

Relationships Between Landbird Densities and Forest Structure in the National Park of American Samoa, 2011–2023

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Introduction

Due to differences in the resolution of habitat data collected in 2023 from 2011 and 2018, a qualitative analysis comparing vegetation composition and structure across survey years was provided in Appendix D of the report “Population Densities and Trends of Landbirds in the National Park of American Samoa” (Hunt et al. 2026).

Here, we compare bird densities per station within each unit across the three surveys relative to habitat structure (canopy cover and tree height) using principal component analyses (PCA). Principal component analysis is used to reduce the number of variables to a few indices (i.e., combinations of variables) that are linear combinations of the original variables (Sharma 1996). Principal component analysis provides an objective way of combining indicators so that variation in the data is minimized. While typically applied to datasets with many variables, we use it here to aggregate two habitat indicators of bird densities for the three surveys and two units, which we treat as independent. That is, we use PCA as a descriptive, exploratory data analysis tool, rather than an inferential analysis (Jolliffe and Cadima 2016). This allows us to assess changes among years and units using the same component structure.

The 2011 survey included sampling points along legacy and random transects (Judge et al. 2013), which were resampled during the 2023 survey, except for the random transect on Mount Lata in the Ta‘ū Unit. However, sampling in 2018 was conducted only on the legacy transects and excluded sampling above 850 m in the Mount Lata region in the Ta‘ū Unit (Judge et al. 2021). Therefore, we conducted the PCA with data from (1) the transects sampled in all three surveys, and (2) data collected from all transects surveyed, regardless of being repeatedly sampled. This preliminary analysis allows us to determine if changes in the spatial coverage yields non-representative sampling of canopy cover and canopy height and produces spurious results. Moreover, this analysis allows for assessing the relative magnitudes and sign patterns of the principal components (PCs) loadings and PC scores (Jolliffe and Cadima 2016).

We fitted the PCAs using the stats package (version 3.6.2) in base R, which standardizes the data to zero mean and unit variance. We converted the categorical canopy cover and canopy height variables to ordinal numerical values, and defined survey year and island as factor variables. We fitted a singular value decomposition of the centered and scaled data matrix using the `prcomp` function. Only two PCs were retained, and eigenvalues and eigenvectors of the correlation matrix and percent variance explained were output. Representations of the fitted PCA to the datasets in two-dimensional space accounting for variance with variable vectors were produced with the `ggbiplot` package (version 0.6.2; Vu et al. 2024). We assessed the strength of correlation between measurements of canopy cover, canopy height, and overall bird density based on their coefficient values with the following criteria: 0.0 = none, >0 to 0.3 = weak, >0.3 to 0.5 = moderate, >0.5 to 0.7 = strong, >0.7 to 1 = very strong.

PCA with Data from Consistently Sampled Transects

Principal component analysis of canopy cover, canopy height, and overall bird densities for data subset to only the transects that were repeatedly sampled during all three surveys, revealed that

47.4% of the variation in the dataset was explained by PC1, which was strongly (>0.50) correlated with canopy cover and canopy height (Table 1, Figure 1). Bird density was very strongly (0.83) positively correlated with PC2, which explained 32.7% of the variation in the data. On Ta'ū, PC1 explained 53.9% of the variation, and bird density, canopy cover and canopy height were strongly correlated with the principal component. PC2 explained 29.6% of the variation, and bird density was very strongly, canopy cover was weakly negatively, and canopy height was strongly negatively correlated with the principal component. Tutuila showed a narrower spread of bird densities than Ta'ū, with bird density negative moderately and canopy cover and canopy height strongly correlated with PC1, which explained 43.6% of variation (Figures 2 and 3). On PC2, bird density was negative very strongly correlated, while canopy height was negative moderately and canopy cover was weakly correlated, and the principal component explained 33.1% of variation.

Table 1. Loadings of the first two principal components (PCs) for three separate principal component analyses (PCAs) of bird density, canopy cover, and canopy height. PCAs were conducted for both island units, the Ta'ū Unit, and the Tutuila Unit. All PCAs used combined data from only transects that were repeatedly sampled in 2011, 2018, and 2023.

Measurement	Both Units		Ta'ū		Tutuila	
	PC1	PC2	PC1	PC2	PC1	PC2
Eigenvalue	1.42	0.98	1.62	0.89	1.31	0.99
Percentage of Variance Explained	47.37	32.68	53.94	29.64	43.60	33.06
Bird Density	0.41	0.83	0.50	0.75	-0.25	-0.95
Canopy Height	0.70	-0.02	0.67	-0.03	0.67	-0.32
Canopy Cover	0.59	-0.55	0.55	-0.66	0.70	0.04

