Technical Report HCSU-097

FOREST BIRD POPULATION TRENDS WITHIN HALEAKALĀ NATIONAL PARK

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Abstract

In 2017, the comprehensive east Maui bird surveys allowed for an update in status and evaluation of trends in bird populations within Haleakalā National Park. This report describes a finer-scale analysis of the park lands, distinguishing between the upper Kīpahulu Valley plus adjacent high-elevation areas compared to the rest of the park. I report abundance estimates and assess trends for six native and three non-native bird species within the park. Overall abundance estimates are consistent with those in previous reports, but there is some evidence for different densities between the two areas of the park, and relative densities of some species may vary from survey to survey. With two possible exceptions (native ʻapapane and non-native red-billed leiothrix), recent trends indicate that bird populations are in decline.

Introduction

The Kīpahulu Valley, plus some adjacent high-elevation areas, is an important conservation area in Haleakalā National Park on the Island of Maui. It is home to several native bird species, including the endangered ʻākohekohe (*Palmeria dolei*), kiwikiu (*Pseudonestor xanthophrys*), and Maui ʻalauahio (*Paroreomyza montana newtoni*). The area was part of the original Hawaii Forest Bird Surveys (Scott *et al.* 1986) beginning in 1980 and has since been surveyed for birds at semi-regular intervals by the Hawaii State Division of Forestry and Wildlife and by the National Park Service Inventory and Monitoring Program.

As part of these surveys, a National Park Service Natural Resource Report (Judge *et al.* 2019) provided estimates and trends assessments for native and non-native birds across east Maui, including estimates for Haleakalā National Park. Because the Kīpahulu area is of special management concern, and the possibility that bird populations in the region might behave differently than within the park as a whole, park managers requested a separate analysis to look at abundance and trends specifically in Kīpahulu.

The aim of this report is to re-analyze some of the data collected for the Judge *et al.* (2019) report to focus on Haleakalā National Park. In addition, for those species with sufficient observations, I provide an alternative, more robust assessment of trends using the entire available time series of abundance estimates. I also provide distinct abundance estimates and trend assessments for both the Kīpahulu Valley region (including adjacent high-elevation areas) and the non-valley areas of the park.

Methods

Source Data

In the area of east Maui, forest bird surveys were conducted by state and federal agencies sporadically from 1980 to 2017 following the protocol described in Camp (2011). The survey methods and effort are described in Judge *et al.* (2019). The analyses in this report are based upon the same source data as described in that document, augmented by additional survey data collected from 1993 to 2008 (Brinck *et al.* 2020). Non-native species that are present in east Maui but only occasionally detected within the park boundaries were not analyzed.

Area of Inference

The geographic range of the survey transects limits the extent of inference that can be made from those surveys. Figure 1 shows the boundary of inference used in the Judge *et al.* (2019) report along with the area of Haleakalā National Park. The abundance estimates and trends assessments in this report refer to the intersections of the park boundary and the survey inference area. Observations outside these areas are used to fit detection functions for each bird species but are not used to estimate density.

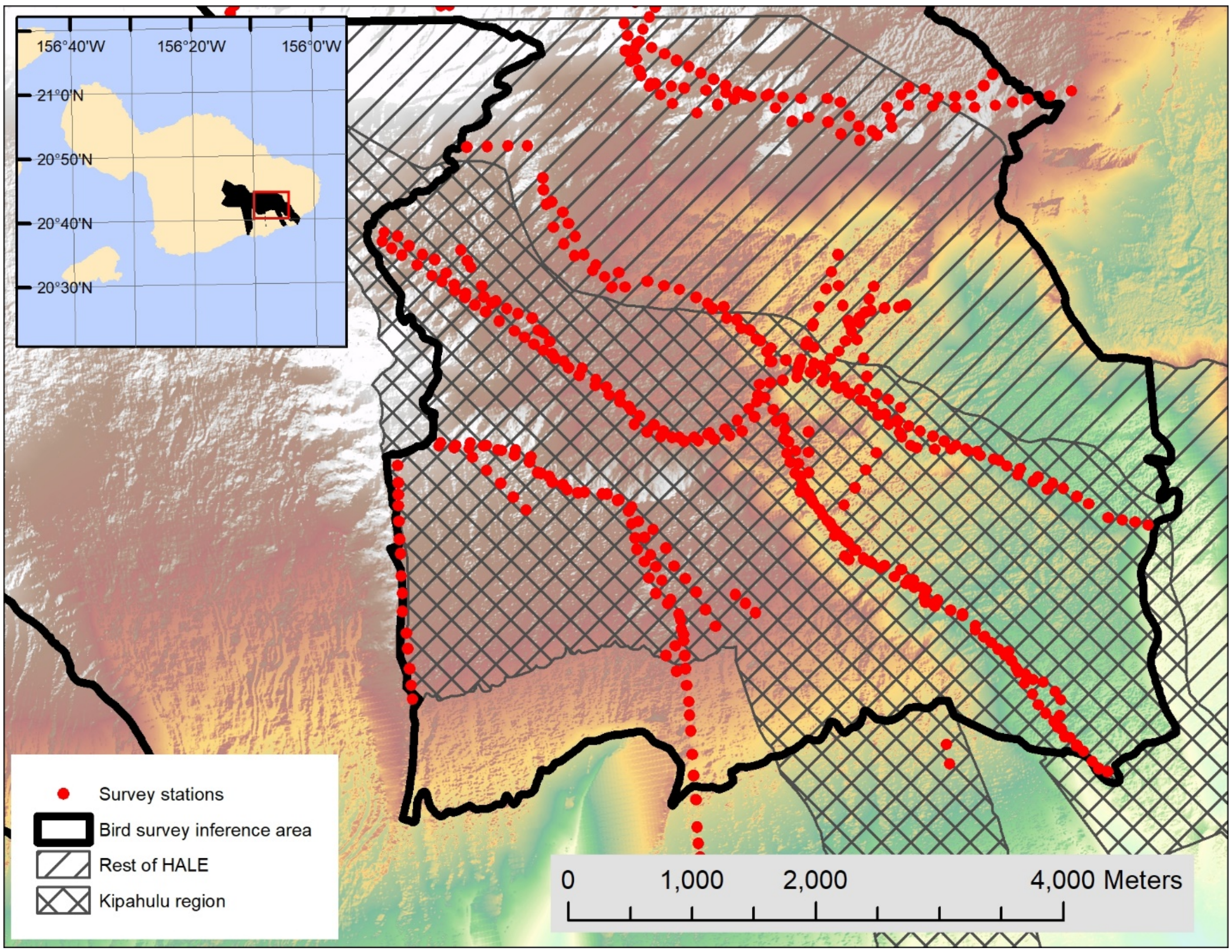


Figure 1. Area of inference within Haleakalā National Park. The area of inference from the forest bird surveys is indicated with a black outline. The grey cross-hatching indicates the extent of Haleakalā National Park (HALE), and the double cross-hatching distinguishes the Kīpahulu Valley and related high-elevation areas from the non-valley regions of the park. Red dots indicate the survey stations within and near the inference area. In this report, inference is limited to the intersection of those areas with abundance and trends for the valley and non-valley regions of the park. The inset map shows Maui Island with HALE and the extent of the larger map.

The park area is further divided into the Kīpahulu Valley and adjacent high-elevation areas (hereafter "valley") and the rest of the park ("non-valley"). Three species of birds (ʻākohekohe, kiwikiu, and Maui ʻalauahio) are considered range-restricted, meaning their occupied habitat is smaller than the survey area (though still extending beyond the park boundaries). Figure 2a–c shows the ranges of those species relative to the areas within Haleakalā National Park, and Table 1 gives the area of the inference ranges (their intersection). Three other native species (ʻapapane [*Himatione sanguinea*], Hawaiʻi ʻamakihi [*Chlorodrepanis virens*], and ʻiʻiwi [*Drepanis coccinea*]) and three non-native species (Japanese bush-warbler [*Horornis diphone*], warbling white-eye [*Zosterops japonicus*, formerly "Japanese white-eye"], and red-billed leiothrix [*Leiothrix lutea*]) were considered to have an unrestricted range, extending through the entire surveyed area of interest. It is worth remarking that in the Judge *et al.* (2019) report, ʻiʻiwi are classified as restricted, but as their restricted range covers the surveyed park habitat they are considered unrestricted here.

