POWER ANALYSIS FOR TREND DETECTION IN HAWAIIAN HOARY BAT OCCUPANCY IN THE HAWAIIAN ISLANDS

Prepared for:

Kawailoa Wind, LLC

Prepared by:

Western EcoSystems Technology, Inc.
456 SW Monroe Ave, Suite 106
Corvallis, OR 97333

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Table of Contents

INTRODUCTION 1
METHODS 1
  Modeling approach 1
  Pilot data 2
  Power simulation 3
RESULTS 4
  Example GRTS Sample 13
DISCUSSION 15
REFERENCES 16

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INTRODUCTION

Kawailoa Wind, LLC is working with the U.S. Fish and Wildlife Service (USFWS) and Hawaii Division of Forestry and Wildlife (DOFAW) to design research related to Hawaiian hoary bats (*Lasirus cinereus semotus*; ʻope'ape'a) as partial fulfillment of mitigation obligations, that can be implemented in Hawaii to fulfill obligations under the Habitat Conservation Plans for the Kawailoa Wind, LLC and other operational wind energy projects on the islands of Maui and Oahu. Two of the top priorities for Hawaiian hoary bat research identified by the Hawaiian hoary bat working group include assessments of population size and estimation of population trends. Estimation of actual population size is not currently considered feasible; however assessing population trends is considered an achievable goal. Therefore, Kawailoa Wind, LLC is working with the USFWS and DOFAW to design a monitoring program to estimate trends in Hawaiian hoary bat occupancy across the islands of Hawaii, Maui, Oahu, and Kauai. At the request of Kawailoa Wind, LLC, Western EcoSystems Technology, Inc. (WEST) conducted an initial power analysis to determine the approximate annual sample size of sites required to detect Hawaiian hoary bat occupancy trends of various magnitudes.

METHODS

Modeling approach

Occupancy is defined as the proportion of a population where a species or community of interest is present (MacKenzie et al. 2006) and is a useful metric of distribution and range. Occupancy is a scale-dependent measurement that is determined by the scale of the sites (patches or sampling units) within which occupancy is assessed. When a species is detected perfectly (i.e., detection probability equals one) within each patch, then occupancy is estimated as the proportion of sampled patches that were occupied. When the detection rate of a species is less than one, multiple visits to a site within a season are required to estimate both detection and occupancy rates with mixture models (MacKenzie et al. 2002). Occupancy rates are then adjusted using models for imperfect detection to account for units in which the species was undetected.

Estimation of trends over time requires annual sampling to estimate occupancy and multiple visits to each site within the sampling period (i.e., each year) to estimate the detection rate. The dynamic occupancy model is often used to account for changes in the occupancy status of a site over time (MacKenzie et al. 2003, 2006). The dynamic occupancy model estimates the initial occupancy rate, the detection rate, and two population dynamics parameters (extinction rate and colonization rate). The extinction rate parameter is the probability that a site occupied one year is unoccupied the next. The colonization rate parameter measures the probability that an unoccupied site becomes occupied the following year. The two population dynamics parameters are imposed upon the initial occupancy rate to induce changes in occupancy over time.

Pilot data

A pilot data set from a five-year study of Hawaiian hoary bat in Hawaii provides the basis for a power simulation (Gorresen et al. 2013). The goal of the study was to examine relationships between occupancy, habitat characteristics, and seasonal differences. Twenty-five survey areas were sampled, with each survey area containing multiple sample sites. Sample sites were spaced roughly 800 m apart. Each sample site was surveyed using Anabat SD1 or Anabat II detectors (Titley Electronics, Ballina, New South Wales, Australia). Monitoring occurred from January 2007 through May 2012. Each site was visited an average of 7 nights. For the purposes of this analysis/discussion, a visit is equated to a detector night and the two terms are used interchangeably throughout. Sampling was conducted across seasons for the 5 year period to provide estimates of dynamic occupancy model parameters by season and year and for a set of related covariates. Sites were treated as being independent.

A subset of the Gorresen et al. (2013) data was used to inform this power simulation. To better meet the assumptions of population closure, only visits occurring in the middle of a season were used for the occupancy analysis. The estimates of the dynamic occupancy parameters for the subsets of data by season are provided in Table 1. The extinction parameter is low and the detection probability is high in the combined lactation/post-lactation season, leading to more accurate occupancy estimate for this time period than in other seasons. The parameter estimates from this time period provide the basis for the power simulation to detect trends in occupancy over time, as measured during the combined lactation/post-lactation season.

Table 1: Dynamic Occupancy Model Estimates By and Across Reproductive Seasons (single sampling period per season and year)

Season	Years	Dates	Occupancy (SE)	Colonization (SE)	Extinction (SE)	Detection (SE)
Pre-pregnancy	2007-2012	Dec 15-Mar 31	0.3591 (0.1862)	0.3869 (0.1535)	0.1337 (0.0859)	0.4359 (0.0257)
Pregnancy	2007-2012	Apr 1-Jun 15	0.7080 (0.1432)	0.9981 (0.0450)	0.2639 (0.0873)	0.6059 (0.0278)
Lactation	2007 – 2010	Jun 16-Aug 31	0.6787 (0.1462)	0.6895 (0.3328)	0.1066 (0.0986)	0.6341 (0.0273)
Post-lactation	2007-2011	Sept 1-Dec 14	0.8276 (0.1536)	0.9994 (0.0158)	0.2526 (0.0856)	0.4876 (0.0281)
Lactation/ Post-lactation	2007-2011	Jun 16-Dec 14	0.6611 (0.1421)	0.6400 (0.2481)	0.0686 (0.0664)	0.6270 (0.0253)
All seasons	2007-2012	ALL	0.5946 (0.1282)	0.4718 (0.1652)	0.2074 (0.0788)	0.4563 (0.0208)

Power simulation

A Monte Carlo simulation was used to generate random samples of data reflecting dynamic occupancy parameter estimates from the pilot data and exhibiting a known trend. For simulations of 500 iterations each, a sample of occupancy indicators was modeled based on inputs of initial occupancy, colonization rate, extinction rate, detection probability, the number of sites, monitoring period length (in years), number of visits to a site each year (i.e., number of detector nights), and the annual trend (p). The annual trend is the proportional increase or decrease in the occupancy rate each year. For example, an annual 1% decrease is represented by $p = -0.01$. The dynamic occupancy variation (MacKenzie et al. 2006) was applied using the *unmarked* package (Fiske and Chandler 2011) in the R statistical software (2015).

