, 0, 0.0769230769, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.1538461538, 0.1538461538,
0, 0, 0, 0, 0.0769230769, 0.076394194, 0.0769230769, 0.0769230769,
0, 0.0769230769, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0.0769230769, 0, 0, 0, 0.0769230769, 0, 0,
0.2307692308, 0, 0, 0, 0, 0.0769230769, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0.1538461538, 0.0769230769, 0, 0, 0, 0, 0, 0, 0,
0, 0.0769230769, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.0767459708,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.0769230769, 0.2307692308,
0.3846153846, 0.1538461538, 0.5384615385, 0.3076923077, 0.72,
0.9230769231, 0.4615384615, 0.3846153846, 0.6153846154, 0.3846153846,
0.3076923077, 0.3846153846, 0.4615384615, 0.3846153846, 1.0769230769,

```
0.6153846154, 0.3076923077, 0.3076923077, 0.1538461538, 0.4615384615,
0.5185185185, 0.56, 0.2307692308, 0.5384615385, 0.3846153846,
0.6153846154, 0.1538461538, 0.5384615385, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.0769230769,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.0769230769, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.0769230769, 0, 0, 0, 0,
0, 0, 0, 0, 0.0769230769, 0, 0.2307692308, 0.0769230769,
0.0769230769, 0, 0, 0.0740740741, 0.0769230769, 0, 0.3076923077,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.0769230769, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0.0769230769, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0.3076923077, 0.3846153846, 0, 0.3846153846,
0.1538461538, 0.1538461538, 0.0769230769, 0, 0, 0, 0.3076923077,
0, 0.0769230769, 0.0769230769, 0, 0.1538461538, 0.24, 0.16,
0.3076923077, 0.0769230769, 0.3846153846, 0.4615384615, 0.0769230769,
0.32, 0.16, 0.4444444444, 0.1538461538, 0, 0.0769230769,
0.1666666667, 0.3079291763, 0, 0, 0.16, 0, 0.1538461538,
0.1538461538, 0.0769230769, 0.0769230769, 0, 0, 0, 0, 0,
0, 0.0769230769, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
"Park", "Loc_Type", "Transect", "Transect2", "X_Coord_Start",
"Y_Coord_Start", "Algae", "Coral", "CorallineAlgae", "Invert",
"Substrate", "TurfAlgae", "Other"), row.names = c(NA, -390L), class = "data.frame")
```

[illegible]

[illegible]