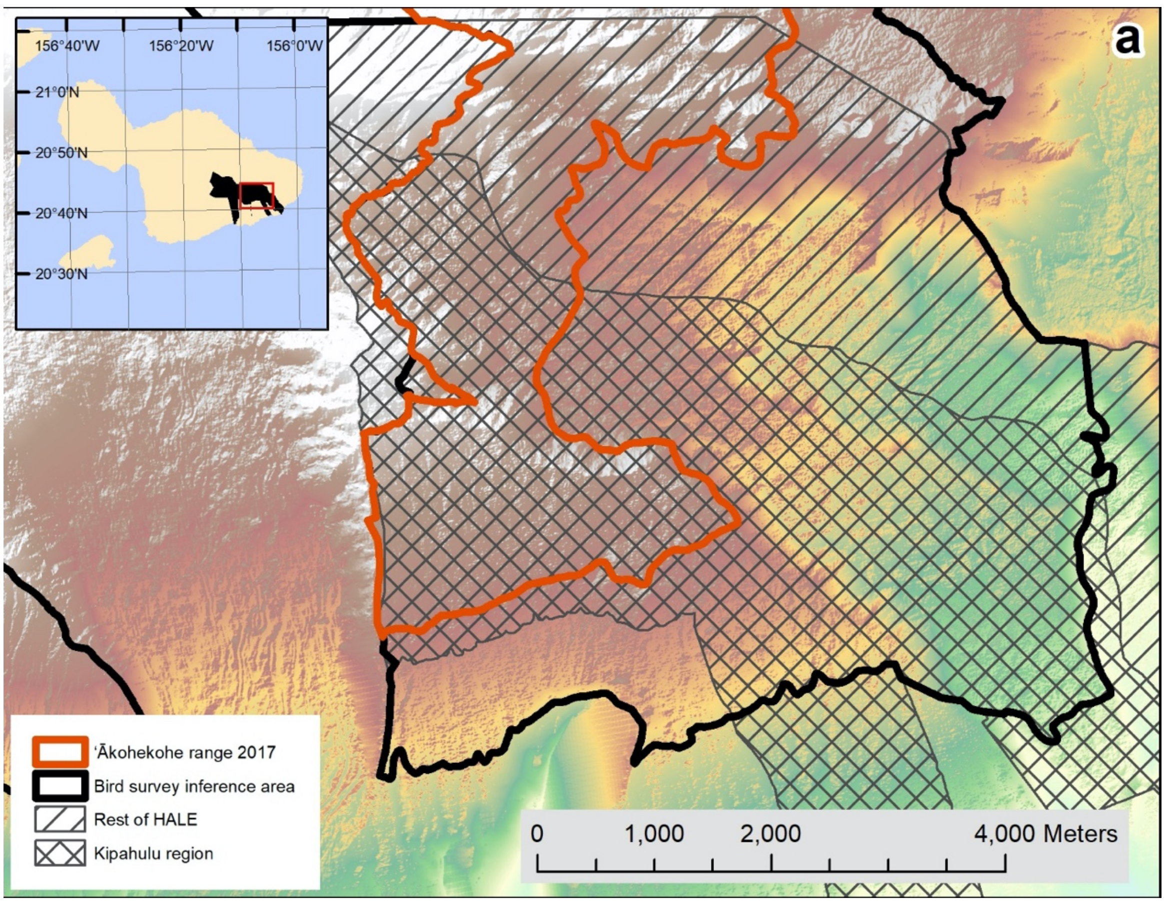
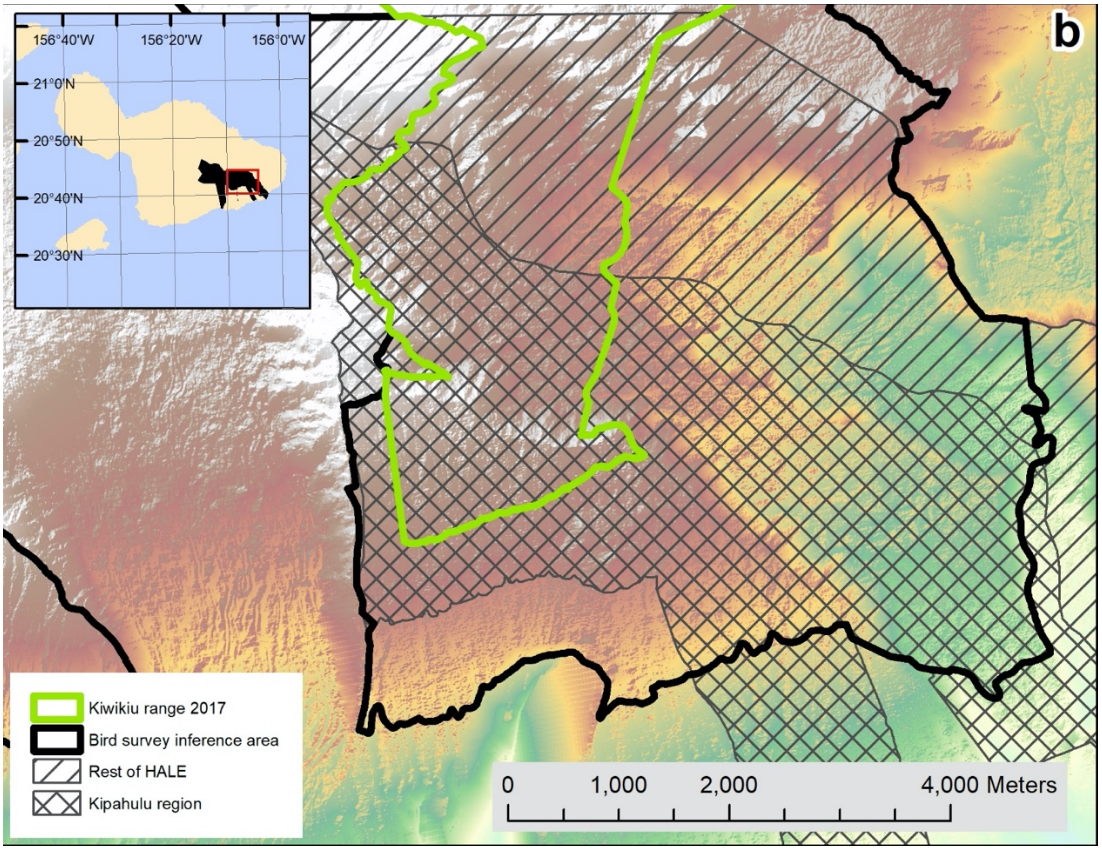


Figure 2. Area of inference for restricted-range species. These three figures show the ranges of ʻākohekohe (a), kiwikiu (b), and Maui ʻalauahio (c) along with the survey inference area. Abundance estimates and trend assessments for these species in Haleakalā National Park (HALE) are restricted to the intersection of the species ranges and the valley (Kīpahulu region) or non-valley areas of the park.


b
156°40'W
156°20'W
156°0'W
21°0'N
20°50'N
20°40'N
20°30'N
Kiwikiu range 2017
Bird survey inference area
Rest of HALE
Kipahulu region
0
1,000
2,000
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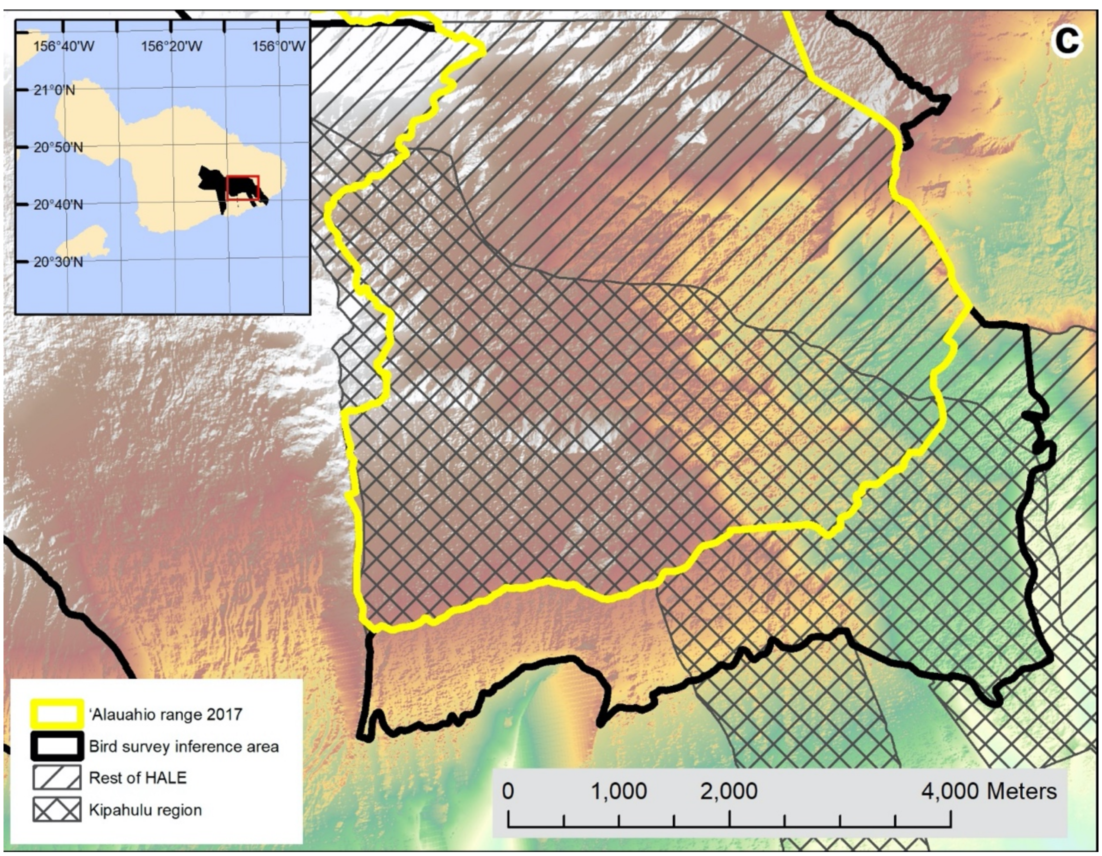
c
156°40'W
156°20'W
156°0'W
21°0'N
20°50'N
20°40'N
20°30'N
'Alauahio range 2017
Bird survey inference area
Rest of HALE
Kipahulu region
0
1,000
2,000
4,000 Meters

Table 1. Area of occupied species habitat in the regions of Haleakalā National Park. These are the areas of the intersection between the species range and the regions of the park. Unrestricted species' (ʻapapane, ʻiʻiwi, Hawaiʻi ʻamakihi, and non-native birds) ranges extend beyond the survey, so their inference area is the full intersection between the survey inference and the park regions.

	Area (ha)	
Species	Valley	Non-valley
ʻĀkohekohe	643	376
Kiwikiu	549	375
Maui ʻalauahio	1,300	1,025
Unrestricted	1,818	1,100

Abundance Estimation

Point-transect distance sampling is used to estimate the density and abundance of forest birds. Using the distances to detected birds, a detection function is estimated for each species. Sometimes environmental or other covariates are used to improve the precision of the detection function. The density at each survey station is estimated from the detection function, and the average density within a region is then multiplied by the area of that region to produce an estimate of abundance (Buckland *et al.* 2001). Density and abundance estimates were generated using program DISTANCE (Thomas *et al.* 2010), and subsequent analyses were performed within the R statistical environment (R version 3.6.3, R Core Team 2019).

In the 2019 Judge *et al.* report, abundance estimates for Haleakalā National Park were obtained by multiplying the average density at survey stations within the park by the area of the park or the area of the subset as appropriate for range-restricted species. This estimate assumes a constant density across the entire park area, which may not be an accurate assumption. For this report, I used the same detection functions reported by Judge *et al.* (2019) to estimate densities. I departed from their methods by sub-dividing the park (into the valley and non-valley regions) and estimating separate densities for each region. I then multiplied densities by the area of each region to estimate distinct abundances, then added them together to calculate abundance for the entire park. This total calculated as the sum of the two regions will not necessarily be the same as the total abundance estimate reported in Judge *et al.* (2019), and this difference will also affect trend assessments for each region. Also, I did not estimate density or abundance for a region if there were fewer than 10 stations surveyed in a region for a given year nor calculate a total for years without an estimate for each region.

Uncertainty in abundance estimates was derived by bootstrap resampling of the survey stations. Within each year and region, the observed stations were randomly re-sampled (with replacement) to match the actual survey effort, and then density and abundance were re-estimated. This procedure was repeated 999 times to produce a range of estimates that incorporate the observed spatial variation within the sample. The 2.5^{th} and 97.5^{th} percentiles of these thousand (random samples plus the observed sample) estimates were used as a 95% credible interval around point estimates of abundance.

Trend Assessment

I used the bootstrap values (generated by program DISTANCE to estimate uncertainty in population abundance) to fit the long-term population trend (1980–2017) with a log-linear regression model. Because the log-linear model is sensitive to gaps in the data and there is a 12-year gap after the first survey in 1980, and because recent trends are of more interest to managers, I also fit a log-linear regression using the 2000–2017 surveys. The evidence of a trend was determined from the bootstrap distribution of slopes, following Camp *et al.* (2015).

I assessed trends in an equivalence-testing approach (Camp *et al.* 2008). I chose a biologically meaningful threshold of population trend as a 25% change over a 25-year period. For a log-linear slope this corresponds to thresholds of >0.0093 for an upward trend or <-0.0119 for a downward trend. The proportion of probability (from the bootstrap distribution of slopes or differences) that exceeds those thresholds is a measure of the evidence for an upward or downward trend, while probability between the thresholds indicates evidence for a stable or negligible trend. I categorized >50% weight as weak, >70% weight as strong, and >90% weight as very strong evidence of a trend. Outcomes where no category has >50% weight indicate a system that is too noisy to detect a trend if present.

Context

To place the results of this report into the context of the Judge *et al.* (2019) report, I also compared park-wide abundance estimates for the endangered and range-restricted ʽākohekohe, kiwikiu, and Maui ʽalauahio. For those same species I also examined the relation between estimated abundance/density in the valley and non-valley regions of the park.

RESULTS

Abundance

Abundance and density estimates for the valley and non-valley regions of Haleakalā National Park are reported below for all nine species (Table 2). For range-restricted species, there were insufficient samples within each region and species range intersection to estimate abundance for both regions in some years. In those years, no total abundance for that species is reported, as there was insufficient survey effort to make an inference for the park as a whole.

