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# **Exploring the environmental factors determining forest bird composition and distribution on the island of Ta'u, American Samoa**

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Master of Science in Ecology



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Place and date

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## ABSTRACT

Basic biological knowledge tends to decrease when one moves from the poles and towards the equator. The most diverse habitat also happens to be centered near the equator and where much conservation initiatives are needed. The following study aims to explore the environmental factors determining avian community composition and distribution across forest habitats on the Pacific island of Ta'u, American Samoa. Fixed radius counts were conducted and habitat structure assessments performed to determine the effect of vegetation on the bird assemblages and occurrence of individual bird species. An NMDS ordination was conducted to investigate bird species abundance. It was observed that the assemblages of vegetational structure on the lowland rainforest, montane and summit scrub habitat are very structured with certain forest birds showing preferences towards them. While disturbed habitat tended to consist much of the island of Ta'u containing a much more varied composition with generalist bird abundant there. General Linear Models (GLM) were used to assess the effect of habitat characteristics on bird assemblage structure and distribution of individual species. Results show that native and introduced vegetation had an effect on the bird distribution, but that the effect differed between individual species and by habitat type. 43% of all the detected landbird individuals were on disturbed habitats, perhaps due to the bird movements between rainforest habitats and disturbed sites. Since Ta'u does not harbour any nonnative forest bird species, those birds could be filling the disturbed/modified habitats. Of conservation concern due to the restricted home range, habitat preference and recently described full specie, the Manu'a Shrikebill (*Clytorhynchus powelli*) was strongly observed to be associated with native habitats. Such habitat was seen to be altered by human activity and feral animals. The study emphasizes the need for additional research to fully understand the forest bird-environmental interactions to direct future conservation initiatives for the island of Ta'u. In addition, management and protection of the altered but diverse lowland environment is needed to allow those habitats of the island to be preserved.

## **INTRODUCTION**

The biological richness of tropical ecosystems is far greater than that of temperate environments, yet it is far less studied (Orme et al. 2005; Sodhi 2008) with research efforts skewed towards the poles (Collen et al. 2008). At a global scale, the lack of baseline research for many regions hinders effective management and conservation efforts (Collen et al. 2008). In the Caribbean for example, few studies of quantitative data have compared bird distribution among different habitats (Currie et al. 2005). While in South East Asia, the need for more studies has impeded much conservation efforts for the designation of conservation areas and priority habitats (Sodhi et al. 2004).

For Pacific island birds, little is known about the life history, movements and resource requirements (Freifeld 1999). To get a better understanding of data gap/unknown life history of flora and fauna, gathering as much data available (Arponen 2012) while identifying and addressing data gaps (Balmford et al. 2005). Threatened species and protected areas have been the focused of much research (Boakes et al. 2010), which can result in a cost-effective strategy to conservation efforts (Myers et al. 2000). Quantifying baseline bird distributions and identifying crucial habitats, is critical for developing effective conservation programs and management policies (Currie et al. 2005). It is worth noting that focusing an exclusive focus on endangered species or threatened habitats may not lead to optimal use of conservation resources since conservation planning could be influenced by multiple factors (Arponen 2012). For island environments, biodiversity conservation is a particularly high priority since they harbour many endemic (Tershy et al. 2015) and unique species. Oceanic islands occupy 3.6% of the global land surface, but account for 26.1% of the world's vascular plants and 23.2% of the terrestrial vertebrates, (Kier 2009). A high degree of endemism occurs because of their geographic isolation and the limited interchange with neighboring mainland or island biotas (Nogué et al. 2013).



More than 550 plant species have been recorded in the American Samoa archipelago, with 30% of these species being endemic to the islands. The island of Ta'u harbours around 330 of these species (Whistler 1992). In total, 68 species of birds have been recorded with 18 native forest birds recorded for the territory. Very little is known about the ecology of this island group (Robinson 1994). For example, few studies have looked at the avian assemblages and how these bird communities are arranged (Robinson 1994). Previous bird studies conducted on American Samoa are restricted to surveys of limited duration, often with only one visit to each location, and few sampling locations (Freifeld 1999). Robinson (1994) provides a list of publications in regards to the ecology of plants and animals for the Samoan archipelagoes. From the author's work, the research in the last century shows that only 114 publications have been made, with 59 of these dealing with birds. That could help explain why so little is known about the ecology of the region. In the last ~40 years there has been an increase in the number of published papers, but a deficit of ecological knowledge is widespread throughout many taxa (Freifeld 1999).

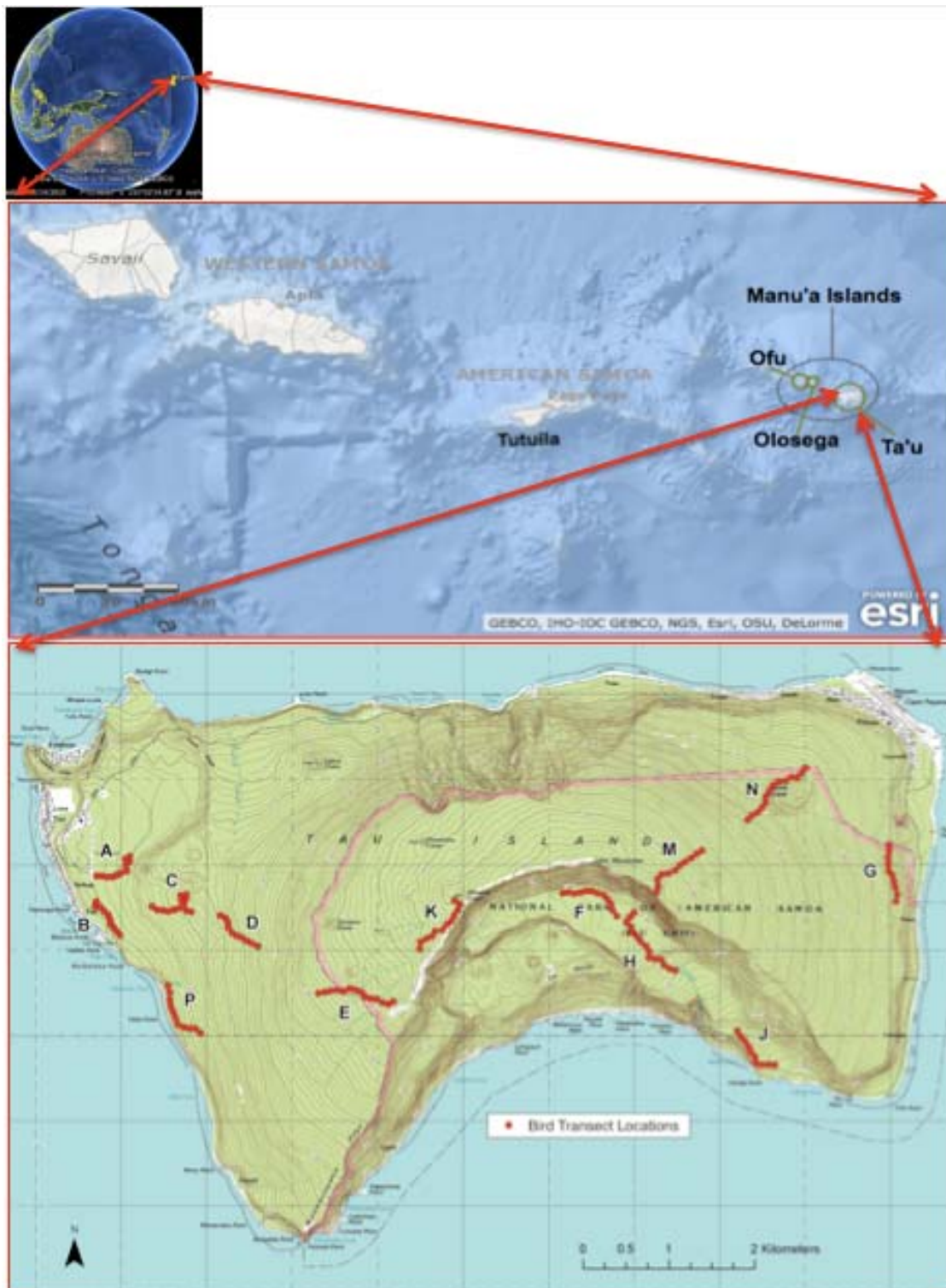
The aim of this paper is to better understand the landbird communities on the island of Ta'u, American Samoa. More specifically, the effect of vegetation structure with environmental attributes such as elevation to assess those bird species distributions and habitat preferences will be explored. To my knowledge, this study represents the first island-wide effort to survey the avifauna of Ta'u and to systematically document bird species distributions, abundance and habitat associations on the island. The work is also the most thorough bird survey (both spatially and temporally) conducted on Ta'u.

## **METHODS**

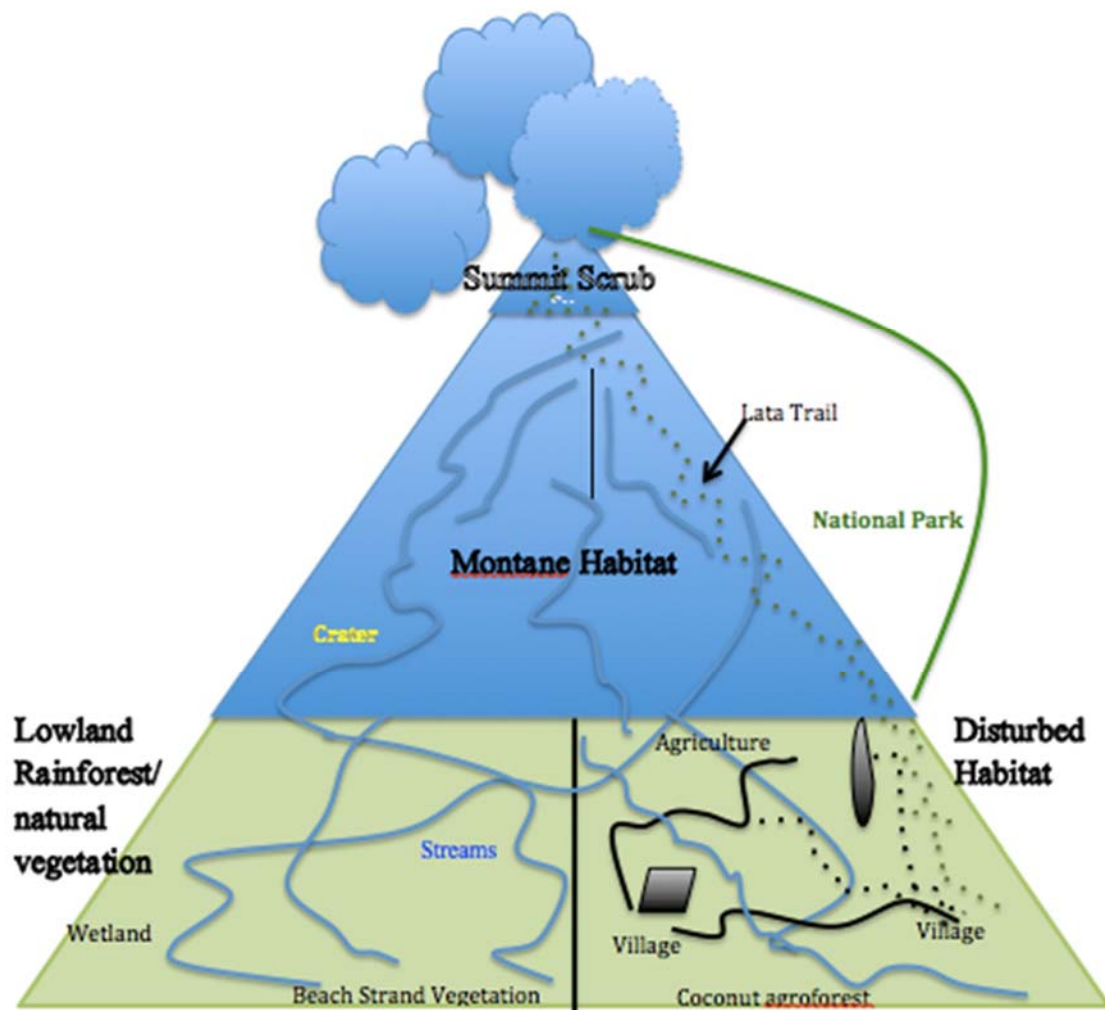
### **Study site**

The current work took place in the central Pacific Ocean, on the island of Ta'u in the American Samoa archipelago located between the Tropic of Capricorn and the equator (Fig.1). As an unincorporated territory of the United States, the American Samoan archipelago consists of five islands: Tutuila, 'Aunu'u, and the Manu'a Island group of Ofu, Olosega, and Ta'u. At ~100km to the east of Tutuila (mainland of American Samoa with a population of ~70,000), the island of Ta'u is inhabited by ~800 people in three villages. With the current terrestrial and marine ecosystems, human population growth and development are not perceived to be a major environmental threat to the island of Ta'u (Atkinson & Medeiros 2006). The island area is that of 39km<sup>2</sup> of the 200km<sup>2</sup> for the territory with the highest point on the island, Lata Mountain, found inside a national park. It reaches an elevation of 966m and is accessible by a single steep and rugged trail. The dramatic landscape and steep slopes characterizing much of the land, limits human and agriculture activity (Hughes et al. 2012), which is restricted to near shoreline areas or where a flatter landscape is present (Atkinson & Medeiros 2006). A schematic representation of the different habitat types along with anthological influences on Ta'u is given (Fig. 2)

