



Technical Report HCSU-035

## 2011 KIWIKIU (MAUI PARROTBILL) AND MAUI `ALAUAHIO ABUNDANCE ESTIMATES AND THE EFFECT OF SAMPLING EFFORT ON POWER TO DETECT A TREND

Kevin W. Brinck<sup>1</sup>, Richard J. Camp<sup>1</sup>, P. Marcos Gorresen<sup>1</sup>, David L. Leonard<sup>2</sup>,  
Hanna L. Mounce<sup>3</sup>, Kelly J. Iknayan<sup>3</sup>, and Eben H. Paxton<sup>4</sup>

<sup>1</sup>Hawai`i Cooperative Studies Unit, University of Hawai`i at Hilo,  
P.O. Box 44, Hawai`i National Park, HI

<sup>2</sup>Pacific Cooperative Studies Unit, University of Hawai`i at Manoa,  
1151 Punchbowl Street, Honolulu, HI

<sup>3</sup>Maui Forest Bird Recovery Project, 2465 Olinda Road, Makawao, HI

<sup>4</sup>U.S. Geological Survey, Pacific Island Ecosystems Research Center, Kilauea Field Station,  
P.O. Box 44, Hawai`i National Park, HI

Hawai`i Cooperative Studies Unit  
University of Hawai`i at Hilo  
200 W. Kawili St.  
Hilo, HI 96720  
(808) 933-0706

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MOUNCE<sup>3</sup>, KELLY J. IKNAYAN<sup>3</sup>, AND EBEN H. PAXTON<sup>4</sup>**

<sup>1</sup> Hawai`i Cooperative Studies Unit, University of Hawai`i at Hilo,  
P.O. Box 44, Hawai`i National Park, HI

<sup>2</sup> Pacific Cooperative Studies Unit, University of Hawai`i at Mānoa,  
1151 Punchbowl Street, Honolulu, HI

<sup>3</sup> Maui Forest Bird Recovery Project, 2465 Olinda Road, Makawao, HI

<sup>4</sup> U.S. Geological Survey, Pacific Island Ecosystems Research Center,  
P.O. Box 44, Hawai`i National Park, HI

Hawai`i Cooperative Studies Unit  
University of Hawai`i at Hilo  
200 W. Kawili St.  
Hilo, HI 96720  
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## BACKGROUND

The Kiwikiu (*Pseudonestor xanthophrys*), also called the Maui Parrotbill, is an endangered, forest bird found only in high elevation, wet forest of the eastern portion of Maui Island. Recent surveys, conducted at five year intervals, have revealed wide variation in abundance estimates (Camp *et al.* 2009). Effective management and conservation requires accurate estimates of abundance, which is difficult for rare species such as the Kiwikiu because low density leads to few observations, resulting in low sample size and high uncertainty in abundance estimates. In addition to being rare, they occur in remote, difficult to access terrain, which makes them difficult to detect and further reduces the accuracy of counts.

The Maui `Alauahio (*Paroreomyza montana*), sometimes called the Maui Creeper, historically occupied the entire island of Maui (Gorresen *et al.* 2009). It has since been extirpated from much of its original habitat and now occurs in forested areas of East Maui where its habitat overlaps with that of the Kiwikiu. Though they share the same habitat, the `Alauahio is much more abundant—by more than two orders of magnitude—and occurs over a wider range than the Kiwikiu.

Both species appear to have no statistically significant population trend from 1980–2001, but abundance estimates vary widely from survey to survey and have wide uncertainties (Camp *et al.* 2009). Ideally survey design should result in estimates precise enough to be able to detect significant declines in abundance that may trigger management intervention.

We wished to improve the accuracy of Kiwikiu abundance estimates and the ability to detect significant trends in abundance. To that end, in 2011, repeated point count surveys were conducted across the Kiwikiu range, excluding Haleakalā National Park (Figure 1). The increased sampling effort increases sample size and improves the precision of estimates, and repeat samples also allowed us to partition within-year and between-year variation in surveys, increasing the statistical power to detect trends.