Table 2. Abundance and density estimates. Each table row shows estimated abundance and density (with 95% bootstrap credible intervals) in the two regions of Haleakalā National Park. Blank cells (e.g., ʽākohekohe in 2011) indicate years where there were insufficient surveys to estimate abundance in that region. Total abundances of valley and non-valley regions are shown just once (on the line for the valley region); no totals are calculated for years where one region was not estimated.

Species	Year	Region	Total	Abundance		Density	
ʽĀkohekohe	1980	Valley	2,873	2,284	(1,589-3,283)	3.6	(2.5-5.1)
	1980	Non-valley		589	(367-945)	1.6	(1.0-2.5)
	1992	Valley	1,157	752	(477-1,186)	1.2	(0.7-1.8)
	1992	Non-valley		405	(195-839)	1.1	(0.5-2.2)
	1993	Valley	2,905	1,716	(1,190-2,475)	2.7	(1.9-3.9)

Species	Year	Region	Total	Abundance		Density	
	1993	Non-valley		1,189	(784-1,804)	3.2	(2.1-4.8)
	1996	Valley	2,868	1,994	(1,443-2,755)	3.1	(2.2-4.3)
	1996	Non-valley		874	(629-1,215)	2.3	(1.7-3.2)
	1997	Valley	2,333	1,675	(1,227-2,285)	2.6	(1.9-3.6)
	1997	Non-valley		658	(296-1,467)	1.8	(0.8-3.9)
	1998	Valley	1,312	736	(354-1,532)	1.1	(0.6-2.4)
	1998	Non-valley		576	(211-1,574)	1.5	(0.6-4.2)
	1999	Valley	2,733	1,606	(1,036-2,490)	2.5	(1.6-3.9)
	1999	Non-valley		1,127	(697-1,823)	3.0	(1.9-4.9)
	2000	Valley	5,353	3,721	(3,116-4,444)	5.8	(4.8-6.9)
	2000	Non-valley		1,632	(1,076-2,476)	4.3	(2.9-6.6)
	2001	Valley	5,404	3,725	(2,972-4,669)	5.8	(4.6-7.3)
	2001	Non-valley		1,679	(1,186-2,376)	4.5	(3.2-6.3)
	2003	Valley		2,631	(1,648-4,202)	4.1	(2.6-6.5)
	2005	Valley	1,550	1,305	(876-1,943)	2.0	(1.4-3.0)
	2005	Non-valley		245	(108-553)	0.7	(0.3-1.5)
	2006	Valley	1,302	797	(324-1,961)	1.2	(0.5-3.1)
	2006	Non-valley		505	(289-884)	1.3	(0.8-2.4)
	2011	Non-valley		275	(111-680)	0.7	(0.3-1.8)
	2012	Valley	1,079	326	(159-670)	0.5	(0.2-1.0)
	2012	Non-valley		753	(408-1,392)	2.0	(1.1-3.7)
	2017	Valley	718	584	(397-859)	0.9	(0.6-1.3)
	2017	Non-valley		134	(78-230)	0.4	(0.2-0.6)
‘Apapane	1993	Valley	86,922	59,986	(55,747-64,548)	33.0	(30.7-35.5)
	1993	Non-valley		26,936	(22,530-32,203)	24.5	(20.5-29.3)

Species	Year	Region	Total	Abundance		Density	
	1996	Valley	89,198	52,265	(44,327-61,625)	28.8	(24.4-33.9)
	1996	Non-valley		36,933	(28,789-47,381)	33.6	(26.2-43.1)
	1997	Valley	96,778	63,419	(56,429-71,275)	34.9	(31.0-39.2)
	1997	Non-valley		33,359	(28,171-39,502)	30.3	(25.6-35.9)
	1998	Valley	77,835	53,081	(47,995-58,707)	29.2	(26.4-32.3)
	1998	Non-valley		24,754	(20,329-30,143)	22.5	(18.5-27.4)
	1999	Valley	75,940	46,666	(41,884-51,993)	25.7	(23.0-28.6)
	1999	Non-valley		29,274	(25,534-33,562)	26.6	(23.2-30.5)
	2000	Valley	70,020	44,286	(41,503-47,255)	24.4	(22.8-26.0)
	2000	Non-valley		25,734	(22,597-29,307)	23.4	(20.5-26.6)
	2001	Valley	54,976	29,732	(27,384-32,280)	16.4	(15.1-17.8)
	2001	Non-valley		25,244	(22,206-28,699)	23.0	(20.2-26.1)
	2003	Valley		62,217	(50,829-76,157)	34.2	(28.0-41.9)
	2005	Valley	43,342	30,710	(28,511-33,079)	16.9	(15.7-18.2)
	2005	Non-valley		12,632	(11,368-14,038)	11.5	(10.3-12.8)
	2006	Valley		44,300	(36,899-53,186)	24.4	(20.3-29.3)
	2008	Valley	74,866	45,081	(38,260-53,117)	24.8	(21.1-29.2)
	2008	Non-valley		29,785	(21,705-40,871)	27.1	(19.7-37.2)
	2011	Non-valley		2,482	(1,875-3,286)	2.3	(1.7-3.0)
	2012	Valley	63,886	39,378	(34,944-44,374)	21.7	(19.2-24.4)

Species	Year	Region	Total	Abundance		Density	
	2012	Non-valley		24,508	(20,832-28,834)	22.3	(18.9-26.2)
	2017	Valley	45,023	32,247	(28,622-36,331)	17.7	(15.7-20.0)
	2017	Non-valley		12,776	(10,388-15,712)	11.6	(9.4-14.3)
Hawai‘i ‘amakihi	1993	Valley	40,494	27,158	(24,752-29,798)	14.9	(13.6-16.4)
	1993	Non-valley		13,336	(11,574-15,368)	12.1	(10.5-14.0)
	1996	Valley	24,378	15,069	(10,760-21,106)	8.3	(5.9-11.6)
	1996	Non-valley		9,309	(6,650-13,029)	8.5	(6.0-11.8)
	1997	Valley	41,444	29,919	(25,592-34,977)	16.5	(14.1-19.2)
	1997	Non-valley		11,525	(9,755-13,616)	10.5	(8.9-12.4)
	1998	Valley	34,633	23,324	(19,978-27,230)	12.8	(11.0-15.0)
	1998	Non-valley		11,309	(9,562-13,375)	10.3	(8.7-12.2)
	1999	Valley	28,049	16,651	(14,605-18,983)	9.2	(8.0-10.4)
	1999	Non-valley		11,398	(10,139-12,814)	10.4	(9.2-11.7)
	2000	Valley	29,793	18,046	(15,662-20,794)	9.9	(8.6-11.4)
	2000	Non-valley		11,747	(9,824-14,046)	10.7	(8.9-12.8)
	2001	Valley	26,766	14,709	(13,321-16,243)	8.1	(7.3-8.9)
	2001	Non-valley		12,057	(10,392-13,989)	11.0	(9.4-12.7)
	2003	Valley		14,976	(10,056-22,304)	8.2	(5.5-12.3)
	2005	Valley	22,140	17,581	(15,637-19,767)	9.7	(8.6-10.9)
	2005	Non-valley		4,559	(3,902-5,328)	4.1	(3.5-4.8)
	2006	Valley		12,786	(8,942-18,283)	7.0	(4.9-10.1)

Species	Year	Region	Total	Abundance		Density	
	2008	Valley	44,632	28,674	(24,098-34,119)	15.8	(13.3-18.8)
	2008	Non-valley		15,958	(8,372-30,416)	14.5	(7.6-27.7)
	2011	Non-valley		756	(453-1,262)	0.7	(0.4-1.1)
	2012	Valley	18,174	13,007	(11,244-15,047)	7.2	(6.2-8.3)
	2012	Non-valley		5,167	(3,856-6,924)	4.7	(3.5-6.3)
	2017	Valley	11,248	7,775	(6,623-9,126)	4.3	(3.6-5.0)
	2017	Non-valley		3,473	(2,707-4,456)	3.2	(2.5-4.1)
ʻIʻiwi	1993	Valley	22,307	14,204	(3,203-62,994)	7.8	(1.8-34.6)
	1993	Non-valley		8,103	(1,821-36,068)	7.4	(1.7-32.8)
	1996	Valley	24,915	16,026	(3,583-71,687)	8.8	(2.0-39.4)
	1996	Non-valley		8,889	(1,943-40,671)	8.1	(1.8-37.0)
	1997	Valley	24,959	16,118	(3,626-71,641)	8.9	(2.0-39.4)
	1997	Non-valley		8,841	(1,984-39,383)	8.0	(1.8-35.8)
	1998	Valley	24,826	15,246	(3,421-67,946)	8.4	(1.9-37.4)
	1998	Non-valley		9,580	(2,147-42,765)	8.7	(2.0-38.9)
	1999	Valley	22,603	15,097	(3,401-67,024)	8.3	(1.9-36.9)
	1999	Non-valley		7,506	(1,680-33,536)	6.8	(1.5-30.5)
	2000	Valley	28,386	18,532	(4,177-82,235)	10.2	(2.3-45.2)
	2000	Non-valley		9,854	(2,210-43,934)	9.0	(2.0-39.9)
	2001	Valley	28,612	17,423	(3,929-77,256)	9.6	(2.2-42.5)
	2001	Non-valley		11,189	(2,511-49,863)	10.2	(2.3-45.3)
	2003	Valley		31,731	(7,081-142,177)	17.5	(3.9-78.2)
	2005	Valley	16,146	12,048	(2,715-53,464)	6.6	(1.5-29.4)
	2005	Non-valley		4,098	(917-18,311)	3.7	(0.8-16.6)

Species	Year	Region	Total	Abundance		Density	
	2006	Valley		15,670	(3,447-71,228)	8.6	(1.9-39.2)
	2008	Valley	20,954	13,398	(3,012-59,590)	7.4	(1.7-32.8)
	2008	Non-valley		7,556	(1,684-33,913)	6.9	(1.5-30.8)
	2011	Non-valley		611	(133-2,799)	0.6	(0.1-2.5)
	2012	Valley	19,722	15,049	(3,386-66,891)	8.3	(1.9-36.8)
	2012	Non-valley		4,673	(1,022-21,365)	4.2	(0.9-19.4)
	2017	Valley	18,129	13,089	(2,946-58,176)	7.2	(1.6-32.0)
	2017	Non-valley		5,040	(1,131-22,462)	4.6	(1.0-20.4)
Kiwikiu	1980	Valley	130	0	(0-0)	0.0	(0.0-0.0)
	1980	Non-valley		130	(49-344)	0.3	(0.1-0.9)
	1992	Valley	239	123	(51-296)	0.2	(0.1-0.5)
	1992	Non-valley		116	(37-363)	0.3	(0.1-1.0)
	1993	Valley	233	141	(75-266)	0.3	(0.1-0.5)
	1993	Non-valley		92	(31-271)	0.2	(0.1-0.7)
	1996	Valley	844	721	(654-796)	1.3	(1.2-1.4)
	1996	Non-valley		123	(30-505)	0.3	(0.1-1.3)
	1997	Valley	31	0	(0-0)	0.0	(0.0-0.0)
	1997	Non-valley		31	(5-182)	0.1	(0.0-0.5)
	1998	Valley	131	0	(0-0)	0.0	(0.0-0.0)
	1998	Non-valley		131	(53-327)	0.4	(0.1-0.9)
	1999	Valley	0	0	(0-0)	0.0	(0.0-0.0)
	1999	Non-valley		0	(0-0)	0.0	(0.0-0.0)
	2000	Valley	257	126	(63-251)	0.2	(0.1-0.5)
	2000	Non-valley		131	(42-414)	0.4	(0.1-1.1)
	2001	Valley	263	234	(113-488)	0.4	(0.2-0.9)
	2001	Non-valley		29	(5-169)	0.1	(0.0-0.5)