The climate on Ta'u is governed by the oceanic temperatures and produces microclimatic conditions affecting the floral distribution (Amerson Jr et al. 1982). The average minimum temperature on the higher elevations is between 17-20°C (62-68°F) with a maximum of 22-26°C (72-78°F) and fluctuating by a few degrees between day and night (and several degrees warmer on the lower elevations). Seasonal variation throughout the year is small (Amerson Jr et al. 1982; Whistler 1994). High rainfall on the island results in a dense and diverse rainforest. Annual rainfall ranges from 350cm in the lowlands to over 840cm at higher elevations (Craig 2009), with estimates of over 1,015cm on the



**Figure 1.** Map of the Central Pacific region with Australia as reference and the Samoan Islands (created on [www.esri.com](http://www.esri.com)). Lower map is of Ta'u with transect point locations.



**Figure 2.** Schematic representation of Ta'u main habitat types and anthropological influences.

higher elevations (Amerson Jr et al. 1982) and harbouring a unique ecosystem known as the summit scrub. Relative humidity remains high throughout the year on the island (Whistler 1998) with no distinct dry season (Amerson Jr et al. 1982).

### *Avian biogeography*

Avifaunal diversity in the Samoan islands is mostly indigenous and low compared to mainland continents, with an absence of the species radiations of the isolated archipelagoes in the central and eastern Pacific islands (Atkinson & Medeiros 2006). The relatively low biodiversity of the islands may be due to their geologically recent formation, with Ta'u being one of the younger islands, dating to the Pliocene (Amerson Jr et al. 1982). Unlike the older western Polynesian islands, the Samoan young basalt-rich volcanic rocks have a radiometric age of 2.8 million years and lack limestone rocks (Steadman & Pregill 2004).

During more recent times, extinctions in the region suggest that many bird species went extinct with the onset of human settlement to the islands 3,000 years ago (Kirch & Hunt 1993). As of late, the Samoan islands avian composition have remained relatively unchanged, with a total of 68 species of birds have been documented for American Samoa (Craig 2009). There have been two documented extinctions, that of the Mao (*Gymnomyza samoensis*) (Atkinson et al. 2016) and Tooth-billed Pigeon (*Didunculus strigirostris*) (Weisler et al. 2016). The Mao (an meliphagid honeyeater) is still extant on Sava 'i in the Independent Western Samoa, but was last seen in 1977 on Tutuila island (Jarvi et al. 2003). Previous evidence of the Tooth-billed Pigeon was discovered for the first time on the territory by an archeological exploration dated from 2730–2460 cal BP on the island of Ofu (Weisler et al. 2016). The Spotless Crake (*Zapornia tabuensis*) was also once distributed in Tutuila, but can now only be found from archeological excavations (Steadman & Pregill 2004). The only extant population of that species in American Samoa appears to be on Ta'u (Rauzon & Fialua 2003).

Since existing gradients may be gradual, plant community changes may also be gradual, obscuring boundaries and blending community types with soil moisture, elevation, and slope as key environmental factors (Amerson Jr et al. 1982). In general, four main types of rainforest are found in Ta'u; *Dysoxylum* lowland forest, mixed lowland forest, montane forest, and summit scrub. The dominant canopy species in the Ta'u lowland forests is often *Syzygium inophylloides* (Amerson Jr et al. 1982), since it can persist through strong winds (Webb et al. 2014). The mixed lowland forest that was prevalent in the interior of Ta'u is now less extensive due to agriculture, but undisturbed lowland forest is still present (Whistler 1992). The disturbed vegetation consists of managed land, disturbed wetland, secondary scrub and secondary forest (Whistler 1994). The littoral community is composed of an herbaceous strand, littoral shrubland, and the littoral forest. For the purpose of this study, disturbed vegetation has been used to describe the disturbed vegetation habitats. These plant communities are discussed in detail by Whistler (1992).

With a cooler microclimate at the mountaintop, subtropical genera like *Weinmannia* can be found on the island (Whistler 1992). The rainfall experienced on the island is due to orographic precipitation, from the condensation of water when moisture-laden tradewinds ascend the mountain (Atkinson & Medeiros 2006). Given such wet conditions, terrestrial and epiphytic herbaceous species such as mosses, ferns and orchids are also very abundant (Whistler 1992). The wind on the montane scrub causes many of the trees to be shorter in stature than those in the lower elevation, also where the richest flora on the island is found (Whistler 1992).

#### *Site selection*

Survey sites were selected subjectively by scouting potential sites suitable for forest bird point count transects. Whenever possible, existing trails/paths, edges or clearings were utilized to decrease the amount of disturbance to the dense and diverse vegetation. The study focused on forest birds, so littoral/coastal vegetation was not sampled in this study.

Detailed maps and topographical information of the island were provided by the Department of Marine and Wildlife Resources (DMWR; Fig 1). The study was conducted from May-September 2013 with two surveys conducted (survey one (S1) during June/July and survey two (S2) August/September) on the island of Tau, American Samoa.

### *Point Counts*

Point count surveys were conducted using fixed-radius point counts following the methods described by (Ralph et al. 1993) and due to limited space, topography, and dense vegetation on the island, 75m between each point was used. At each survey site, flagging tape was used to mark the station and GPS locations recorded for a total of 153 fixed-radius point counts representing the different habitats (Disturbed-55, lowland rainforest-34, Montane-53 and montane scrub-11) used by forest birds on the island (Table 1).

Daily surveys started 30 minutes before sunrise, at 06.30 (dawn) and continued for three hours before bird activity subsided. Surveys were then repeated at the same points from around 15.45h until 18.20 (dusk) (Blake 1992). All forest birds species detected during the point count surveys (Table 1) were recorded within a 25-m radius (given the dense vegetation), and the number of individuals of each species was recorded (Freifeld 1999; Hutto et al. 1986; Ralph et al. 1993). Each point count lasted 5 minutes and the minute interval each bird was detected was noted (Ralph & Sauer 1995). The distance to each bird was measured using a Bushnell Scout 1000 Arc Rangefinder.

**Table 1.** Bird species encountered on Ta'u with common scientific and Samoan name and four letter code. Status : E=endemic, M=migrant, R= resident, S= sea visitor. Conservation status: CL=candidate listing, LC=least concern, MC=Management concern. Guilds: F=frugivore, I=insectivore, H=herbivore, M=molluscivore, N= nectarivore, O=omnivore, P=piscivore, V=vertebrate (carnivore). Gray text indicates species that were incidental observations, thus not included in the analysis.

Common name	Scientific Name	Samoan Name	Four letter code	Status	Conservation	Guild
Barn Owl	<i>Tyto alba</i>	Lulu	BAOW	R	LC	V
Buff-banded Rail	<i>Gallirallus philippensis</i>	Ve'a	BARA	R	LC	O
Blue-crowned Lorikeet	<i>Vini australis</i>	Segavao, Sega'ula	BCLO	R	LC	N
Long-tailed Cuckoo (Koel)	<i>Eudynamis taitensis</i>	Aleva	LTCU	M	LC (pop trend decreasing)	V, I, F
Many-colored Fruit-Dove	<i>Ptilinopus perousii</i>	Manuma	MCFD	R	CL, LC (pop trend decreasing)	F
Pacific Pigeon	<i>Ducula pacifica</i>	Lupe	PAPI	R	LC (pop trend decreasing)	F
Purple-capped Fruit-dove	<i>Ptilinopus porphyraceus</i>	Manutagi	PCFD	R	LC (Stable pop)	F
Purple Swamphen	<i>Porphyrio porphyrio</i>	Manu ali'i	PUSW	R	LC (pop trend unknown)	H, I
Manu'a Starling	<i>Aplonis tabuensis</i>	Miti vao	MAST	R	LC (pop trend unknown)	F, I
Peale's Kingfisher	<i>Todiramphus chloris</i>	Ti'otala	PEKI	R	LC (pop trend decreasing)	I, V
Samoan Starling	<i>Aplonis atrifusca</i>	Fuia	SAST	E	LC (pop trend unknown)	F, I, N, V
Manu'a Shrikebill	<i>Clytorhynchus [vitiensis] powelli</i>	Sega o le vau	MASB	E	LC (Pop trend unknown)	I
Spotless Crake	<i>Zapornia tabuensis</i>	-	SPCR	R	CL, MC	O
Wattled Honeyeater	<i>Foulehaio carunculata</i>	Iao	WAHO	R	LC (pop trend decreasing)	N, I
White-rumped Swiftlet	<i>Aerodramus spodiopygia</i>	Pe'ape'a	WRSW	R	LC (Stable pop)	I

At each point, data collected included the following variables: date, station identification, start time, temperature, cloud cover, wind (Beaufort scale) and background noise. For each bird detection, the minute interval, species, number of individuals, distance and the cardinal direction of each bird were recorded. Point counts were not conducted during rainy, windy, foggy or noisy conditions, which can interfere with the ability to detect birds (Ralph et al. 1993). Should be noted that point count does carry some assumptions to them. Hutto et al. (1986) describe these in detail: i) birds are within the sampled area,



ii) birds don't move, iii) are not double counted, iv) distances are measured without error, v) each sighting is an independent event and vi) points are randomly places.

### *Habitat characteristics*

A Habitat Structure Assessment (HSA) was conducted at each avian survey point following Nott et al. (2003). The HSA was performed at the completion of the first and the second avian point count survey period. Data collected included: date, station ID, coordinates of plot center, slope, aspect, topographical position of the point, open ground and water cover inside the 25-meter radius of count, canopy cover for each cardinal direction, canopy class, canopy height, height class, and elevation. At each point, the species composition of the canopy, understory, and undergrowth vegetation were identified to the species level using Webb (2009). Plant species not identified to the species level were also recorded according to where in the forest strata those were detected (undergrowth, understory, and/or canopy). Photographs from each cardinal direction were also taken at every point (Camp et al. 2011) to represent the characteristic features of those site.

### *Statistical analysis*

Bird and plant species not identified to the species level were excluded from the analyses. The statistical analysis and models were conducted using R version 3.2.1 (R Development Core Team 2015).

*Species abundance* - A Poisson Generalized Linear Model (GLM) was used to examine the effect of the response variable (number of individuals of a given species detected) and the composition of the explanatory variables (environmental attributes). Such models can be used to describe the distribution of forest birds by relating response variable to the

spatially referenced covariates (Augustin et al. 1996). The number of birds recorded at each station was used in the multivariate analyses along with the habitat variables (Freifeld 1999) to determine what effects those variables could have on bird species diversity. The Akaike Information Criterion (AIC) was used to compare the different models created without random effects. Best models were obtained for each bird species, where non-significant variables were removed stepwise from the model to obtain the lowest AIC value (Webb et al. 2014), so retaining the most relevant and significant predictors.