Annual occupancy estimates were derived from the dynamic occupancy by smoothing, which obtains estimates from an occupancy model that is conditional on the observed data (Weir et al. 2012). Trend estimates were obtained from a log-linear regression of smoothed occupancy estimates of the dynamic occupancy model fit. The two-sided trend test is based on the rejection area falling outside of the 95%-confidence interval of the back-transformed year coefficient with degrees of freedom equal to the number of years in the monitoring period less 2. Partial autocorrelation plots of the annual smoothed occupancy estimates indicate no substantial autocorrelation.

A declining population was generated for annual samples of 25, 50, 75, 100, 125, 150, 175, 200, and 300 sites. Three monitoring periods and two net trend rates were examined. Trends were generated over monitoring periods of 5, 10, and 20 years for net declines of 20% and 40%. The combinations of monitoring period length and net decline result in different annual trends (Table 2). Over a monitoring period of 5 years, a net decline of 20% corresponds to an average decline of 5.4% each year. Similarly, a 40% net decline over 5 years implies a 12.0% annual decline. For a monitoring period of 10 years, net declines of 20% and 40% correspond to annual declines of 2.4% and 5.5%, respectively. Annual declines of 1.2% and 2.7% represent net trends of 20% and 40%, respectively, over a 20-year monitoring period. These six trends were imposed onto simulated populations generated from the occupancy parameters estimated from the pilot data. The initial occupancy rate was assumed to be 0.6611, with a detection rate of 0.6270, a constant extinction rate of 0.0686, and a colonization rate simulated to induce the desired trend. Test size was obtained as the proportion of iterations for which the null hypothesis was rejected at the 0.05 level when no trend was simulated. Similarly, test power was approximated as the proportion of iterations for which the null hypothesis is rejected when a non-zero trend is simulated. Trend testing was conducted for a two-sided test of no trend and a one-sided test for a decline in the occupancy rate over time.

Table 2: Annual trends for each levels of net trend and monitoring period length

Years	Annual Decline 20% net trend	Annual Decline 40% net trend
5	-5.4%	-12.0%
10	-2.4%	-5.5%
20	-1.2%	-2.7%

RESULTS

Note that some variability is present in the results due to the inherent variability of running simulations. Simulations of 500 iterations were used. Simulations incorporating iterations of 1000 or more would reduce simulation variability but require more time to run. Therefore, broad interpretation of these results is required. For example, power results may not always increase monotonically as the sample size increases because of variation among the random samples generated. The overall increasing pattern is of more interest in this simulation.

Test size was computed for the trend test from the log-linear regression model for the two hypotheses, given sample sizes, two monitoring periods, and three variations on the number of nights of monitoring (Table 3). The trend test demonstrates nearly-nominal test size for both the one-sided and two-sided trend tests. Site-by-year replication of 3 nights often exhibit test size that is slightly higher than nominal.

Table 2: Trend Test Size (for tests conducted at α = 0.05)

Test direction	Sites	5 years			10 years			20 years		
		3 nights	5 nights	7 nights	3 nights	5 nights	7 nights	3 nights	5 nights	7 nights
Two-sided	25	0.068	0.050	0.050	0.074	0.052	0.042	0.070	0.052	0.038
Two-sided	50	0.078	0.052	0.070	0.064	0.050	0.042	0.076	0.056	0.050
Two-sided	75	0.056	0.042	0.046	0.046	0.044	0.056	0.070	0.050	0.048
Two-sided	100	0.054	0.074	0.066	0.060	0.060	0.052	0.054	0.056	0.046
Two-sided	125	0.064	0.070	0.054	0.060	0.060	0.046	0.052	0.040	0.040
Two-sided	150	0.072	0.058	0.060	0.072	0.054	0.058	0.060	0.036	0.032
Two-sided	175	0.058	0.050	0.054	0.064	0.044	0.062	0.074	0.040	0.048
Two-sided	200	0.072	0.056	0.050	0.066	0.056	0.054	0.060	0.054	0.048
Two-sided	300	0.066	0.048	0.062	0.066	0.054	0.050	0.076	0.058	0.054
One-sided	25	0.066	0.054	0.046	0.058	0.042	0.050	0.062	0.042	0.050
One-sided	50	0.078	0.060	0.060	0.048	0.044	0.044	0.072	0.048	0.046
One-sided	75	0.062	0.044	0.044	0.042	0.076	0.046	0.066	0.046	0.056
One-sided	100	0.046	0.070	0.060	0.050	0.054	0.050	0.064	0.038	0.030
One-sided	125	0.054	0.064	0.054	0.068	0.068	0.048	0.064	0.044	0.050
One-sided	150	0.054	0.052	0.066	0.078	0.066	0.062	0.060	0.042	0.034
One-sided	175	0.062	0.038	0.066	0.062	0.052	0.052	0.074	0.052	0.046
One-sided	200	0.076	0.040	0.062	0.064	0.064	0.048	0.052	0.052	0.052
One-sided	300	0.070	0.036	0.066	0.070	0.058	0.044	0.052	0.040	0.068

Nearly-nominal confidence interval coverage is attained for the trend estimate from log-linear regression for all scenarios (Table 4). Coverage is slightly low for the occupancy trend estimated from data collected in three nights each year but does not appear to be impacted by the trend magnitude, number of sites, or monitoring period length.