## METHODS

### Point Counts

The East Maui forest was surveyed for forest birds in 1980 and again in 1992, 1996, and 2001 using standardized point count surveys (Scott *et al.* 1986, Camp *et al.* 2009). Between March and May of 2006 and March and June of 2011 trained observers conducted point counts along eight transects totaling 214 stations in 2006 and 227 stations in 2011. In 2006 stations along three transects (7–9, identified as “core” transects for the Kiwikiu) were surveyed two to four times each (mean 3.2 visits/station), and in 2011 all stations were surveyed three times, and stations on the core transects were surveyed from three to nine times (mean 7.4 visits/station). These transects run from high to low elevation and cross the 3,693 ha Kiwikiu range, beginning above and ending below the forest habitat where they are known to persist.

During each visit observers conducted standardized eight-minute point counts, recording the species, distance, and type of detection (aural or visual) for each bird observed. Observers also recorded the time, cloud cover, rain intensity, and prevailing and gusting wind strength on a Beaufort scale.

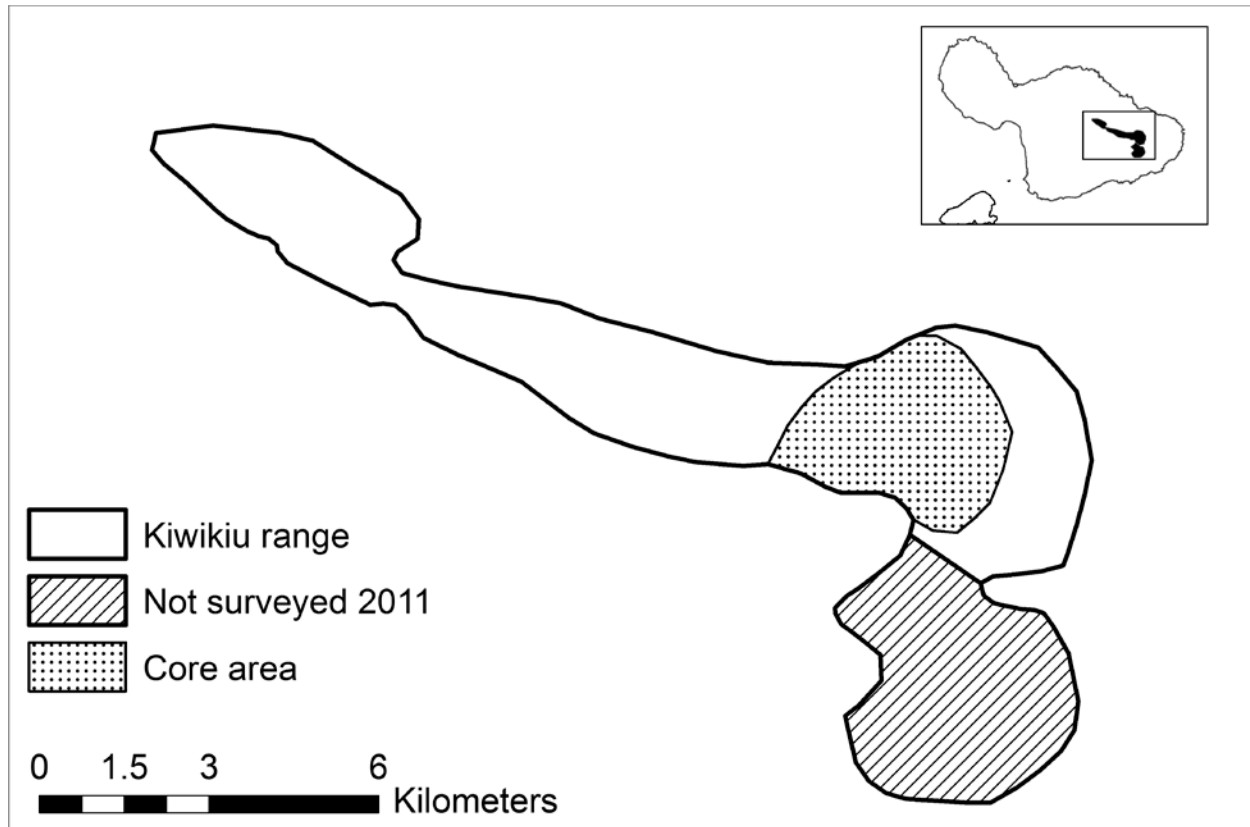


Figure 1. The Kiwikiu range with the barred area indicating Kīpahulu Valley in Haleakalā National Park, which was not included in this analysis. The majority of Kiwikiu observations occurred in the core area (dotted).

### Density Estimates

Using the point count data, Kiwikiu and ʻAlauahio densities were estimated using program DISTANCE, version 6.0, release 2 (Thomas *et al.* 2010). Detectability model selection was based on the corrected Akaike’s Information Criterion (AICc; Burnham and Anderson 2002). Both detection type and survey year were used as covariates in the model. There were too few detections per individual observer to estimate the observer effect on detectability. We also stratified the area surveyed to within and outside the core of the known Kiwikiu range (Figure 1).

Estimates of abundance accounting for varying detectability among surveys were calculated using point-transect sampling methods to produce comparable estimates across years. DISTANCE models account for imperfect detection of birds by estimating detection probability as a function of distance from the observer. Covariates to the detection model account for different environmental and behavioral factors that alter detectability across years, allowing for comparable abundance estimates. As a simplifying