28L, 21L, 20L, 23L, 18L, 31L, 27L, 19L, 31L, 36L, 23L, 29L,
 32L, 21L, 21L, 28L, 18L, 21L, 16L, 21L, 21L, 26L, 21L, 29L,
 25L, 23L, 14L, 20L, 25L, 23L, 20L, 26L, 10L, 18L, 19L, 30L,
 21L, 26L, 18L, 25L, 29L, 38L, 31L, 24L, 21L, 23L, 21L, 27L,
 17L, 26L, 24L, 24L, 26L, 29L, 28L, 26L, 25L, 24L, 34L, 22L,
 21L, 32L, 31L, 20L, 27L, 24L, 18L, 32L, 21L, 22L, 21L, 20L,
 23L, 24L, 30L, 20L, 11L, 25L, 37L, 20L, 24L, 27L, 38L, 22L,
 25L, 28L, 34L, 28L, 25L, 35L, 27L, 36L, 38L, 31L, 33L, 32L,
 22L, 25L, 29L, 14L, 27L, 18L, 26L, 29L, 23L, 25L, 11L, 20L,
 40L, 30L, 21L, 18L, 32L, 21L, 20L, 30L, 31L, 37L, 34L, 25L,
 25L, 17L, 35L, 45L, 39L, 40L, 44L, 24L, 40L, 28L, 36L, 19L,
 23L, 19L, 24L, 20L, 12L, 30L, 34L, 24L, 21L, 23L, 38L, 24L,
 25L, 29L, 31L, 21L, 25L, 22L, 18L, 28L, 21L, 38L, 34L, 35L,
 25L, 37L, 32L, 26L, 28L, 23L, 21L, 22L, 20L, 17L, 16L, 20L,
 40L, 28L, 22L, 29L, 30L, 26L, 26L, 27L, 19L, 22L, 18L, 20L,
 20L, 36L, 25L, 31L, 28L, 23L, 16L, 14L, 14L, 20L, 39L, 21L,
 29L, 23L, 24L, 27L, 16L, 25L, 38L, 25L, 22L, 19L, 28L, 21L,
 19L, 26L, 29L, 17L, 31L, 23L, 26L, 20L, 24L, 24L, 27L, 33L,
 29L, 34L, 20L, 12L, 19L), Biomass = c(10185.67, 6677.32,
 1867.65, 6162.12, 719.66, 4201.31, 14071.5, 7972.52, 8308.9,
 6392.55, 12544.85, 9155.19, 12128.48, 8329.47, 11193.73,
 14008.14, 12897.77, 9455.74, 8571.15, 3956.55, 15059.76,
 15105.18, 4791.65, 8369.65, 457.46, 22536.19, 6830.34, 7455.24,
 4880.57, 4905.28, 11556.77, 12781.74, 4126.76, 7732.1, 4128.14,
 5046.66, 11023.28, 2960.85, 50346.88, 7142.67, 5501.75, 6347.62,
 9342.34, 14532.66, 14325.76, 8600.61, 3697.5, 6471.08, 6719.27,
 9627.8, 12276.77, 4661.62, 2974.74, 3169.66, 9727.49, 4879.78,
 5176.85, 36162.72, 28367.27, 13508.77, 14011.12, 15544.39,
 3075.41, 5324.5, 5276.72, 4535.88, 4231.84, 8015.58, 5025.62,
 7321.73, 5126.55, 3140.26, 12396.45, 10847.47, 13452.21,
 2243.47, 10499.47, 11702.63, 3126.62, 4140.96, 7484.16, 2014.63,
 6541.57, 5759.49, 9171.92, 5589.93, 6311.25, 7159.13, 6228.62,
 9546.61, 23662.02, 12897.64, 3509.2, 5767.9, 1991.41, 5306.76,
 8194.93, 5173.65, 9288.89, 5161.14, 6615.4, 3588.12, 9444.34,
 18136.41, 7378.55, 7139.82, 6256.36, 31651.97, 5441.56, 5651.23,
 21246.6, 5106.7, 7207.8, 15092.41, 9234.46, 12436.01, 6029.96,
 6124.64, 5095.71, 10204.3, 6881.64, 6935.25, 60378.55, 24300.59,
 19953.18, 862.66, 9976.71, 37523.95, 21688.88, 28020.73,
 34573.49, 29793.42, 22415.02, 6356.96, 9784.45, 28054.65,
 23182.13, 8202.64, 55819.19, 34523.01, 29804.94, 34555.63,
 23148.35, 24161.29, 47740.75, 30772.74, 27585.41, 41461.32,
 3692.36, 7582.3, 5582.17, 10946.97, 99854.77, 14350.93, 12725.52,
 514.74, 6287.59, 44309.49, 25998.1, 7917.29, 15403.5, 14386.27,
 6820.74, 4579.99, 18821.27, 20557.34, 50584.75, 21283.44,
 37220.38, 21102.71, 4665.27, 20160.92, 50963.24, 49354.22,
 25002.66, 67280.41, 26010, 131218.46, 15999.38, 33707.61,