Species	Year	Region	Total	Abundance		Density	
	2005	Valley	18	18	(3-100)	0.0	(0.0-0.2)
	2005	Non-valley		0	(0-0)	0.0	(0.0-0.0)
	2006	Non-valley		0	(0-0)	0.0	(0.0-0.0)
	2011	Non-valley		0	(0-0)	0.0	(0.0-0.0)
	2012	Valley	311	87	(22-336)	0.2	(0.0-0.6)
	2012	Non-valley		224	(72-697)	0.6	(0.2-1.9)
	2017	Valley	39	0	(0-0)	0.0	(0.0-0.0)
	2017	Non-valley		39	(12-131)	0.1	(0.0-0.4)
Maui ʻalauahio	1980	Valley	18,900	11,074	(8,159-15,030)	8.5	(6.3-11.6)
	1980	Non-valley		7,826	(5,177-11,830)	7.6	(5.0-11.5)
	1992	Valley	50,297	30,000	(25,455-35,356)	23.1	(19.6-27.2)
	1992	Non-valley		20,297	(15,203-27,097)	19.8	(14.8-26.4)
	1993	Valley	35,916	21,446	(17,881-25,723)	16.5	(13.8-19.8)
	1993	Non-valley		14,470	(10,625-19,705)	14.1	(10.4-19.2)
	1996	Valley	58,418	40,830	(29,794-55,953)	31.4	(22.9-43.0)
	1996	Non-valley		17,588	(12,197-25,362)	17.2	(11.9-24.7)
	1997	Valley	54,634	38,940	(31,404-48,283)	30.0	(24.2-37.1)
	1997	Non-valley		15,694	(11,612-21,212)	15.3	(11.3-20.7)
	1998	Valley	41,654	23,273	(18,698-28,967)	17.9	(14.4-22.3)
	1998	Non-valley		18,381	(13,186-25,621)	17.9	(12.9-25.0)
	1999	Valley	44,542	25,516	(20,565-31,658)	19.6	(15.8-24.4)
	1999	Non-valley		19,026	(13,736-26,354)	18.6	(13.4-25.7)

Species	Year	Region	Total	Abundance		Density	
	2000	Valley	46,358	27,899	(22,598-34,444)	21.5	(17.4-26.5)
	2000	Non-valley		18,459	(12,834-26,551)	18.0	(12.5-25.9)
	2001	Valley	34,072	16,343	(12,994-20,556)	12.6	(10.0-15.8)
	2001	Non-valley		17,729	(13,143-23,914)	17.3	(12.8-23.3)
	2003	Valley		35,117	(21,418-57,579)	27.0	(16.5-44.3)
	2005	Valley	20,317	12,993	(10,349-16,313)	10.0	(8.0-12.6)
	2005	Non-valley		7,324	(5,297-10,127)	7.1	(5.2-9.9)
	2006	Valley	20,005	15,471	(10,138-23,610)	11.9	(7.8-18.2)
	2006	Non-valley		4,534	(1,947-10,558)	4.4	(1.9-10.3)
	2008	Valley	71,916	26,577	(19,944-35,416)	20.4	(15.3-27.2)
	2008	Non-valley		45,339	(24,603-83,551)	44.2	(24.0-81.5)
	2011	Non-valley		911	(474-1,752)	0.9	(0.5-1.7)
	2012	Valley	28,386	12,517	(9,188-17,051)	9.6	(7.1-13.1)
	2012	Non-valley		15,869	(10,166-24,770)	15.5	(9.9-24.2)
	2017	Valley	19,288	8,601	(6,323-11,699)	6.6	(4.9-9.0)
	2017	Non-valley		10,687	(7,739-14,759)	10.4	(7.5-14.4)
Japanese bush-warbler	1993	Valley	6,931	4,153	(3,696-4,666)	2.3	(2.0-2.6)
	1993	Non-valley		2,778	(2,225-3,469)	2.5	(2.0-3.2)
	1996	Valley	4,508	3,198	(2,560-3,994)	1.8	(1.4-2.2)
	1996	Non-valley		1,310	(509-3,377)	1.2	(0.5-3.1)
	1997	Valley	7,306	4,422	(3,709-5,271)	2.4	(2.0-2.9)
	1997	Non-valley		2,884	(2,136-3,894)	2.6	(1.9-3.5)

Species	Year	Region	Total	Abundance		Density	
	1998	Valley	5,964	3,745	(3,197-4,387)	2.1	(1.8-2.4)
	1998	Non-valley		2,219	(1,707-2,886)	2.0	(1.6-2.6)
	1999	Valley	6,475	4,127	(3,589-4,746)	2.3	(2.0-2.6)
	1999	Non-valley		2,348	(1,891-2,915)	2.1	(1.7-2.7)
	2000	Valley	8,488	5,299	(4,659-6,027)	2.9	(2.6-3.3)
	2000	Non-valley		3,189	(2,680-3,795)	2.9	(2.4-3.5)
	2001	Valley	6,295	3,772	(3,435-4,142)	2.1	(1.9-2.3)
	2001	Non-valley		2,523	(1,998-3,185)	2.3	(1.8-2.9)
	2003	Valley		3,411	(1,419-8,198)	1.9	(0.8-4.5)
	2005	Valley	6,233	4,539	(4,087-5,041)	2.5	(2.2-2.8)
	2005	Non-valley		1,694	(1,459-1,966)	1.5	(1.3-1.8)
	2006	Valley		2,166	(935-5,015)	1.2	(0.5-2.8)
	2008	Valley	11,330	6,457	(5,562-7,496)	3.6	(3.1-4.1)
	2008	Non-valley		4,873	(3,789-6,267)	4.4	(3.4-5.7)
	2011	Non-valley		125	(66-240)	0.1	(0.1-0.2)
	2012	Valley	6,321	3,929	(3,529-4,374)	2.2	(1.9-2.4)
	2012	Non-valley		2,392	(1,851-3,091)	2.2	(1.7-2.8)
	2017	Valley	5,009	3,704	(3,231-4,247)	2.0	(1.8-2.3)
	2017	Non-valley		1,305	(989-1,722)	1.2	(0.9-1.6)
Warbling white-eye	1993	Valley	55,237	37,661	(33,614-42,196)	20.7	(18.5-23.2)
	1993	Non-valley		17,576	(15,077-20,489)	16.0	(13.7-18.6)
	1996	Valley	49,679	26,042	(19,453-34,862)	14.3	(10.7-19.2)
	1996	Non-valley		23,637	(16,440-33,983)	21.5	(14.9-30.9)
	1997	Valley	59,785	34,572	(26,882-44,463)	19.0	(14.8-24.5)

Species	Year	Region	Total	Abundance		Density	
	1997	Non-valley		25,213	(20,009-31,770)	22.9	(18.2-28.9)
	1998	Valley	39,181	25,174	(21,200-29,892)	13.9	(11.7-16.4)
	1998	Non-valley		14,007	(11,567-16,962)	12.7	(10.5-15.4)
	1999	Valley	46,267	28,258	(24,517-32,569)	15.5	(13.5-17.9)
	1999	Non-valley		18,009	(14,319-22,650)	16.4	(13.0-20.6)
	2000	Valley	40,824	26,278	(22,942-30,100)	14.5	(12.6-16.6)
	2000	Non-valley		14,546	(11,289-18,742)	13.2	(10.3-17.0)
	2001	Valley	40,117	27,140	(23,825-30,915)	14.9	(13.1-17.0)
	2001	Non-valley		12,977	(9,704-17,354)	11.8	(8.8-15.8)
	2003	Valley		26,042	(7,744-87,577)	14.3	(4.3-48.2)
	2005	Valley	24,598	19,345	(17,167-21,800)	10.6	(9.4-12.0)
	2005	Non-valley		5,253	(4,355-6,336)	4.8	(4.0-5.8)
	2006	Valley		23,871	(15,567-36,607)	13.1	(8.6-20.1)
	2008	Valley	41,459	33,580	(26,956-41,832)	18.5	(14.8-23.0)
	2008	Non-valley		7,879	(7,644-8,121)	7.2	(7.0-7.4)
	2011	Non-valley		862	(467-1,589)	0.8	(0.4-1.4)
	2012	Valley	39,346	31,017	(26,192-36,731)	17.1	(14.4-20.2)
	2012	Non-valley		8,329	(5,722-12,123)	7.6	(5.2-11.0)
	2017	Valley	27,437	20,083	(16,429-24,549)	11.1	(9.0-13.5)
	2017	Non-valley		7,354	(4,959-10,905)	6.7	(4.5-9.9)
Red-billed leiothrix	1993	Valley	9,049	6,426	(5,465-7,557)	3.5	(3.0-4.2)

Species	Year	Region	Total	Abundance		Density	
	1993	Non-valley		2,623	(1,999-3,443)	2.4	(1.8-3.1)
	1996	Valley	10,379	6,423	(4,539-9,088)	3.5	(2.5-5.0)
	1996	Non-valley		3,956	(2,504-6,250)	3.6	(2.3-5.7)
	1997	Valley	10,855	6,628	(4,846-9,064)	3.6	(2.7-5.0)
	1997	Non-valley		4,227	(3,286-5,436)	3.8	(3.0-4.9)
	1998	Valley	6,772	4,407	(3,643-5,330)	2.4	(2.0-2.9)
	1998	Non-valley		2,365	(1,644-3,403)	2.2	(1.5-3.1)
	1999	Valley	9,082	4,775	(3,825-5,961)	2.6	(2.1-3.3)
	1999	Non-valley		4,307	(3,530-5,256)	3.9	(3.2-4.8)
	2000	Valley	10,914	6,760	(5,746-7,952)	3.7	(3.2-4.4)
	2000	Non-valley		4,154	(3,444-5,009)	3.8	(3.1-4.6)
	2001	Valley	9,255	5,954	(5,300-6,688)	3.3	(2.9-3.7)
	2001	Non-valley		3,301	(2,693-4,046)	3.0	(2.4-3.7)
	2003	Valley		9,153	(8,949-9,360)	5.0	(4.9-5.2)
	2005	Valley	7,137	5,321	(4,708-6,013)	2.9	(2.6-3.3)
	2005	Non-valley		1,816	(1,484-2,222)	1.7	(1.3-2.0)
	2006	Valley		8,875	(6,579-11,973)	4.9	(3.6-6.6)
	2008	Valley	9,346	7,500	(6,615-8,503)	4.1	(3.6-4.7)
	2008	Non-valley		1,846	(1,805-1,888)	1.7	(1.6-1.7)
	2011	Non-valley		361	(249-522)	0.3	(0.2-0.5)
	2012	Valley	9,298	5,184	(4,426-6,071)	2.9	(2.4-3.3)
	2012	Non-valley		4,114	(3,237-5,229)	3.7	(2.9-4.8)
	2017	Valley	6,775	4,835	(4,127-5,664)	2.7	(2.3-3.1)
	2017	Non-valley		1,940	(1,468-2,563)	1.8	(1.3-2.3)

Trends

Table 3 summarizes the evidence for increasing, decreasing, or stable populations within the areas of Haleakalā National Park and for the surveyed area as a whole. Figures 3–11 show point estimates of abundance along with log-linear regression lines and bootstrap confidence envelopes (for the 2000–2017 regression).