calculation in deriving density from detectability, the effective area surveyed by an observer is obtained by integrating the product of the detection function and the area surveyed to produce the effective detection radius—the radius of a circle with area equal to the effectively surveyed area. Model uncertainty is represented in density calculations as the variance of the effective detection radius ( $\sigma_r^2$ ).

Following the procedure detailed in Thomas *et al.* (2010), abundance of a bird species in the survey area is estimated as

$$\hat{N} = d \cdot A \quad (\text{Equation 1})$$

where  $d$  is the estimated density and  $A$  is the total survey area of interest. Estimated density is calculated as

$$\hat{d} = \frac{n_{counted}}{a_{surveyed}} \quad (\text{Equation 2})$$

Where  $n_{counted}$  is the number of birds counted and  $a_{surveyed}$  is the effective area examined by the observers in the course of the survey. If  $s$  is the number of stations and  $v$  is the number of visits to each station, then

$$n_{counted} = s \cdot v \cdot \delta \quad (\text{Equation 3})$$

where  $\delta$  is the number of birds counted per station, and

$$a_{surveyed} = s \cdot v \cdot \pi \cdot r_{eff}^2 \quad (\text{Equation 4})$$

where  $r_{eff}$  is the effective detection radius from the distance model. The effective detection radius is derived from the detection function and so will vary depending upon the value of covariates such as the survey year. The estimated density is then

$$\hat{d} = \frac{\delta}{\pi \cdot r_{eff}^2} \quad (\text{Equation 5})$$

### Variance Partitioning

Using the stations within the Kiwikiu range along the core transects in 2006 and 2011, which were surveyed three times in 2006 and up to nine times in 2011, the variance in the number of detections at a given station was partitioned into between-year ( $\sigma_B^2$ ) and within-year ( $\sigma_W^2$ ) variance by modeling the number of detections at a given visit to a station as a constant  $\delta$ , with variance

$$\sigma_\delta^2 = \sigma_B^2 + \sigma_W^2 \quad (\text{Equation 6})$$

Note that this assumes constant density among all stations on those transects, as well as constant density between 2006 and 2011 (i.e., no change in Kiwikiu abundance). We also assume a normal distribution of the number of Kiwikiu detected, which is unusual for a count response ranging from 0 to 4, but given the large number of station visits (466 total) we believe it is a justified simplifying assumption.