*Community composition* - Nonmetric multidimensional scaling (NMDS) was applied to determine the community composition of forest birds across different habitats. NMDS ordination illustrates multivariate associations, by rank correlation and distances in a reduced ordination space (Clarke 1993). For the analyses, NMDS was used with a Bray-Curtis dissimilarity matrix from the forest birds relative abundance (Kennedy et al. 2010), since it is a distance-based ordination to measure ecological distance (Faith et al. 1987). The statistical significance of the performed ordination was determined by a k=100 permutation test.

## RESULT

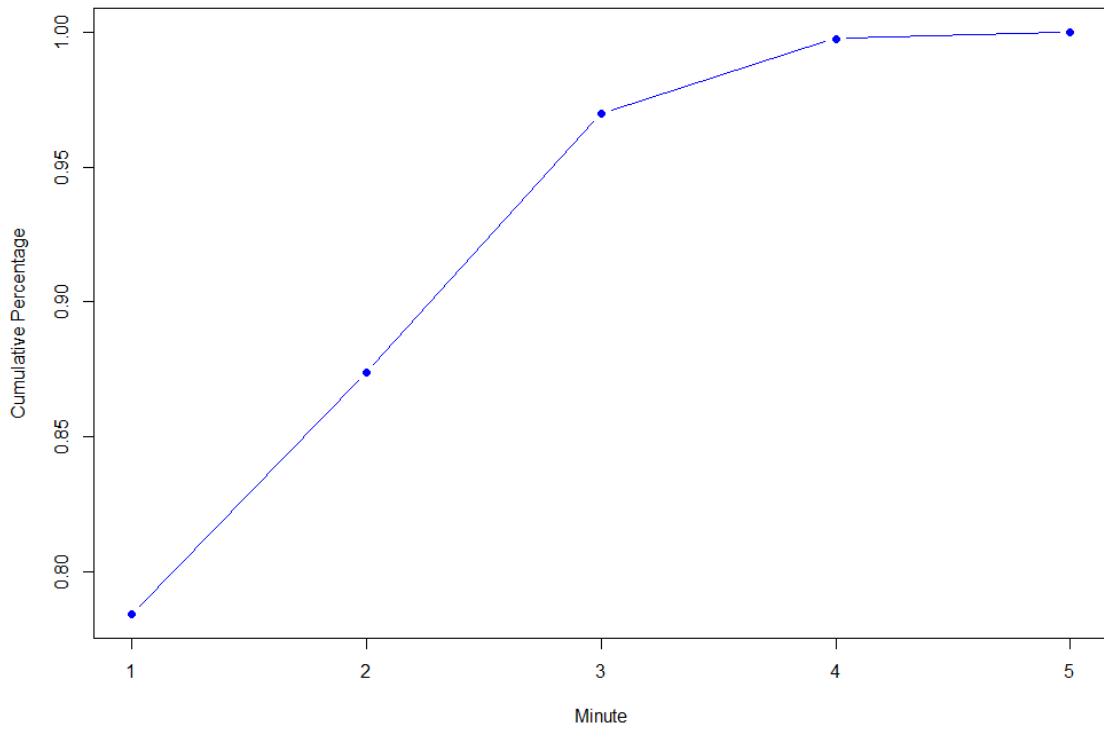
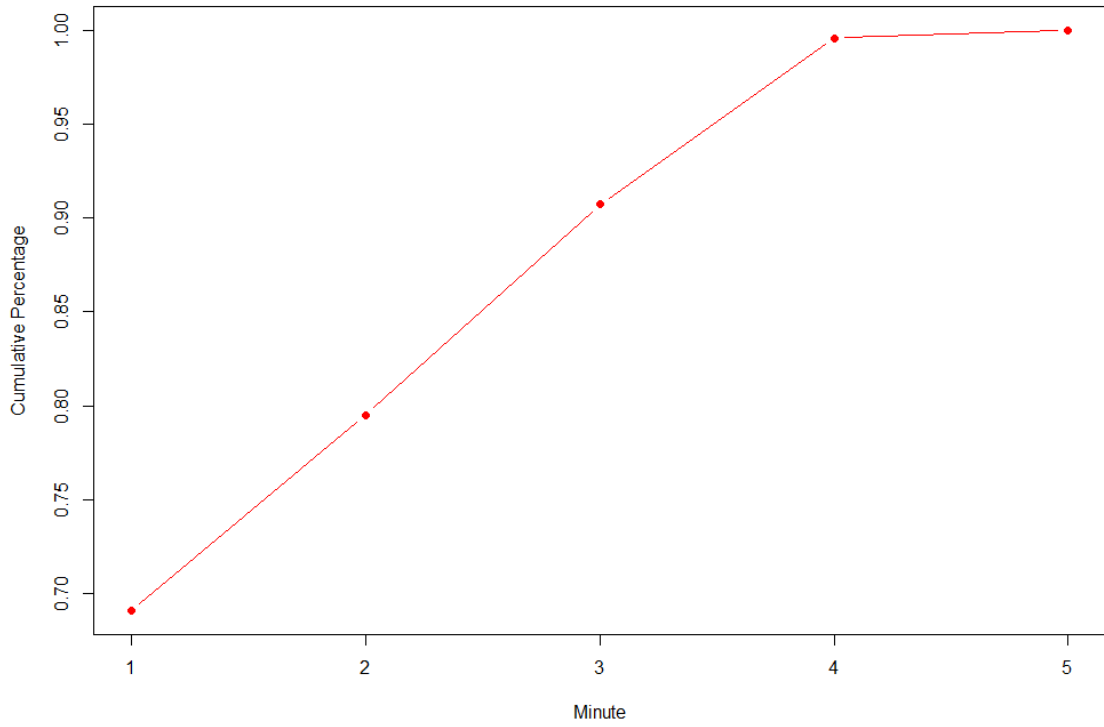
*Bird species richness and abundance* - A total of 1,876 individual birds from 11 species were recorded during the point counts . In addition, incidental observations of Long-tailed Cuckoo, Purple Swamphen, Barn Owl, and Many-colored Fruit-dove were made outside of the survey period. During S1, 1140 individuals were recorded with a significant reduction to 667 for S2 (beta=-0.383, p=<0.001). Nearly all the species experienced a decline in the number of individuals detected between S1 and S2, with the exception of the Polynesian and Samoan Starling. Two transects (N and P) had an increase and three no change in the number of bird species detected between S1 and S2 (Table 2).

**Table 2.** Habitat type, elevational range, number of bird and plant species for each transect surveyed on the island of Tau, American Samoa.

Transect	Habitat Type	No. of survey points	Elevational Range		S1 bird species	S2 bird species	No. of bird species	No. of plant species
			Min.	Max.				
A	Disturbed	11	78	111	8	8	10	19
B	Disturbed	10	63	71	10	8	10	19
C	Disturbed	13	159	223	11	11	13	19
D	Rainforest	10	272	367	10	6	10	18
E	Montane	14	587	679	9	6	8	8
F	Montane	12	489	527	10	NA	10	16
G	Disturbed	10	132	193	8	8	10	9
H	Montane	15	380	490	11	9	14	14
J	Rainforest	10	58	213	9	8	9	16
K	Montane	12	777	875	6	NA	6	12
M	Summit scrub	11	783	955	5	3	5	12
N	Rainforest	14	353	573	8	9	9	14
P	Disturbed	11	78	142	9	10	11	15

Most birds were detected during the first minute of the point count (68% and 77% for S1 and S2, respectively), and by the fourth minute, 99% of the birds encountered during the surveys were detected (Fig. 3). By the fifth minute, the effort spent for that additional minute did not contribute to any new detections, (for S1, only 6 of 1140 individuals were detected during the last minute of the point counts).

Wattled Honeyeater was by far the most frequently detected bird species, accounting for nearly half of all the bird detections. At some point count locations, it was the only bird species detected. Wattled Honeyeater and White-rumped Swiftlet were detected on all of the 13 transects surveyed. The Blue-crowned Lorikeet, Purple-capped Fruit-dove, and Manu'a Starling were detected at 92% of the point count stations. From the first to the second survey, the most significant decrease was observed for Wattled Honeyeater, Blue-crowned Lorikeet, Pacific Pigeon and Purple-capped with the latter two having a decrease in detection of at least 84%.



**Figure 3.** Cumulative proportion graph of birds detections during the fixed avian point counts. The graphs illustrates that by the third minute, at least 90% of the bird species are detected for both S1 (top graph) and S2 (lower graph).

Table 3. Bird abundance during S1 (n=1140) and S2 (n=667), the detection change from both bird count and the transects on which each bird species was observed.

Species	Survey one (S1)						Survey two (S2)						Change S1 to S2 (%)	Transect Detected (%)
	Transect detected	Individual (% total)	Disturbed (%)	Lowland Rainforest	Montane	Summit Scrub	Transect detected	Individual (% total)	Disturbed	Lowland Rainforest	Montane	Summit Scrub		
BCLO	A-H, J, K, M, N, P	187 (16)	69 (37)	38 (20.3%)	77 (41.2%)	3 (1.6%)	A-E, G, H, J, N, P	82 (11.5)	38 (42.7%)	15 (18.2)	0	-56	100	
BARA	A, B, C, F, J, M	12 (1.02)	9 (75)	1 (8.1%)	1 (8.1%)	1 (8.1%)	B, G, H, J, P	11 (1.55)	4 (66.6%)	1 (16.6%)	0	-8	69	
MASB	C-F, H, P	22 (1.88)	5 (22.7)	1 (4.5%)	16 (72.7%)	0	C, E, P	9 (1.27)	6 (66.6%)	3 (33.3%)	0	-59	46	
MAST	C-H, J, K, N, P	29 (2.48)	8 (27.5)	8 (27.5%)	13 (44.8%)	0	A, B, C, E, J, N, P	31 (4.37)	18 (58%)	2 (6.4%)	0	7	92	
PAPI	A-D, F, G, H, J, N, P	88 (7.53)	39 (44.3)	40 (45.4%)	9 (10.2%)	0	A-D, J, N, P	11 (1.55)	5 (45.4%)	6 (54.5%)	0	-87	69	
PEKI	A, C, D, E, G, J, N, P	15 (1.28)	5 (33.3)	9 (60%)	1 (6.6%)	0	A, C, D, G, H, N, P	10 (1.41)	7 (70%)	1 (10%)	0	-33	69	
PCFD	A-H, J, K	52 (4.45)	18 (34.6)	10 (19.2%)	24 (46.1%)	0	C, G, J, N, P	10 (1.41)	4 (40%)	6 (60%)	0	-84	92	
SAST	A-H, J, N, P	86 (7.36)	44 (51.1)	19 (22.1%)	23 (26.7%)	0	A-E, G, H, J, N, P	91 (12.8)	45 (49.4%)	19 (20.8%)	0	5	84	
SPCR	H, M	11 (0.94)	0	0	6 (54.5%)	5 (45.4%)	H, M	4 (0.56)	0	1 (2.5%)	3 (7.5%)	-63	15	
WAHO	All	537 (45.9)	185 (34.4)	117 (21.8%)	202 (37.6%)	33 (6%)	All	349 (49.3)	169 (48.4%)	56 (16%)	23 (6.6%)	-35	100	
WRSW	All	101 (8.64)	53 (52.4)	12 (11.8%)	29 (28.7%)	7 (6.9%)	A, B, C, E, G, H, J, M, N, P	63 (8.89)	45 (71.4%)	11 (17.4)	1 (1.5%)	-37	100	
<b>TOTAL</b>	<b>TOTAL</b>	<b>1,140 (63)</b>	<b>435 (38)</b>	<b>255(22.3)</b>	<b>401(35.1)</b>	<b>49 (4.3)</b>	<b>TOTAL</b>	<b>667 (36.9)</b>	<b>341(51%)</b>	<b>109 (16.3)</b>	<b>27 (4%)</b>	<b>-41</b>		

Before detailing the GLM analyses results, the key main points is given.