In Figures 3–11, point estimates (with 95% credible intervals) and best-fit log-linear models (with 95% credible bands) are shown for both regions of Haleakalā National Park along with their total.

Table 3. Log-linear trends assessments of population abundance for all species. There are two assessments, from either 1980 or 1993 (depending on data availability) to 2017 and from 2000 to 2017. Trends are shown for both the valley and non-valley regions of Haleakalā National Park as well as the total trend within the park as a whole. Numbers show the percent weight of evidence for a particular trend. The summary column shows the overall trend with ↑ indicating an upward trend, ↓ a downward trend, and = a neutral trend or stable population. The number of symbols (1–3) indicates whether the evidence for that trend is weak, strong, or very strong. A question mark (?) indicates that no category has a majority of weight, so the trend assessment is indeterminate.

Species	Span	Region	Downward	Neutral	Upward	Summary
ʻĀkohekohe	1980–2017	Valley	100%	0%	0%	↓↓↓
		Non-valley	99%	1%	0%	↓↓↓
		Park-wide	100%	0%	0%	↓↓↓
	2000–2017	Valley	100%	0%	0%	↓↓↓
		Non-valley	100%	0%	0%	↓↓↓
		Park-wide	100%	0%	0%	↓↓↓
ʻApapane	1993–2017	Valley	100%	0%	0%	↓↓↓
		Non-valley	100%	0%	0%	↓↓↓
		Park-wide	100%	0%	0%	↓↓↓
	2000–2017	Valley	33%	67%	0%	=
		Non-valley	100%	0%	0%	↓↓↓
		Park-wide	29%	71%	0%	==
Hawaiʻi ʻamakihi	1993–2017	Valley	100%	0%	0%	↓↓↓
		Non-valley	100%	0%	0%	↓↓↓
		Park-wide	100%	0%	0%	↓↓↓
	2000–2017	Valley	100%	0%	0%	↓↓↓
		Non-valley	100%	0%	0%	↓↓↓
		Park-wide	100%	0%	0%	↓↓↓
ʻĪʻiwi	1993–2017	Valley	8%	92%	0%	===
		Non-valley	100%	0%	0%	↓↓↓

Species	Span	Region	Downward	Neutral	Upward	Summary
		Park-wide	93%	7%	0%	↓↓↓
	2000–2017	Valley	100%	0%	0%	↓↓↓
		Non-valley	100%	0%	0%	↓↓↓
		Park-wide	100%	0%	0%	↓↓↓
Kiwikiu	1980–2017	Valley	32%	39%	29%	?
		Non-valley	99%	0%	0%	↓↓↓
		Park-wide	84%	14%	3%	↓↓↓
	2000–2017	Valley	100%	0%	0%	↓↓↓
		Non-valley	42%	11%	48%	?
		Park-wide	81%	11%	8%	↓↓↓
Maui ‘alauahio	1980–2017	Valley	83%	17%	0%	↓↓↓
		Non-valley	94%	6%	0%	↓↓↓
		Park-wide	8%	92%	0%	===
	2000–2017	Valley	100%	0%	0%	↓↓↓
		Non-valley	100%	0%	0%	↓↓↓
		Park-wide	99%	1%	0%	↓↓↓
Japanese bush-warbler	1993–2017	Valley	0%	99%	0%	===
		Non-valley	100%	0%	0%	↓↓↓
		Park-wide	0%	100%	0%	===
	2000–2017	Valley	10%	89%	1%	===
		Non-valley	100%	0%	0%	↓↓↓
		Park-wide	93%	7%	0%	↓↓↓
Warbling white-eye	1993–2017	Valley	62%	38%	0%	↓
		Non-valley	100%	0%	0%	↓↓↓
		Park-wide	100%	0%	0%	↓↓↓
	2000–2017	Valley	17%	81%	2%	==
		Non-valley	100%	0%	0%	↓↓↓
		Park-wide	63%	37%	0%	↓↓
Red-billed leiothrix	1993–2017	Valley	1%	99%	1%	===
		Non-valley	100%	0%	0%	↓↓↓
		Park-wide	26%	74%	0%	==
	2000–2017	Valley	97%	3%	0%	↓↓↓
		Non-valley	100%	0%	0%	↓↓↓
		Park-wide	87%	13%	0%	↓↓

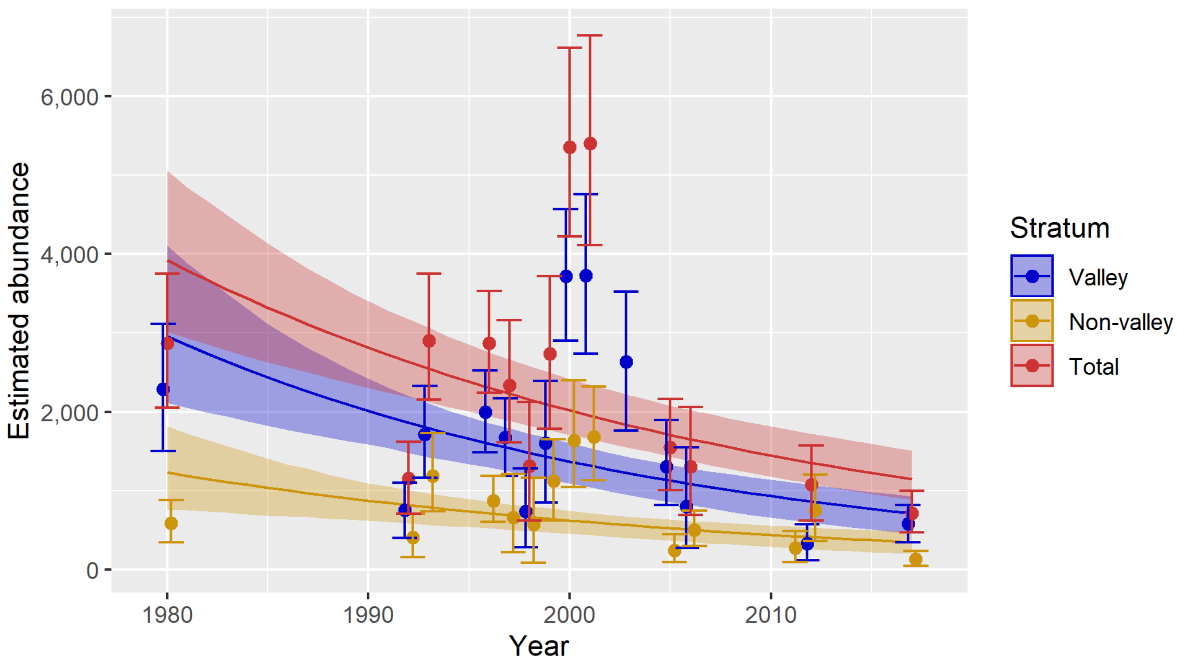

Figure 3. Abundance over time for ‘ākohekohe (*Palmeria dolei*). Points show estimated abundance with 95% credible intervals for the valley and non-valley regions as well as their total. Lines show best-fit log-linear curves to the point estimates.

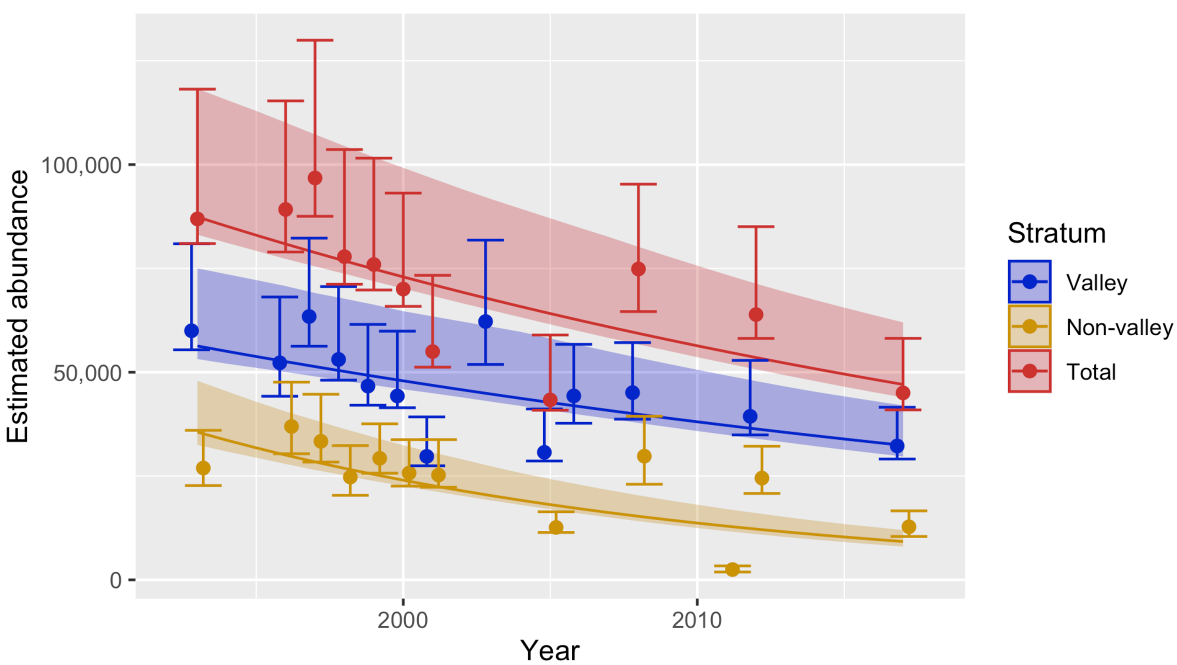

Figure 4. Abundance over time for ‘apapane (*Himatione sanguinea*). Points show estimated abundance with 95% credible intervals for the valley and non-valley regions as well as their total. Lines show best-fit log-linear curves to the point estimates.