The measured  $\sigma_B^2$  assumes that all of the observed differences between 2006 and 2011 are due to uncertainty in the observation process. If there were an actual change in density from 2006 to 2011 then the measured  $\sigma_B^2$  is too large. Similarly if Kiwikiu density varies considerably within the core area  $\sigma_W^2$  is too large. If either or both are true then  $\sigma_\delta^2$  is an over-estimate and actual uncertainties will be smaller than predicted and the calculated sampling effort to achieve a given monitoring goal will be greater than is actually needed. If the true distribution of counts per station is multinomial or a hierarchical Poisson process with a very small mean and a large variance (conditions under which a normal approximation would break down even with large



sample size) then again this estimate of  $\sigma_\delta^2$  will be too large and our predictions are conservative.

Total variance ( $\sigma_\delta^2$ ) was calculated as the total variation in the number of detections across both years. Within-year variance was calculated as the (weighted) mean variance in the number of detections in each year. Between-year variance was calculated in two ways: as the variance of the mean number of detections across both years, and as the difference between  $\sigma_\delta^2$  and  $\sigma_W^2$ . As the latter was always larger than the former we chose it as a conservative estimate for further calculations.

### Power Analysis

Power is the probability that a statistical test will detect an effect given that the effect is actually present (Zar 1996). We estimated the power of a simple linear regression to detect a 50% decline in density over 25 years, given varying intervals of 1, 3, or 5 years between surveys. Although in theory regression models incorporating auto-correlation between successive estimates would be a preferable technique, simple linear regression was used because the current series of estimates is sparse and variable, and does not allow us to estimate the degree of temporal auto-correlation. Power estimates using simple linear regression will be over-estimates predicting more power than estimates of the ability to detect a real decline incorporating temporal auto-correlation.

Given the estimates of between- and within-year variance, we estimated power by simulating abundance estimates across a 25-year span. The mean simulated abundance was calculated as a linear decline beginning with the density observed in 2011 and progressing evenly to the final density (75% or 50% of the initial density) in the final year 2035. Between- and within-year variances were similarly scaled linearly. For each year the  $\sigma_d^2$  was calculated for the number of stations ( $s$ ), visits ( $\nu$ ), and effective detection radius ( $r_{eff}$ ).

The between- and within-year variances contribute to the uncertainty in the number of birds counted at a station in inverse proportion to the number of stations and visits respectively. If the between-year variance scaled for a particular year is  $\sigma_{By}^2$  and within-year is  $\sigma_{Wy}^2$ , the per-observation variance is their sum as in Equation 6, and the variance in the number counted for that year  $\sigma_{\delta_y}^2$  is the per-observation variance scaled for  $s$  stations times  $\nu$  visits producing  $s \cdot \nu$  total observations.

$$\sigma_{\delta_y}^2 = s^2 \cdot \nu^2 \cdot \left( \frac{\sigma_{By}^2}{s} + \frac{\sigma_{Wy}^2}{\nu} \right) \quad (\text{Equation 7})$$

For calculating the density given  $s$ ,  $\nu$ , and  $r_{eff}$  and converting from detection distances in meters to densities in birds per hectare it is useful to define a constant ( $K$ )

$$K = \frac{10,000}{s \cdot \nu \cdot \pi} \quad (\text{Equation 8})$$

The estimated density is then

$$\widehat{d}_y = \delta_y \cdot \frac{K}{r_{eff}^2} \quad (\text{Equation 9})$$

and the estimated variance of  $d$ , via the delta method (Casella and Berger 1990), is

$$\widehat{\sigma}_d^2 = \frac{K^2 \cdot \sigma_\delta^2}{r^4} + \frac{4 \cdot v^2 \cdot d_y^2}{r^6 \cdot \sigma_{ref}^2} \quad (\text{Equation 10})$$

A random normal abundance estimate was generated for each year, and a simple linear regression was estimated for the series. The number of stations ( $s$ ) was held constant at 44 (the number of stations in the core habitat sampled in 2011) and  $v$  ranged from 1 to 10 visits per station survey. This procedure was repeated 10,000 times and the simulated power was calculated as the proportion of significant ( $p(H_0 \text{ of slope} = 0) < 0.10$ ) regressions.