 7402.56, 17410.77, 76002.2, 11771.15, 4866.72, 1813.43, 16592.99,
 22916.95, 22218.72, 36305.02, 14383.1, 30709.08, 6846.79,
 2564.4, 11118.91, 68976.6, 16131.78, 19698.18, 9451.09, 3287.85,
 39645.73, 9403.7, 39921.89, 24242.17, 162469.41, 31063.03,
 27852.43, 29049.47, 5467.69, 14475.35, 5378.11, 15047.02,
 19141.14, 42902.71, 34382.06, 668.75, 5590.85, 145936.41,
 16867.78, 4482.21, 9759.54, 19326.65, 10547.26, 8611.85,
 17995.5, 2704.78, 20488.87, 13913.81, 46840.61, 15267.35,
 34520.92, 18818.35, 39116.94, 57619.37, 45927.98, 36465.26,
 8783.09, 7528.13, 4125.08, 37629.19, 6746.99, 6965.33, 28539.22,
 14385.51, 10530, 1204.44, 11867.17, 44705.05, 21275.8, 10814.42,
 25844.12, 22782.91, 7921.74, 6165.65, 11193.82, 18052.77,
 13357.45, 151507.07, 20702.57, 31748.98, 5561.66, 54169.17,
 22308.97, 36935.19, 49125.63, 35200.02, 58622.25, 37319.86,
 7025.51, 7359.15), Density = c(28.64, 11.52, 13.76, 16.64,
 6.72, 24.64, 14.08, 4.16, 12.56, 7.44, 20.08, 16.24, 11.44,
 7.36, 16.24, 39.52, 13.92, 18.96, 16, 9.84, 7.04, 6.88, 8.08,

```

14.72, 2.96, 9.36, 10.4, 15.92, 14.48, 13.04, 26.72, 19.52,
8.08, 10.88, 12.88, 15.28, 12.56, 3.12, 30.48, 11.76, 9.68,
13.76, 14.32, 16.32, 18.88, 24.32, 14.4, 23.44, 16.24, 13.52,
15.12, 12.64, 9.36, 8.16, 12.64, 21.76, 4.4, 12.56, 21.76,
11.76, 26.24, 27.52, 24.16, 24.96, 27.04, 14.24, 20.56, 9.12,
9.6, 13.6, 20.16, 8.56, 19.2, 12.56, 22.4, 6.72, 10.08, 29.6,
14.56, 10.64, 21.84, 5.28, 3.68, 5.52, 17.76, 8, 20.64, 18.48,
9.28, 15.28, 18.88, 31.84, 9.2, 8.72, 10.96, 16.56, 12.88,
5.68, 8.16, 11.2, 21.44, 12.64, 15.04, 14.08, 17.52, 14.96,
15.2, 20.72, 11.28, 21.68, 15.28, 13.04, 6.72, 18, 21.68,
5.44, 18.48, 14.96, 4.32, 9.12, 4.48, 13.52, 17.92, 9.44,
74.16, 4.56, 9.04, 29.92, 12.48, 28.4, 27.36, 17.04, 13.92,
15.52, 7.92, 25.52, 9.28, 14.24, 23.84, 24.48, 17.36, 27.2,
23.76, 9.04, 19.36, 16.08, 8.24, 21.76, 4.24, 13.6, 3.28,
11.92, 29.44, 5.6, 34.96, 6.96, 13.36, 32.24, 15.2, 18.24,
8.32, 10.56, 7.44, 6.56, 6.8, 14.48, 14.72, 16.72, 22.8,
9.68, 16.08, 14.4, 36.32, 25.44, 17.76, 25.52, 4.56, 15.92,
9.28, 24.32, 4.96, 9.36, 16.32, 4.88, 38.24, 7.36, 13.2,
42.4, 18.96, 26.56, 16.16, 26.8, 13.04, 14.56, 8.88, 10.4,
3.6, 5.28, 17.76, 42, 20.8, 23.44, 31.84, 18.48, 49.44, 37.84,
16.24, 16, 24, 22.08, 3.84, 7.2, 5.36, 3.84, 31.36, 9.12,
9.44, 31.76, 15.2, 9.68, 6, 14.56, 6.32, 5.28, 9.12, 2.88,
6.96, 6.96, 5.6, 8.16, 14.4, 10.72, 18.32, 20.56, 20.64,
7.76, 4.08, 2.72, 6, 9.92, 4.88, 7.76, 9.52, 5.28, 30.32,
6.16, 12.16, 24.64, 19.36, 22.24, 9.12, 9.28, 5.12, 3.84,
6.8, 6.64, 3.28, 20.32, 3.36, 10.64, 10.08, 12.56, 32.56,
14.32, 23.04, 21.04, 30, 14.8, 2.88, 4.16)), .Names = c("Island",
"Park", "Year", "Loc_Type", "Transect", "Transect2", "Richness",
"Biomass", "Density"), row.names = 61:330, class = "data.frame")