Table 4: Observed Confidence Interval Coverage

Net trend	Sites	5 years			10 years			20 years		
		3 nights	5 nights	7 nights	3 nights	5 nights	7 nights	3 nights	5 nights	7 nights
-20%	25	0.948	0.948	0.944	0.944	0.956	0.970	0.934	0.938	0.948
-20%	50	0.954	0.954	0.968	0.936	0.940	0.970	0.930	0.944	0.944
-20%	75	0.940	0.962	0.956	0.934	0.930	0.972	0.928	0.944	0.942
-20%	100	0.952	0.960	0.944	0.934	0.946	0.958	0.936	0.940	0.956
-20%	125	0.954	0.944	0.934	0.934	0.942	0.964	0.942	0.954	0.958
-20%	150	0.948	0.954	0.944	0.940	0.942	0.962	0.938	0.960	0.956
-20%	175	0.956	0.948	0.944	0.934	0.924	0.966	0.940	0.964	0.940
-20%	200	0.942	0.952	0.946	0.932	0.934	0.970	0.932	0.962	0.944
-20%	300	0.942	0.956	0.960	0.944	0.922	0.944	0.906	0.962	0.946
-40%	25	0.942	0.950	0.960	0.934	0.950	0.932	0.924	0.948	0.942
-40%	50	0.926	0.968	0.954	0.920	0.928	0.952	0.942	0.948	0.938
-40%	75	0.930	0.952	0.946	0.948	0.964	0.952	0.922	0.970	0.928
-40%	100	0.944	0.936	0.934	0.956	0.956	0.944	0.922	0.950	0.930
-40%	125	0.948	0.940	0.952	0.950	0.952	0.938	0.918	0.940	0.940
-40%	150	0.940	0.946	0.944	0.944	0.936	0.942	0.924	0.938	0.948
-40%	175	0.942	0.946	0.942	0.938	0.952	0.950	0.908	0.938	0.944
-40%	200	0.932	0.956	0.946	0.932	0.944	0.946	0.896	0.924	0.938
-40%	300	0.946	0.962	0.946	0.938	0.944	0.938	0.888	0.926	0.946

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Simulation power increases as a function of the number of sites for two-sided trend tests (Table 5) and one-sided trend tests for population declines (Table 6). Power simulation results for the 5-, 10- and 20-year monitoring periods are provided in Figures 1 through 6, respectively. As expected, the trends for the 40% declines are detected with higher power for all monitoring periods, the power increases with the length of the monitoring period, and the one-sided trend test for a decline has slightly higher power that the test of a non-directional alternative hypothesis.

Table 5: Simulation Power for a Two-Sided Trend Test Conducted at α = 0.05

Net trend	Sites	5 years			10 years			20 years		
		3 nights	5 nights	7 nights	3 nights	5 nights	7 nights	3 nights	5 nights	7 nights
-20%	25	0.112	0.106	0.118	0.214	0.226	0.192	0.390	0.406	0.404
-20%	50	0.198	0.188	0.186	0.420	0.378	0.366	0.656	0.696	0.694
-20%	75	0.252	0.292	0.234	0.546	0.526	0.520	0.826	0.854	0.862
-20%	100	0.318	0.380	0.312	0.642	0.686	0.658	0.922	0.926	0.944
-20%	125	0.348	0.380	0.392	0.704	0.758	0.746	0.958	0.968	0.980
-20%	150	0.434	0.412	0.430	0.794	0.824	0.824	0.978	0.984	0.992
-20%	175	0.494	0.498	0.492	0.868	0.870	0.876	0.994	0.992	0.996
-20%	200	0.548	0.550	0.546	0.898	0.894	0.902	1.000	0.998	0.996
-20%	300	0.678	0.712	0.698	0.988	0.966	0.982	1.000	1.000	1.000
-40%	25	0.294	0.290	0.288	0.656	0.590	0.610	0.912	0.894	0.898
-40%	50	0.522	0.502	0.502	0.908	0.898	0.890	0.998	0.996	0.994
-40%	75	0.684	0.662	0.632	0.974	0.988	0.972	1.000	1.000	0.998
-40%	100	0.794	0.770	0.742	0.998	0.998	0.994	1.000	1.000	1.000
-40%	125	0.856	0.852	0.852	1.000	0.998	0.998	1.000	1.000	1.000
-40%	150	0.914	0.896	0.902	1.000	1.000	1.000	1.000	1.000	1.000
-40%	175	0.956	0.936	0.928	1.000	1.000	1.000	1.000	1.000	1.000
-40%	200	0.964	0.962	0.958	1.000	1.000	1.000	1.000	1.000	1.000
-40%	300	0.998	0.990	0.988	1.000	1.000	1.000	1.000	1.000	1.000

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Table 6: Simulation Power for a One-Sided Decreasing Trend Test Conducted at α = 0.05

Net trend	Sites	5 years			10 years			20 years		
		3 nights	5 nights	7 nights	3 nights	5 nights	7 nights	3 nights	5 nights	7 nights
-20%	25	0.202	0.216	0.210	0.338	0.350	0.298	0.510	0.552	0.532
-20%	50	0.318	0.348	0.344	0.530	0.542	0.526	0.770	0.816	0.824
-20%	75	0.418	0.472	0.386	0.668	0.708	0.686	0.890	0.918	0.924
-20%	100	0.490	0.546	0.512	0.772	0.794	0.780	0.946	0.962	0.976
-20%	125	0.558	0.588	0.586	0.832	0.878	0.852	0.974	0.986	0.992
-20%	150	0.632	0.668	0.638	0.876	0.918	0.900	0.996	0.996	0.994
-20%	175	0.690	0.696	0.698	0.938	0.934	0.942	0.998	0.998	0.998
-20%	200	0.740	0.754	0.734	0.948	0.952	0.962	1.000	1.000	1.000
-20%	300	0.840	0.880	0.858	0.998	0.994	1.000	1.000	1.000	1.000
-40%	25	0.488	0.460	0.490	0.776	0.738	0.774	0.954	0.944	0.952
-40%	50	0.724	0.722	0.718	0.960	0.970	0.966	1.000	1.000	0.998
-40%	75	0.858	0.860	0.844	0.998	1.000	0.988	1.000	1.000	1.000
-40%	100	0.912	0.924	0.906	1.000	1.000	0.998	1.000	1.000	1.000
-40%	125	0.952	0.964	0.972	1.000	1.000	1.000	1.000	1.000	1.000
-40%	150	0.978	0.974	0.988	1.000	1.000	1.000	1.000	1.000	1.000
-40%	175	0.986	0.986	0.996	1.000	1.000	1.000	1.000	1.000	1.000
-40%	200	0.996	0.994	0.996	1.000	1.000	1.000	1.000	1.000	1.000
-40%	300	1.000	1.000	0.998	1.000	1.000	1.000	1.000	1.000	1.000