### Stratifying the Survey Area

Inspection of the results of the 2011 and previous surveys revealed that the majority of Kiwikiu detections are on the core stations of transects 7–9. We investigated the potential precision benefits of stratifying Kiwikiu habitat inside and outside this core area (Figure 1) by conducting a *post-facto* stratified survey from 1980–2011 using only detections from the habitat outside Kīpahulu Valley in Haleakalā National Park. `Alauahio detections were much less concentrated, and their range extends outside of Kiwikiu habitat, so we did not investigate the results of stratification for them.

## RESULTS

### Bird Abundance

The 95% confidence interval for Kiwikiu abundance in 2011 was between 209 and 674 birds (point estimate: 421 birds, Table 1). This estimate was for the 36.9 km<sup>2</sup> northeastern Maui habitat excluding 13.7 km<sup>2</sup> of known bird habitat within Haleakalā National Park (Figure 1) that was not surveyed in 2011. There were no birds detected outside the known Kiwikiu range, so the estimate of bird abundance outside its range is zero.

The best-fit detection function for Kiwikiu used a half-normal function with no adjustment terms. No covariates were significant. Right-tail truncation was set at 69.0 m, the distance where detection probability was approximately 10%.

Within the 36.9 km<sup>2</sup> Kiwikiu range, the 95% confidence range for `Alauahio abundance was between 52,729 and 57,921 (point estimate: 55,262 birds; Table 1). For this model right-tail truncation was set at 38.0 m. The best-fit model used a hazard-rate base function with two polynomial adjustment terms of orders 4 and 6. Survey year was a significant covariate.

The model effective detection radius for Kiwikiu was 37.2 m with a variance of 1.91. For `Alauahio the effective detection radius was 15.1 m with a variance of 0.02.

### Variance Partitioning

For Kiwikiu, the between-year variance in number of detections per visit was estimated at 0.0365, and within-year variance was estimated at 0.0829. For `Alauahio between-year variance was 0.1992 and within-year variance was 1.364.

### Power Analysis

In general, power increases with increasing number of visits to each station during each annual survey and with fewer years between surveys (Table 2, Figure 2). To achieve 90% power to detect a 50% decline over 25 years for Kiwikiu would require four visits per station for each of

Table 1. Abundance point estimates, 95% bootstrapped confidence intervals (CI), and number of on-point detections for Kiwikiu and Maui `Alauahio within the Kiwikiu range by year. Asterisked values (1992, 2006, and 2011) indicate years when Kīpahulu Valley was not surveyed and refer only to the northern area in Figure 1).

Year	Kiwikiu			Maui `Alauahio		
	# detections	Abundance	95% CI	# detections	Abundance	95% CI
1980	19	704	543–1,451	243	53,966	51,979–56,023
1992	18	592*	265–978	475	95,224*	91,856–98,718
1996	13	1,105	582–2,605	94	69,185	65,477–73,103
2001	23	717	487–1,589	190	66,592	63,246–70,115
2006	22	861*	433–1,345	254	60,030*	57,770–62,378
2011†	24	421*	209–674	517	55,262*	52,729–57,921

† Although no Kiwikiu were detected outside the core area, the species persists at low densities and a small group breeds in Waikamoi at the western edge of the species' range (Gorresen *et al.* 2009, Hawai`i Division of Forestry and Wildlife, unpublished data).

\* These abundance estimates do not include Kīpahulu Valley in Haleakalā National Park (line-shaded area in Figure 1).

Table 2. The effect of repeated visits on the coefficient of variation (CV) of estimated Kiwikiu abundance in a single year, and estimated power to detect a 50% decline in abundance over 25 years for Kiwikiu and Maui `Alauahio.