- 1) The abundance of bird from that of the first to the second survey had a significant decrease for Wattled Honeyeater, Blue-crowned Lorikeet, Pacific Pigeon, Purple-capped Fruit-dove and when all species were pool.
- 2) An increase in the percentage of canopy cover had a significant decrease on the Spotless Crake and the White-rumped Swiftlet.
- 3) The increase in elevation saw a significant decrease for the Blue-crowned Lorikeet and Pacific Pigeon and for all the species overall.
- 4) The increased abundance/prevalence of introduced midstory plant species had a significant decrease for the Blue-crowned Lorikeet, White-rumped Swiftlet and for all the species overall.

### Species accounts

*Wattled Honeyeater* - Detected at all the points surveyed, the Wattled Honeyeater had a significant decrease from S1 to S2 (beta=-0.228, SE=0.069, z=-3.312, p=<0.001). The only variable having any effect on Wattled Honeyeater is the native undergrowth plants with a nonsignificant negative effect (beta=-0.045, SE=0.031, z=-1.462, p=0.144).

*Buff-banded Rail* - The presence of introduced undergrowth plants (beta=-1.633, SE=0.611, z=-2.673, p=0.008) and the increase in elevation (beta=-0.004, SE=0.001, z=-2.874, p=0.004) both had a negative effect on Buff-banded Rail. While detections increased on bare ground (beta=0.981, SE=0.587, z=1.670, p=0.095) and sites with native canopy plant species (beta=0.593, SE=0.262, z=2.261, p=0.024).

*Manu'a Starling* - Bare ground (beta=0.742, SE=0.398, z=1.864, p=0.062), presence of water (beta=0.682, SE=0.327, z=2.085, p=0.037), native undergrowth plant species (beta=0.234, SE=0.132, z=1.764, p=0.078) and native midstory (beta=0.261, SE=0.107, z=2.446, p=0.014) all had a positive effect on the detection of the Manu'a Starling. Introduced undergrowth plants species had a negative effect on the species detection (beta= -0.666, SE=0.358, z=-1.862, p=0.063). Native canopy species (beta=-0.430, SE=0.165, z=-2.673, p=0.009) and elevation (beta=-0.001, SE=0.001, z=-1.695, p=0.090)

had a negative effect on the species. While introduced midstory plants did not have an effect on the species ( $\beta=-0.535$ ,  $SE=0.355$ ,  $z=-1.504$ ,  $p=0.132$ ).

*Blue-crowned Lorikeet* - A significant negative effect was seen from the first to the second survey ( $\beta=-0.633$ ,  $SE=0.134$ ,  $z=-4.729$ ,  $p<0.001$ ), elevation ( $\beta=-0.002$ ,  $SE=0.000$ ,  $z=-5.667$ ,  $p<0.001$ ) and with introduced midstory plant species ( $\beta=-0.666$ ,  $SE=0.162$ ,  $z=-4.10$ ,  $p<0.001$ ). Native undergrowth ( $\beta=-0.105$ ,  $SE=0.058$ ,  $z=-1.828$ ,  $p=0.068$ ) and introduced undergrowth plant species ( $\beta=-0.277$ ,  $SE=0.155$ ,  $z=-1.793$ ,  $p=0.073$ ) both had the same negative effect. Native midstory plants did not have an effect on the Blue-crowned Lorikeet ( $\beta=-0.083$ ,  $SE=0.051$ ,  $z=-1.615$ ,  $p=0.106$ ).

*White-rumped Swiftlet* - A significant negative effect on the detection of the White-rumped Swiftlet was the result when the canopy percentage is tested ( $\beta=-0.023$ ,  $SE=0.005$ ,  $z=-4.598$ ,  $p<0.001$ ). On the contrary, the exact opposite was the result when bare ground ( $\beta=0.873$ ,  $SE=0.212$ ,  $z=4.116$ ,  $p<0.001$ ) was considered. Introduced canopy plants had a positive effect on the species ( $\beta=0.571$ ,  $SE=0.215$ ,  $z=2.661$ ,  $p=0.008$ ), while introduced undergrowth plant species had a negative effect ( $\beta=-0.494$ ,  $SE=0.234$ ,  $z=-2.115$ ,  $p=0.034$ ). Native undergrowth plant species ( $\beta=-0.151$ ,  $p=0.114$ ), elevation ( $\beta=-0.001$ ,  $p=0.123$ ) and the abundance from from the first to the second survey did not have an effect on the swiftlet detection ( $\beta=-0.260$ ,  $p=0.111$ ).

*Peale's Kingfisher* - Water ( $\beta=1.027$ ,  $SE=2.418$ ,  $z=2.418$ ,  $p=0.016$ ), canopy percentage ( $\beta=0.068$ ,  $SE=0.027$ ,  $z=2.541$ ,  $p=0.011$ ) and introduced undergrowth plant species ( $\beta=2.057$ ,  $SE=1.024$ ,  $z=2.008$ ,  $p=0.045$ ) all had about the same positive effect on the Peale's Kingfisher detections.

*Pacific Pigeon* - A significant negative effect on the abundance of the pigeon was the result with the increase in elevation ( $\beta=-0.003$ ,  $SE=0.001$ ,  $z=-5.155$ ,  $p<0.001$ ) and from the first to second survey conducted ( $\beta=-2.036$ ,  $SE=0.320$ ,  $z=-6.362$ ,  $p<0.001$ ).



Introduced midstory plants also had a negative effect on the pigeon (beta=-0.722, SE=0.238, z=-3.030, p=0.002).

*Spotless Crane* - Canopy percentage has a very significant negative effect on the crane (beta=-0.064, SE=0.011, z=-5.581, p<0.001). While the presence of water at the survey site has a significant positive effect (beta=1.985, SE=0.690, z=2.877, p=0.004).

*Samoan Starling* - Elevation effect on Samoan Starling was negative (beta=-0.001, SE=0.000, z=-2.874, p=0.004). The native canopy plant species also had a negative effect on the species (beta=-0.231, SE=0.092, z=-2.525, p=0.012).

*Purple-capped Fruit-dove* - A negative effect was the result for the abundance of the fruit-dove when elevation (beta=-0.002, SE=0.001, z=-2.316, p=0.021) is analyzed. The first to second survey conducted also had a negative effect on the species, but with a much more significant effect (beta=-1.429, SE=0.347, z=-4.120, p<0.001). A similar negative effect was seen in regards to introduced midstory plants (beta=0.002, SE=0.001, z=-2.316, p=0.135). Water presence on the plot though had a positive effect on the abundance of the fruit-dove (beta=0.930, SE=0.268, z=3.470, p=0.001).

**Table 4.** Analyzed bird species using Generalized Linear Model with Poisson distributed error (log-link). The variables listed is the best model for each individual bird species and for all the species combined.

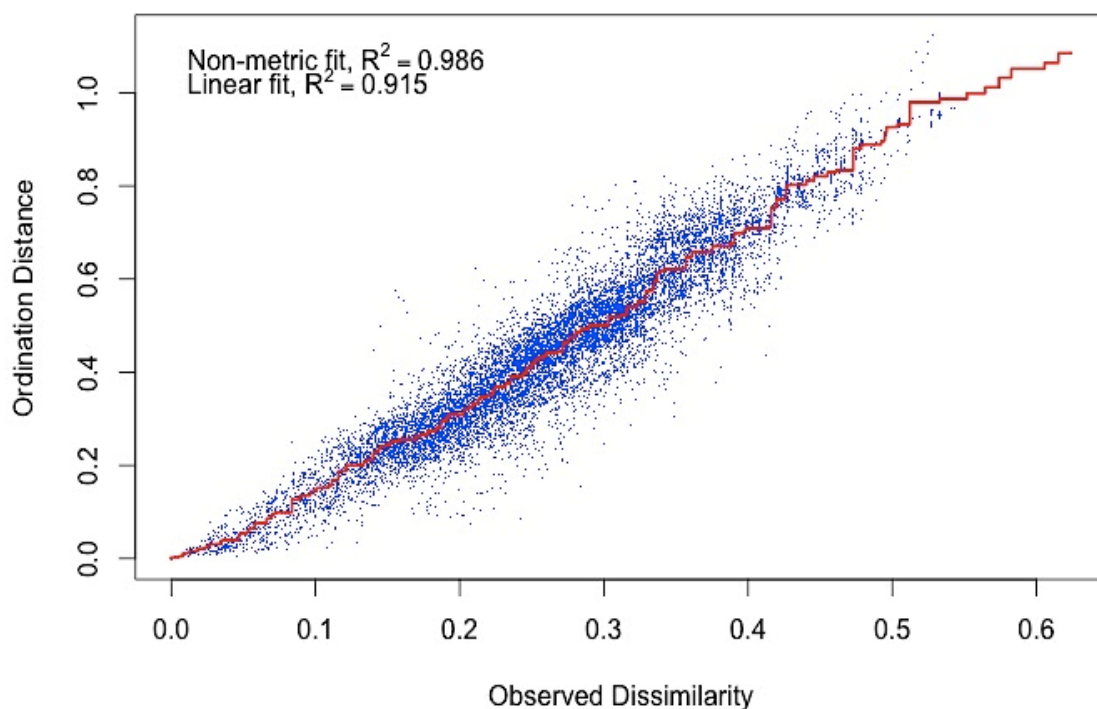
<b>All Species</b> AIC: 1309.8	beta	SE	z	p	<b>WRSW</b> AIC:546.06	beta	SE	z	p
(Intercept)	3.094	0.162	19.137	<0.001	(Intercept)	2.021	0.600	3.369	<0.001
Second Survey	-0.383	0.049	-7.806	<0.001	Second Survey	-0.260	0.163	-1.592	0.111
Slope	-0.006	0.003	-2.362	0.018	Slope	-0.023	0.010	-2.198	0.028
Water percent	0.090	0.057	1.575	0.115	Bare ground	0.873	0.212	4.116	<0.001
Canopy percent	-0.005	0.002	-3.330	<0.001	Canopy percentage	-0.023	0.005	-4.598	<0.001
Elevation	-0.001	0.000	-7.549	<0.001	Elevation	-0.001	0.001	-1.543	0.123
Native canopy plants	-0.079	0.028	-2.832	0.005	Native undergrowth plants	-0.151	0.096	-1.578	0.114
Native undergrowth plants	-0.039	0.023	-1.715	0.086	Intro. canopy plants	0.571	0.215	2.661	0.008
Intro. midstory plants	-0.233	0.064	-3.656	<0.001	Intro. undergrowth plants	-0.494	0.234	-2.115	0.034
<b>SAST</b> AIC:569.96					<b>PEKI</b> AIC:162.62				
(Intercept)	0.211	0.249	0.850	0.395	(Intercept)	-10.14	2.500	-4.058	<0.001
Elevation	-0.001	0.000	-2.874	0.004	Water percent	1.027	0.425	2.418	0.016
Native canopy plants	-0.231	0.092	-2.525	0.012	Canopy percentage	0.068	0.027	2.541	0.011
Intro. canopy plants	0.291	0.181	1.607	0.108	Intro. undergrowth plants	2.057	1.024	2.008	0.045
<b>BARA</b> AIC: 125.69					<b>PAPI</b> AIC:337.46				
(Intercept)	-0.912	0.925	-0.986	0.324	(Intercept)	-0.552	0.493	-1.121	0.262
Aspect	-0.006	0.003	-2.393	0.017	Second Survey	-2.036	0.320	-6.362	<0.001
Bare ground	0.981	0.587	1.670	0.095	Elevation	-0.003	0.001	-5.155	<0.001
Elevation	-0.004	0.001	-2.874	0.004	Native undergrowth plants	0.133	0.082	1.621	0.105
Native canopy plants	0.593	0.262	2.261	0.024	Intro. midstory plants	-0.722	0.238	-3.030	0.002
Intro. undergrowth Plants	-1.633	0.611	-2.673	0.008	Intro. undergrowth plants	1.152	0.432	2.667	0.008
<b>MAST</b> AIC: 311.12					<b>BCLO</b> AIC: 780.89				
(Intercept)	-1.838	0.656	-2.800	0.005	(Intercept)	1.713	0.247	6.931	<0.001
Aspect	0.004	0.002	2.349	0.019	Second Survey	-0.633	0.134	-4.729	<0.001
Bare ground	0.742	0.398	1.864	0.062	Slope	-0.012	0.007	-1.818	0.069
Water percent	0.682	0.327	2.085	0.037	Elevation	-0.002	0.000	-5.667	<0.001
Elevation	-0.001	0.001	-1.695	0.090	Native midstory plants	-0.083	0.051	-1.615	0.106
Native canopy plants	-0.430	0.165	-2.598	0.009	Native undergrowth plants	-0.105	0.058	-1.828	0.068
Native midstory plants	0.261	0.107	2.446	0.014	Intro. midstory plants	-0.666	0.162	-4.100	<0.001
Native undergrowth plants	0.234	0.132	1.764	0.078	Intro. undergrowth plants	-0.277	0.155	-1.793	0.073
Intro. midstory plants	-0.535	0.355	-1.504	0.132	<b>MASB</b> AIC:183.22				
Intro. undergrowth plants	-0.666	0.358	-1.862	0.063	(Intercept)	-1.960	0.570	-3.439	<0.001
<b>PCFD</b> AIC:292.13					Second Survey	-0.599	0.402	-1.489	0.136
(Intercept)	-0.725	0.317	-2.288	0.022	Bare ground	1.826	0.495	3.689	<0.001
Second Survey	-1.429	0.347	-4.120	<0.001	Native canopy plants	-0.824	0.246	-3.353	<0.001
Water percentage	0.930	0.268	3.470	0.001	Native midstory plants	0.618	0.134	4.599	<0.001
Elevation	-0.002	0.001	-2.316	0.021	Intro. canopy plants	-1.141	0.570	-2.003	0.045
Intro. midstory plants	-0.512	0.342	-1.496	0.135	Intro. undergrowth plants	-1.058	0.427	-2.478	0.013
<b>SPCR</b> AIC:84.179					<b>WAHO</b> AIC: 939.12				
(Intercept)	-0.114	0.394	-0.288	0.773	(Intercept)	1.313	0.058	22.690	<0.001
Water percentage	1.985	0.690	2.877	0.004	Second Survey	-0.228	0.069	-3.312	<0.001
Canopy percent	-0.064	0.011	-5.581	<0.001	Native undergrowth plants	-0.045	0.031	-1.462	0.144