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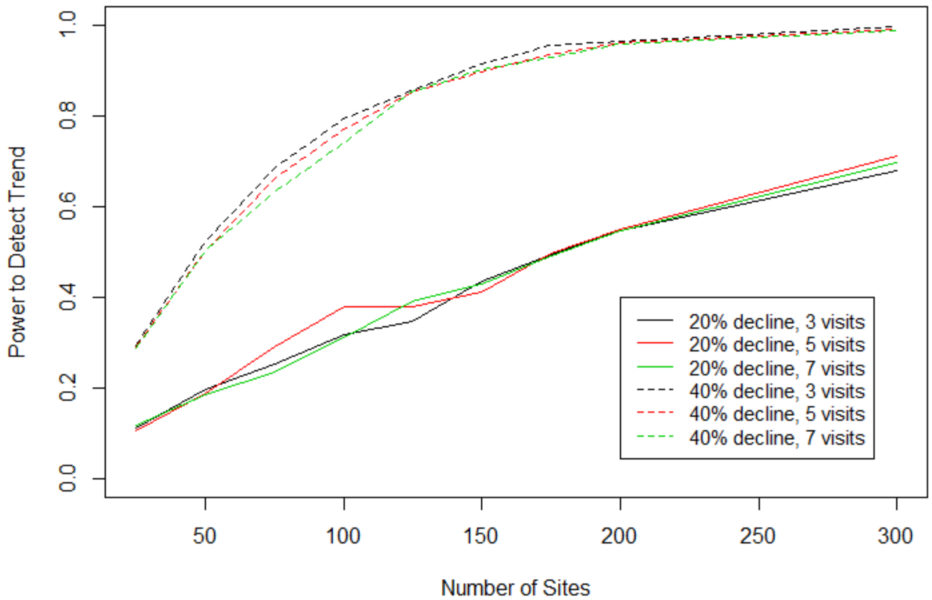

Figure 1: Power to detect Hawaiian hoary bat occupancy trends *in either direction* over a 5-year monitoring period

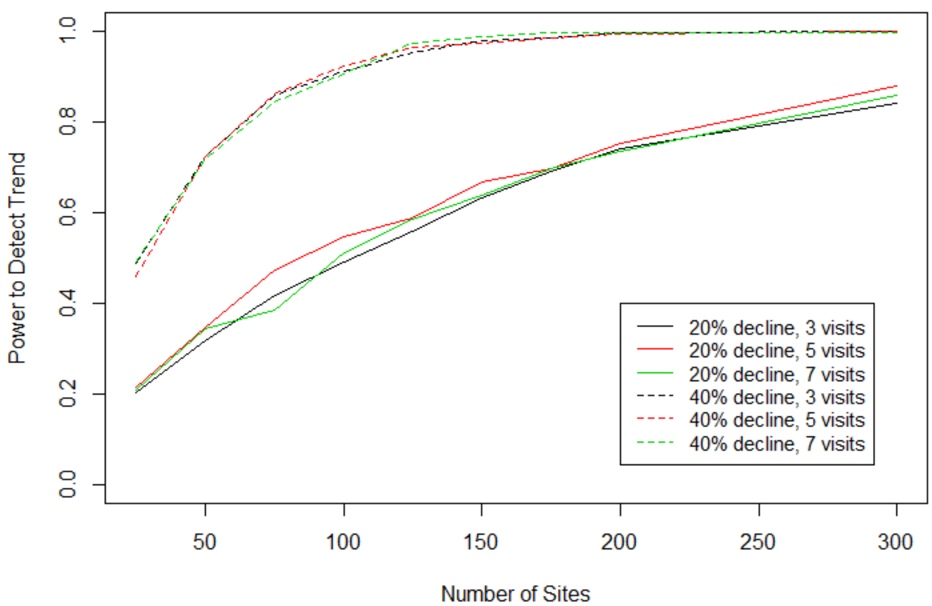

Figure 2: Power to detect *decreasing* Hawaiian hoary bat occupancy trends over a 5-year monitoring period

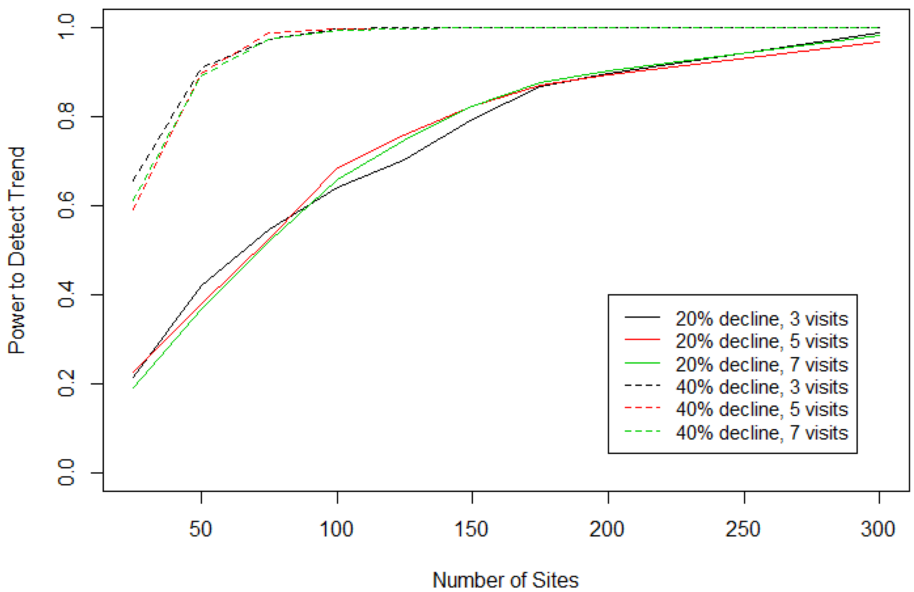

Figure 3: Power to detect Hawaiian hoary bat occupancy trends *in either direction* over a 10-year monitoring period