Visits per station	CV abundance	Years between surveys					
		Kiwikiu			`Alauahio		
		1	3	5	1	3	5
1	50.6%	19%	13%	12%	28%	16%	14%
2	22.3%	46%	24%	18%	68%	36%	26%
3	14.7%	75%	40%	30%	94%	60%	43%
4	11.6%	93%	57%	43%	100%	80%	64%
5	10.0%	99%	74%	56%	100%	93%	78%
6	9.2%	100%	85%	68%	100%	98%	90%
7	8.6%	100%	92%	78%	100%	100%	96%
8	8.3%	100%	96%	85%	100%	100%	98%
9	8.1%	100%	98%	90%	100%	100%	100%
10	8.0%	100%	99%	93%	100%	100%	100%

25 annual surveys, seven visits per station with eight surveys (one survey every three years), and nine visits per station on five surveys (one survey every five years). This corresponds to a relative effort of 100, 56, and 45 station visits across the 25 year span—though logistic costs associated with organizing and conducting a survey would need to be considered to perform a definitive cost/benefit analysis.

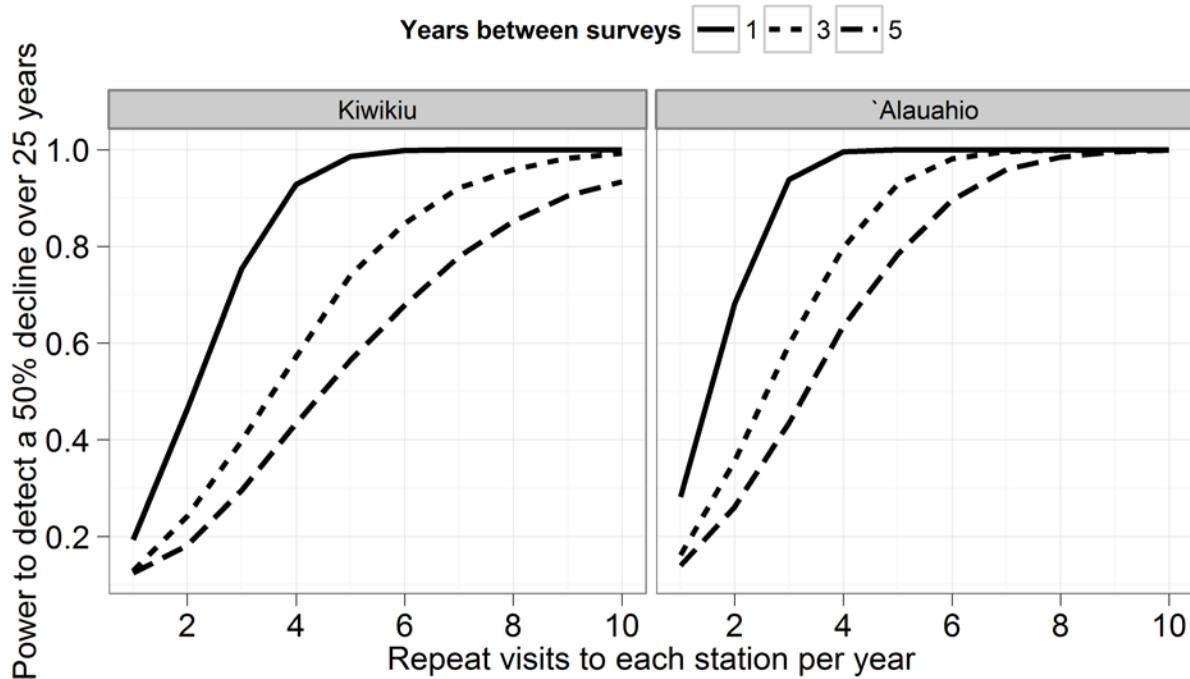


Figure 2. Power to detect a 50% decline over 25 years for the Kiwikiu and Maui `Alauahio. Curves represent the increasing power with increasing number of visits to each station in each survey year. Line types indicate that power decreases as the number of years between surveys increases from annually, to every three years, to every five years.

For `Alauahio the corresponding effort to reach 90% power are three visits for annual surveys, five visits surveying every three years, and six visits surveying every five years. Relative effort for the three survey schemes is 75, 40, and 30 station visits.