**Table 5.** Arrow denotes change of increase or decrease in bird detection in regard to variable tested on the GLM. An asterisk indicates a significant effect with blue highlight to emphasize the significance. The species are grouped according to their habitat association from the NMDS plot. Red boxes indicate disturbed habitat, green is the lowland rainforest, yellow is the montane habitat and the last habitat is that of the spotless crane with habitat association of summit scrub. Lower portion (below solid line) of the table represent the Primary (P) and Secondary (S) habitat preference of each bird species as described by Amerson Jr et al. (1982).

Variable	BARA	WRSW	PEKI	PAPI	SAST	WAHO	MAST	BCLO	PCFD	MASB	SPCR	All Species
Second Survey		↓		↓*		↓*		↓*	↓*			↓*
Slope		↓						↓				↓
Water %			↑				↑		↑		↑	
Canopy %		↓*	↑								↓*	↓
Elevation	↓	↓		↓*	↓		↓	↓*	↓			↓*
Aspect	↓						↑					
Bare ground	↑			↑			↑					
Native Canopy plants	↑				↓		↓					↓
Native midstory plants							↑	↓				
Native Undergrowth plants	↓	↓		↑		↓	↑	↓				↓
Intro. Canopy plants		↑			↑							
Intro. midstory plants		↓*		↓			↓	↓*	↓			↓*
Intro. Undergrowth plants							↓	↓				
Rainforest	S	S	S	P	P	P	P	S	P	P		
Disturbed	P	P	P	S	P	P	S	P	S			
Montane		S	S		P	S	P	S				
Summit Scrub		P	S		P	S	P	S				

### Spatial organization of the bird assemblage

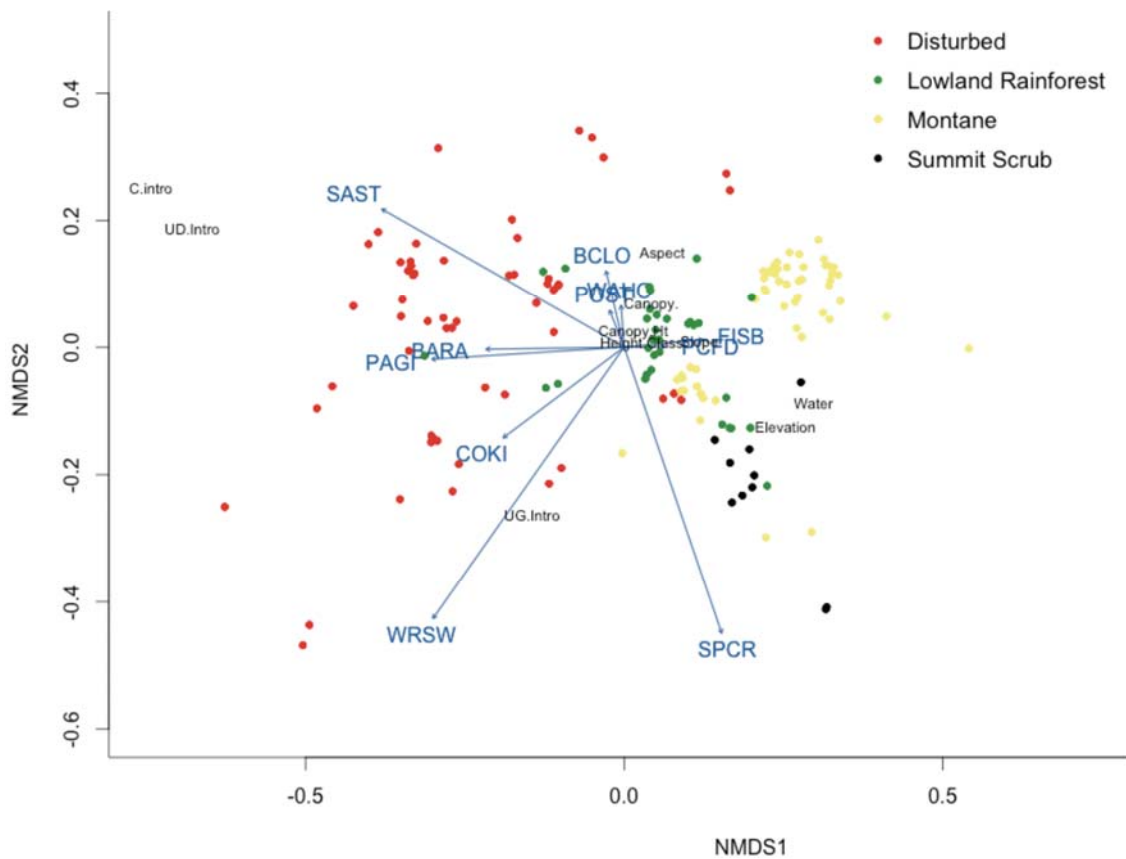
An NMDS ordination for the landbird and their habitat association resulted in a resolution of  $k=3$  axis, with a stress of 0.122, a non-metric fit of  $R^2=0.986$  and a linear fit of  $R^2=0.915$  (Fig. 4). From the plant species at the survey sites, the main/core habitat composition for the four habitat types did not exhibit substantial overlap, which could suggest that few species are shared among those habitats (Fig. 5).



**Figure 4.** Stressplot of nonmetric multidimensional scaling (NMDS) ordination for NMDS1 and NMDS2 (stress 0.1221).

There was a strong association for disturbed sites for Pacific Pigeon, White-rumped Swiftlet, Banded Rail, Peale's Kingfisher and Samoan Starling (Fig. 5). Those sites were characterized with environmental variables such as road/bare ground cover, introduced canopy, understory and undergrowth plant species. The lowland rainforest avian assemblage was composed of Manu'a Starling, Blue-crowned Lorikeet, Wattled Honeyeater and Purple-capped Fruit-dove. At those sites, a dense canopy percentage, a

tall canopy height and indigenous understory plant species were associated with the lowland rainforest habitat. Moving up the elevational gradient, on montane habitats the only bird species that was associated with that habitat was the Manu'a Shrikebill. The environmental factors associated with that habitat were the presence of water and an increase in elevation. At the top of the island, the summit scrub habitat, the only species that also had a very strong association for that habitat was the Spotless Crake. The only variable on that habitat that had a strong association for the Spotless Crake was the presence of indigenous undergrowth plant species.



**Figure 5.** NMDS plot of bird communities at 153 survey points, grouped in four habitat types (disturbed, lowland rainforest, montane and summit scrub). The figure illustrates variation in the bird community structure on Ta'u. The relative position of the surveyed sites is based on the species grouping, with similar sites having similar scores in multidimensional space. Blue text indicates bird species codes from table 1. Brown text indicates environmental attributes at survey sites - UD.intro = introduced understory plants, C.intro = introduced canopy plants, UG.intro = introduced undergrowth plants, C.indi = indigenous canopy plants, UD.indi = indigenous understory plants, UG.indi = indigenous undergrowth plants, Canopy.Ht = Canopy height, Canopy. = canopy percentage. In general, bird species were associated with disturbed sites. From the horizontal blue arrow indicates the gradient is from disturbed sites on the left of the gradient to native habitat on the right.

## Discussion

### Species richness and abundance

*In comparison with other islands* - Eventhough the length of the census was that of several months, generalities can be drawn and compared with other islands for the avifauna present for Ta'u. Understory birds such as the shrikebill, depends on well-developed shrub layer absent/modified from disturb sites. That is so since less disturbed forest provides a richer prey base for insectivorous species such as the shrikebill (Steadman & Freifeld 1998). As in those populations in Tonga, shrikebills in Ta'u are vulnerable to habitat modifications and feral animal influences (Steadman & Freifeld 1998). Like other islands, eventhough the patchy distribution of some species (e.g. lorikeets, pigeons/doves,), or those of more generalist (e.g. honeyeaters, starlings), trees produce "generalist" fruits, a tight strong reliance of a single or few vertebrate seed dispersals is apparent on such isolated island (Webb et al. 1999). When Low abundance species like that of the kingfisher or pigeon experience a drastic change in abundance, that might may not be biologically significant if it was only recorded once or twice at a site (Freifeld et al. 2004). Unlike abundance of Pacific Pigeon on Tutuila can be kept low from hunting pressures and/or habitat modifications, Ta'u population was not deterred by disturbed habitat. Just as in Tonga (Steadman & Freifeld 1998), the vocal frugivore was abundant on the lowland habitats surveyed. That the remaining mature forest in Tonga sustain the only extant population of forest dependent forest birds, can serve as a source-sink mechanisms (Steadman & Freifeld 1998), is of ecological importance. For Ta'u species such as the Spotless Crake are now only found on isolated and localized native habitats, away from disturbance that could affect their population.

*Expected results* - It was no surprise how prevalent Wattled Honeyeater are throughout the different habitats given the species ability to persist on a wide variety of food source. From other studies, the abundance of the species was lower in Tonga than that of Tutuila, with the likely cause from the presence of other insectivores (Freifeld 1999).

During the 1986 bird surveys for Ta'u, a total of 7,095 individual bird species were recorded (Engbring & Ramsey 1989), compared to the 1,807 for the present effort. Should mention that during those surveys, variable circular plot method were used, each point count was 150-m apart, entire survey period from 18-26 July and 8-minute counts were used. On a study by McShea and Rappole (1997), it was found that within 50m from the observer, song rate of birds was half than that of individuals beyond 50m. Given that the fixed point counts were 75m and that birds recorded were within 25m from the plot center, could account for the reduced detection in bird species. Future survey efforts should increase distance between survey point counts from 75 to 100m, since the spacing used might not allow the abundance to be entirely reflective of population dynamics of Ta'u. In addition, radius of surveyed sites should be increase from 25 to 50m.