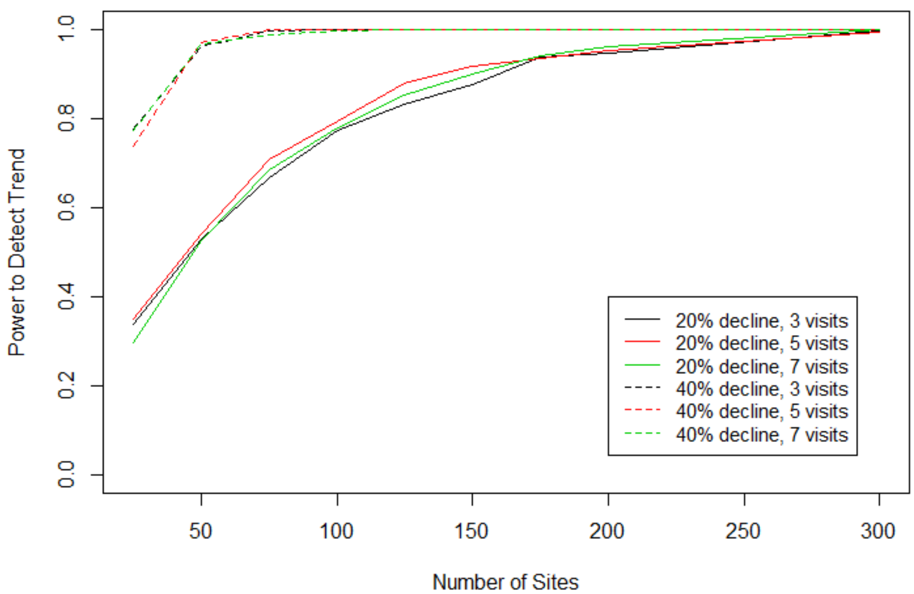

Figure 4: Power to detect *decreasing* Hawaiian hoary bat occupancy trends over a 10-year monitoring period

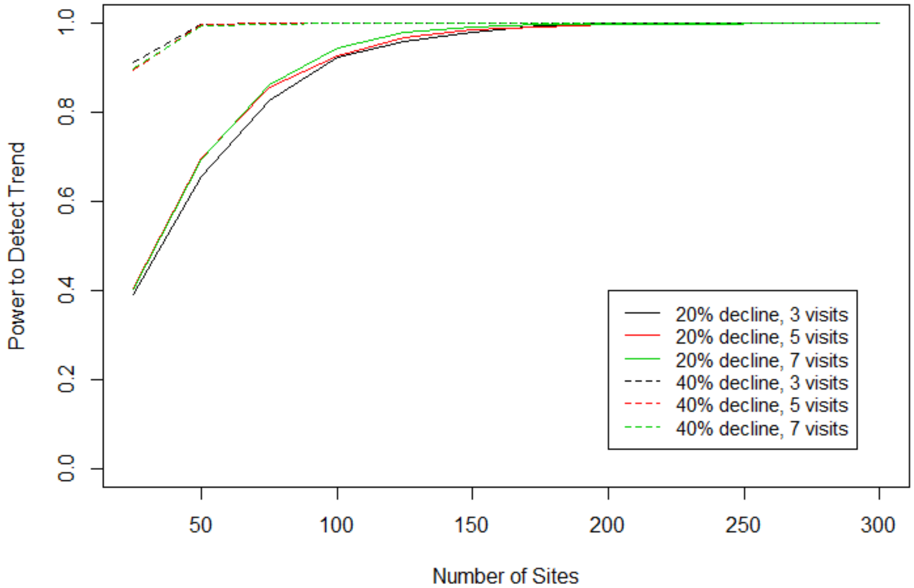

Figure 5: Power to detect Hawaiian hoary bat occupancy trends *in either direction* over a 20-year monitoring period

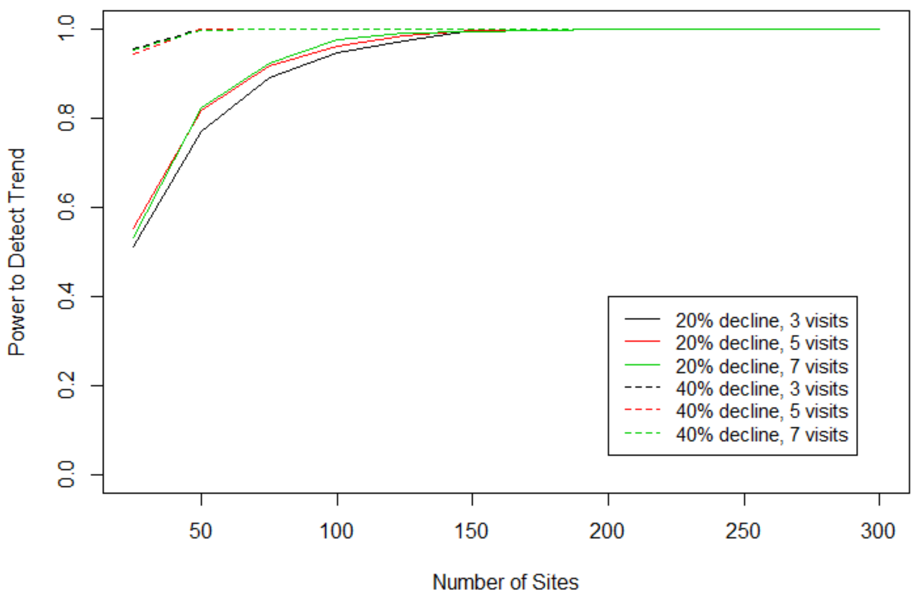

Figure 6: Power to detect *decreasing* Hawaiian hoary bat occupancy trends over a 20-year monitoring period

Relative bias is calculated as $\frac{\hat{p} - p}{|p|}$, where $\hat{p}$ is the estimated and *p* is the true annual percentage trend. The absolute value of the true trend is used so that the direction of the trend bias may be assessed. The trend estimate obtained from the log-linear regression of smoothed occupancy estimates is generally unbiased, with relative bias ranging from by -5% to 7% for samples of least 50 sites per year (Table 7).