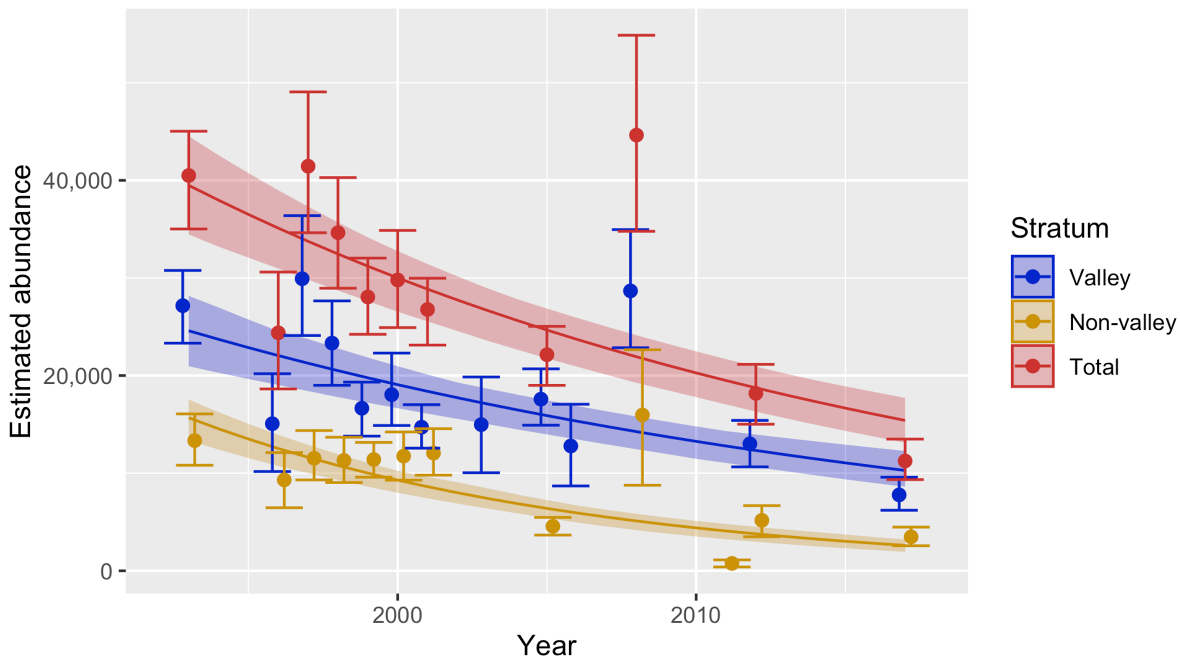

Figure 5. Abundance over time for Hawai'i 'amakihi (*Chlorodrepanis virens*). Points show estimated abundance with 95% credible intervals for the valley and non-valley regions as well as their total. Lines show best-fit log-linear curves to the point estimates.

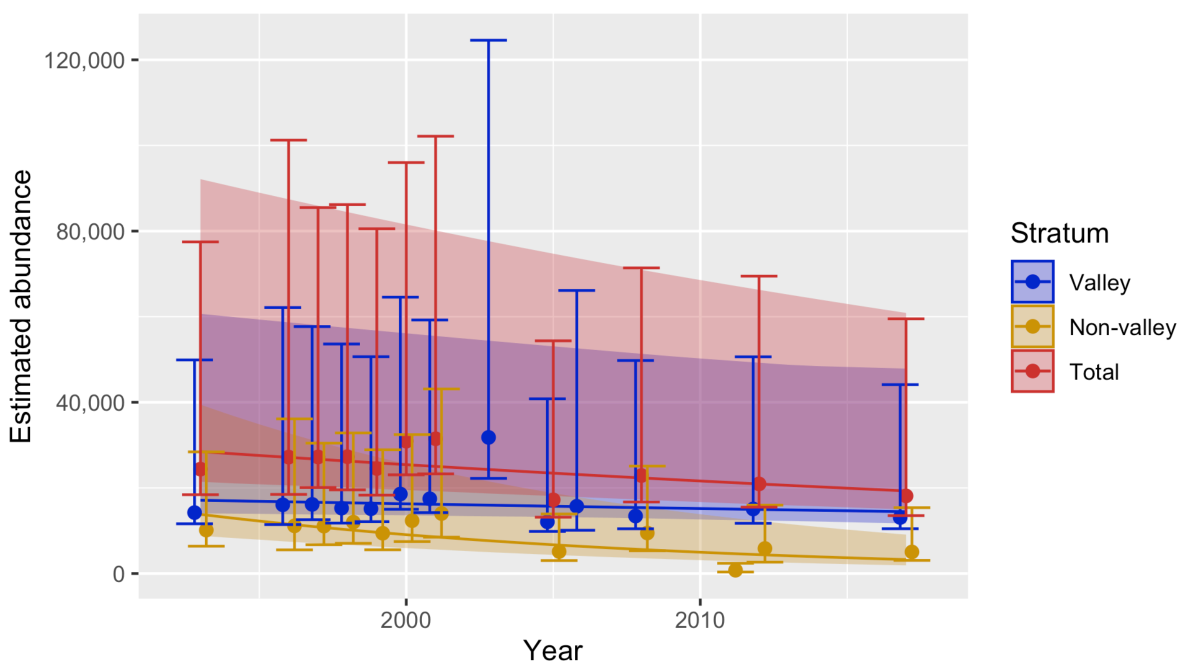

Figure 6. Abundance over time for 'i'iwi (*Drepanis coccinea*). Points show estimated abundance with 95% credible intervals for the valley and non-valley regions as well as their total. Lines show best-fit log-linear curves to the point estimates.

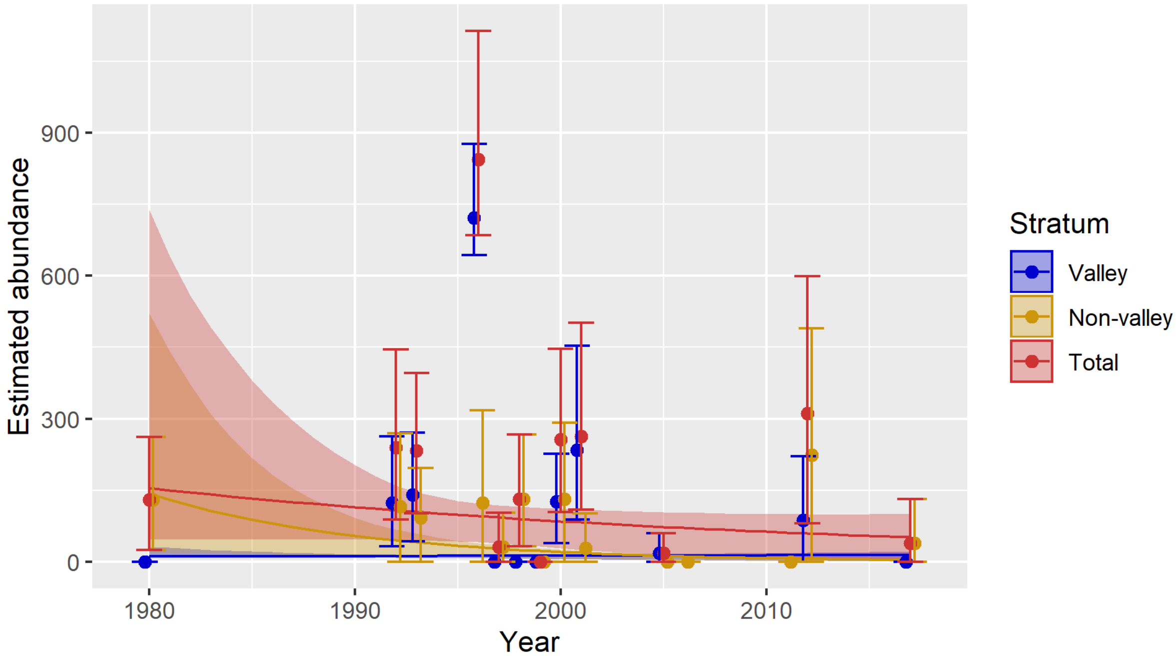

Figure 7. Abundance over time for kiwikiu (*Pseudonestor xanthophrys*). Points show estimated abundance with 95% credible intervals for the valley and non-valley regions as well as their total. Lines show best-fit log-linear curves to the point estimates.

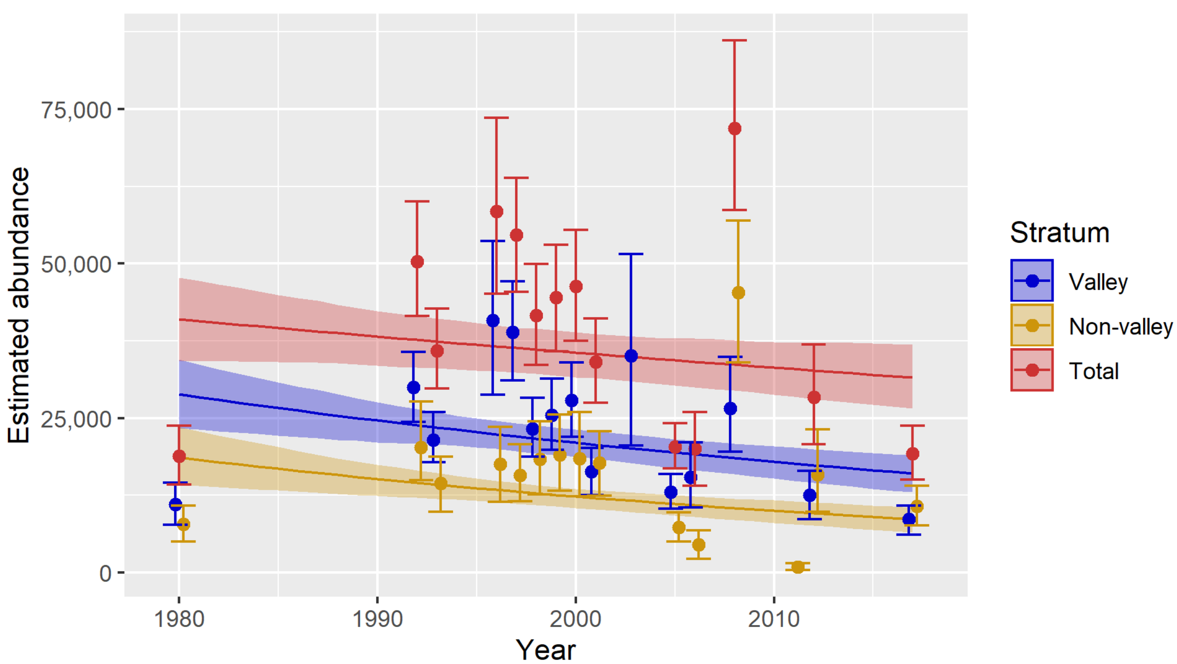

Figure 8. Abundance over time for Maui ʻalauahio (*Paroreomyza montana newtoni*). Points show estimated abundance with 95% credible intervals for the valley and non-valley regions as well as their total. Lines show best-fit log-linear curves to the point estimates.

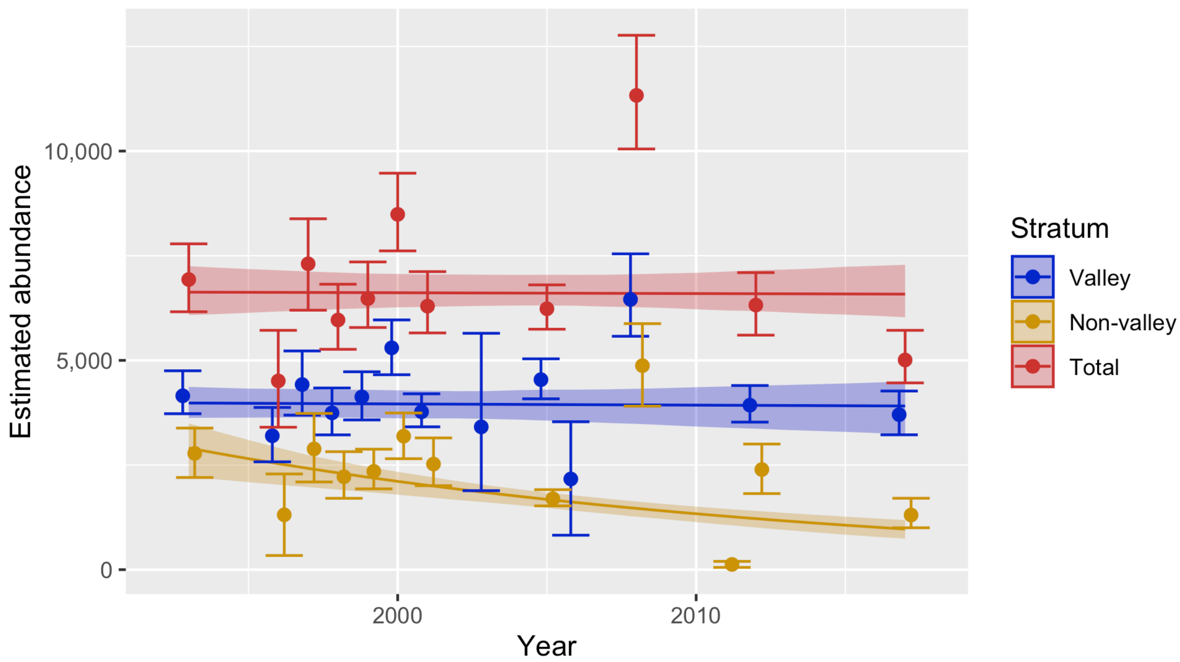

Figure 9. Abundance over time for Japanese bush-warbler (*Horornis diphone*). Points show estimated abundance with 95% credible intervals for the valley and non-valley regions as well as their total. Lines show best-fit log-linear curves to the point estimates.