```

```

Rugosity <-
structure(list(Park = structure(c(2L, 2L, 2L, 2L, 2L, 2L, 2L,
2L, 2L, 2L, 2L, 2L, 2L, 2L, 2L, 2L, 2L, 2L, 2L, 2L,
2L, 2L, 2L, 2L, 2L, 2L, 1L, 1L, 1L, 1L, 1L, 1L, 1L, 1L,
1L, 1L, 1L, 1L, 1L, 1L, 2L, 2L, 2L, 2L, 2L, 2L, 2L, 2L, 2L,
2L, 2L, 2L, 2L, 2L, 1L, 1L, 1L, 1L, 1L, 1L, 1L, 1L, 1L, 1L,
1L, 1L, 1L, 1L, 2L, 2L, 2L, 2L, 2L, 2L, 2L, 2L, 2L, 2L, 2L,
2L, 2L, 2L, 1L, 1L, 1L, 1L, 1L, 1L, 1L, 1L, 1L, 1L, 1L, 1L,
1L, 1L), .Label = c("KAHO", "KALA"), class = "factor"), Transect = structure(c(1L,
2L, 3L, 4L, 5L, 6L, 7L, 8L, 9L, 10L, 11L, 12L, 13L, 14L, 15L,
1L, 2L, 3L, 4L, 5L, 6L, 7L, 8L, 9L, 10L, 11L, 12L, 13L, 14L,
15L, 1L, 2L, 3L, 4L, 5L, 6L, 7L, 8L, 9L, 10L, 11L, 12L, 13L,
14L, 15L, 1L, 2L, 3L, 4L, 5L, 6L, 7L, 8L, 9L, 10L, 11L, 12L,
13L, 14L, 15L, 1L, 2L, 3L, 4L, 5L, 6L, 7L, 8L, 9L, 10L, 11L,
12L, 13L, 14L, 15L, 1L, 2L, 3L, 4L, 5L, 6L, 7L, 8L, 9L,
10L, 11L, 12L, 13L, 14L, 15L), .Label = c("F01", "F02", "F03",
"F04", "F05", "F06", "F07", "F08", "F09", "F10", "F11", "F12",
"F13", "F14", "F15"), class = "factor"), Year = c(2006, 2006,
2006, 2006, 2006, 2006, 2006, 2006, 2006, 2006, 2006, 2006,
2006, 2006, 2007, 2007, 2007, 2007, 2007, 2007, 2007, 2007,
2007, 2007, 2007, 2007, 2007, 2007, 2007, 2007, 2007, 2007,
2007, 2007, 2007, 2007, 2007, 2007, 2007, 2007, 2007, 2007,
2008, 2008, 2008, 2008, 2008, 2008, 2008, 2008, 2008, 2008,
2008, 2008, 2008, 2008, 2008, 2008, 2008, 2008, 2008, 2008,
2008, 2008, 2008, 2008, 2008, 2008, 2008, 2008, 2009, 2009,
2009, 2009, 2009, 2009, 2009, 2009, 2009, 2009, 2009, 2009,
2009, 2009, 2009, 2009, 2009, 2009, 2009, 2009, 2009, 2009,
2009, 2009, 2009, 2009), Rugosity = c(1.41, 1.45, 1.72, 1.42,
1.43, 1.3, 2, 1.94, 1.65, 1.49, 1.62, 1.7, 1.42, 1.44, 1.49,
1.49, 1.39, 1.65, 1.43, 1.44, 1.25, 2.16, 1.95, 1.68, 1.49, 1.61,
1.75, 1.42, 1.43, 1.56, 1.81, 1.46, 1.89, 1.58, 2.27, 1.97, 1.78,
1.49, 1.46, 2.07, 2.31, 2.4, 1.9, 1.48, 1.75, 1.46, 1.43, 1.63,
1.43, 1.52, 1.27, 2.2, 2.04, 1.69, 1.51, 1.68, 1.64, 1.47, 1.45,
1.57, 2.03, 1.61, 1.82, 1.76, 2.03, 1.91, 1.86, 1.57, 1.78, 2.46,
2.62, 3.17, 1.93, 1.64, 1.98, 1.57, 1.5, 1.64, 1.6, 1.51, 1.28,
2.19, 2.04, 1.62, 1.55, 1.9, 1.66, 1.52, 1.45, 1.64, 1.73, 1.62,
1.92, 1.7, 1.89, 2.08, 1.84, 1.51, 1.75, 2.2, 1.66, 2.41, 1.96,
1.66, 1.98)), .Names = c("Park", "Transect", "Year", "Rugosity"
), row.names = c(NA, -105L), class = "data.frame")