Table 7: Relative Bias of the Trend Estimate

Net trend	Sites	5 years			10 years			20 years		
		3 nights	5 nights	7 nights	3 nights	5 nights	7 nights	3 nights	5 nights	7 nights
-20%	25	0.0061	-0.0677	-0.0260	0.0243	-0.0070	-0.0449	0.0536	-0.0296	-0.0037
-20%	50	0.0262	-0.0504	-0.0234	0.0563	-0.0025	0.0114	0.0416	-0.0265	-0.0240
-20%	75	0.0237	-0.0331	-0.0033	0.0440	0.0020	-0.0014	0.0460	-0.0138	-0.0255
-20%	100	0.0430	-0.0164	-0.0048	0.0515	0.0052	0.0143	0.0441	-0.0013	-0.0128
-20%	125	0.0504	-0.0065	0.0026	0.0680	0.0066	0.0152	0.0444	-0.0090	-0.0096
-20%	150	0.0292	-0.0073	0.0023	0.0681	0.0139	0.0147	0.0484	-0.0067	-0.0064
-20%	175	0.0305	-0.0045	-0.0108	0.0576	0.0163	0.0102	0.0505	-0.0052	-0.0044
-20%	200	0.0233	-0.0074	-0.0138	0.0554	0.0232	0.0006	0.0516	-0.0041	-0.0094
-20%	300	0.0227	0.0018	-0.0095	0.0468	0.0182	-0.0071	0.0586	0.0008	-0.0001
-40%	25	-0.0197	-0.0047	-0.0427	0.0011	-0.0111	-0.0436	0.0035	-0.0120	-0.0156
-40%	50	-0.0071	0.0028	-0.0226	0.0102	-0.0063	-0.0155	0.0243	-0.0004	-0.0038
-40%	75	0.0000	-0.0040	-0.0142	0.0222	-0.0007	-0.0083	0.0379	0.0013	-0.0034
-40%	100	0.0133	0.0037	-0.0072	0.0163	0.0054	-0.0079	0.0458	0.0027	-0.0026
-40%	125	0.0239	0.0102	-0.0126	0.0201	0.0037	-0.0042	0.0482	0.0059	-0.0024
-40%	150	0.0217	0.0085	-0.0035	0.0203	0.0054	-0.0040	0.0454	0.0031	-0.0033
-40%	175	0.0200	0.0107	-0.0035	0.0232	0.0079	-0.0022	0.0466	0.0053	-0.0056
-40%	200	0.0179	0.0076	-0.0034	0.0272	0.0039	-0.0032	0.0467	0.0067	-0.0035
-40%	300	0.0129	0.0047	-0.0019	0.0293	0.0098	0.0028	0.0429	0.0064	0.0002

Mean relative bias of the occupancy estimates was calculated as the mean of the relative bias of each annual estimate of occupancy compared to the true occupancy rate. Let $\hat{\Psi}_t$ be the estimate of the true occupancy rate Ψ_t in year *t*, *t* = 1, 2, …, *T*. The mean relative bias of the occupancy estimates was calculated as $\frac{1}{T}\sum_{t=1}^{T}\frac{\hat{\Psi}_t - \Psi_t}{\Psi_t}$. Mean relative bias of the occupancy estimates was calculated for each iteration, then the mean of those values was calculated across the 1,000 iterations. The trend estimate obtained from the log-linear regression of smoothed occupancy estimates is generally unbiased, with relative bias ranging from -0.0085 to 0.0099 (Table 8).

Table 8: Mean Relative Bias of the Annual Occupancy Estimates

Net trend	Sites	5 years			10 years			20 years		
		3 nights	5 nights	7 nights	3 nights	5 nights	7 nights	3 nights	5 nights	7 nights
-20%	25	0.0029	-0.0007	-0.0010	0.0016	0.0001	-0.0021	0.0020	0.0025	-0.0018
-20%	50	0.0040	-0.0025	-0.0012	0.0023	-0.0007	-0.0003	-0.0001	0.0021	-0.0010
-20%	75	0.0030	-0.0019	-0.0008	0.0001	0.0002	-0.0001	0.0010	0.0019	-0.0002
-20%	100	0.0035	-0.0018	-0.0009	-0.0007	0.0005	-0.0006	0.0015	0.0018	-0.0002
-20%	125	0.0030	-0.0006	-0.0006	0.0010	-0.0006	-0.0012	0.0008	0.0013	-0.0004
-20%	150	0.0032	-0.0016	-0.0006	0.0012	-0.0008	-0.0013	-0.0001	0.0006	-0.0003
-20%	175	0.0024	-0.0012	-0.0003	0.0014	-0.0010	-0.0014	-0.0002	0.0002	0.0002
-20%	200	0.0013	-0.0022	-0.0004	0.0012	-0.0004	-0.0014	0.0000	0.0002	0.0001
-20%	300	0.0008	-0.0008	-0.0018	0.0007	0.0000	-0.0018	-0.0002	0.0002	-0.0002
-40%	25	0.0099	0.0031	-0.0085	-0.0011	0.0015	-0.0047	0.0027	0.0016	0.0002
-40%	50	0.0049	0.0019	-0.0055	-0.0011	0.0027	-0.0005	0.0016	0.0020	0.0004
-40%	75	0.0016	0.0022	-0.0035	-0.0003	0.0011	-0.0005	0.0016	0.0003	-0.0009
-40%	100	0.0028	0.0042	-0.0016	0.0007	0.0017	0.0002	0.0019	-0.0001	-0.0003
-40%	125	0.0039	0.0021	-0.0039	0.0012	0.0011	-0.0003	0.0022	-0.0004	-0.0008
-40%	150	0.0030	0.0019	-0.0030	0.0004	0.0009	0.0001	0.0013	-0.0003	-0.0011
-40%	175	0.0031	0.0025	-0.0026	0.0003	0.0014	0.0005	0.0018	-0.0004	-0.0009
-40%	200	0.0028	0.0017	-0.0031	0.0007	0.0008	0.0012	0.0019	0.0000	-0.0011
-40%	300	0.0010	0.0008	-0.0022	0.0003	0.0007	0.0012	0.0016	-0.0001	-0.0002

The precision of the occupancy estimates was also assessed by examining the mean coefficient of variation (CV) for the first-year occupancy estimate. The dynamic occupancy model allows estimation of the occupancy rate for the first year of the monitoring period, with estimates of occupancy in subsequent years calculated as a function of the extinction and colonization rates. Calculating standard errors for estimates of occupancy after the first year requires bootstrapping; therefore, to reduce computation time, the precision of only the first-year estimate of occupancy was assessed. The mean CV across the 1,000 iterations for each simulation is provided in Table 9. CV ranges from 0.0414 to 0.1583 for all sample sizes and falls consistently below 0.1000 for sample sizes of at least 75 sites per year. Precision of the first-year occupancy estimate improves as the number of sites increases and as the number of nights of sampling within a year increases. Precision is not impacted by the magnitude of the trend.