*Reasons for detection of species only by incidental observation* - With the exception of Many-colored Fruit-dove, Barn Owl and Purple Swamphen, all the other surveyed species expected to be recorded were detected during the survey efforts performed. For those species not detected, that could be due to the survey method used and the layout of the transects (e.g. swamphen), or due to their rarity or localized in nature (e.g. Many-colored Fruit-dove) (Freifeld et al. 2004) or simply due to a migratory species (e.g. Long-tailed Cuckoo). Species recorded only by incidental observations can also be due to the species not vocalizing or being cryptic, thus not getting detected at a site.

*Abundance change between survey efforts* - Survey methods of short time intervals might not necessarily illustrate the pattern, complexity and fluctuations overtime of species (Freifeld et al. 2004; Scott et al. 1984). Such methods though can provide an insight to the population demographics at a single time. From the present survey efforts, a decrease from the first to second survey might could be due to birds localizing tracking fruit patches, so concentrating certain species spatially to take advantage of abundant and patchy food sources during the survey. Perhaps, for the present effort that was seen from the sharp decrease in abundance from the first to second survey for species for both Columbidae species, which say a sharp decrease of at least 84%. Another species, which tends to be fairly vocal thus more likely to be detected than other, is the Blue-crowned

Lorikeet. That species experienced a detection reduction of 56%. In Hawaii, It has been found that nectarivorous birds species performed mass movements, to patchy and locally distributed areas, by which areas can see a high density shift by such populations (Scott et al. 1986). This though does not explain the high abundance and dominance of wattled honeyeaters across every habitat surveyed. With the exception of both starling species who saw an increase in abundance by 6% (due perhaps to their plasticity to forage on a wide food source), it could also be said that the avifauna could be tracking a food source not yet fully understood. Lilac-crowned Parrots in western Mexico, are able to track seed abundances thus making them vital dispersals of canopy tree species (Renton 2001). As previously mentioned, other species might not necessarily be vocal during certain time of the year, or are performing pre/post breeding season activities, reacting to hunting pressures and so forth.

*Most detections in the first three minutes* - As seen on figure 3, at least 90% of the species were detected by the third minute, and as previously mentioned, 99% of those by the fourth minute. It has been found that the detection rate of new species during the first 5 minute was three times higher than those of 10- to 15-minute interval (Lynch 1995). For that reason, investing more time on longer surveys might not yield additional useful data. The implication of knowing which minute interval can yield the greatest detected species can be valuable for anyone trying to maximize the data gathered in the least amount of time, thus able to survey more sites during a survey period. Thus, efforts to survey forest bird species are maximized if survey period are performed until the cumulative count levels off and thus avoiding overcounting of individuals in the process (McCallum 2005). Resources can be better used by having more survey points to cover a wider area, thus additional demographics data. With that knowledge, future research can be into acquired the most efficient data on bird populations in the, especially when funds are limited.



## Spatial organization of the bird assemblage

The different habitats supported distinct bird assemblages, as indicated by the clustering of sites from the same habitat type in the NMDS ordination (Fig. 5). As such four distinct bird assemblages can be observed. The main “habitat” is that of disturbed sites which was seen to be composed of a varied composition. Bird species correlated with disturbed sites included Pacific Pigeon, White-rumped Swiftlet, Samoan Starling, Peale's Kingfisher and the Banded Rail. The environmental attributes also included bare ground, introduced undergrowth, understory and canopy plant species.

Much overlap is seen between disturbed and lowland rainforest habitat since most of the disturbed habitat was a former rainforest, hence tends to be in close proximity. Also, it appears that most of the lowland rainforest surveyed has been degraded. The bird species, habitat association and environmental attributes tie-in together to illustrate how avian species distributes themselves on the island. It is no surprise that disturbed sites will be inhabited by edge, generalist or omnivorous bird species able to exploit not only those altered locations but the natives ones as well.

Eventhough the island remoteness, no ecosystem on Earth's surface is free from the pervasive influence of humans (Chapin III et al. 2000; Vitousek et al. 1997). Atkinson and Medeiros (2006) suggested that environmental stress does not currently present a threat to the Ta'u ecosystem, given it relatively intact state. The results obtained in my study indicate otherwise. On remote islands, such as those in the sub-Antarctic, human activity/influence have now resulted with half of the introduced angiosperm there (Convey 2007). For Ta'u island, eventhough the protected area of the national park harbours much native biota, those can be outcompeted by introduced organisms (Chapin III et al. 2000). With the establishment of the National Park in 1991, agricultural activity ceased in the low elevational range of the park, primarily on the eastern side of the island (Webb et al. 2006). From the work conducted, it was found that introduced canopy, understory and undergrowth plant species are taking over the lowland areas of the island, thus rainforest habitat.

From the lowland to the montane habitat, an overlap between the plants present could be due to the transition between the two habitats, which could harbor similar plant species, and perhaps bird species. A small overlap of plants species between the montane and the summit scrub habitat is mainly due to the upper section of the montane habitat sharing similar vegetation to the lower section of the summit scrub. That is also the natural gradient as one moves up in elevation on the island (excluding disturbed sites). The primary factors contributing to disturbance are agricultural activities, feral animals, infrastructure (airport), and invasive plant species, with all the disturbed sites located in the lowland rainforest habitat. Habitat disturbance is becoming increasingly prevalent on Ta'u.

A range of responses is seen in relation to the variables tested. Forest birds that were detected in disturbed sites could probably do so in part by their ability to take advantage and exploit those habitats. Freifeld (1999) study, found that many of the bird species included in the analysis were detected in most of the transects surveyed, which could indicate infrequent foraging on isolated food patches in less optimal habitats.

Freifeld (1999) observed that the distinction between native and non-native vegetation on Tutuila was important to understanding the distribution of birds. In disturbed sites, a higher percentage of bare ground tended to be present with a strong gradient on those sites towards such disturbance (Fig. 5). Freifeld (1999) found that in Tutuila, native plants such as *Ficus scabra* and *Macaranga harveyana* can be associated with fallow plantations on disturbed sites, which can provide food for frugivorous landbirds. For Ta'u, that could explain why a higher detection of birds was observed on disturbed sites. In addition, disturbed sites tended to be less densely foliated than the native rainforest sites. While the presence of native canopy and undergrowth plant species resulted in a decreased detection of birds. That could perhaps be due to because birds could be tracking fruit to take advantage of those resources.

The forest bird species associated with disturbed sites were Samoan Starling, Pacific Pigeon, White-rumped Swiftlet, Buff-banded Rail, Manu'a Starling and Peale's Kingfisher, constituting 45% of the landbird surveyed in Ta'u. Those disturbed habitat accounted for 39% of the transects surveyed. Freifeld (1999) work in Tutuila, observed that disturbed environments provided nonnative landbird species like mynas with more nesting and foraging resources than native forest. Since Ta'u does not yet have any nonnative forest bird species, that niche is being occupied by those five bird species identified above by this study as being associated with disturbed sites. Freifeld (1999) also found that managed land supported more food plants for some bird species than native forest. Food plants mentioned were coconut, banana, breadfruit and papaya providing a supply of nectar and fruit all year with ornamental flowers exploited by nectivorous bird species such as Blue-crowned Lorikeet and Wattled Honeyeater in Ta'u. Amerson Jr et al. (1982). Amerson Jr et al. (1982) mentions that Samoan Starling could be the only native forest bird who can consume large fruits such as bananas and papayas, but for the present effort other species were also observed foraging on such fruits (e.g. Blue-crowned Lorikeet, Wattled Honeyeater). It could be though that Samoan Starling facilitate the access to such fruits for other species.

#### Species account

The Manu'a Starling and Samoan Starling were habitat generalists and were observed along most transects during both surveys (84% and 92% for S1 and S2, respectively). However, Manu'a Starling appeared to show a slight preference for lowland rainforest montane forest and summit scrub over disturbed habitat. These observations are consistent with earlier descriptions of habitat use by these species (Amerson Jr et al. 1982). Manu'a Starling was observed on lowland rainforest foraging on *Dysoxylum* fruits. On other observations, the species was seen fending off Wattled Honeyeaters potentially from the fruit laden *Dysoxylum* tree. Samoan Starling tends to breed during the dry season (April-September), which coincides with copious fruiting by *Dysoxylum*

trees (Freifeld et al. 2004; Trail 1994)

Their generalist habitat use may reflect the plasticity in their diet, which includes fruits and nectare, invertebrates and small vertebrates (Trail 1992). This can be seen with flying foxes (*Pteropus* spp.) which can take advantage of behavioral or reproductive plasticity strategies to facilitate population recovery from severe storms (Grant et al. 1997). As such, Samoan Starling species are thus not under immediate threat from habitat disturbance (Freifeld 1999). In fact, the Samoan Starling may play an important role in the recolonization of native plants in anthropogenically disturbed sites as it has been shown to disperse a variety of native seeds (Sherman & Fall 2010). As, an example, *Macaranga harveyana*, a native species, was detected primarily on disturbed sites. Samoan Starling frequently forage on the fruits, thus helping to further spread the pioneer species (Trail 1994). As found by Hjerpe et al. (2001), fruit consuming birds had a higher abundance at burned sites than those that did not consume fruits. If further habitat degradation takes place, the ecological role of forest regeneration by seed dispersal could be jeopardize from the reduction of such species.

The Pacific Pigeon occurred in all habitats except the summit scrub (Table 3). The species was found to have a nearly the same preference for disturbed and lowland rainforest (n=44 and n=46, respectively out of n=99 for all sites). Its presence in disturbed sites contrasts with findings on Tutuila, where it is known to avoid human-modified areas and dependent on native habitats there (Sherman & Fall 2010). Their absence from disturbed sites on Tutuila may be due to a higher hunting pressure from the local human population thus resulting in shy behaviour. On Ta'u, hunting pressure is low and may allow the species to occupy areas even close to human settlements. The hunting is ominous, because the pigeon is an extremely important seed disperser on many Pacific islands. For example, the species is known to disperse seeds of native large-seeded forest plants over long distances on Tonga (McConkey & Drake 2002). McConkey et al. (2004) found that most seeds were dispersed within 50m of fruiting tree, but that seeds could travel up to 3km. Foraging flocks of Pacific Pigeon are known to move among the islands in search of fruiting trees (Watling 1982). The ecological service such *Columbidae*

species provides can in turn help maintain tree genetic diversity thus native ecosystem there. Tree species recruitment (particularly large-seeded trees) may be affected if this large frugivore experiences dramatic local declines or is locally extirpated. In the current study, the pigeon was regularly observed feeding on *Myristica inutilis* fruits and on Tutuila it was only recorded on *Dysoxylum* tree species. Historically, a *Ducula* spp. in Tonga was able to consume seeds that were 8-10cm in diameter, but none can now be found on Polynesia today (Steadman 1997).

From the NMDS plot conducted (Fig. 5) and in accordance with Amerson Jr et al. (1982) the habitat association for White-rumped Swiftlet was that of disturbed sites. An interesting observation made by the present effort in that introduced midstory plants had a significant decrease in the abundance of swifts. As an above canopy/edge foraging specie, the fact that the midstory plants had such an influence could be of concern. Insect diversity can be sharply reduced in the presence of introduced canopy species, which can have a cascading effect to the ecosystem. For example, studies of invertebrates on tamarisk, found that the arthropod diversity on the invasive tree was only 30% of that from willow trees (Pendleton et al. 2011). Given that swiftlet feed exclusively on insects, a decrease in the abundance of insects, could be part of the reason for the significant decrease by nonnative midstory plant species.