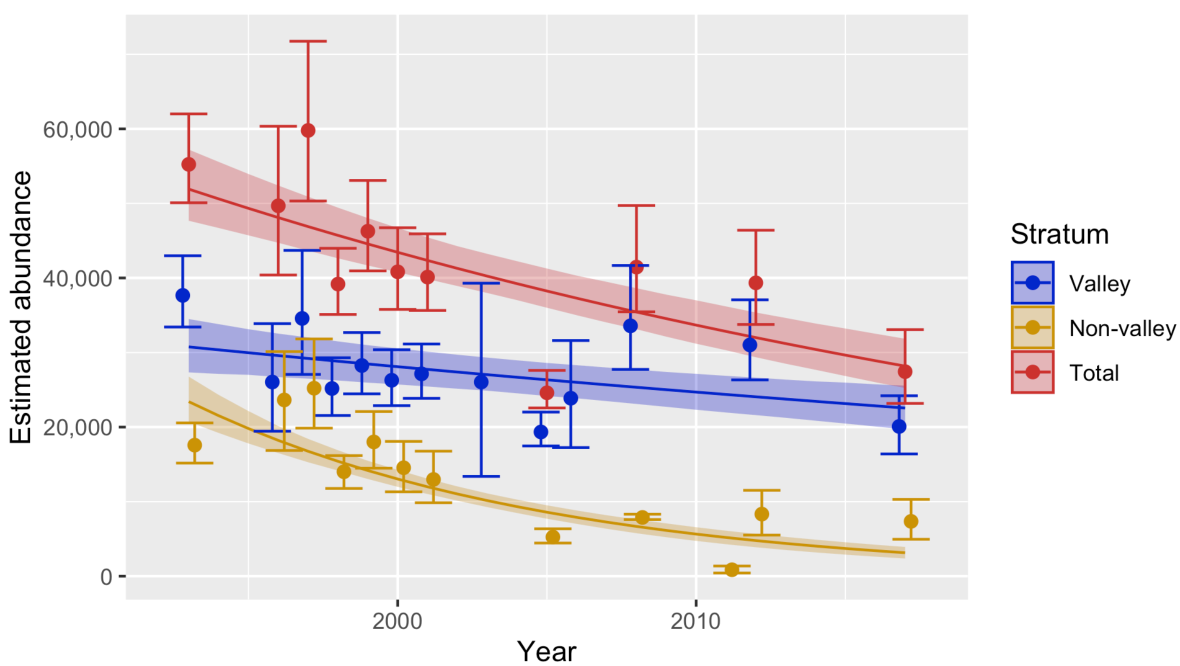

Figure 10. Abundance over time for warbling white-eye (*Zosterops japonicus*). Points show estimated abundance with 95% credible intervals for the valley and non-valley regions as well as their total. Lines show best-fit log-linear curves to the point estimates.

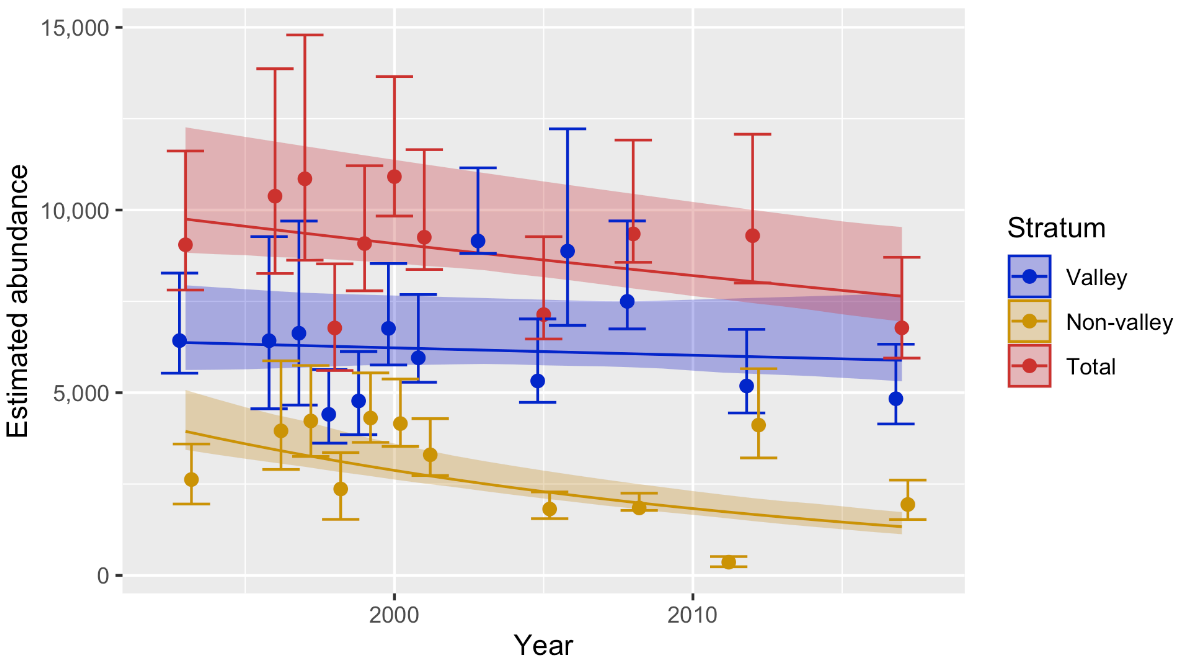

Figure 11. Abundance over time for red-billed leiothrix (*Leiothrix lutea*). Points show estimated abundance with 95% credible intervals for the valley and non-valley regions as well as their total. Lines show best-fit log-linear curves to the point estimates.

Context

Figure 12 shows the relation between the park-wide estimates of the endangered species as reported in Judge *et al.* (2019) versus this report. Coefficient of determination (R^2) correlations for the estimates are: 0.97 for ʽākohekohe, 0.80 for kiwikiu, and 0.92 for Maui ʽalauahio.

Figure 13 shows the relation between density estimates from this report for the two regions of Haleakalā National Park and the overall density estimate from Judge *et al.* (2019). R^2 correlations for the non-valley and valley density estimates are: 0.81 and 0.92 for ʽākohekohe, 0.05 and 0.58 for kiwikiu, and 0.49 and 0.90 for Maui ʽalauahio. *P*-values (t-test, 13 df) for the significance of a regression between non-valley and valley densities are <0.01, 0.51, and 0.14, respectively. Figure 14 shows the relation between the estimated densities for the two regions of Haleakalā National Park. The between-region density correlations are 0.66 for ʽākohekohe, 0.04 for kiwikiu, and 0.17 for Maui ʽalauahio.

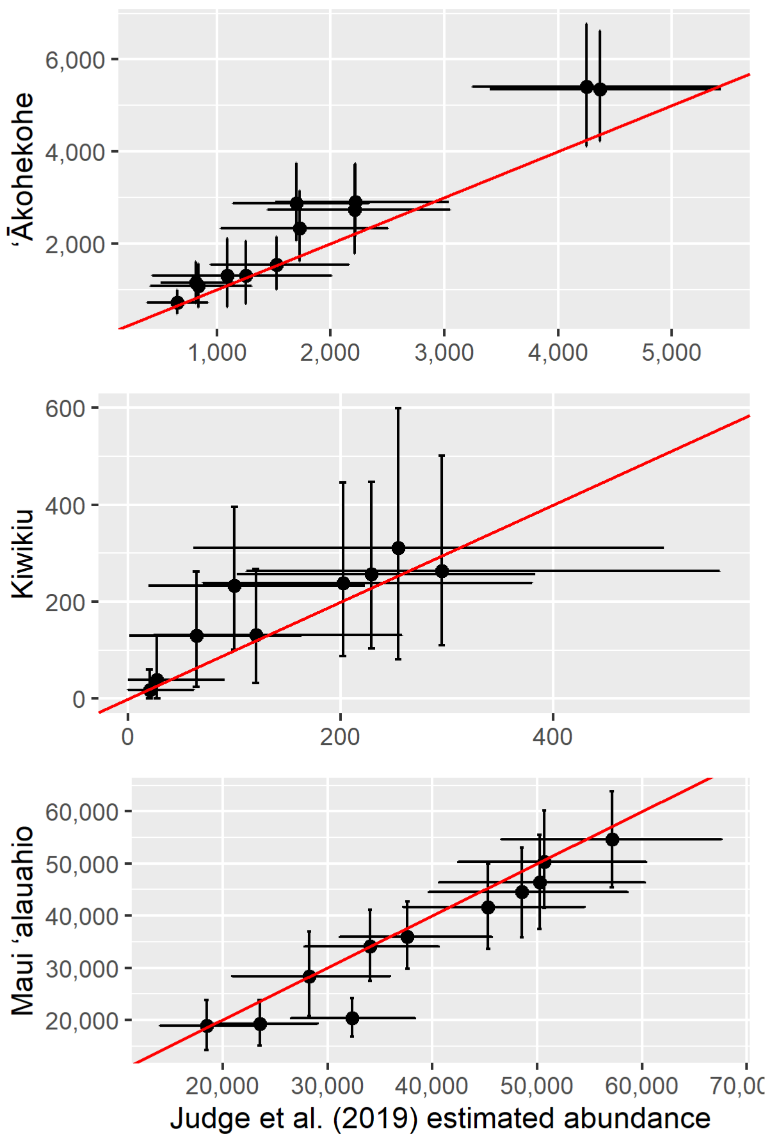

Figure 12. Comparison of abundance estimates in the current report versus Judge *et al.* (2019). The red line shows a one-to-one correspondence, when abundance estimates from both sources are the same. Most estimate uncertainty whiskers include the 1:1 line, the exception being Maui ʻalauahio in 2005.