Table 9: Mean Coefficient of Variation of the First-Year Occupancy Estimate

Net trend	Sites	5 years			10 years			20 years		
		3 nights	5 nights	7 nights	3 nights	5 nights	7 nights	3 nights	5 nights	7 nights
-20%	25	0.1566	0.1459	0.1448	0.1545	0.1469	0.1439	0.1567	0.1456	0.1479
-20%	50	0.1100	0.1024	0.1020	0.1097	0.1038	0.1019	0.1106	0.1024	0.1025
-20%	75	0.0896	0.0835	0.0833	0.0896	0.0846	0.0832	0.0897	0.0832	0.0833
-20%	100	0.0778	0.0724	0.0718	0.0778	0.0727	0.0723	0.0778	0.0720	0.0720
-20%	125	0.0697	0.0647	0.0642	0.0695	0.0651	0.0647	0.0695	0.0641	0.0643
-20%	150	0.0633	0.0592	0.0586	0.0634	0.0595	0.0590	0.0635	0.0586	0.0587
-20%	175	0.0587	0.0548	0.0541	0.0586	0.0550	0.0545	0.0587	0.0543	0.0544
-20%	200	0.0550	0.0512	0.0506	0.0549	0.0515	0.0508	0.0549	0.0509	0.0508
-20%	300	0.0449	0.0418	0.0414	0.0447	0.0420	0.0414	0.0448	0.0416	0.0415
-40%	25	0.1552	0.1476	0.1455	0.1561	0.1475	0.1446	0.1583	0.1458	0.1442
-40%	50	0.1094	0.1037	0.1021	0.1098	0.1028	0.1021	0.1105	0.1030	0.1017
-40%	75	0.0894	0.0844	0.0834	0.0895	0.0839	0.0830	0.0900	0.0840	0.0828
-40%	100	0.0774	0.0728	0.0721	0.0771	0.0727	0.0717	0.0777	0.0724	0.0716
-40%	125	0.0695	0.0651	0.0644	0.0690	0.0650	0.0643	0.0693	0.0650	0.0642
-40%	150	0.0635	0.0593	0.0589	0.0630	0.0592	0.0587	0.0633	0.0593	0.0585
-40%	175	0.0587	0.0549	0.0545	0.0584	0.0548	0.0542	0.0587	0.0550	0.0540
-40%	200	0.0549	0.0513	0.0510	0.0547	0.0512	0.0506	0.0548	0.0514	0.0506
-40%	300	0.0448	0.0419	0.0416	0.0447	0.0420	0.0414	0.0446	0.0419	0.0414

Example GRTS Sample

For illustrative purposes, a sampling frame of 3 mi^2 grid cells was imposed onto the island of Hawaii and an equiprobable GRTS sample of 150 sites was selected from the population of 1451 grid cells (Figure 7). The spatially-balanced sample placed sites in urban areas (in red) and in high-elevation areas that may not be included in the target population if annual monitoring were restricted to the lactation and post-lactation seasons. Note that this frame can be reduced to include specific parameters (e.g., only large landowners, sites within a mile of a road) so long as accurate spatial information is available.

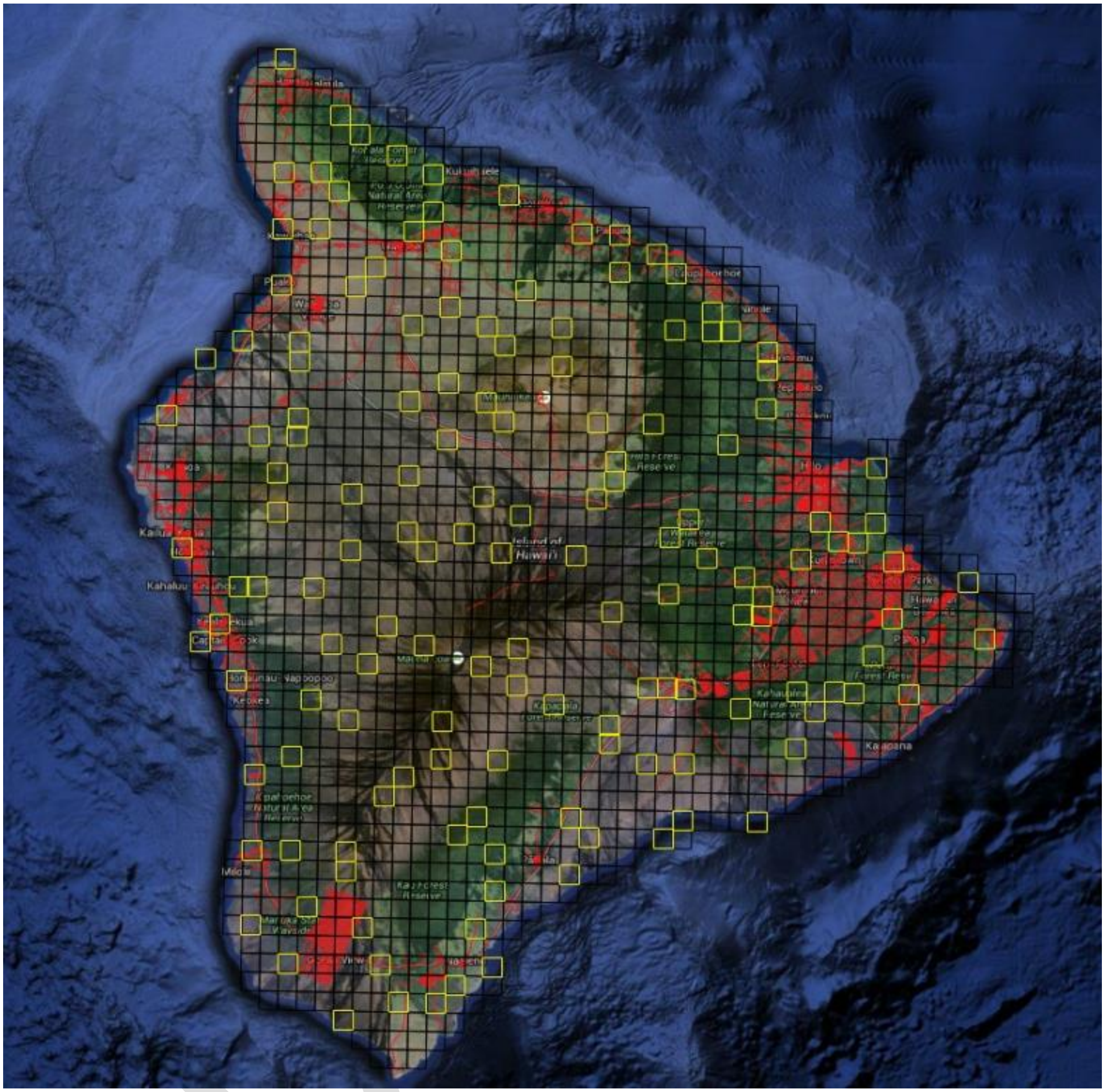

Figure 7: Example GRTS sample of 150 points on the island of Hawaii

DISCUSSION

These results suggest that the occupancy estimates from the dynamic occupancy model are accurate and precise estimators of true annual occupancy and the trend estimate from the log-linear regression model provides the basis for a powerful trend test under certain assumptions. The log-linear regression trend estimator is relatively unbiased and attains nearly-nominal confidence interval coverage under all simulation scenarios examined for the given occupancy parameters.