The abundance among the habitats was highest from the disturbed habitat then montane, lowland rainforest and the lowest abundance was that on summit scrub for the swifts (Table 3). Amerson Jr et al. (1982) classified the species as primarily on disturbed and summit scrub sites, while closed canopy habitat are a secondary preference to the species since it depends on open type habitat to forage for insects on the wing. The species is a rather abundant aerial landbird but vocally cryptic (Freifeld et al. 2004). It is an insectivore continuously catching insects on the wing on nearly every habitat type (Thibault et al. 2015). Survey methods used for surveying the species from within the forest may not be appropriate to detecting White-rumped Swiftlet given that they can forage above the canopy quietly (Steadman & Freifeld 1998).

In Australia, White-rumped Swiftlet and the two subspecies there are among the 100 most sensitive terrestrial species with the two subspecies of swiftlets found where breeding habitat is protected and inaccessible on the relicts of Gondwanan rainforest near the Queensland's (Garnett & Franklin 2014). Even though it is protected, with a high sensitivity to climatic changes, threats to the continual persistence of the species are jeopardize. Modeled changes of climate change for the subspecies has revealed that reduction in insect abundance could reduce it's breeding success (Garnett & Franklin 2014). As such, (Tarburton 1998) found that during dry years, a reduce amount of saliva to construct their nest results in a collapsed nest as well as starving fledglings. The author also found that the population is also affected by predation from cats inside the caves of breeding swiftlets. For all the Samoan archipelagos, Amerson Jr et al. (1982) estimated the population to be at 350,000, but could be vulnerable to due to restricted nesting inside dark caves. Since very little is known about swiftlet for American Samoa, it is unknown if the sensitivity to dry/drought weather caused by climate change on Australia also holds true to the population of Ta'u and nearby pacific islands if climatic changes and habitat deterioration continue unabated.

In the current study, the Buff-banded Rail was observed at all the disturbed sites and thus had the strongest association with such habitat (Fig. 5), However it also occurred in the other habitats surveyed. This is consistent with its classification as an edge species, occupying a variety of habitats from wetlands to forest where it is able to exploit much of the disturbed and open habitat (Engbring & Ramsey 1989). Plant species present at such sites were *Stachytarpheta urticifolia*. Such species has been considered a threat to many pacific islands. For the rail, the survey methods used here could be inappropriate for determining the rail's abundance given that the species vocalizes irregularly and it's cryptic behavior, thus underestimating the abundance (Steadman & Freifeld 1998).

Another edge species, Peale's Kingfisher with habitat preference for disturbed sites, was detected throughout every habitat type at 69% of the transects. They can also be found on a myriad of habitat from open habitat to deep inside forest, where it would sit motionless from a perch waiting for prey items (Engbring & Ramsey 1989). As characterized by Amerson Jr. et al (1982; Table 5), the primary habitat preference is disturbed sites with rainforest, montane and summit scrub as secondary preference.

The NMDS analyses illustrates that certain species of forest bird (e.g. Blue-crowned Lorikeet, Wattled Honeyeater, Purple-capped Fruit-dove, Manu'a Shrikebill, Spotless Crake), seems to only be associated with the remaining native forest habitat available on the island. Just like other Samoan islands (Engbring & Ramsey 1989; Freifeld 1999; Freifeld et al. 2001), Wattled Honeyeater is the most abundant forest bird on Ta'u and most detected for the survey conducted. Unlike Tutuila where it was mostly absent from disturbed habitats due to nonnative birds (Freifeld 1999), in Ta'u it was detected on all habitat types. According to the NMDS ordination performed and previous work (Freifeld 1999), the species tends to prefer native habitat. Amerson Jr et al. (1982) describes the habitat preference as primary for lowland rainforest and disturbed sites. With that said, a year around supply of fruit and nectar on disturbed sites, villages and plantations can be present. In addition, without the direct competition from other bird species for such resources, the species can proliferate (Freifeld et al. 2001).

From the NMDS analyzes conducted here, indicates that Blue-crowned Lorikeet is primarily a rainforest species and recorded at all transects surveyed. Introduced midstory plants present had a significant negative effect on the species (Table 4). The lorikeet is a nectivore that consumes pollen gathered with its brushy-tipped tongue, as well as fruits (Engbring & Ramsey 1989; Steadman & Freifeld 1998). Amerson Jr et al. (1982) describes the species as primarily on disturbed sites and secondary on all other habitats types.

Purple-capped Fruit-dove was primarily detected on native forest habitat. That coincides with other studies where it was rarely on disturbed sites and when present on disturbed sites could be due to the presence of native or other food source there (Freifeld 1999). The habitat preference for this species is different habitats such as old native forest, scrubby second growth and agricultural forest while also distributed on suitable habitat (Engbring & Ramsey 1989). On Tutuila, Purple-capped Fruit-dove was mostly found on remote and higher elevations locations due in part to hunting pressures by locals (Freifeld 1999).

Not detected on the surveys conducted, the Many-colored Fruit-dove is primarily a forest bird. The distribution is mostly dictated by fruiting trees and as a dietary specialist feeds mainly on native banyan trees of *Ficus obliqua* and *F. prolixa* (Engbring & Ramsey 1989; Trail 1992). Due to its limited dietary composition could contribute to the species low numbers on American Samoa. The species tends to congregate in small foraging groups of birds (Engbring & Ramsey 1989). The presence or probability of a species does not certainly reflect suitability of a species to that habitat (Hutto 1998) but helps predict where it could likely occur. With that said, the few previous efforts to locate Spotless Crake for example, has led to new discoveries. The remaining native habitat of lowland rainforest could be crucial for species such as the Manu'a Shrikebill, Spotless Crake and *Columbidae* species which tends to depend on certain/specific type of vegetation cover, food resources or other environmental variables not readily available and/or fully understood.

From the surveys conducted, Spotless Crake were only detected at Latuiti stream and Lata ridge summit trail, both inside the national park and very localize in distribution. Spotless Crake was the only species that was associated with the summit scrub habitat at the Lata Mountain. Spotless Crake tends to be found on densely vegetated wetlands, cultivated areas, rice paddies, fern colored hillsides and forested landscapes (Perlo 2011). Engbring and Ramsey (1989) found Spotless Crake on subsistence agricultural sites, which has decreased in the last decades. It has been postulated that the decreased in habitat from such farming method along with the loss of wetland habitat has led to a



decrease of Spotless Crake in Ta'u (Engbring & Ramsey 1989; Hoyo et al. 1996). As to how little is known of Spotless Crake throughout its range, the species was recorded on the isolated and understudied island of Futuna as a breeder on 2014 with three individuals heard (Thibault et al. 2015).

The fact that the Spotless Crake is no longer found on the lowland habitat indicates it has been extirpated (in part) due to the presence of Norway Rats (*Rattus norvegicus*), which has also been found on at the Lata mountain summit (Rauzon & Fialua 2003). Since inside of the park seems like the only remaining viable habitat, rats at the summit raises concern. Throughout the pacific islands, local extinctions and population reductions have been the result when nonnative species are present (Hoyo et al. 1996). As of 2016 and after 20 years of being listed as a candidate for consideration of being endangered or threatened, such listing of the species was removed by the US government (US.GOV 2016). According to the surveys performed for the present work, given the limited natural history known of the species, it is recommended that it should be placed back as a candidate species until further research is gathered and a better understanding of the species ecology is obtained for the Ta'u population (Engbring & Ramsey 1989).

Another species, which has only of recently been described an endemic to the Manu'a island archipelago with a global home range of less than 56km<sup>2</sup>, requires native habitat is the Manu'a Shrikebill. Engbring and Ramsey (1989) mentioned that Manu'a Shrikebill preference for moderately dense and moist understory of native forest while avoiding understory where there were partially open forest canopy. In accordance with those authors, Manu'a Shrikebill was found on mature densely vegetated habitat. Feral ungulates were also present on those habitats and are greatly altering much of the native lowland rainforest and contributing to the increasing disturbance environment (not measured on this study). On the adjacent island of Olosega, pig activity has been document with extensive damage on the same habitat inhabited by Manu'a Shrikebill (Engbring & Ramsey 1989). On Tonga (Steadman & Freifeld 1998), observed that population declines of shrikebills can be due to a combination of deforestation, understory clearing, by pigs and predation by cats and rats. It is very likely that activity of

such introduced species is having a negative effect on the bird species restricted or mostly found on undergrowth vegetation. In addition, introduced rats were observed on the same habitat as the Manu'a Shrikebill. Another introduced species, feral cats frequent the nearby forest around the Ta'u village. A scat from a cat was also found on the upper section less than a meter away from the Lafuiti stream, some 8km away from the nearest village. With how much rain the island receives and the location of the scat along the stream, one could assume the individual was in the area fairly recent before my observation of the scat. Also, with how far the nearest village is to the location of the scat found, that could indicate that cats are indeed present on those native habitat, but to what degree is yet to known.

#### Threats to the island

For Ta'u, climate change may be a threat to the future of not just the coastal ecosystem, but of the unique and remote highland environment. As suggested by Boyle et al (2015), an urgent need for detailed studies of life history variation of tropical montane birds is required. The global landmass identified as mountainous is that of 25% with understudied flora and fauna, so knowing the demography of high taxa should be a conservation priority (Martin 2012). Boyle et al (2015) concluded that low fecundity in avian species will result in lower reproductive potential to recover from perturbations, especially as fewer than half of the species experienced greater survival at higher elevations. Such species have been exposed to less selective pressures and competition, so island species have evolve to be less competitive (Simberloff 1995) than those in continental landmasses, especially in terms of coping with alien species. Thomas et al. (2004) global projection scenarios for the next 50 years of species 'committed to extinction' (not the number of species that will become extinct during this period) due to climate change is at 18% at the minimum to 35% at the maximum. In addition to such detrimental effect, invasive species has also been showed to have grave consequences to native flora and fauna.

In American Samoa, as in virtually all around the world, unlike natural modifications, most disturbances to the environment are now caused by man, primarily clearing of land for villages and plantations (Amerson Jr et al. 1982). The results/by-product can also be the spread of foreign species to previously inaccessible regions. A major impact on native populations have been caused by invasive/foreign species, which have become one of the most important drivers of recent extinctions of native island species (Arcilla et al. 2015; Steadman 1995). As such, remaining indigenous biota of islands is threatened with extinction by invasive species (Gillespie et al. 2008). Impact on islands of human-transported species, and predation has created a radical restructuring of island ecosystems (Boivin et al. 2016). Our dominance and pervasive behavior has lead to an increasing global biogeographical homogeneity caused by the widespread transmission of nonnative flora and fauna into new areas (Vitousek et al. 1997). As much as 1.6 times as many mammal species and three times as many bird species have been introduced to islands than to mainland ecosystems (Simberloff 2013). Such expansion could be facilitated by absence of native species with similar niches on islands.

Probability of bird species been extinction has been positively correlated with the number of exotic predatory mammals on islands (Blackburn et al. 2004). Cats, rodents, dogs, pigs and rats have the most detrimental impacts, and endemic island faunas are most vulnerable (Lowe et al. 2000). Given that the most affected species are insular, this indicates that management of invasive species on islands should be a conservation priority to reduce global biodiversity loss (Doherty et al. 2016). Rats, for example, have reached over 80% of the world's islands and are among the most successful invasive mammals (Caut et al. 2008). That has been due to the generalist foraging strategy and high adaptability to new environments (Jones et al. 2008).

Ta'u, rodent trapping on Mt. Lata have confirmed the presence of Norway Rats (O'Connor & Rauzon 2004). Ground dwelling birds on such remote islands are threatened by the activity of nonnative species (Clout & Lowe 2000). The presence of rats on Mt. Lata is a conservation threat to ground nesters and foragers, such as crakes, breeding seabirds, and shrikebills. During the surveys conducted in this study, rats were

seen foraging on a Hibiscus tree 11m above ground. Other observations suggest that rats are ubiquitously distributed across the island, with the highest concentrations most likely near human establishments. Polynesian rat is also found on all islands in American Samoa, with house mouse, roof rat, and Norway rat found only on islands that have a seaport like those in Tutuila, Aunu'u, Ofu and Ta'u (Amerson et al 1982).