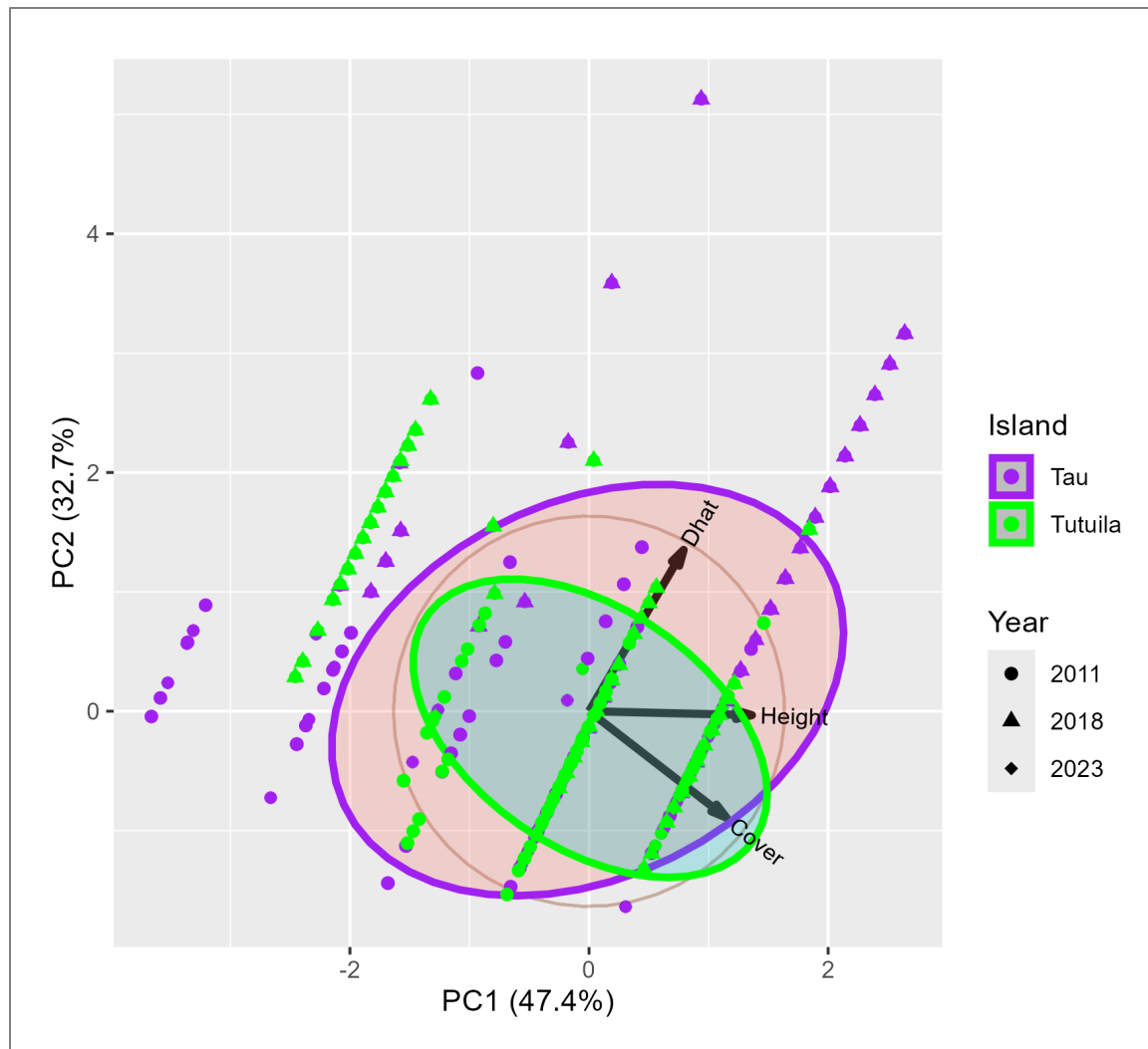


Figure 1. Principal component analysis (PCA) biplot of bird densities (Dhat), tree canopy height, and canopy cover at each survey station from the repeatedly sampled transect, pooled across island units (purple = Ta'u; green = Tutuila) and survey years (circle = 2011, triangle = 2018, diamond = 2023). Amber circle shows the centered dataset, whereas the purple and green ellipses show the centered data of Ta'u and Tutuila, respectively. PC1 explains 47.4% of the variation in the data, is strongly correlated with canopy cover and canopy height, and moderately correlated with bird density. PC2 explains 32.7% of the variation in the data, is very strongly correlated with bird density, strongly negatively correlated with canopy cover, and weakly negatively correlated with canopy height. The following thresholds determined correlation strength: 0.0 = none, >0 to 0.3 = weak, >0.3 to 0.5 = moderate, >0.5 to 0.7 = strong, >0.7 to 1 = very strong.