To achieve power of 0.80 for a two-sided trend test, annual samples of about 100- 125 sites would be needed to detect a 40% decline in occupancy over the 5-year monitoring period (Table 5). For net trends of 20% and 40% over 10 years, annual sample sizes of 150 and 50 sites, respectively, would be required to attain power of 0.80. For a 20-year monitoring period, detecting net trends of 20% and 40% with a two-sided trend test requires annual monitoring of 75 and 25 sites, respectively. These power simulations indicate that the annual sample size of sites is more important than the number of within-year revisits to a site for improving trend test power. For estimation in the likelihood framework, annual sampling of the same sites rather than implementing a panel design is recommended (MacKenzie et al. 2005).

Higher power for trend testing may be obtained by examining only a test for a decline in the population-level occupancy rate (Table 6). For example, a 40% decline over 5 years is detected with a one-sided trend test by sampling 75 sites per year rather than 125 for similar power of a two-sided trend test. If detecting population declines is more pressing than detecting trends in either direction, smaller sample sizes may be sufficient for monitoring. Similarly, trend test power is higher for longer monitoring periods even if annual sample sizes or annual trend magnitudes are smaller. Increasing the temporal sample size by consistent sampling over time provides the basis for a powerful trend test.

These sample size estimates are not dependent on the extent of the island but are simply based on the variability introduced by the model parameters. Sample size approximation for the other three islands will require an assessment of occupancy parameters if the parameters are believed to be different. If differences in island size or elevation impact the detection probability or other dynamic occupancy parameters, then the sample results may differ for those islands. For islands without pilot data, the first year of monitoring data could be used to inform a power analysis to determine if each sample size is appropriate for trend detection at each island.

The number of visits (detector nights) is not as influential on the power to detect trend as the number of independent sites examined. This result suggests that detectors could be moved within a season to other locations to increase the sample size if this would provide a cost savings relative to purchase and monitoring of more detectors. Furthermore, restricting annual sampling to a single season (or as in the pilot data, two contiguous seasons) reduces variability in the sample and might allow reduction of the sampling frame if Hawaiian hoary bats do not occupy certain areas during those times of the year. Frame reduction could simplify the field season and reduce the effort needed to move detectors within a season.

Mean relative bias and the CV of annual occupancy estimates may provide useful criteria for sample size approximation if estimates based on a power analysis for trend prove unattainable. If trend detection for longer monitoring periods of 10 to 20 years is of interest, the sample sizes that provide adequately unbiased and precise estimates of annual trend may provide the best guideline for sampling design planning.

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For potential discussion on the 12/1/15 call, the following 2 graphics provided to illustrate the effect of a reduced level of occupancy and lower probability of detection, which may be more representative of some islands.

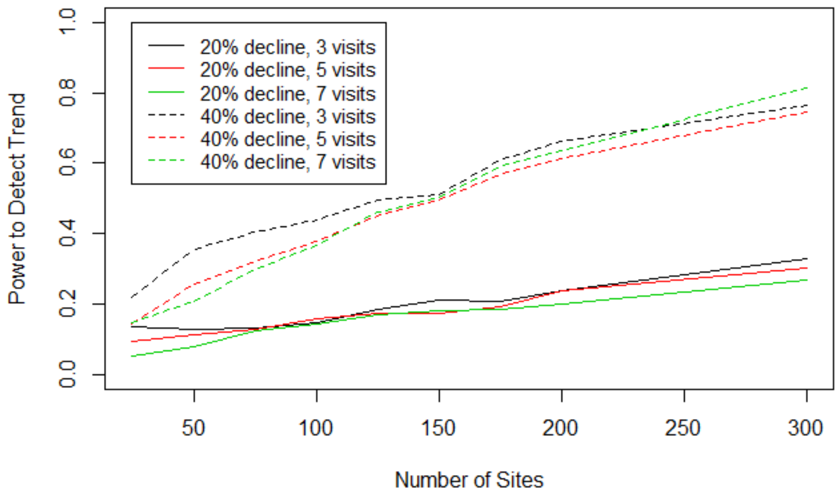

Figure 8: Power to detect Hawaiian hoary bat occupancy trends *in either direction* over a 5-year monitoring period for a population with initial occupancy of 0.3306, a detection rate of 0.3200, and an extinction rate of 0.0686.

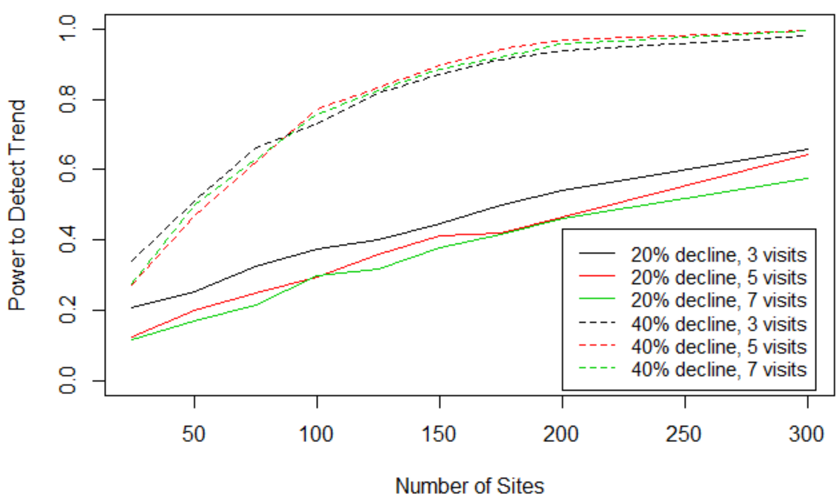

Figure 9: Power to detect Hawaiian hoary bat occupancy trends *in either direction* over a 10-year monitoring period for a population with initial occupancy of 0.3306, a detection rate of 0.3200, and an extinction rate of 0.0686.