The effect of rats on the native fauna on Ta'u is yet to be investigated. However, the extinction of the Blue-crowned Lorikeet from the island of Uvea of the French territory of Wallis and Futuna has been associated with the introduction of the black rat at the end of 19th or early 20th century (Thibault et al. 2015). It is therefore likely that rats may have the same effect on Tau. As documented by other researchers, the impact of such invasives can lead to extinctions of native fauna and even flora (Doherty et al. 2016). The Lorikeet is a long-lived species so a decline caused by rats predated on their eggs or chicks may not be apparent immediately (Rinke 1986 cited in Thibault 2015). As such, extinction debt may be easily be overlooked due a delayed detection of it, which can pose a challenge for conservation initiatives (Kuussaari et al. 2009). A species adaptation to its environment has lead to much speciation. That specialization can also make them vulnerable to extinction debt, which can be a precursor to extinction (Bocedi et al. 2013; Hagen et al. 2012). Extinction and extirpation rates underestimate human impacts because not all species under pressure has gone extinct. Hawaiian geese (*Branta sandvicensis*) has survived the pre-historic colonization of Hawaii by humans, but aDNA research shows drastic reduction in their genetic diversity after human arrival (Paxinos et al. 2002). To further the effect of extinction, ecosystem processes like decomposition, pollination, and seed dispersal, can lead to trophic cascading effects (Anderson et al. 2011), leading to a further loss of ecological services.

Pig and cow activity was evident on several of the transects surveyed. Such activity consisted of uprooted vegetation, knocked down/destroyed trees, cow dung and footprints as well as old bard wire fence inside the rainforest or running parallel to trails from previous farm plots demarcating such boundaries. Pigs and cows destroy understory vegetation, preventing the recruitment of sapling and the regeneration of the forest from

becoming established. To further the impact of nonnative plants, fallen *Morinda citrifolia* may attract rats and pigs (Nelson 2006), helping spread the alien species. Heavy disturbance by these animals may be why crakes were not detected on any of the western transects during this study. In New Zealand, pigs have greatly altered the plant communities of Auckland with the result of restricting some native species to sites that are inaccessible to pigs (Simberloff 2013). The same can be said with what has happened in Ta'u. Structurally the habitat looks adequate for crakes on the western side of the island, but disturbance to the ground might be too much of an alteration for that species. However, it is hard to say if the species has been entirely extirpated from the area given the species' cryptic behavior.

On Ta'u, cows are present in the lowland and into the montane habitat along accessible paths like trails or clearings. If these animals reach the higher elevations of Ta'u, grazing on native slow regenerating plants would be a concern (Cabin et al. 2002). On the island of Rorotonga, hoofed animals have not been able to be present due to the dense, ruggedness and steep topography of the native vegetation (Merlin 1985). Manu'a Shrikebill would likely be greatly affected by the activity of these nonnative species, since the species breeds and forages only a few meters from the ground. Spotless crakes, as well as breeding seabirds found on the island also rely on the undergrowth for its persistence.

From human modification of native habitat, hunting to global warming landbirds of Ta'u, as in many other islands prone to habitat degradation, face many challenges to such vulnerabilities (Chip'Guard et al. 2001). If the trend continues, 1,210 species of birds worldwide are expected to go extinct in the decades to come with several others still not determined due to deficient data on their status (Pimm et al. 2006). For islands, absence of prey and predator coevolution has led to a serious threat to the biota of the Guam ecosystem (Fritts & Rodda 1998). For Savai'I, on the neighboring island of Independent (Western) Samoa, during the last 25 years, the focus has been on conserving the lowland rainforest which has been vital for the bird species there, in unison with that to the highlands. That is since birds are now making daily movements to and from higher

elevations tracking food resources and thus spreading seeds across a wider area (Butler 2012). Such initiatives of conserving different habitats, must be taken to reverse the global extinction crises. Ta'u still harbours much native habitat located mostly above lowland rainforest, as such preserving the diverse lowland communities will be essential to promote long-term ecological functions.

## **Conclusion**

At the current time, conservation programs can not restore the once diverse Polynesian avifauna (Steadman 1997), but understanding the mechanisms that shape those communities is essential. Determining the extent by which anthropologically alterations affect native biotas will continue be a challenge, especially on remote and isolated areas. This work is just the first step into the management of such an understudied ecosystem. Future studies are needed to survey the remote areas of the island. The effects of non-native fauna on the island also needs to be quantified to understand the extent to which feral animals, such as pigs, cats, cows and rats, are affecting the native biota of the island. Science education and training of Samoan nationals may be one way to implement and maintain long-term empirical efforts.

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## Appendix

**Table 6.** Plants species observed during the habitat structure assessment. The plots on which each plant was detected and at which forest level (canopy, midstory and/or undergrowth) along with the status is provided

Species	Family	Samoan/ common name	Transect			Status
			Canopy strata	Midstory Strata	Undergrowth Strata	
<i>Adenanthera pavonina</i>	Fabaceae	Lopa	G, N	A, N, P	-	Modern introduction <sup>5</sup>
<i>Alphitonia zizyphoides</i>	Rhamnaceae	Toi	C, D, P	C	-	Indigenous to Samoa <sup>1</sup>
<i>Artocarpus altilis</i>	Moraceae	Ulu	A, B, G	-	G	Polynesian Introduction <sup>2</sup>
<i>Astronidium navigatorum</i>	Melastomaceae		F, H, K, M, N	C, D, E, F, K, M, N	-	Endemic <sup>2, 5</sup>
<i>Asplenium nidus</i>	Aspleniaceae	Laugapapa, bird's nest fern	-	F, J, P	A, F, H, J	Indigenous <sup>1</sup>
<i>Barringtonia asiatica</i>	Barringtoniaceae	Futu	B, D	B, P	-	Indigenous to Samoa <sup>1, 5</sup>
<i>Cananga odorata</i>	Annonaceae	Moso'oi	A, B, C, N, P	A, B, C, D, P	-	Introduction <sup>1, 5</sup>
<i>Christella harveyi</i>	Thelypteridaceae		-	-	A, B, C, D, F, G, J	Indigenous <sup>1, 5</sup>
<i>Cocos nucifera</i>	Arecaceae	Niu	A, B, C, J, P	A, B, C	-	Introduced <sup>1, 5</sup>
<i>Cyathea decurrens</i>	Cyatheaceae	Olioli (common name for genus)	M	M	-	Indigenous to Samoa <sup>5</sup>
<i>Cyathea lumulata</i>	Cyatheaceae	Olioli (common name for genus)	A	A, B, C, J, P	-	Indigenous <sup>5</sup>
<i>Cyathea vaupelii</i>	Cyatheaceae	Olioli (common name for genus)	-	E, F, H	-	Endemic <sup>4</sup>
<i>Cyathea spp.</i>	Cyatheaceae		E, F, H, J, K, M, N	B, E, F, H, N	-	
<i>Cyrtandra angustivenosa</i>	Gesneriaceae		-	K, M	-	Endemic <sup>4</sup>
<i>Cyrtandra spp.</i>			-	-	-	
<i>Dicksonia brackenridgei</i>	Cyatheaceae		K, M	-	-	Indigenous <sup>4</sup>
<i>Dysoxylum samoense</i>	Meliaceae	Mamala, Maota mamala, Tufaso	A, B, C, D, G, J, P	B, G	-	Endemic <sup>2, 5</sup>
<i>Dysoxylum spp.</i>			N	-	-	
Ferns			A	-	All transects	
<i>Ficus obliqua</i>	Moraceae	Aoa, banyan	F, H, N	-	-	Indigenous <sup>5</sup>
<i>Ficus spp.</i>			All transects	A, C, D, F, G, H, J, K, M, N	-	
<i>Freycinetia reineckeii</i>	Pandanaceae	Le'ie (common name for genus)	-	F, M, N, P	-	Endemic <sup>2, 5</sup>
<i>Freycinetia spp.</i>			-	A, B, C, D, E, F, H, J, K,	-	
<i>Freycinetia storckii</i>	Pandanaceae	Le'ie (common name for genus)	-	-	-	Indigenous <sup>2, 5</sup>
<i>Hibiscus tiliaceus</i>	Malvaceae	Fau, fau tu, beach hibiscus	-	D, E, F, H, J, K, M, N, P	K, M, N	Indigenous <sup>5</sup>
<i>Gahnia vitiensis</i>	Cyperaceae		-	-	M	Indigenous <sup>4, 5</sup>

<i>Kleinhovia hospita</i>	Malvaceae	Fu'afu'a	B	C	-	Indigenous <sup>5</sup>
<i>Leucaena leucocephala</i>	Fabaceae	Fuapepe, lusina, wild tamarind	-	A	-	Introduced <sup>2,5</sup>
<i>Macaranga harveyana</i>	Euphorbiaceae	Lau pata, pata, papata	A, B, D	A, C,	-	Indigenous <sup>2,5</sup>
<i>Macaranga stipulosa</i>	Euphorbiaceae	lau fatu, patafatu	F, H	-	-	Endemic <sup>4</sup>
<i>Manihot esculenta</i>	Euphorbiaceae	Manioka, tapioka, cassava	-	B, G	-	Modern introduction <sup>2,5</sup>
<i>Morinda citrifolia</i>	Rubiaceae	Nonu, nonu togi, nonu vao	-	C	-	Polynesian Introduction <sup>2,5</sup>
<i>Musa spp.</i>	Musaceae	Fa'i	-	A	-	Introduced <sup>2</sup>
<i>Myristica inutilis</i>	Myristicaceae	Atone, Samoan nutmeg	A, B, J, N, P	A, B, C, D, G, J, N	-	Indigenous <sup>2,5</sup>
<i>Nephrolepis hirsutula</i>	Nephrolepidaceae	Vao tuaniu Fanua mamala, foga mamala, mamala	-	-	A, B, C, D, J,	Indigenous <sup>1,5</sup>
<i>Omalanthus nutans</i>	Euphorbiaceae		-	C	-	Indigenous <sup>2,5</sup>
Orchids			-	F	F, H	
<i>Panicum maximum</i>	Poaceae		-	-	A	Introduced <sup>3</sup>
<i>Palaquium stehlinii</i>	Sapotaceae	Gasu	H	-	-	Endemic <sup>5</sup>
<i>Psychotria insularum</i>	Rubiaceae	Matalafi, olapito	-	P	-	Indigenous <sup>2,5</sup>
<i>Sarcopygme pacifica</i>	Rubiaceae	U'unu	-	D, F, J	-	Endemic <sup>5</sup>
<i>Schizostachyum glaucofolium</i>	Poaceae	Ofe, ofe samoa, bamboo	B	-	-	Polynesian Introduction <sup>1,5</sup>
<i>Sida rhombifolia</i>	Malvaceae	Mautofu [Cuba jute]	-	-	-	Polynesian Introduction <sup>2,5</sup>
<i>Sphaerostephanos unitus</i>	Thelypteridaceae		-	-	A, B	Indigenous <sup>5</sup>
<i>Stachytarpheta urticifolia</i>	Verbenaceae	Fua pepe, mautofu	-	-	A, B, C, D	Modern introduction <sup>2,5</sup>
<i>Sterculia fanaiho</i>	Sterculiaceae	Fana'io	N	-	-	Indigenous <sup>2,5</sup>
<i>Syzygium inophylloides</i>	Myrtaceae	Asi toa, asi	C, D, J, K, P	-	-	Indigenous <sup>5</sup>
<i>Syzygium spp.</i>			C, D, E, H, K, N	E	-	
<i>Trema cannabina</i>	Ulmaceae	Magele	-	C	-	Indigenous <sup>2,5</sup>
Vines			-	B, F, G, H, J, M	B	
<i>Weinmannia affinis</i>	Cunoniaceae		E, K, M	N	-	Indigenous <sup>1</sup>

References: Amerson, Whistler & Schwaner 1982<sup>1</sup>, Ragone & Lorence, 2006<sup>2</sup>, Space and Flynn, 2000<sup>3</sup>, Whistler, 1992<sup>4</sup>, Whistler, 1998<sup>5</sup>