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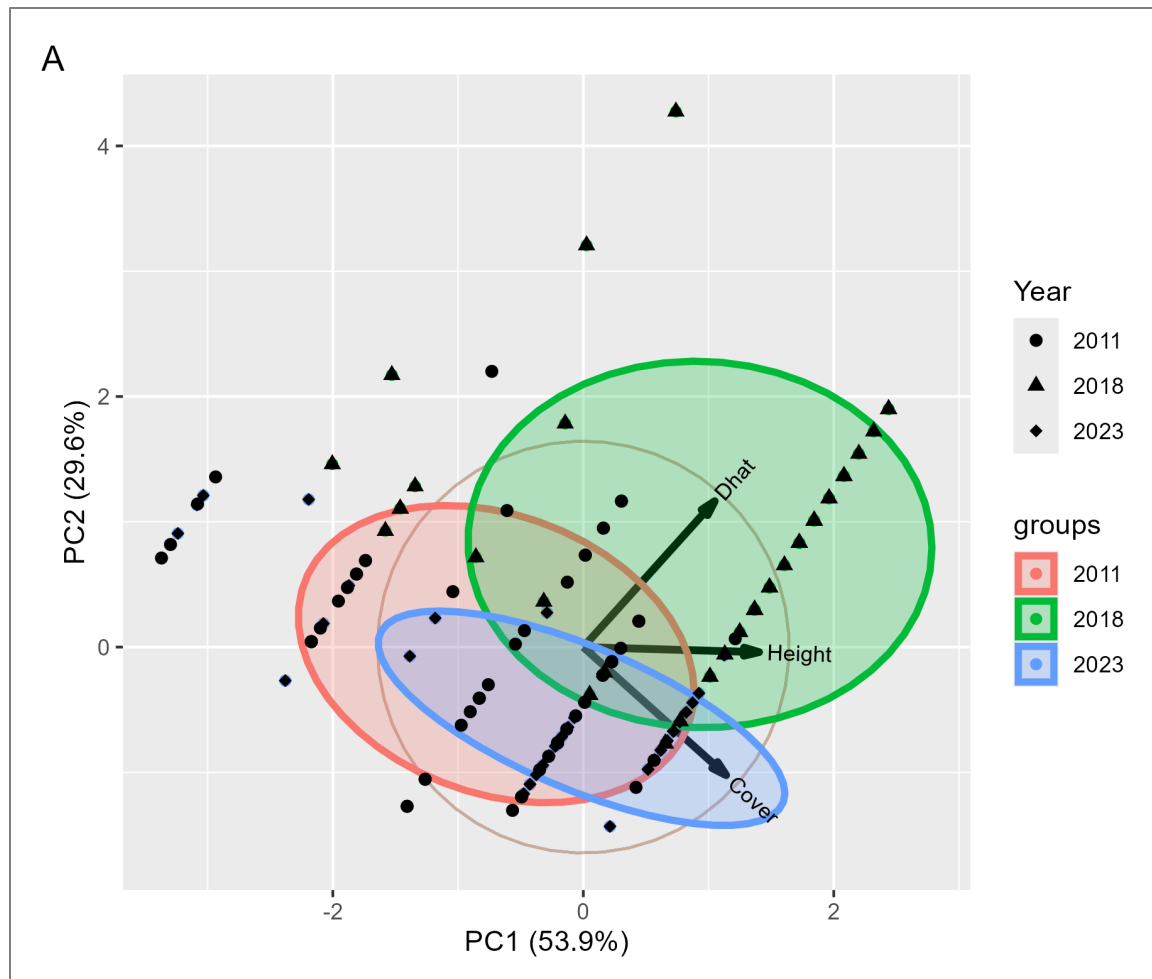


Figure 2. Principal component analysis (PCA) biplots of bird densities (Dhat), tree canopy height, and canopy cover at each survey station, pooled across survey years (circle = 2011, triangle = 2018, diamond = 2023), for Ta'u (A) and Tutuila (B). Amber circles show the centered data of each island unit, whereas pink, green, and blue ellipses show the centered data for 2011, 2018, and 2023, respectively. For Ta'u (A), PC1 is moderately correlated with bird density, canopy cover, and canopy height. PC2 is strongly correlated with bird density, moderately negatively correlated with canopy cover, and weakly negatively correlated with canopy height. For Tutuila (B), PC1 is weakly negatively correlated with bird density and strongly correlated with canopy cover and canopy height. PC2 is strongly negatively correlated with bird density, moderately negatively correlated with canopy height, and weakly correlated with canopy cover. The following thresholds determined correlation strength: 0.0 = none, >0 to 0.3 = weak, >0.3 to 0.5 = moderate, >0.5 to 0.7 = strong, >0.7 to 1 = very strong.