Using the observed within-year variation among repeat visits to stations in the core area of Kiwikiu habitat, the relative effect of increased survey effort on the precision of a single year's estimate is given in Table 2. With a single visit per year the estimated coefficient of variation (CV) of the abundance estimate is greater than 50%, but with five repeat visits CV drops to 10%. An additional five visits (10 total) further reduces the CV by only 2% more, to 8%.

### Stratifying the Survey Area

In general, stratifying Kiwikiu range to inside and outside the core habitat divides the range into a small (941 ha), relatively densely populated area and a larger (2,752 ha), sparsely populated area. Table 3 shows that in most years the majority of the estimated Kiwikiu abundance is in the larger, less dense area outside the core area, the exception being 2011 when all detections were inside the core. Producing separate density estimates for the two strata and adding the point estimates together results in a moderate (34%) increase in the abundance estimate for 1980, but moderate to large decreases (-8% to -44%) in the other years (Table 4).

Table 3. Kiwikiu abundance point estimates, 95% bootstrapped confidence intervals (CI), and number of on-point detections for the non-Kīpahulu Valley portion of Kiwikiu habitat, also partitioned to inside and outside the core habitat (see Figure 1). In 1996 only inside core transects were surveyed, so outside and total estimates are not available (na). The stations column indicates the number of distinct stations surveyed that year, and effort is the total number of station visits counting repeat visits to stations.

Year	Stations	Effort	Total non-Kīpahulu range			Inside core			Outside core		
			Detections	Abundance	95% CI	Detections	Abundance	95% CI	Detections	Abundance	95% CI
1980	121	121	24	946	452–1,568	15	263	68–478	9	683	227–1,261
1992	120	132	8	332	57–685	7	233	31–538	1	99	0–313
1996	50	53		na		10	414	122–767		na	
2001	119	148	9	544	168–1,006	5	95	22–190	4	449	104–932
2006	119	218	22	796	215–1,695	17	226	99–380	5	570	0–1,394
2011	119	482	24	239	65–209	24	129	66–201	0	0	–

Table 4. Total Kiwikiu abundance point estimates and 95% bootstrapped confidence intervals (CI) for the non-Kīpahulu Valley portion of Kiwikiu habitat both with and without stratification. In 1996 only inside core transects were surveyed, so total estimates are not available (na). Also shown is the range of the confidence interval and the ratio of that range to the abundance estimate (relative range). Percent (%) change summarizes the effect of stratification on the abundance estimate introduced by stratifying.

Year	Without stratification				With stratification				
	Abundance	95% CI	CI range	Relative range	Abundance	95% CI	CI range	Relative range	% change
1980	704	543–1,451	908	1.29	946	452–1,568	1,116	1.18	34%
1992	592	265–978	713	1.20	332	57–685	628	1.89	-44%
1996			na				na		
2001	717	487–1,589	1,102	1.54	544	168–1,006	838	1.54	-24%
2006	861	433–1,345	912	1.06	796	215–1,695	1,480	1.86	-8%
2011	421	209–674	465	1.10	239	65–209	144	0.60	-43%

The effect of stratifying on precision is also variable. Using the width of the 95% bootstrap confidence interval divided by the abundance estimate as proxy for relative precision, Table 4 reveals that in two years (1992 and 2006) stratifying decreases precision, in 1980 and 2011 it improves precision, and in 2001 it has no effect on relative precision of the estimate.

## DISCUSSION

Kiwikiu abundance in 2011 appears to have declined from the 2006 survey but the difference is not statistically significant with large overlaps in the confidence intervals. In the same period *Alauahio* abundance estimates show no evidence of a significant change. Although only detected in the core area during the 2011 systematic survey, it is known that *Kiwikiu* exist outside the core area in low densities. Because of their low density and smaller numbers *Kiwikiu* in low density areas would be even more difficult to detect, and precise estimates of their numbers would require even more survey effort than in the core habitat. Alternative methods of estimating abundance, such as mark-resight techniques, might be more efficient at producing precise estimates of low-density populations than simply increasing point-transect survey effort.