```

67

APPENDIX D: Power results in tabular format

Table D.1: Power analysis results for different variables at both parks using two Type-I error levels (α), and three levels of change detection (γ).

Years of annual sampling	$\alpha = 0.05$			$\alpha = 0.10$		
	$\gamma = 0.01$	$\gamma = 0.02$	$\gamma = 0.04$	$\gamma = 0.01$	$\gamma = 0.02$	$\gamma = 0.04$
Coral Percent Cover						
KALA						
10	0.25	0.67	1.00	0.34	0.76	1.00
20	0.94	1.00	1.00	0.96	1.00	1.00
30	1.00	1.00	1.00	1.00	1.00	1.00
40	1.00	1.00	1.00	1.00	1.00	1.00
50	1.00	1.00	1.00	1.00	1.00	1.00
KAHO						
10	0.22	0.71	1.00	0.35	0.84	1.00
20	0.65	0.99	1.00	0.77	1.00	1.00
30	0.90	1.00	1.00	0.95	1.00	1.00
40	0.99	1.00	1.00	1.00	1.00	1.00
50	1.00	1.00	1.00	1.00	1.00	1.00
Coralline Algae Percent Cover						
KALA						
10	0.06	0.13	0.17	0.16	0.18	0.27
20	0.13	0.27	0.68	0.22	0.35	0.80
30	0.21	0.61	1.00	0.31	0.73	1.00
40	0.39	0.95	1.00	0.55	0.96	1.00
50	0.71	1.00	1.00	0.81	1.00	1.00
KAHO						
10	0.04	0.07	0.08	0.11	0.10	0.13
20	0.04	0.06	0.10	0.11	0.11	0.20
30	0.05	0.08	0.14	0.09	0.16	0.26
40	0.07	0.09	0.18	0.10	0.17	0.27
50	0.07	0.10	0.18	0.11	0.17	0.29
Algae Percent Cover						
KALA						
10	0.07	0.08	0.13	0.14	0.16	0.23
20	0.09	0.16	0.47	0.16	0.27	0.61
30	0.14	0.40	0.95	0.22	0.57	0.97
40	0.27	0.78	1.00	0.41	0.85	1.00
50	0.45	0.97	1.00	0.57	0.98	1.00
KAHO						
10	0.09	0.08	0.15	0.13	0.13	0.21
20	0.09	0.17	0.56	0.17	0.28	0.66
30	0.17	0.50	0.98	0.27	0.60	0.99
40	0.31	0.84	1.00	0.43	0.90	1.00
50	0.56	0.99	1.00	0.63	1.00	1.00
Turf Algae Percent Cover						
KALA						
10	0.13	0.10	0.10	0.22	0.19	0.18
20	0.23	0.18	0.13	0.33	0.27	0.22
30	0.24	0.19	0.11	0.32	0.26	0.20
40	0.18	0.14	0.09	0.28	0.23	0.18
50	0.18	0.10	0.11	0.27	0.19	0.17
KAHO						
10	0.49	0.95	1.00	0.67	0.98	1.00
20	0.72	0.99	1.00	0.84	1.00	1.00
30	0.73	0.99	1.00	0.84	1.00	1.00
40	0.70	0.98	1.00	0.82	1.00	1.00