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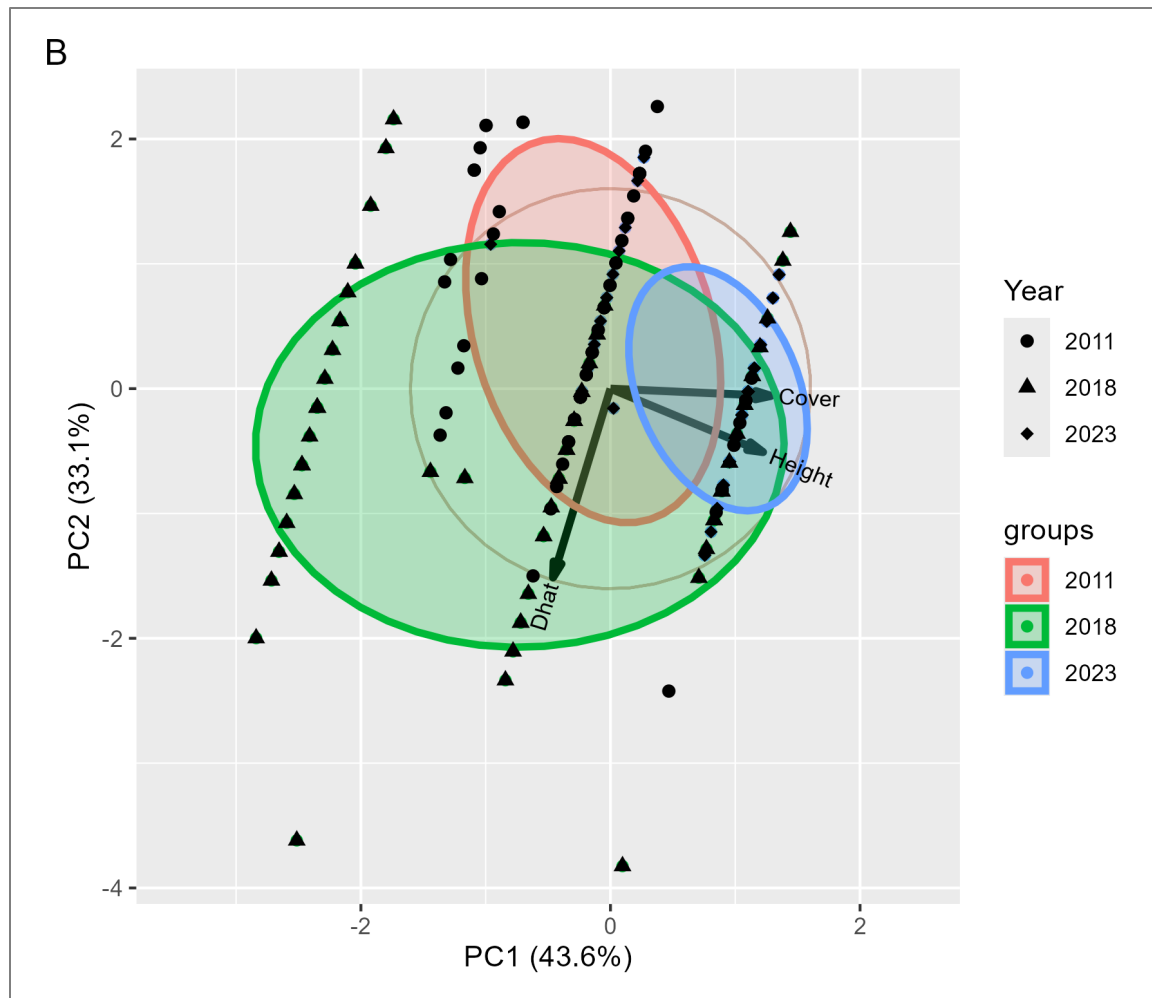


Figure 3. Principal component analysis (PCA) biplots of bird densities (Dhat), tree canopy height, and canopy cover at each survey station from repeatedly sampled transects, pooled across survey years (circle = 2011, triangle = 2018, diamond = 2023), for Ta'u (A) and Tutuila (B). Amber circles show the centered data of each island unit, whereas pink, green, and blue ellipses show the centered data for 2011, 2018, and 2023, respectively. For Ta'u (A), PC1 is moderately correlated with bird density, canopy cover, and canopy height, and PC2 is very strongly correlated with bird density, weakly negatively correlated with canopy cover, and strongly negatively correlated with canopy height. For Tutuila (B), PC1 is weakly negatively correlated with bird density and strongly correlated with canopy cover and canopy height, whereas PC2 is very strongly negatively correlated with bird density, moderately negatively correlated with canopy height, and weakly correlated with canopy cover. The following thresholds determined correlation strength: 0.0 = none, >0 to 0.3 = weak, >0.3 to 0.5 = moderate, >0.5 to 0.7 = strong, >0.7 to 1 = very strong.

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PCA with Data from All Transects

Principal component analysis of canopy cover, canopy height, and overall bird densities for data from all sampling points, regardless of being sampled during all three surveys, revealed that 47.2% of the variation in the dataset was explained by PC1, which was strongly (>50%) correlated with canopy cover and canopy height (Table 2; Figure 4). Bird density was very strongly (>70%)

positively correlated with PC2, which explained 31.4% of the variation in the data. Ta'ū showed a broader spread of bird densities than Tutuila, and a weakly positive association between PC1 and PC2. In contrast, Tutuila showed a moderate negative association between PC1 and PC2. This roughly translated to weak and moderate associations between canopy cover, canopy height, and bird density on Ta'ū and Tutuila, respectively.

Table 2. Loadings of the first two principal components (PCs) for three separate principal component analyses (PCAs) of bird density, canopy cover, and canopy height. PCAs were conducted for both island units, the Ta'ū Unit, and the Tutuila Unit. All PCAs used combined data from all transects sampled in 2011, 2018, and 2023.

Measurement	Both Units		Ta'ū		Tutuila	
	PC1	PC2	PC1	PC2	PC1	PC2
Eigenvalue	1.42	0.94	1.59	0.82	1.30	1.01
Percentage of Variance Explained	47.21	31.42	52.84	27.23	43.40	33.51
Bird Density	0.41	0.86	0.52	0.80	-0.27	-0.92
Canopy Height	0.68	-0.09	0.64	-0.11	0.65	-0.40
Canopy Cover	0.61	-0.49	0.57	-0.59	0.71	0.02

In the PCA for the Ta'ū Unit, PC1 explained 53% of the data with strong correlations of canopy height, canopy cover, and bird density (Table 2). The right shift of the data along the PC1 axis in 2018 and subsequent left shift back to its origin in 2023 (Figure 5) coincides with the increase and subsequent decrease of both canopy height and bird densities. PC2 explained 27% of the variation in the data, was very strongly correlated with bird density, and also shifted away from the PC2 origin in 2018 and back toward the PC2 origin in 2023, tracking an increase and decrease in bird density. The spread of bird densities also increased in 2018 and contracted in 2023.

In the PCA for the Tutuila Unit, PC1 explained 43% of the data, with strong correlations of canopy height and canopy cover (Table 2). The left shift of the data along the PC1 axis in 2018 and subsequent right shift back to its origin in 2023 (Figure 6) coincides with the decrease and subsequent increase in canopy cover. Conversely, the spread of the canopy cover data increases in 2018 and decreases in 2023. PC2 explained 34% of the variation in the data and was very strongly negatively correlated with bird density. The negative shift in the data in the PC2 axis in 2018 reflects the increase in bird density, and the shift back to the PC2 origin in 2023 reflects the decrease in bird density. The spread of bird density data likewise expanded in 2018 and contracted in 2023.