This technique of variance partitioning followed by power simulations under a range of sampling designs can be used to determine the sampling effort to meet quantitatively defined monitoring goals. In this study we used a goal of detecting a 50% decline over 25 years, which is a large if gradual change with significant implications for the long-term viability of the species. Different degrees of decline (or increase) could be used for power simulations, as could shorter or longer time spans.

The magnitude of between- and within-year variation also has an effect on the sampling effort needed to reach a specified monitoring goal. *Alauahio* were present in greater densities than *Kiwikiu* in the study area, but between-year variation was more than five times that of *Kiwikiu*, and within-year variation 16 times greater. Despite their greater density, their distribution within the surveyed area was much more variable, meaning the sampling effort to meet monitoring goals for *Alauahio* is only slightly less than for *Kiwikiu*.

Additionally this study used a desired goal of 90% power with an acceptable 10% false positive rate—a situation where both Type I and Type II errors are the same (Di Stefano 2003). Different error rates or asymmetric error rates could be used—the precautionary principle would argue for greater power with a larger Type I error rate (e.g., 95% power with 20% false positives) in order to increase the chances of detecting a declining population threatened with extinction.

For this monitoring study we examined intervals of one, three, and five years between surveys with varying amounts of effort (visits per station) within each survey. Measuring survey effort solely in terms of the number of station visits, the sparsest survey design (with visits every five years) was the most efficient way to meet the goal of detecting a 50% decline over 25 years. It is important to note that this efficiency does not account for additional logistic costs associated with conducting surveys. Also there are other monitoring goals that might be affected by survey interval; with five years between surveys a sudden, catastrophic population event may go undetected for as long as five years.

To detect sudden, catastrophic declines a hybrid survey protocol might be employed. A subset of the highest-density area could be surveyed between survey intervals. If the number of detections were below a specified threshold, that would trigger an out-of-cycle full survey to ascertain the population status. Such a threshold could be based on the median or 3<sup>rd</sup> quartile of detections on the subset in previous years.

These power simulations were based on surveys in the highest density Kiwikiu core region. Because detections per survey effort are lower there, variation in counts per station decreases (because the vast majority of counts are zero) but the estimated density is extrapolated to a much larger area, resulting in proportionally larger uncertainty in abundance (larger CV). As such, detecting trends in abundance outside the core area will require more intensive sampling effort than within the core.

### **Future Elaboration**

Stratifying the Kiwikiu range estimates to inside and outside the core habitat has the potential to improve precision in population abundance estimates, but the results are mixed across the five surveys described in Table 4. If the core area identified in the 2011 survey represents a persistent phenomenon, then stratifying would significantly increase precision in the abundance estimate. However, in all previous surveys there were detections outside the core resulting in a positive density of birds there, which, when extrapolated to the entire range, resulted in a majority of abundance existing outside the core. It is known from observations outside the standardized surveys that Kiwikiu are present outside the core area (Hawai`i Division of Forestry and Wildlife, unpublished data). In 2011 outside-core stations were surveyed three times each; future survey efforts might allocate extra survey effort to the outside-core strata to increase the odds of detecting any birds that are there. To avoid bias, survey effort allocation must be decided before surveys commence (Thompson 1992).

A potential weakness of this simulation method involves the assumption of normally distributed detections during an annual survey. The law of large numbers shows that for a sufficiently large number of stations this assumption will be valid, for small, zero-inflated count values (such as the Kiwikiu show) “sufficiently large” may be greater than the number of visits analyzed in this study (3–9 visits at 44 stations). For survey regimes with lower survey effort per year this is especially a concern (e.g., Hawai`i Division of Forestry and Wildlife surveys in Pu`u Wa`awa`a and the Mauna Kea Forest Reserve). Instead, individual detections at a station might be modeled as a binomial process, a multinomial process, or a hierarchal binomial/Poisson process.

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