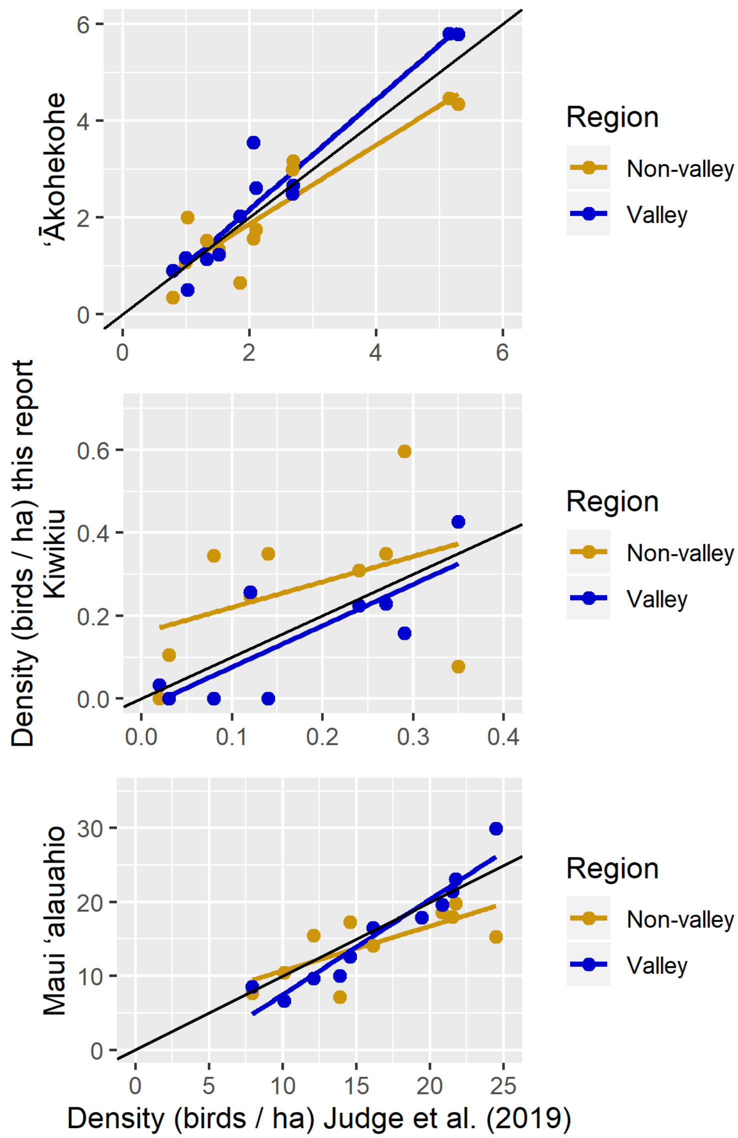

Figure 13. Densities in Haleakalā National Park as a whole versus valley and non-valley regions. Black lines indicate a 1:1 relation, colored lines show best linear relations for valley and non-valley sub-regions of the park.

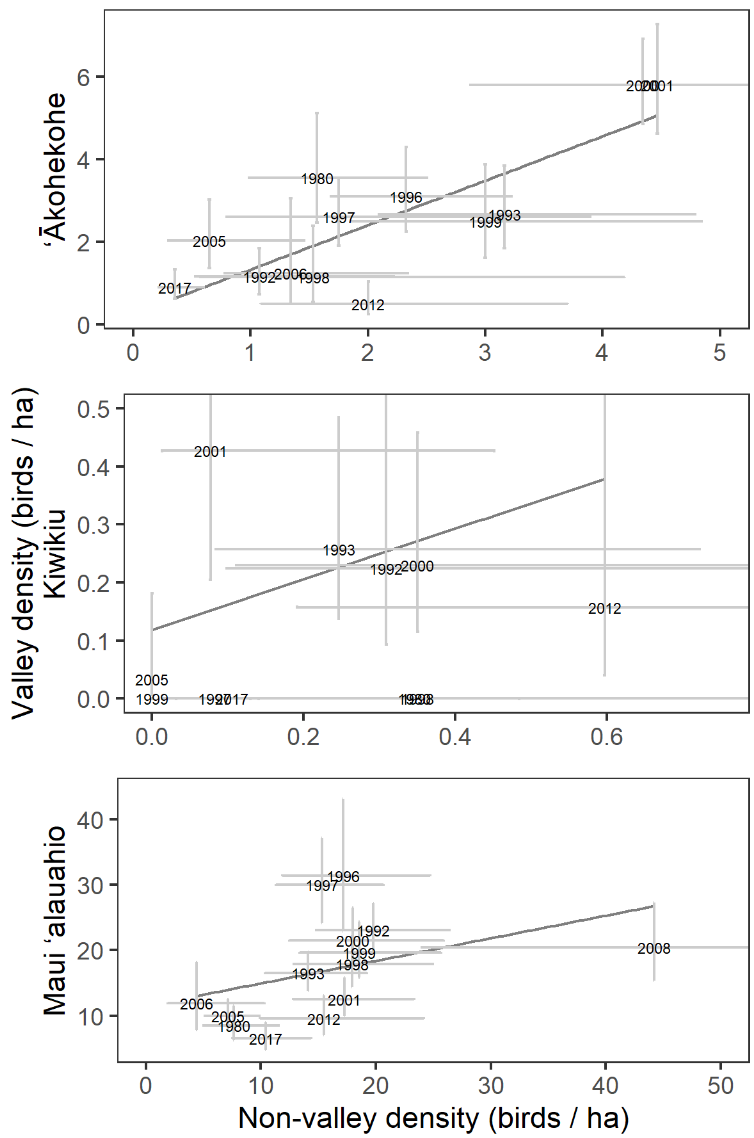

Figure 14. Relative densities in the two regions of Haleakalā National Park. Numbers indicate the year of the estimate. The dark gray line is the best-fit line showing the relation between the densities. Note on all three charts the rightmost extent of the error whiskers has been truncated to show horizontal detail. For kiwikiu the vertical extent is truncated at 0.5 birds/ha, excluding one point in 1996 where the valley density was 1.31 (1.19–1.45) and non-valley density was 0.33 (0.08–1.35) birds/ha.

Conclusions

In general no species, in any region, in either time series, showed evidence for an increasing population. There are two cases (kiwikiu in the valley area for the 1980–2017 trends and non-valley for the 2000–2017 trends) where the trend assessment is inconclusive. There are some cases with evidence for a stable population. The recent (2000–2017) trends assessment for

ʽapapane shows weak evidence for a stable population in the valley region and strong evidence for overall stability despite a downward trend in the non-valley regions of the park. In the longer-range time series both ʽiʽiwi and Maui ʽalauahio show evidence for regional and overall stability (respectively). In addition, all three non-native species show some evidence for stability in at least one region, in at least one time series.

The Judge *et al.* (2019) estimates for abundance within Haleakalā National Park assume that density for a species is constant across the area of inference within the park. This analysis allows for different density estimates for the valley (and adjacent high-elevation areas) and non-valley regions of the park. Nevertheless, Figure 12 and Table 2 show that the park-wide abundance estimates are very similar and highly correlated with the lowest R^2 (of 0.80) for kiwikiu, which also had the widest uncertainty intervals. Further inspection of Figure 12 shows a pattern for this report to tend to estimate slightly higher for ʽākohekohe and kiwikiu, and slightly lower for Maui ʽalauahio. In almost all cases (the exception being Maui ʽalauahio in 2005) the two methods of estimating total park abundance include each other within the 95% credible interval. Despite the correlation in park-wide estimates between the two methods, Figures 13 and 14 show that the densities in the two regions are different from each other and different from the homogenous density reported in the 2019 report. Moreover, while the densities of ʽākohekohe are highly correlated, those of kiwikiu and Maui ʽalauahio seem to be less so.

ʽĀkohekohe

There is strong evidence of decline in ʽākohekohe abundance in both regions of the park, and across the park in general. Figure 3 demonstrates how ʽākohekohe abundance estimates appear anomalously high (relative to other years) in the early 2000s, raising concerns that the apparent population decline might be driven by a population boom around then. Because the apparent outliers occur in two consecutive years (2000 and 2001), they are more likely to represent a real population effect rather than coincidence. However, the longer-term series incorporating earlier estimates reinforces the conclusion of a general decline despite the effects of a boom in the early millennium.

ʽApapane

In the 2000–2017 trend assessment, ʽapapane show evidence of stable populations in the valley region and a decrease in the non-valley region, but overall evidence of a stable population. Figure 4 illustrates why the longer-term series shows evidence of a decline since 1993, as pre-2000 estimates were usually higher.

Hawaiʽi ʽAmakihi

Hawaiʽi ʽamakihi show strong evidence of a decline in all areas at both time scales despite a spike in abundance in 2008 (Figure 5). The spike may reflect a real population change, document the result of a year or more of especially good conditions resulting in a population boom, or be a coincidence intersecting with an idiosyncrasy of the survey method. For example, a rare irruption of an invertebrate prey species when the survey was conducted might have resulted in higher detection rates within the park for that year, yet not extreme enough to have a statistically significant effect on the detection function.

ʽIʽiwi

For the 1993–2017 time series, ʽiʽiwi show strong evidence for a stable trend in the valley region but strong evidence of a decline (in all regions) in the 2000–2017 time series (Figure 6). Table 2 shows and Figure 6 illustrates that uncertainty in ʽiʽiwi estimates are asymmetric, with greater uncertainty in the positive direction than the negative direction.

Kiwikiu
Kiwikiu show strong evidence for a negative trend, except (as mentioned above) when the trends assessment was determined to be inconclusive. Figure 7 shows the wide year-to-year variation in abundance estimates. This is a common problem when using distance methods to estimate the density of extremely uncommon species like kiwikiu. This variation likely also explains a lack of significant correlation (Figure 14) between estimates for the valley and non-valley regions.

Maui ʽAlauahio
In the 1980–2017 log-linear regression there is strong evidence of a stable trend for Maui ʽalauahio in the park as a whole, despite strong evidence of a decline in each portion of the park taken individually. This apparent discrepancy in total versus component trends is possibly, in this case, a weakness of using a log-linear model for the observed population trend. In Figure 8 one can see that the 1980 estimates for Maui ʽalauahio are lower than the following five surveys, and in fact the trend assessments for Maui ʽalauahio from 2000–2017 show strong evidence for a decline in all categories.

Japanese Bush-warbler
In both time ranges, the non-valley region of the park shows strong evidence for a decline in Japanese bush-warbler abundance. The valley region shows a stable trend in both time ranges, while the total abundance is stable in the longer series but declining from 2000–2017. Figure 9 shows how this difference may be driven by a sharp spike in abundance estimated for the 2008 surveys.

Warbling White-eye
The 2000–2017 valley region shows evidence for a stable population of warbling white-eye, though declining for the entire 1993–2017 series. There is evidence for declining abundance in the non-valley region and the park as a whole (Figure 10).

Red-billed Leiothrix
In the longer time series (1993–2017) red-billed leiothrix show a stable population for the valley region and for the total, with a decline in the non-valley region. The more recent period (2000–2017) shows evidence for a decline in both regions and the total (Figure 11).

DISCUSSION

The high correlation between the overall abundance estimates in the Judge *et al.* (2019) report and this document shows how inferences are not dissimilar on a park-wide level. However, this report also shows there are differences in densities within the park, between the high-elevation Kīpahulu Valley and adjacent regions versus the rest of the park.

This report also uses bootstrap estimates to produce trends assessments in an equivalency framework. Unfortunately, from a conservation perspective, the conclusion seems to be almost universal: recent trends indicate a community-wide significant decrease in bird abundance. The sole evidence for increase, ʽiʽiwi in the non-valley regions of the park, indicates that there may be value in finer-scale estimates of bird density. Differential responses may help to identify differences in habitat or response to climate change or management regime that may in turn inform the management of declining native bird populations.

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