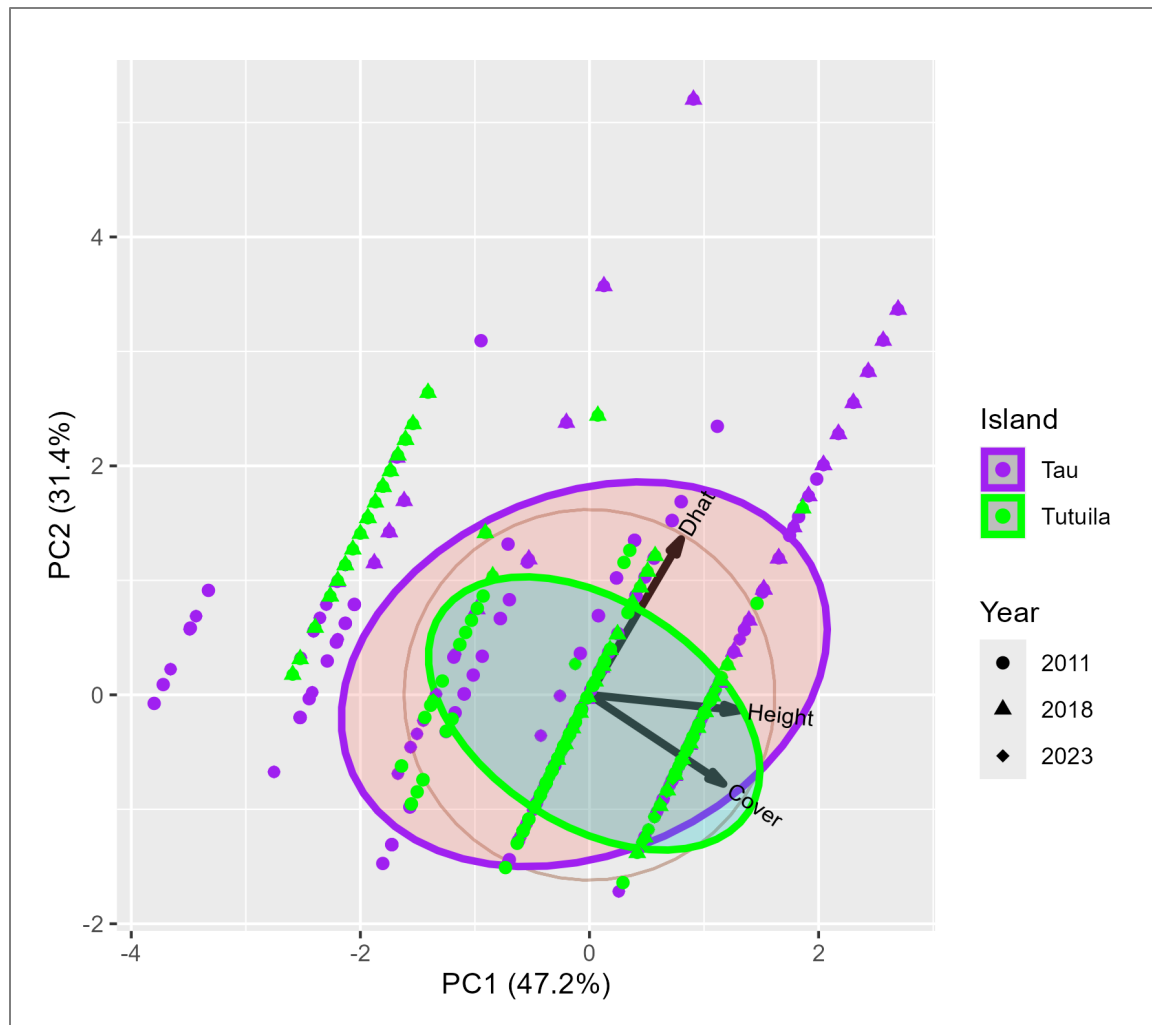


Figure 4. Principal component analysis (PCA) biplot of bird densities (Dhat), tree canopy height, and canopy cover at each survey station, pooled across island units (purple = Ta'ū; green = Tutuila) and survey years (circle = 2011, triangle = 2018, diamond = 2023). Amber circle shows the centered dataset, whereas the purple and green ellipse shows the centered data of Ta'ū and Tutuila, respectively. PC1 explains 47.2% of the variation in the data, is strongly correlated with canopy cover and canopy height, and moderately correlated with bird density. PC2 explains 31.4% of the variation in the data, is strongly correlated with bird density, moderately negatively correlated with canopy cover, and weakly negatively correlated with canopy height. The following thresholds determined correlation strength: 0.0 = none, >0 to 0.3 = weak, >0.3 to 0.5 = moderate, >0.5 to 0.7 = strong, >0.7 to 1 = very strong.

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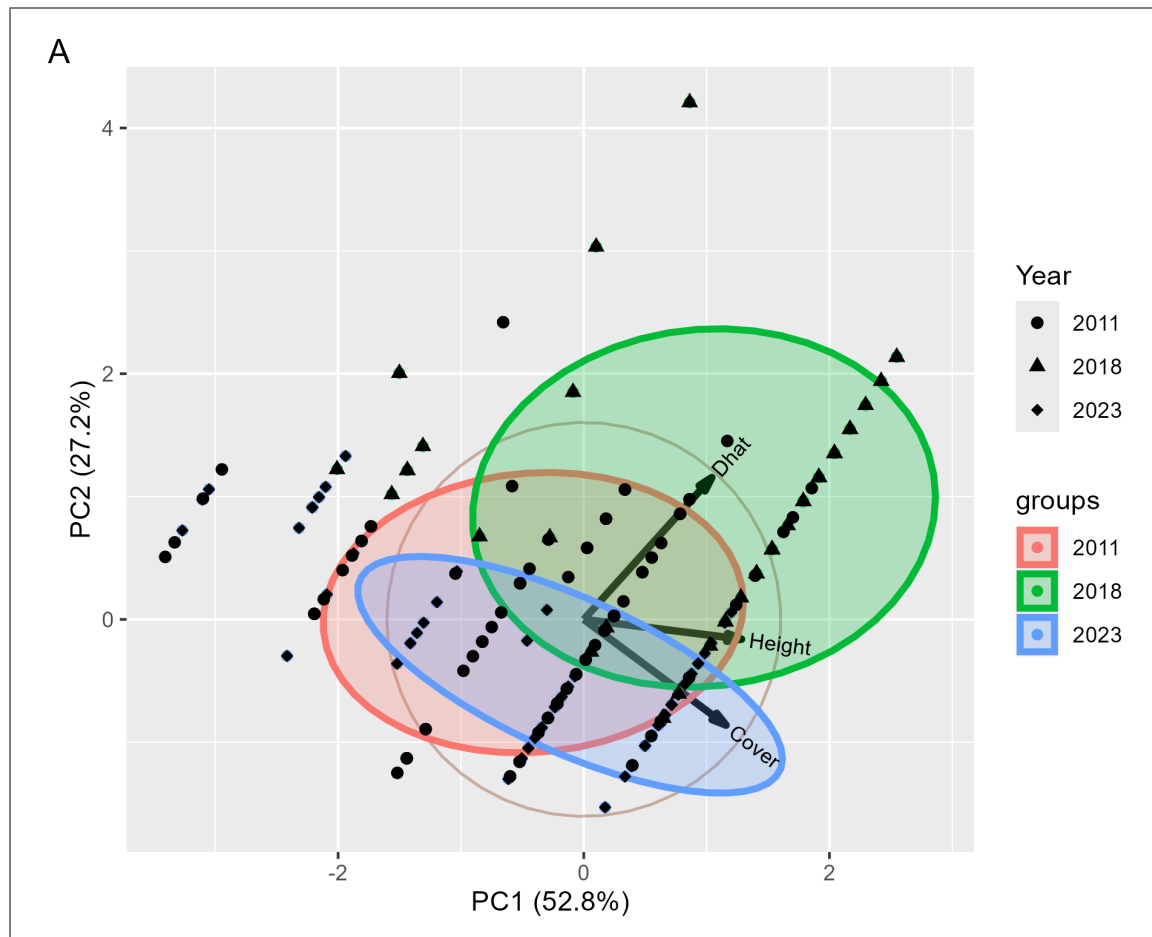


Figure 5. Principal component analysis (PCA) biplots of bird densities (Dhat), tree canopy height, and canopy cover at each survey station, pooled across survey years (circle = 2011, triangle = 2018, diamond = 2023), for Ta'u (A) and Tutuila (B). Amber circles show the centered data of each island unit, whereas pink, green, and blue ellipses show the centered data for 2011, 2018, and 2023, respectively. For Ta'u (A), PC1 is moderately correlated with bird density, canopy cover, and canopy height. PC2 is strongly correlated with bird density, moderately negatively correlated with canopy cover, and weakly negatively correlated with canopy height. For Tutuila (B), PC1 is weakly negatively correlated with bird density and strongly correlated with canopy cover and canopy height. PC2 is strongly negatively correlated with bird density, moderately negatively correlated with canopy height, and weakly correlated with canopy cover. The following thresholds determined correlation strength: 0.0 = none, >0 to 0.3 = weak, >0.3 to 0.5 = moderate, >0.5 to 0.7 = strong, >0.7 to 1 = very strong.

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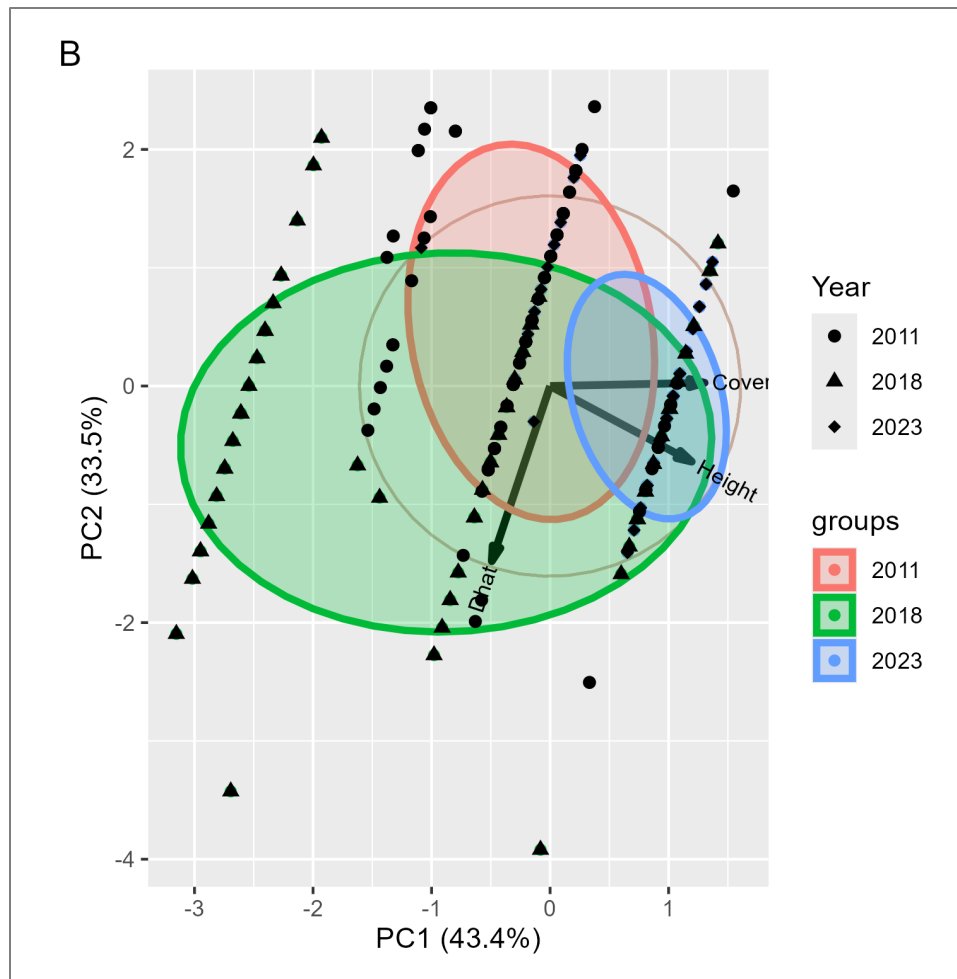


Figure 6. Principal component analysis (PCA) biplots of bird densities (Dhat), tree canopy height, and canopy cover at each survey station from all transects, pooled across survey years (circle = 2011, triangle = 2018, diamond = 2023), for Ta'ū (A) and Tutuila (B). Amber circles show the centered data of each island unit, whereas pink, green, and blue ellipses show the centered data for 2011, 2018, and 2023, respectively. For Ta'ū (A), PC1 is strongly correlated with bird density, canopy cover, and canopy height, and PC2 is very strongly correlated with bird density, moderately negatively correlated with canopy cover, and weakly negatively correlated with canopy height. For Tutuila (B), PC1 is weakly negatively correlated with bird density and strongly correlated with canopy cover and canopy height, whereas PC2 is very strongly negatively correlated with bird density, moderately negatively correlated with canopy height, and weakly correlated with canopy cover. The following thresholds determined correlation strength: 0.0 = none, >0 to 0.3 = weak, >0.3 to 0.5 = moderate, >0.5 to 0.7 = strong, >0.7 to 1 = very strong.

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Interpretation of PCA

There were only minor differences in the relative magnitudes and sign patterns of the PC loadings and PC scores between the two analyses. As such, the PCA gave very similar results regardless of whether data from all transects were used or not. In addition, changes in the correlation strength between the two analyses were minor with differences in correlation ranging between -0.07 and 0.08 (Tables 1 and 2). Canopy cover in both units went from negative moderate to negative weak

correlation on PC1, and from positive strong to positive very strong correlation on PC1 in the Tutuila Unit when including data from all transects. The very high proportion of variability explained by the two-dimensional principal subspace (80.05% for resampled transects only, and 78.63% for all transects) provides ample evidence (total variability >70% for each PCA and differences in total variability <2%) that changes in the spatial coverage, therefore, did not adversely affect the representative sampling of canopy cover and canopy height with respect to bird density, nor did changes in the spatial coverage produce spurious results. In this case, the relative magnitudes and sign patterns are meaningful. Therefore, we provide an interpretation based on fitting a PCA to data from all transects.

In the Ta'ū Unit, overall bird density was strongly correlated with the percentage of canopy trees >10 m in height, which increased from 2011 to 2018, and then decreased in 2023 (Figure 5; Appendix D of Hunt et al. 2026). However, the increase in canopy height by ≥ 5 m from 2011 to 2018 and the subsequent decrease in canopy height by ≥ 5 m in 2023, rather than immediately following Tropical Cyclone Gita, is biologically unrealistic. Rather than following an ecological sequence of events, these patterns likely reflect differences in sampling effort near the summit of Mount Lata, which was greater in 2011 and in 2023 than in 2018 (Judge et al. 2013, 2022). The summit region tends to have fewer and lower stature trees, as well as lower densities of landbirds, than the lower elevation forested areas. Higher detections of invasive *M. crenata*, which thrives in full sunlight, in 2011 and 2018 also appear consistent with higher sampling effort in the summit region in those years (Appendix D of Hunt et al. 2026). Canopy cover, however, which decreased by 12% across the three surveys, did not consistently track with changes in canopy height or bird densities or the pattern expected by such changes in sampling.

In the Tutuila Unit, bird density tracked inversely with canopy cover. Canopy cover decreased in 2018 and then increased in 2023 whereas overall bird density increased and then decreased, respectively (Figure 6). This was contrary to our expectations. Gita's passage in 2018 was farther from Ta'ū and closer to Tutuila, where torrential rain and destructive wind gusts up to 157 km/hr (NOAA 2018) likely defoliated trees and reduced nectar and fruit resources for native landbirds (Wiley and Wunderle 1993). Differences in sampling effort on Tutuila ($n = 99, 73$, and 96 in 2011, 2018, and 2023, respectively) were proportionally much smaller than for Ta'ū ($n = 86, 48$, and 106) and therefore the detection of reduced canopy cover in 2018 and increased canopy cover in 2023 is likely a real change. Increased canopy height in 2018 and 2023 (Appendix D of Hunt et al. 2026) could reflect continuing succession from a previous tropical cyclone before Gita, although a >55% increase in trees >10 m tall in only five years is considerable. Overall bird density increasing, rather than decreasing, in 2018, followed by a decrease in 2023 possibly reflects defoliation following Gita making landbirds easier to detect than true population changes, as there were no upward trends detected in 2018 (Judge et al. 2021). However, at the species level, increases in Crimson-crowned Fruit Dove and Pacific Imperial Pigeon in 2023 track with increases in canopy cover, which may be partly attributed to their recovery. Future surveyors could record phenology of fruiting canopy trees to examine possible relationships with frugivore density. The PCA provided aggregate scores for each principal component dimension, which provided an overall assessment of bird densities with

respect to changes in canopy cover and canopy height, information that can help managers understand the influence of the habitat on birds.

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