Years of annual sampling	$\alpha = 0.05$				$\alpha = 0.10$	
	$\gamma = 0.01$	$\gamma = 0.02$	$\gamma = 0.04$	$\gamma = 0.01$	$\gamma = 0.02$	$\gamma = 0.04$
50	0.67	0.96	1.00	0.79	0.99	1.00
Macro-invertebrate Percent Cover						
KALA						
10	0.07	0.12	0.20	0.11	0.21	0.27
20	0.13	0.32	0.85	0.18	0.46	0.93
30	0.27	0.79	1.00	0.37	0.86	1.00
40	0.57	0.99	1.00	0.69	1.00	1.00
50	0.83	1.00	1.00	0.91	1.00	1.00
KAHO						
10	0.06	0.07	0.17	0.12	0.17	0.27
20	0.07	0.19	0.57	0.17	0.31	0.74
30	0.10	0.31	0.81	0.19	0.45	0.92
40	0.12	0.38	0.87	0.19	0.53	0.96
50	0.12	0.42	0.89	0.17	0.56	0.98
Rugosity						
KALA						
10	0.99	1.00	1.00	0.99	1.00	1.00
20	1.00	1.00	1.00	1.00	1.00	1.00
30	1.00	1.00	1.00	1.00	1.00	1.00
40	1.00	1.00	1.00	1.00	1.00	1.00
50	1.00	1.00	1.00	1.00	1.00	1.00
KAHO						
10	0.25	0.69	1.00	0.35	0.80	1.00
20	0.76	1.00	1.00	0.86	1.00	1.00
30	0.90	1.00	1.00	0.96	1.00	1.00
40	0.94	1.00	1.00	0.96	1.00	1.00
50	0.96	1.00	1.00	0.96	1.00	1.00
Fish Density						
KALA						
10	0.09	0.11	0.39	0.13	0.22	0.49
20	0.15	0.35	0.92	0.21	0.52	0.96
30	0.20	0.52	0.99	0.26	0.64	0.99
40	0.20	0.59	0.99	0.30	0.71	1.00
50	0.22	0.61	0.99	0.31	0.70	0.99
KAHO						
10	0.14	0.44	0.94	0.28	0.54	0.97
20	0.72	1.00	1.00	0.81	1.00	1.00
30	1.00	1.00	1.00	1.00	1.00	1.00
40	1.00	1.00	1.00	1.00	1.00	1.00
50	1.00	1.00	1.00	1.00	1.00	1.00
Fish Biomass						
KALA						
10	0.16	0.42	0.93	0.24	0.55	0.96
20	0.74	1.00	1.00	0.85	1.00	1.00
30	0.99	1.00	1.00	1.00	1.00	1.00
40	1.00	1.00	1.00	1.00	1.00	1.00
50	1.00	1.00	1.00	1.00	1.00	1.00
KAHO						
10	0.10	0.23	0.58	0.17	0.30	0.69
20	0.20	0.53	0.99	0.25	0.66	0.99
30	0.24	0.66	1.00	0.35	0.77	1.00
40	0.26	0.72	1.00	0.37	0.80	1.00
50	0.28	0.73	1.00	0.39	0.83	1.00
Fish Species Richness						
KALA						
10	0.86	1.00	1.00	0.91	1.00	1.00
20	1.00	1.00	1.00	1.00	1.00	1.00

Years of annual sampling		$\alpha = 0.05$				$\alpha = 0.10$	
		$\gamma = 0.01$	$\gamma = 0.02$	$\gamma = 0.04$	$\gamma = 0.01$	$\gamma = 0.02$	$\gamma = 0.04$
KAHO	30	1.00	1.00	1.00	1.00	1.00	1.00
	40	1.00	1.00	1.00	1.00	1.00	1.00
	50	1.00	1.00	1.00	1.00	1.00	1.00
	10	0.17	0.50	0.98	0.27	0.68	0.99
	20	0.41	0.92	1.00	0.56	0.96	1.00
Coral Settlement KALA	30	0.55	0.97	1.00	0.64	1.00	1.00
	40	0.58	0.98	1.00	0.67	1.00	1.00
	50	0.60	0.98	1.00	0.67	1.00	1.00
	10	0.04	0.05	0.06	0.11	0.12	0.12
	20	0.05	0.06	0.14	0.12	0.14	0.23
	30	0.06	0.09	0.19	0.15	0.12	0.30
	40	0.06	0.10	0.21	0.15	0.13	0.35
	50	0.05	0.10	0.23	0.14	0.13	0.36

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 988/121406, June 2013

National Park Service
U.S. Department of the Interior



Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA™