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ABUNDANCE, DISTRIBUTION, AND REMOVALS OF FERAL PIGS AT BIG ISLAND NATIONAL WILDLIFE REFUGE COMPLEX 2010-2015

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Abstract

The Hakalau Forest Unit (HFU) of Big Island National Wildlife Refuge Complex (BINWRC) has intensively monitored non-native ungulate presence and distribution during surveys of all managed areas since 1988. In this report we: 1) provide results from recent ungulate surveys and the number of removals at HFU to determine the distribution, abundance, and efficacy of removals of feral pigs, the dominant ungulate, from 2010 to 2015; 2) present results of surveys of the presence and distribution of several ungulate species at the Kona Forest Unit (KFU) of BINWRC from November of 2012 to April of 2015; 3) present results of surveys of weed presence and cover at both refuge units; and 4) present comparative analyses of forest canopy cover at KFU from visual estimates and geospatial imagery. Removals of feral pigs at HFU appear to have significantly decreased pig abundance over the study period from 2010–2015. A grand total of 1,660 feral pigs were removed from managed areas of HFU from 2010 until September of 2015. Management units 2 and 4 contained the majority of pigs at HFU. Recent surveys recorded high densities of pigs in the unenclosed, unmanaged area of Lower Maulua, reaching 14.9 ± (3.2) pigs/km^2 in March of 2015. The total amount of ungulate sign ranged from 22.2 to 54.3 percent of plots surveyed at KFU from November of 2012 to April of 2015. The ability to differentiate sign of ungulate species remains problematic at KFU; although there appears to have been a significant decline in feral cattle sign at KFU, this result is likely to be unreliable because cattle and pig sign were not differentiated consistently during later surveys. Spatial distributions in weed cover are distinctive; however, some weed species may not be reliably represented due to observers' inconsistencies in recording data and abilities to recognize less common weeds.

Introduction

The Hakalau Forest Unit (HFU) of Big Island National Wildlife Refuge Complex (BINWRC) has intensively managed feral pigs (*Sus scrofa*) and monitored presence of pigs and weeds during surveys of all managed areas since 1988. Results of all available data regarding pig management activities through 2004 were compiled and analyzed by Hess et al. (2006). Further analyses of feral pig abundance at HFU from 2010–2013 were reported by Hess et al. (2013) and results of ungulate and weed surveys through 2014 were reported by Leopold et al. (2015). The distribution and relative abundance of feral pigs, weeds, and vegetation composition and structure was also monitored and reported for the Kona Forest Unit (KFU) of BINWRC, although absolute abundance estimates of ungulates were not determined for this area (Leopold et al. 2015). None of the previous reports included data or analyses on the number of feral pigs that have been removed since 2010. Analyses of continued monitoring of feral pig abundance, distribution, and management actions of recent feral pigs removals may provide an updated perspective and inform management decisions, as well as insight about potential relationships between feral pigs and weeds. The objective of this report is to analyze recent feral ungulate surveys at BINWRC to determine current pig abundance and distribution relative to management removals of feral pigs from 2010–2015 and to help managers identify priority areas for ungulate management. In this report we: 1) provide results from recent ungulate surveys and the number of removals at HFU to determine the distribution, abundance, and efficacy of removals feral pigs, the dominant ungulate, from 2010 to 2015; 2) present results of surveys of the presence and distribution of several ungulate species at the KFU of BINWRC from November of 2012 to April of 2015; 3) present results of surveys of weed presence and cover at both refuge units; and 4) present comparative analyses of forest canopy cover at KFU from geospatial imagery and visual estimates reported in Leopold et al. (2015) to determine if estimates of canopy cover from geospatial imagery obviate the need for visual estimates made in the field during future vegetation surveys.

METHODS

Ungulate and Weed Surveys

Surveys were conducted for the presence, distribution, and age of non-native ungulate activity consisting of scat, digging, tracks, or browsed vegetation within 50-m^2 contiguous plots using field methods consistent with Stone et al. (1991). At HFU, 417 stations, each with approximately 20 sample plots, along 17 transects were surveyed during 2010–2015. At KFU, 147 stations, each with approximately 17 sample plots, along four transects were surveyed during 2012–2015. Ungulate sign was categorized as fresh (F), intermediate (I), or old (O) for evidence of digging, scat, tracks and trails, or browse as described by Stone et al. (1991). The presence and cover of weeds was also recorded at the same sample plots. Weed cover was surveyed for Florida blackberry (*Rubus argutus*), banana poka (*Passiflora tarminariana*), photinia (*Photinia davidiana*), English holly (*Ilex aquifolium*), and gorse (*Ulex europaeus*) at HFU and for Koster's curse (*Clidemia hirta*), strawberry guava (*Psidium cattleianum*), and fireweed (*Senecio madagascariensis*) at KFU. Amount of cover for each weed species was estimated in five categories: < 5%; 6–25%; 26–50%; 51–75%; and > 75%. Observers were trained in distance measurement by pacing and in identifying and ageing sign by more experienced observers. Surveys were conducted at HFU during November 2010 and 2011; October 2012; March, May, September, and December of 2013; March, June, September, and December of 2014; and March, June, and September of 2015 (Table 1). Twenty-three additional survey plots from Management Unit 8 (Pua Akala) were augmented in September of 2014. Surveys were conducted at the KFU during November 2012, March, June, and September of 2013, March 2014, and January and April of 2015 (Table 2).

Canopy Cover at KFU

We investigated alternative remote methods to examine vegetation structure at KFU because we were unable to gain access to conduct additional ground-based vegetation surveys during much of 2014 and 2015. To examine accuracy and bias for two methods of canopy cover estimation, we compared canopy cover estimates from 20 vegetation plots at KFU using aerial imagery from Pictometry (EagleView Technologies, Inc. 2015) to estimates of canopy cover made visually from the ground as reported in Leopold et al. (2015). We used the most recent images available for the KFU area, which were from 2009. UTM coordinates of vegetation plot corners were marked on the clearest image available. Cover was determined to be the proportion of plot area occupied by plant material, and estimated in increments of 5%. All images were saved as .jpg files.

Data Management

Date, observer, transect, station, and status of ungulate sign was entered for each plot surveyed on a Microsoft Excel spreadsheet (Appendix 1, 2). Fresh sign was given priority over intermediate sign, which were both given priority over old sign for each of the four types of sign: digging, scat, browse, or tracks/trails. The single highest priority sign in any of the categories was used to represent the status of ungulate sign for each plot for analyses. All data were error-checked for ≤ 1% entry error. Data were summarized and joined to their spatial coordinates (Appendix 3, 4, 5) using RStudio (RStudio Team 2015) and plotted using ArcGIS 10.2.1 Geographic Information System (ESRI, Redlands, CA). Locations were assigned to appropriate management units by UTM coordinates.

Analyses

We calculated the proportion of plots with fresh or intermediate pig sign (p) in each management unit during each survey. Old sign was previously determined to be a poor predictor of pig abundance and not used in further analyses (Hess et al. 2006). Proportions were transformed to arcsine values for analyses to determine feral pig abundance (Sokal and Rohlf 1981). Estimated pig density ($\widehat{D}$) in unenclosed areas and estimated population sizes within enclosed units with 95% predictive confidence intervals were determined based on the estimated best regression equation and its variance (S = 2.290) from Hess et al. (2006):

$$\widehat{D}\ (\text{pigs/km}^2) = 20.665 * \text{arcsine}\ (\sqrt{p})$$

Estimated pig density was then multiplied by the area of each enclosed unit to determine the estimated number of pigs present. We compiled the total annual number of feral pigs reported to have been removed from management units at HFU between 2010 and 2015. We recombined the maximum estimated abundance within each management unit for each year as indicated in Table 3 and compared estimates to total annual removals and removals within management units.

Weed presence was summarized by percent of stations where each species was detected (Appendix 6, 7). The maximum percent of weed cover from each station was also displayed in six categories: 0% sign (white); < 5% (green); 5–25% (blue); 26–50% (yellow); 51–75% (orange); > 75% (red).

RESULTS

Ungulates

A grand total of 23,395 plots were resurveyed at HFU between September of 2014 and September 2015 (Table 1). The total amount of feral pig sign ranged from 6.7 to 20.2 percent of plots surveyed at HFU since November of 2010 (Table 2). Estimated total feral pig abundance (± 95% confidence intervals) at HFU ranged from 489.1 (± 105.6) in November 2010 to 237.2 (± 51.2) in September 2015 (Table 3). Estimated total feral pig abundance during sequential surveys at HFU appears to have steadily decreased over this time period (Figure 1). Confidence intervals of estimates in June and September of 2015 were exclusively less than those of November 2010 and 2012, and March 2013 indicating a significant decrease in feral pig abundance over the study period despite the addition of the 2.3 km^2 area of Management Unit 8 (Pua Akala) in September of 2014 (Table 3). Management Unit 2 (Shipman) consistently contained the greatest number of pigs during the entire study period, ranging from 121.4 (± 26.2) in May of 2013 to 247.8 (± 53.5) in December of 2013 (Figure 2). Unit 4 (Upper Maulua) contained the second highest number of pigs, ranging from a high of 165.6 (± 35.7) in September of 2014 to a low of 61.9 (± 13.4) in September of 2015. Although there had been a significant decline in pig density in the unenclosed area of Lower Maulua from 15.1 (± 3.3) pigs/km^2 in November of 2010 to 6.6 (± 1.4) pigs/km^2 in March of 2014, recent surveys recorded high densities of pigs in this area, reaching 14.9 ± (3.2) pigs/km^2 in March of 2015 (Figure 3).

Table 1. Summary of transects, and number of stations and plots surveyed at Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, from September of 2014 until September of 2015. The number of sampled transects and stations varied between surveys, and some stations were not sampled because they extended into unmanaged areas. Twenty-four additional stations were augmented to transects 1, 1A, 2, and 3 at Pua Akala (Unit 8) in September of 2014.

Transect	Number of Stations	Number of Stations Surveyed					Number of Plots Surveyed				
		Sep 2014	Dec 2014	Mar 2015	Jun 2015	Sep 2015	Sep 2014	Dec 2014	Mar 2015	Jun 2015	Sep 2015
1	24	6	23	5	18	20	118	451	100	320	382
1A	25	5	25	6	18	15	92	478	108	350	428
1B	17	0	8	0	8	0	0	158	0	162	0
2	24	13	15	12	10	21	250	294	228	189	458
3	24	14	16	14	10	24	267	304	267	199	474
4	20	7	11	8	11	17	131	215	153	198	333
5	26	8	14	9	15	25	140	281	154	305	490
6	27	7	16	8	16	23	136	260	151	328	440
7	27	21	15	25	0	22	399	261	467	0	436
7A	26	0	9	25	0	24	0	166	501	0	499
8	27	10	26	9	16	25	183	499	171	330	511

8A	26	26	0	25	0	25	519	0	474	0	504
9	27	24	0	24	0	22	503	0	453	0	442
10	28	16	19	27	0	27	309	380	541	0	523
11	28	12	20	0	0	26	240	399	0	0	519
13	31	10	20	11	19	29	202	381	200	363	562
14	31	9	18	10	19	29	174	363	196	358	575
Total	422	188	255	218	160	374	3663	4890	4164	3102	7576

Table 2. Percent of plots with fresh or intermediate feral pig sign within eight enclosed management units and an unenclosed area of the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawaiʽi Island, 2010–2015.

Survey	Management Unit									
	Middle Honohina	Shipman	Lower Honohina	Upper Maulua	Upper Honohina	Middle Hakalau	Middle Papaikou	Pua Akala	Lower Maulua	Total
	2.21 km^2	22.13 km^2	7.99 km^2	8.39 km^2	4.49 km^2	5.23 km^2	7.22 km^2	2.3 km^2	Unenclosed	59.96 km^2
Nov 2010	52.2	17.4	29.7	26.2	38.2	2.5	6.7	--	44.7	20.2
Nov 2011	2.5	--	--	24.9	10.7	--	--	--	--	16.6
Nov 2012	2.2	26.1	27.8	25.5	22.5	3.9	1.0	--	--	19.2
Mar 2013	18.0	23.2	38.4	6.3	9.6	0.2	0.7	--	--	16.5
May 2013	4.4	6.9	27.0	7.7	5.5	0.6	0.0	--	--	6.7
Sep 2013	36.5	13.1	20.9	9.1	14.8	2.0	3.2	13.9	--	12.5
Dec 2013	30.6	26.6	21.0	7.5	1.5	0.0	0.0	--		10.3
Mar 2014	12.0	24.4	10.2	7.5	14.0	0.0	0.0	--	9.9	16.9
Jun 2014	--	27.5	--	18.4	0.0	0.6	0.4	--	--	17.0
Sep 2014	1.2	11.3	2.6	66.7	0.0	0.4	0.0	1.5	36.0	8.0

Dec 2014	0.8	16.7	0.0	39.3	1.7	0.0	0.7	5.2	--	14.6
Mar 2015	0.7	13.8	1.2	21.4	0.0	2.2	5.9	0.3	43.5	10.1
Jun 2015	--	13.9	--	18.6	--	--	0.3	--	--	13.6
Sep 2015	2.4	8.0	0.0	12.2	0.9	2.4	0.2	1.0	32.4	6.8

Table 3. Estimated abundance of feral pigs (± 95% confidence intervals) within eight enclosed management units and an unenclosed area of the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawaiʽi Island, 2010–2015 based on index surveys calibrated with a model developed by Hess et al. (2006). Maximum values within years when multiple surveys were conducted are highlighted in bold text and used to determine maximum annual recombined abundance estimates.

Survey	Feral Pig Abundance									
	Middle Honohina 2.21 km^2	Shipman 22.13 km^2	Lower Honohina 7.99 km^2	Upper Maulua 8.39 km^2	Upper Honohina 4.49 km^2	Middle Hakalau 5.23 km^2	Middle Papaikou 7.22 km^2	Pua Akala 2.3 km^2	Lower Maulua Unenclosed	Total 59.96 km^2
Nov 2010	33.4 ± 7.2	178.0 ± 38.4	86.3 ± 18.6	84.3 ± 18.2	56.1 ± 12.1	15.6 ± 3.4	35.4 ± 7.6	--	15.1 ± 3.3/km^2	489.1 ± 105.6
Nov 2011	6.5 ± 1.4	--	--	82.1 ± 17.1	28.1 ± 6.1	--	--	--	--	116.7 ± 24.6
Nov 2012	6.2 ± 1.3	231.6 ± 50.0	84.8 ± 18.3	83.1 ± 17.9	41.0 ± 8.8	6.7 ± 1.4	7.5 ± 1.6	--	--	461.0 ± 99.5
Mar 2013	18.1 ± 3.9	208.2 ± 45.0	**99.9 ± 21.6**	39.7 ± 8.6	**26.6 ± 5.7**	4.0 ± 0.9	11.1 ± 2.4	--	--	407.6 ± 88.0
May 2013	9.7 ± 2.1	121.4 ± 26.2	90.2 ± 19.5	48.9 ± 10.6	21.9 ± 4.7	8.4 ± 1.8	0 ± 0	--	--	300.4 ± 64.9
Sep 2013	**29.6 ± 6.4**	169.7 ± 36.6	78.4 ± 16.9	**53.1 ± 11.5**	36.7 ± 7.9	**15.5 ± 3.3**	**26.7 ± 5.8**	--	7.9 ± 1.7/km^2	409.6 ± 88.4
Dec 2013	8.0 ± 1.7	**247.8 ± 53.5**	78.4 ± 16.9	48.0 ± 10.4	11.5 ± 2.5	0 ± 0	0 ± 0	--	--	393.7 ± 85.0
Mar 2014	**16.1 ± 3.5**	236.5 ± 51.1	**53.7 ± 11.6**	48.2 ± 10.4	**35.6 ± 7.7**	0 ± 0	0 ± 0	--	6.6 ± 1.4/km^2	390.2 ± 84.2
Jun 2014	--	**252.2 ± 54.4**	--	76.8 ± 16.6	0 ± 0	**8.2 ± 1.8**	9.4 ± 2.0	--	--	346.7 ± 74.8

Sep 2014	4.9 ± 1.1	157.0 ± 33.9	27.0 ± 5.8	**165.6 ± 35.7**	0 ± 0	6.6 ± 1.4	0 ± 0	5.8 ± 1.3	13.3 ± 2.9/km^2	366.9 ± 79.2
Dec 2014	4.1 ± 0.9	192.3 ± 41.5	0 ± 0	117.4 ± 25.3	12.1 ± 2.6	0 ± 0	**12.1 ± 2.6**	**10.9 ± 2.4**	--	348.0 ± 75.3
Mar 2015	3.9 ± 0.8	174.3 ± 37.6	**18.4 ± 4.0**	**83.4 ± 18.0**	0 ± 0	16.0 ± 3.4	**36.5 ± 7.9**	2.4 ± 0.5	14.9 ± 3.2/km^2	335.0 ± 72.3
Jun 2015	--	**174.8 ± 37.7**	--	77.3 ± 16.7	--	--	8.4 ± 1.8	--	--	260.5 ± 56.2
Sep 2015	**7.0 ± 1.5**	131.3 ± 28.3	0 ± 0	61.9 ± 13.4	**8.7 ± 1.9**	**16.7 ± 3.6**	6.9 ± 1.5	**4.7 ± 1.0**	12.5 ± 2.7/km^2	237.2 ± 51.2

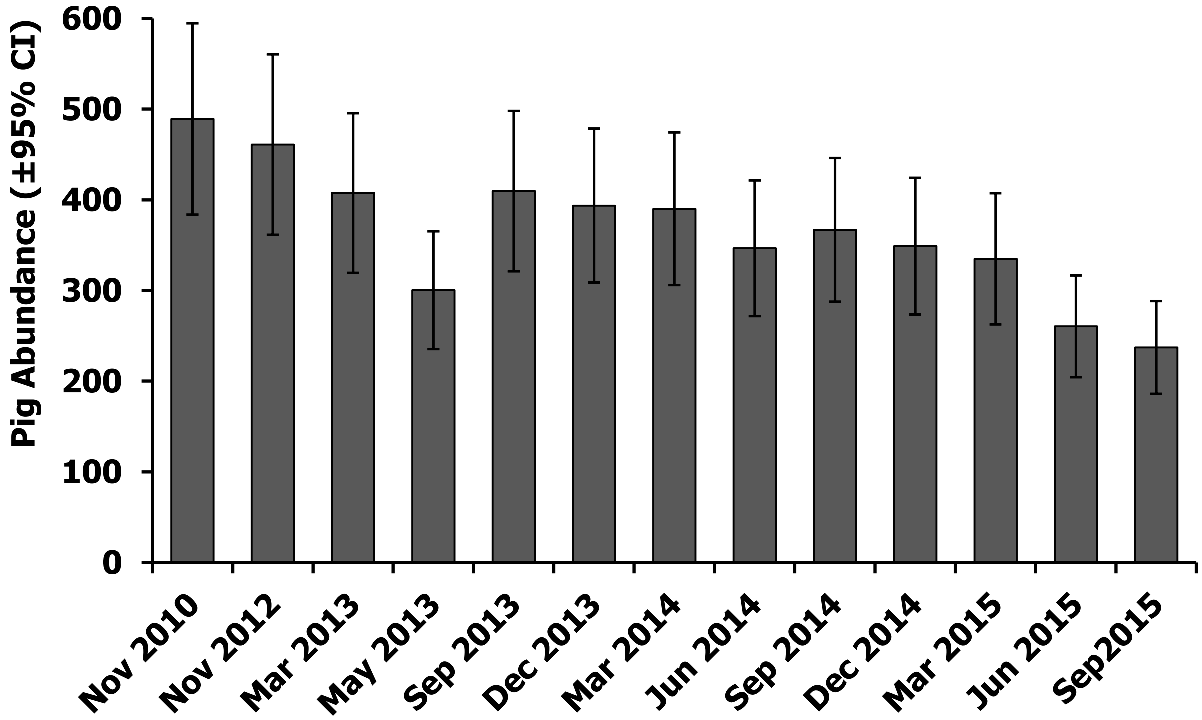

Figure 1. Estimated total abundance of feral pigs (± 95% confidence intervals) at the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, November 2010–September 2015 based on sequential index surveys calibrated with a model developed by Hess et al. (2006). Total pig abundance was underestimated in June of 2014 because two management units were not surveyed. The May 2013 estimate is also anomalously low.

A grand total of 1,660 feral pigs were removed from managed areas of HFU from 2010 until September of 2015. The total number of feral pigs removed annually ranged from 32 in 2010 to 407 in 2013 (Table 4). The total number of feral pigs removed annually approached the estimated highest recombined total abundance in years 2013–2015 (Figure 4). The total number of annual removals and population estimates are highly correlated in years 2012–2015 (R^2 = 0.71). Total removals in year 2013 were greater than 72% of the estimated highest total abundance for the same year which may reflect biases such as underestimation during surveys, possible ingress into one or more management units, or a large number of pigs caught in snares over a period of several years. Annual removals from management units 1, 3, 4, and 8 in some years exceed the estimated highest total abundance, indicating the source of potential biases in particular management units (Figure 4).

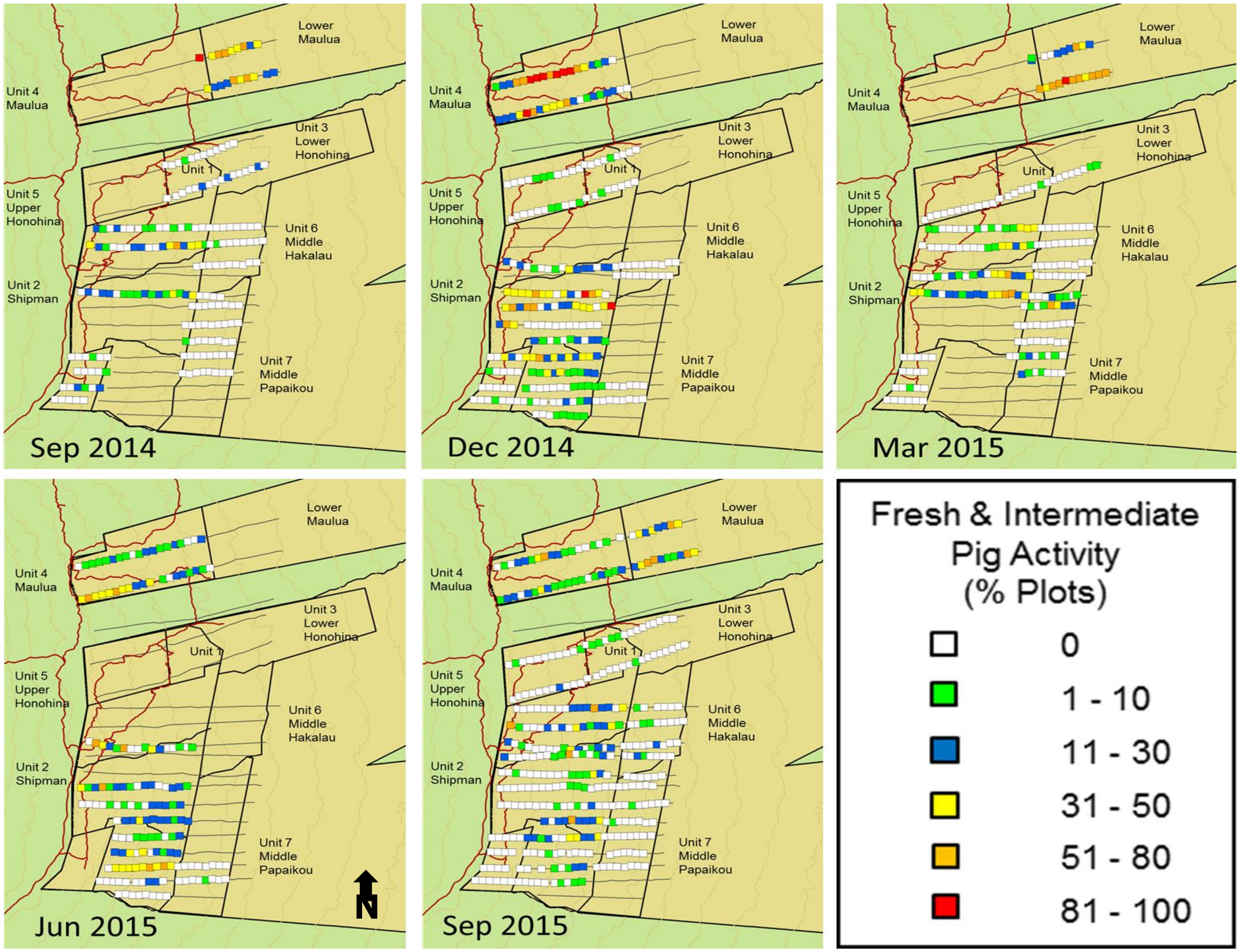

Figure 2. Feral pig sign from eight enclosed management units and one unenclosed area at Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai`i Island, 2014–2015. Values represent the maximum recorded from each sample station.

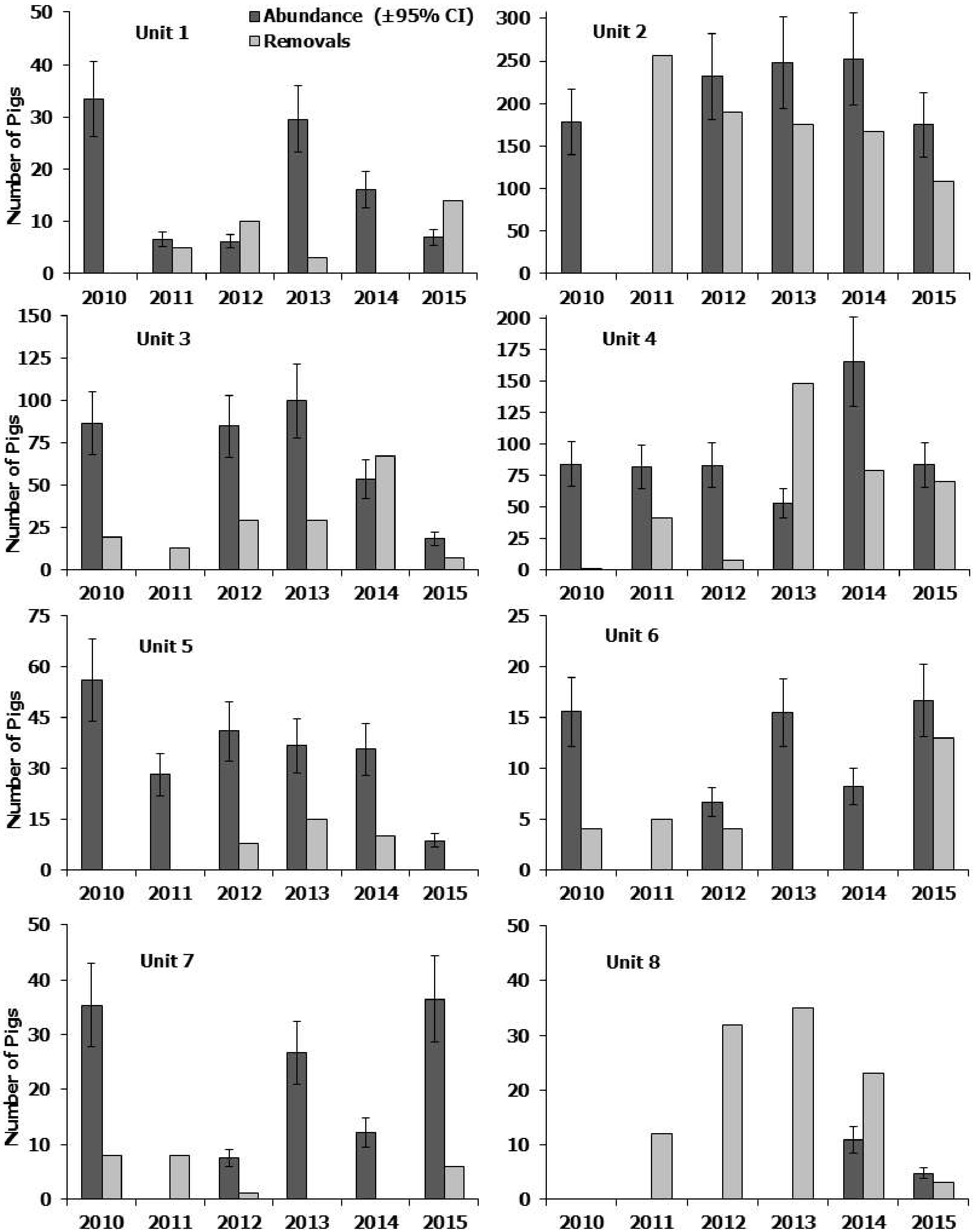

Figure 3. Estimated total maximum abundance (± 95% confidence intervals) and total number of feral pigs removed by year from eight enclosed management units at the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai‘i Island, 2010–2015.

Table 4. Number of feral pigs removed from eight enclosed management units at the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 2010–2015. Totals with asterisks include small numbers of pigs which were removed from unspecified areas.

Management unit		Area km^2	Removals 2010	2011	2012	2013	2014	2015
Middle Honohina	Unit 1	2.21	0	5	10	3	0	14
Shipman	Unit 2	22.13	0	257	189	176	167	109
Lower Honohina	Unit 3	7.99	19	13	29	29	67	7
Upper Maulua	Unit 4	8.39	1	41	8	148	79	70
Upper Honohina	Unit 5	4.49	0	0	8	15	10	0
Middle Hakalau	Unit 6	5.23	4	5	4	0	0	13
Middle Papaikou	Unit 7	7.22	8	8	1	0	0	6
Pua Akala	Unit 8	2.30	0	12	32	35	23	3
Unspecified areas	--	--	0	22	3	1	1	3
Total		59.96	32	363*	284*	407*	347*	227*

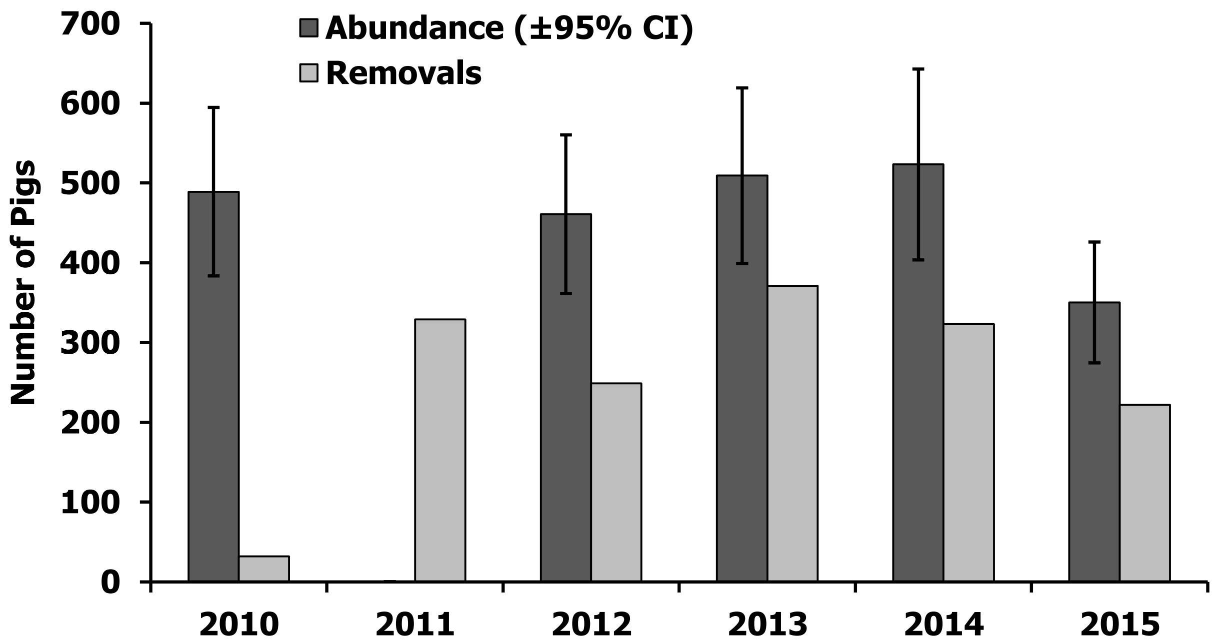

Figure 4. Estimated maximum recombined total abundance (± 95% confidence intervals) of feral pigs and total number of feral pigs removed by year from the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 2010–2015.

A grand total of 4,163 plots were resurveyed at KFU during January and April of 2015 (Table 5). The total amount of ungulate sign ranged from 22.2 to 54.3 percent of plots surveyed at KFU since November of 2012 (Table 6; Figures 5-7). There were no trends in feral pig sign or overall ungulate sign over the course of this study at KFU ($p > 0.31$); however, although there appears to have been a significant decline in feral cattle sign at KFU ($p < 0.03$, $R^2 = 0.65$), this result is likely to be unreliable because cattle and pig sign were not differentiated consistently during later surveys.

Table 5. Summary of transects, and number of stations and plots surveyed at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, during 2012–2015.

		Transect				Total
		1	2	3	4	
	Number of Stations	37	37	35	37	146
	Survey Date					
Number of Stations Surveyed	Nov 2012	37	37	36	37	147
	Mar 2013	37	36	35	37	145
	Jun 2013	37	36	35	37	145
	Sep 2013	37	36	36	37	146
	Mar 2014	37	37	36	35	145
	Jan 2015	37	37	35	36	145
	Apr 2015	37	37	34	37	145
Number of Plots Surveyed	Nov 2012	646	629	565	623	2463
	Mar 2013	613	619	579	692	2503
	Jun 2013	677	585	533	619	2414
	Sep 2013	608	581	474	552	2215
	Mar 2014	555	728	487	570	2340
	Jan 2015	509	555	520	525	2109
	Apr 2015	550	557	426	521	2054

Table 6. Number of plots with fresh or intermediate feral ungulate sign/number of plots surveyed and percent of plots with sign within two enclosed management units of the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 2012–2015.

		Management Unit					
		Upper 7.79 km^2		Middle 7.53 km^2		Total 15.32 km^2	
Type of Sign	Survey Date	Number of Plots	Percent of Plots	Number of Plots	Percent of Plots	Number of Plots	Percent of Plots
Feral Cattle	Nov 2012	203/1227	16.5	509/1236	41.2	712/2463	28.9
	Mar 2013	118/1178	10.0	308/1325	23.2	426/2503	17.0
	Jun 2013	181/1151	15.7	418/1263	33.1	599/2414	24.8
	Sep 2013	223/1131	19.7	291/1070	27.2	514/2201	23.4
	Mar 2014	99/1122	8.8	339/1218	27.8	438/2340	18.7
	Jan 2015	49/959	5.1	51/1150	4.4	100/2109	4.7
	Apr 2015	126/1055	11.9	161/1031	15.6	287/2086	13.8
Feral Pig	Nov 2012	21/1227	1.7	185/1236	15.0	206/2463	8.4
	Mar 2013	44/1178	3.7	76/1325	5.7	120/2503	4.8
	Jun 2013	11/1151	1.0	42/1263	3.3	53/2414	2.2
	Sep 2013	4/1131	0.4	86/1070	8.0	90/2201	4.1
	Mar 2014	7/1122	0.6	176/1218	14.5	183/2340	7.8
	Jan 2015	19/959	2.0	65/1150	5.7	84/2109	4.0
	Apr 2015	46/1055	4.4	165/1031	16.0	211/2086	10.1

All Ungulate	Nov 2012	251/1227	20.5	808/1236	65.4	1059/2463	43.0
	Mar 2013	159/1178	13.5	459/1325	34.6	618/2503	24.7
	Jun 2013	215/1182	18.2	452/1232	36.7	667/2414	27.6
	Sep 2013	456/1157	39.4	739/1044	70.8	1195/2201	54.3
	Mar 2014	126/1153	10.9	462/1187	38.9	588/2340	25.1
	Jan 2015	203/959	21.7	373/1150	32.4	576/2109	27.3
	Apr 2015	169/1055	16.0	295/1031	28.6	464/2086	22.2

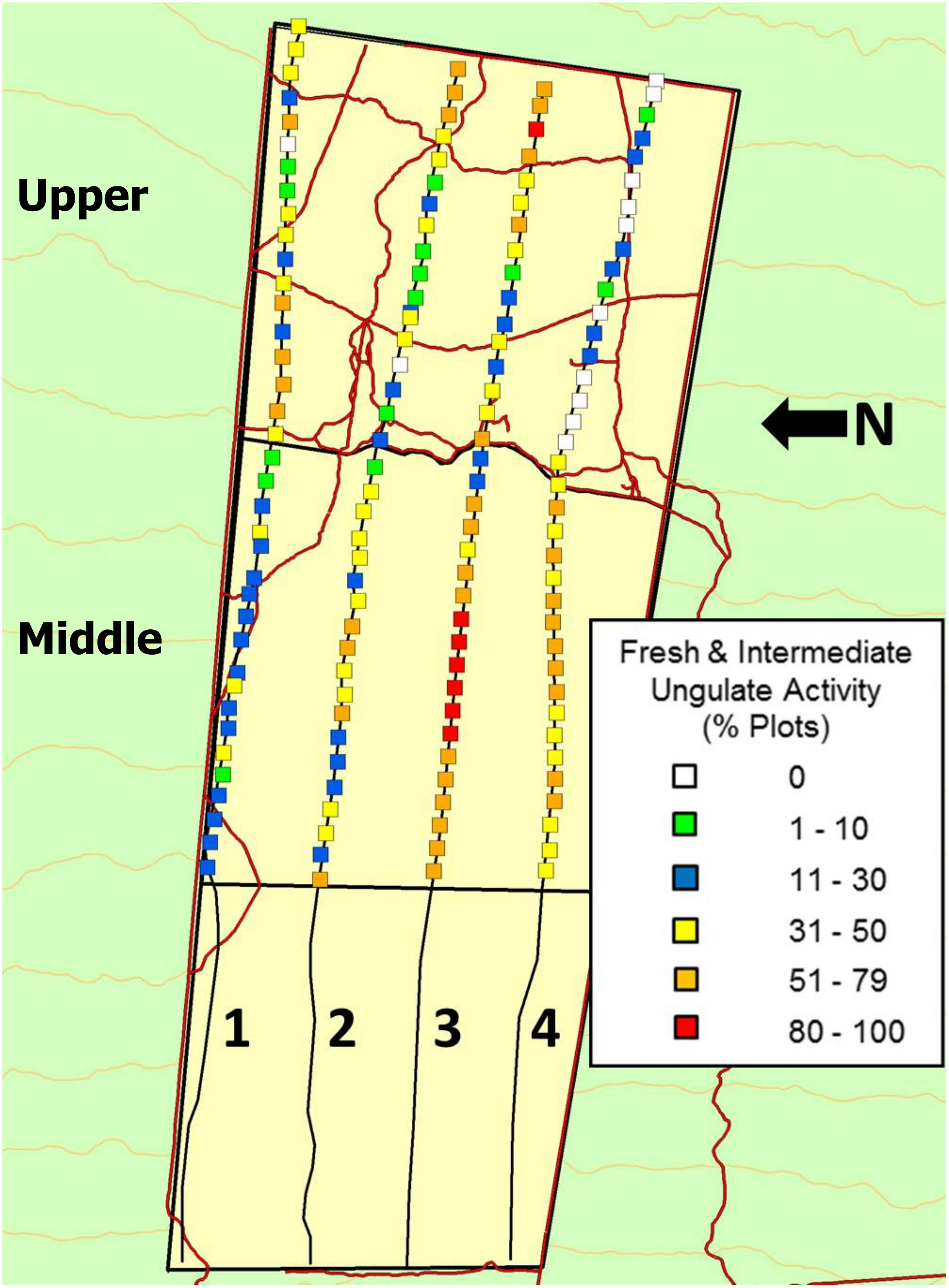

Figure 5. Maximum values of feral ungulate sign from two enclosed management units at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island during January and April of 2015.

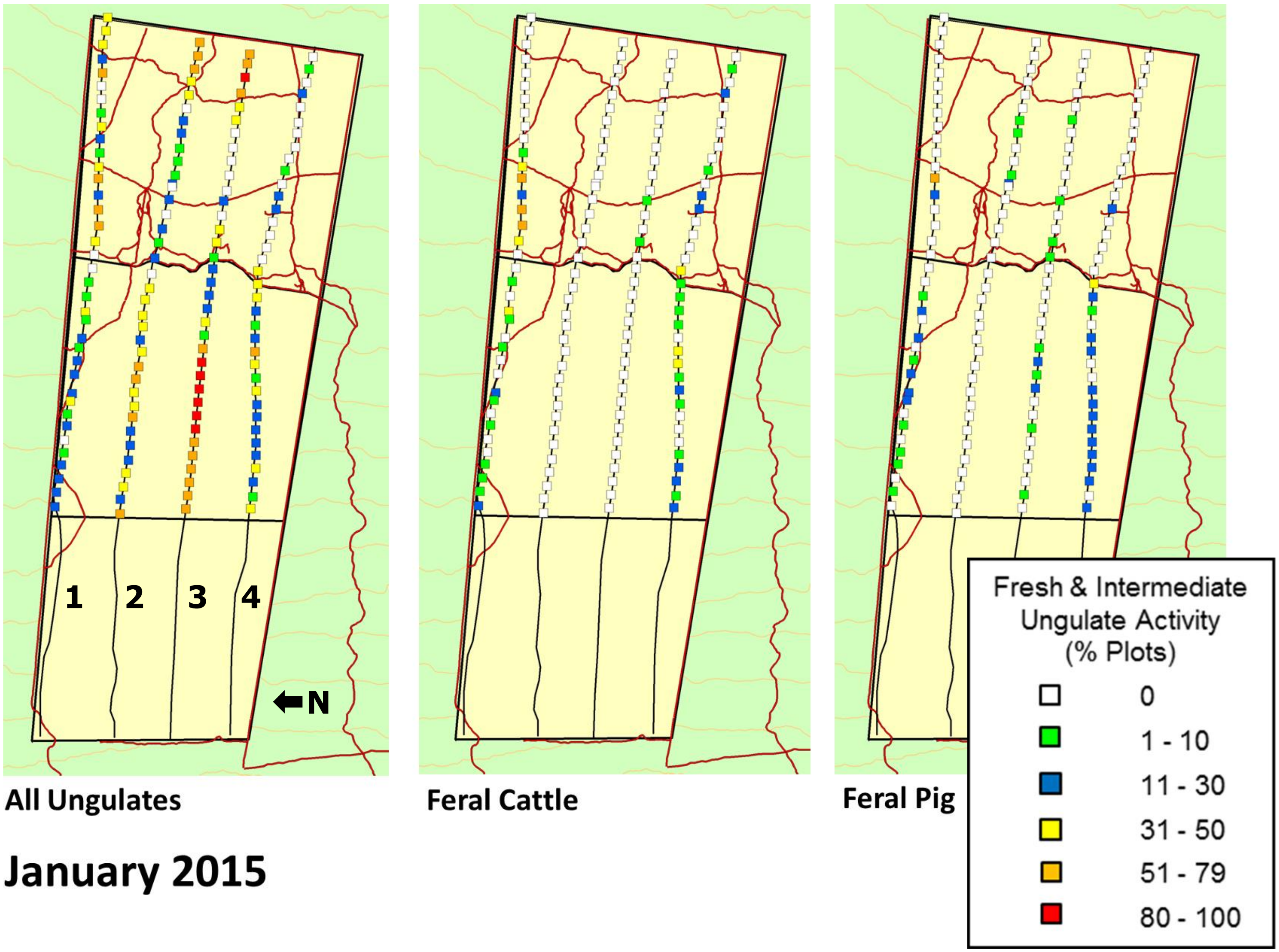

Figure 6. Feral ungulate sign from two enclosed management units at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island during January of 2015. Ungulate sign was not adequately differentiated by species during some surveys.

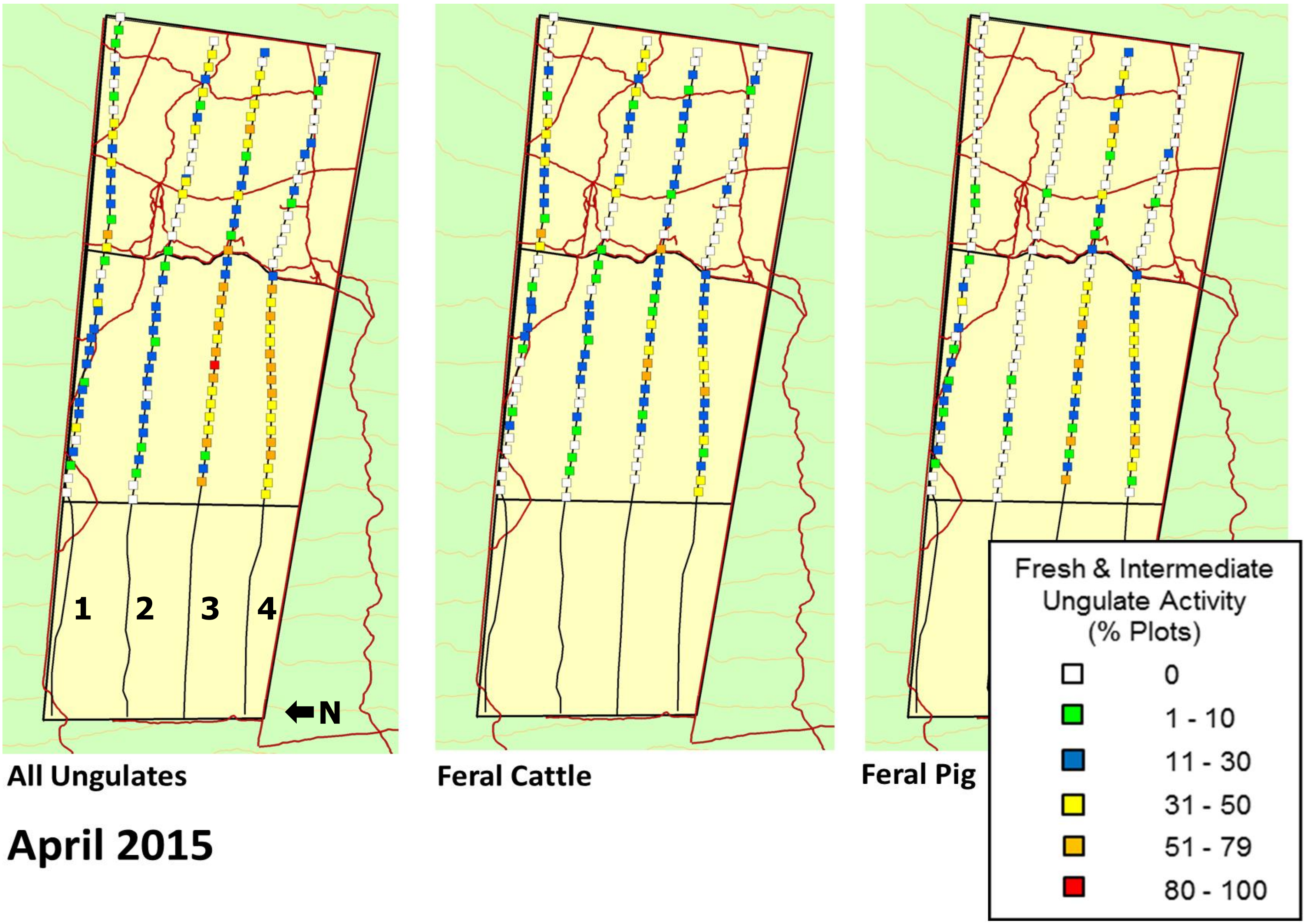

Figure 7. Feral ungulate sign from two enclosed management units at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island during April of 2015.

Weeds

Florida blackberry and banana poka were the two most widely distributed weeds at HFU. Florida blackberry was consistently detected throughout all of the management units at HFU (Figures 8 & 9) at more than 34% of stations during surveys from 2010–2015 (Table 7). Banana poka was detected with moderate–high density coverage throughout unit 4, and was also found consistently in units 1 and 5 (Figures 8 & 9). It was detected at 10.3–37.3% of all stations during surveys from 2010–2015 (Table 8). Three other weed species were less widely distributed. *Photinia davidiana* was found almost exclusively in units 1 and 5 since 2011 (Table 9; Figures 8 & 9). English holly detections were limited to 4 transects in units 2 and 8, with low density coverage at all detections. Gorse was detected at higher elevations throughout units 2, 5, and 8 in low densities.

Koster's curse and strawberry guava were consistently detected in the lower portions of the middle unit and fireweed was detected primarily in the upper unit at KFU (Figures 10 & 11; Table 10). Florida blackberry was recorded three times during the 2012 survey, but could have been confused with *Rubus parviflorus*, which was recorded nine times in the upper unit and two times in the middle unit during 2015 surveys. Christmasberry (*Schinus terebinthifolius*) and palm grass (*Setaria palmifolia*) were not observed in the enclosed management units at KFU although they were widely distributed at lower elevations.

Canopy Cover at KFU

Canopy cover estimates made visually from the ground were an average of 11.5% less than those from Pictometry® imagery (Table 11); however, generally corresponded with estimates using aerial imagery from Pictometry ($R^2 = 0.50$; Figure 12). Differences between Pictometry and visual estimates ranged between -40.0% and 48.24%.

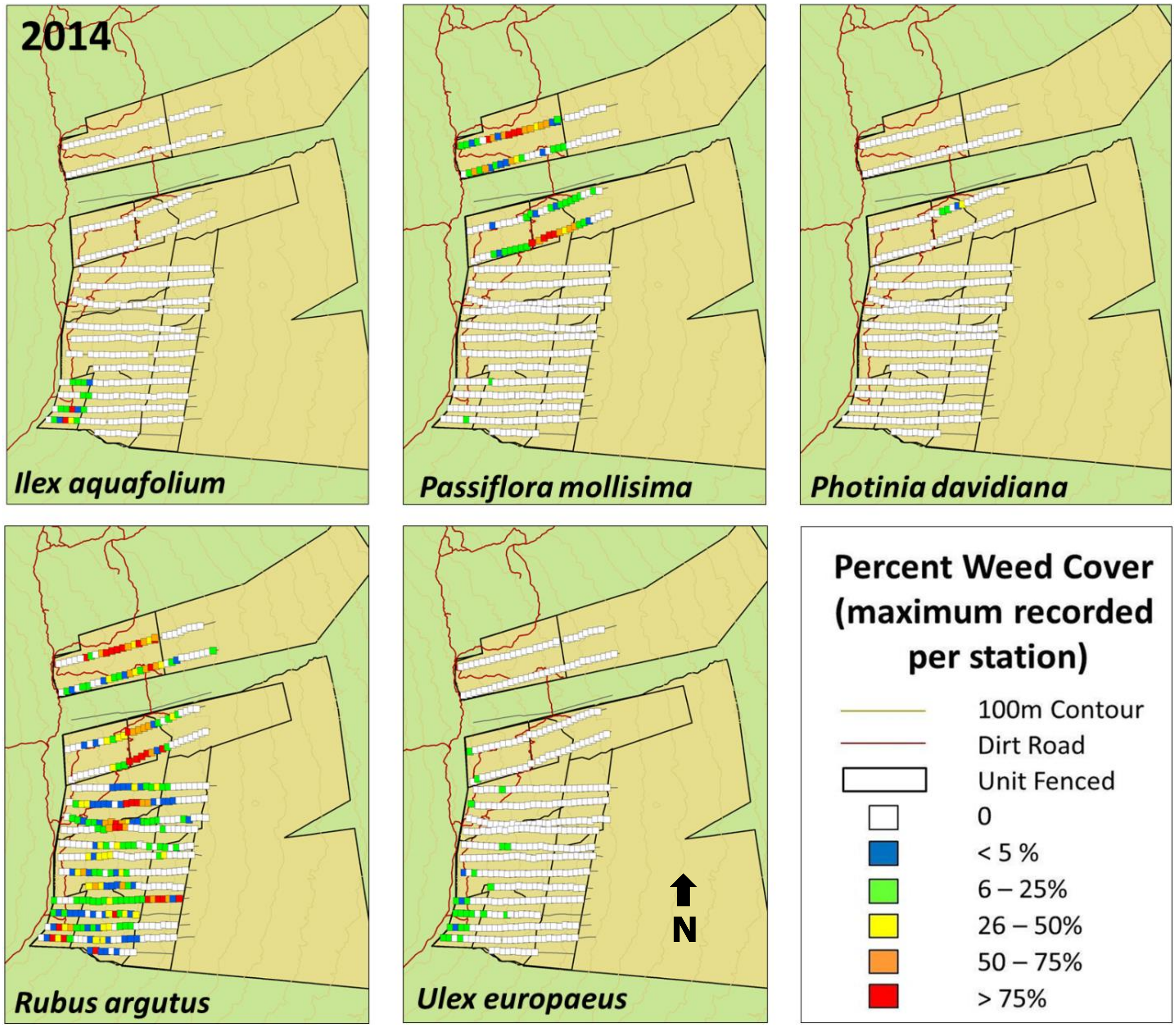

Figure 8. Percent cover of five weed species (*Ilex aquifolium*, *Passiflora tarminariana, Photinia davidiana, Rubus argutus,* and *Ulex europaeus*) in eight enclosed management units at the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai`i Island during 2014. Values presented are the maximum recorded from each sample station during 2014.

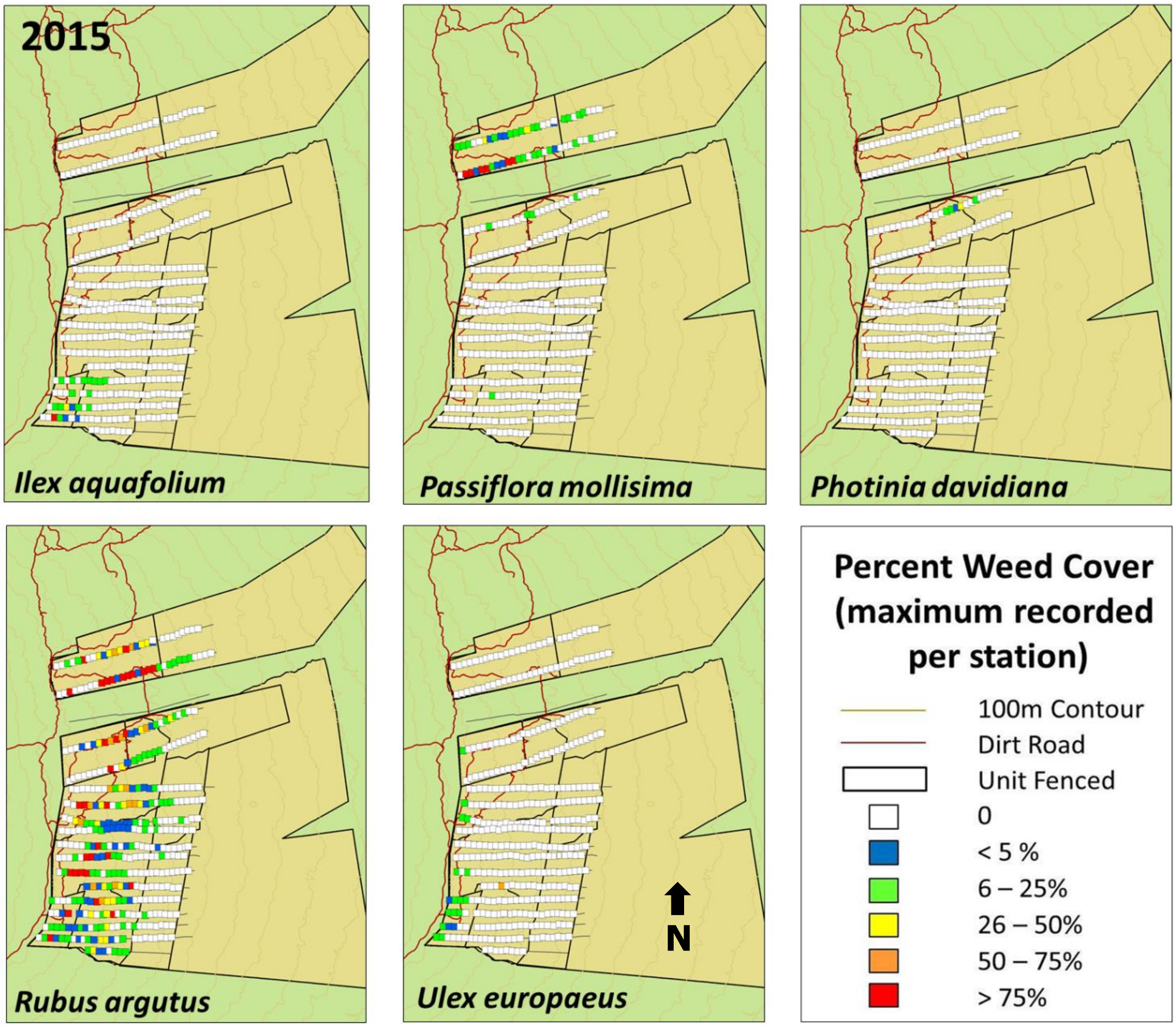

Figure 9. Percent cover of five weed species (*Ilex aquifolium*, *Passiflora tarminariana, Photinia davidiana, Rubus argutus,* and *Ulex europaeus*) in eight enclosed management units at the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai`i Island during 2015. Values presented are the maximum recorded from each sample station during 2015.

Table 7. Number of stations with *Rubus argutus* detections/number of stations surveyed and percent of stations with *R. argutus* detections within eight enclosed management units and an unenclosed area of the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai`i Island, 2010–2015.

Survey	Weed Abundance									
	Middle Honohina	Shipman	Lower Honohina	Upper Maulua	Upper Honohina	Middle Hakalau	Middle Papaikou	Pua Akala	Lower Maulua	Total
	2.21 km^2	22.13 km^2	7.99 km^2	8.39 km^2	4.49 km^2	5.23 km^2	7.22 km^2	2.3 km^2	Unenclosed	59.96 km^2
2010	9/13	67/162	2/14	6/30	5/23	12/30	33/55	0/0	12/21	146/348
	69.2	41.4	14.3	20.0	21.7	40.0	60.0	--	57.1	42.0
2011	13/13	0/0	0/0	24/39	6/23	0/0	0/0	0/0	0/0	43/75
	100.0	--	--	61.5	26.1	--	--	--	--	57.3
2012	3/11	82/179	0/8	15/39	15/23	4/34	3/65	0/0	0/0	122/359
	27.3	45.8	0.0	38.5	65.2	11.8	4.6	--	--	34.0
2013	12/13	120/178	4/19	26/40	12/23	10/37	5/60	0/0	5/20	194/390

	92.3	67.4	21.1	65.0	52.2	27.0	8.3	--	25.0	49.7
2014	13/13	117/180	4/17	30/40	10/23	9/37	21/61	20/22	3/18	224/411
	100	65.0	23.5	75.0	43.5	24.3	34.4	91.0	16.7	54.5
2015	12/13	115/175	5/17	27/40	10/23	6/37	4/62	13/20	5/19	197/406
	92.3	64.6	29.4	67.5	43.5	16.2	6.8	0.65	26.3	48.5

Table 8. Number of stations with *Passiflora tarminariana* detections/number of stations surveyed and percent of stations with *Passiflora tarminariana* detections within eight enclosed management units and an unenclosed area of the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai‘i Island, 2010–2015.

Survey	Weed Abundance									
	Middle Honohina	Shipman	Lower Honohina	Upper Maulua	Upper Honohina	Middle Hakalau	Middle Papaikou	Pua Akala	Lower Maulua	Total
	2.21 km^2	22.13 km^2	7.99 km^2	8.39 km^2	4.49 km^2	5.23 km^2	7.22 km^2	2.3 km^2	Unenclosed	59.96 km^2
2010	0/13	28/162	0/14	0/30	0/23	0/30	11/55	0/0	0/21	39/348
	--	17.3	0.0	0.0	0.0	0.0	20.0	--	0.0	11.2

2011	2/13	0/0	0/0	25/39	1/23	0/0	0/0	0/0	0/0	28/75
	15.4	--	--	64.1	4.3	--	--	--	--	37.3
2012	0/11	1/179	0/8	20/39	3/23	0/34	0/65	0/0	0/0	24/359
	0.0	0.6	0.0	51.3	8.7	0.0	0.0	--	--	6.7
2013	5/13	3/178	2/19	26/40	5/23	0/37	0/60	0/0	0/20	43/390
	38.5	1.7	10.5	65.0	21.7	0.0	0.0	--	0.0	11.0
2014	11/13	1/180	10/17	34/40	10/23	0/37	0/61	1/22	0/18	67/411
	84.6	0.6	58.8	0.85	43.5	0.0	0.0	4.5	0.0	16.3
2015	2/13	1/175	1/17	31/40	1/23	0/37	0/62	0/20	6/19	42/406
	15.4	0.6	5.9	77.5	4.3	0.0	0.0	0.0	31.6	10.3

Table 9. Number of stations with detections of three weed species (*Ilex aquifolium, Photinia davidiana, Ulex europaeus*) within eight enclosed management units and an unenclosed area of the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 2010–2015.

Species/Year	Weed Abundance									
	Middle Honohina	Shipman	Lower Honohina	Upper Maulua	Upper Honohina	Middle Hakalau	Middle Papaikou	Pua Akala	Lower Maulua	Total
	2.21 km^2	22.13 km^2	7.99 km^2	8.39 km^2	4.49 km^2	5.23 km^2	7.22 km^2	2.3 km^2	Unenclosed	59.96 km^2
Ilex aquifolium										
2010	--	1	--	--	--	1	--	--	--	2
2011	--	--	--	--	--	--	--	--	--	0
2012	--	6	--	--	--	--	--	--	--	6
2013	--	7	--	--	--	--	--	--	--	7
2014	--	7	--	--	--	--	--	--	--	7
2015	--	8	--	--	--	--	--	11	--	19
Photinia davidiana										
2010	--	4	1	--	--	--	2	--	--	7
2011	1	--	--	--	--	--	--	--	--	1
2012	--	1	--	--	4	--	--	--	--	5
2013	4	--	1	4	--	--	--	--	--	9
2014	3	--	1	--	--	--	--	--	--	4

2015	3	--	2	--	--	--	--	--	--	5
Ulex europaeus										
2010	--	1	--	--	--	--	--	--	--	1
2011	--	--	--	--	--	--	--	--	--	0
2012	--	3	--	--	--	--	--	--	--	3
2013	--	8	--	--	--	--	--	--	--	8
2014	--	9	--	--	1	--	--	14	--	25
2015	--	6	--	--	1	--	--	12	--	19

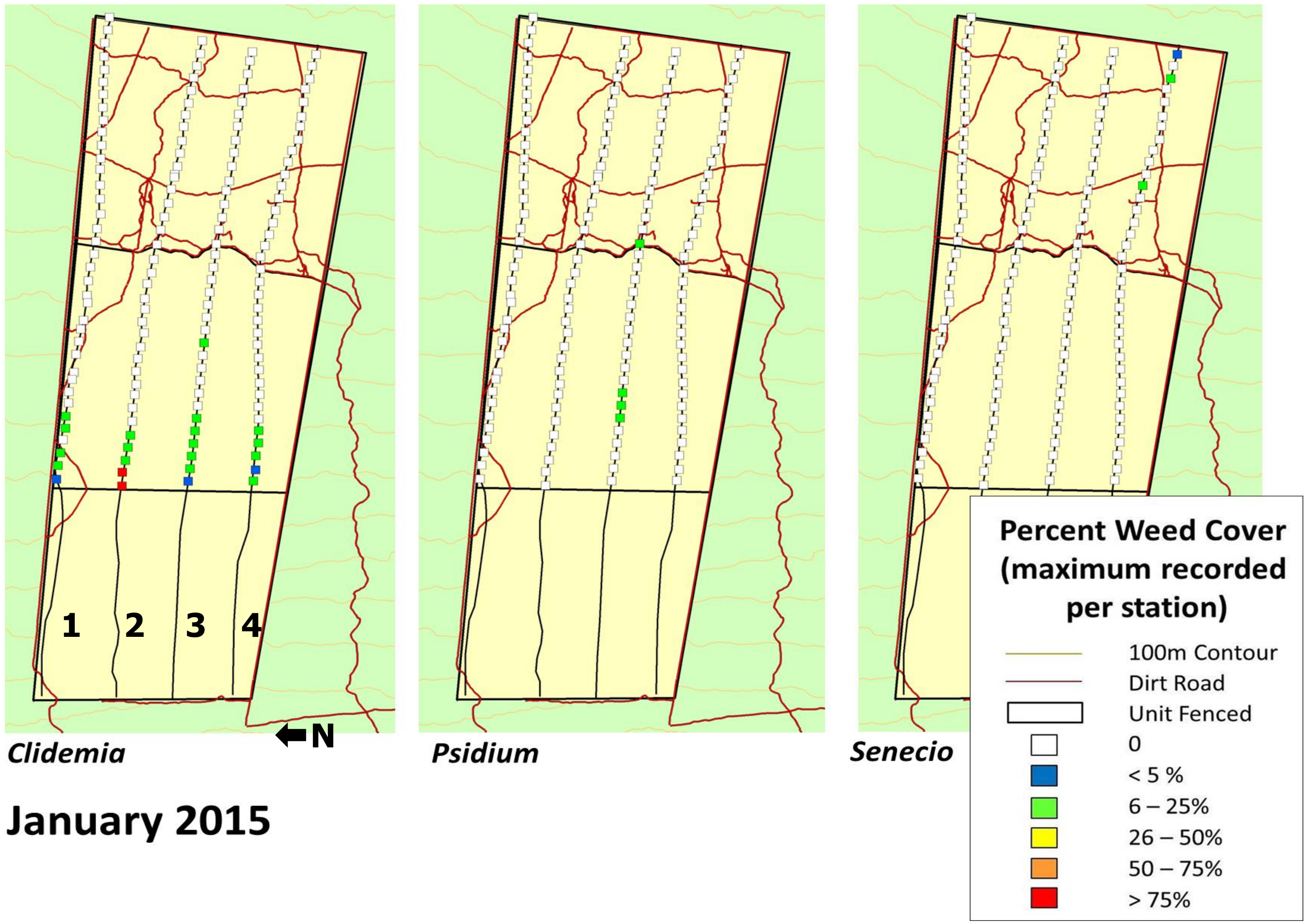

Figure 10. Percent cover of three weed species (*Clidemia hirta*, *Psidium cattleianum,* and *Senecio madagascariensis*) in two enclosed management units at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island during January of 2015. Values presented are the maximum recorded from each sample station.

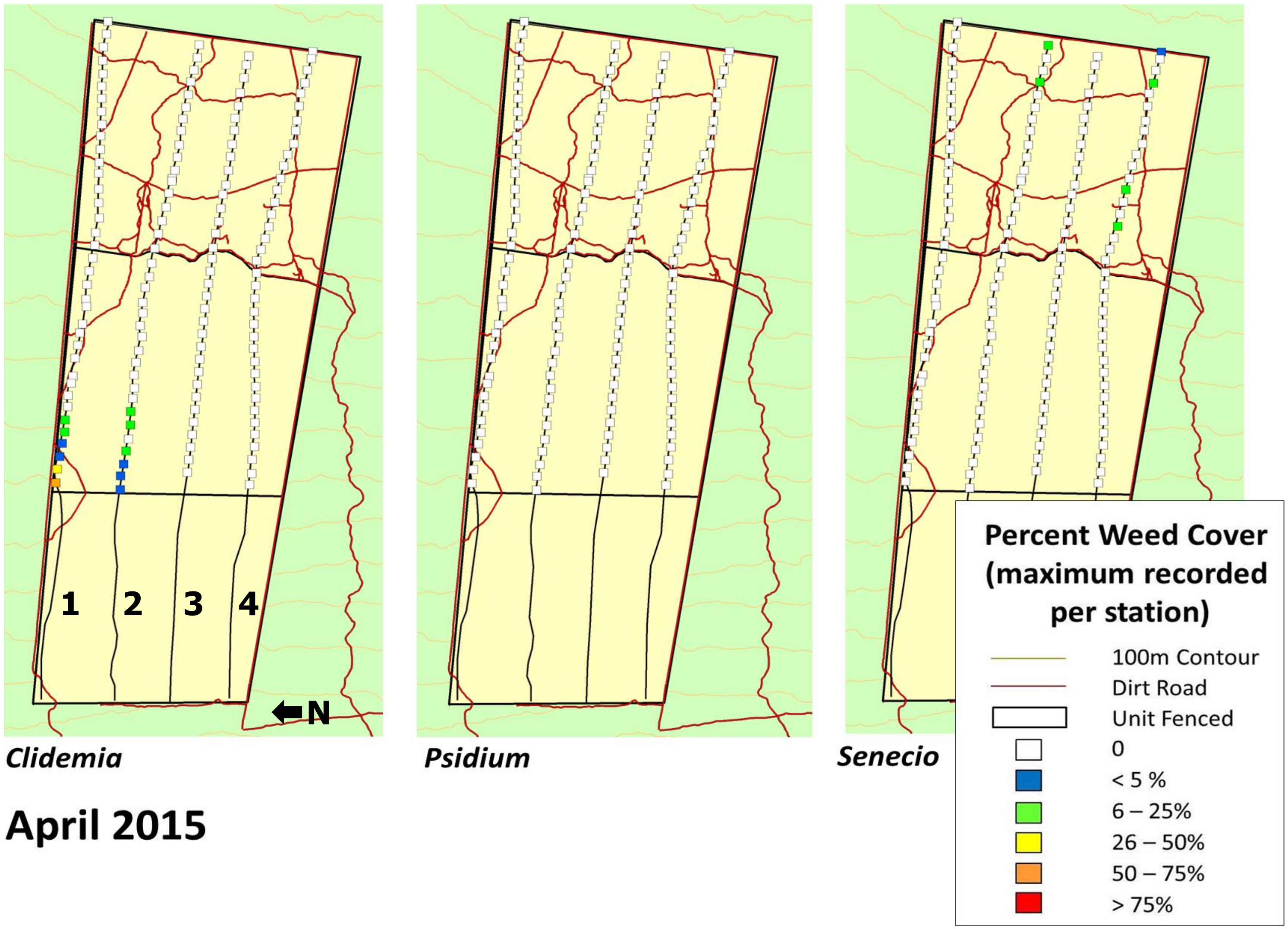

Figure 11. Percent cover of three weed species (*Clidemia hirta*, *Psidium cattleianum*, and *Senecio madagascariensis*) in two enclosed management units at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai`i Island during April of 2015. Values presented are the maximum recorded from each sample station.

Table 10. Number of stations with detections of three weed species (*Clidemia hirta*, *Psidium cattleianum,* and *Senecio madagascariensis*) in two enclosed management units of the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 2012–2015.

Species/Year	Management Unit		
	Upper 7.79 km^2	Middle 7.53 km^2	Total 15.32 km^2
Clidemia hirta			
2012	--	--	0
2013	--	20	20
2014	--	20	20
2015	--	20	20
Psidium cattleianum			
2012	--	20	20
2013	--	16	16
2014	--	1	1
2015	1	3	4
Senecio madagascariensis			
2012	--	--	0
2013	16	--	16
2014	11	--	11
2015	6	--	6

Table 11. Forest canopy cover estimates of 20 vegetation plots across four vegetation types at the KFU of the BINWRC, Hawai'i Island. Vegetation categories included: koa-'ōhi'a forest (KOA), mesic 'ōhi'a forest (MOHIA), subalpine woodland (SW), and wet forest (WF). Canopy cover was estimated visually at transects during 2013 and by using Pictometry aerial imagery from 2009. Values for transect estimates are averages across all transect within each plot.

Plot ID	Estimated Canopy Cover		Difference	
	Pictometry	Visual	Pictometry-Visual	Percent
KOA-15	85	64	21	24.7
KOA-17	85	89	-4	-4.7
KOA-25	55	42	13	23.6
KOA-41	80	67	13	16.3
KOA-7	50	35	15	30.0
MOHIA-29	70	66	4	5.7
MOHIA-35	75	98	-23	-30.7
MOHIA-39	80	87	-7	-8.8
MOHIA-47	85	44	41	48.2
MOHIA-6	65	57	8	12.3
SW-19	40	34	6	15.0
SW-27	45	49	-4	-8.9
SW-3	30	22	8	26.7
SW-4	45	27	18	40.0
SW-49	40	56	-16	-40.0
WF-18	55	60	-5	-9.1
WF-19	70	53	17	24.3
WF-39	85	64	21	24.7
WF-43	80	63	17	21.3
WF-45	65	61	4	6.2
KOA-15	85	64	21	24.7
Mean	65.2	57.2	168	11.5

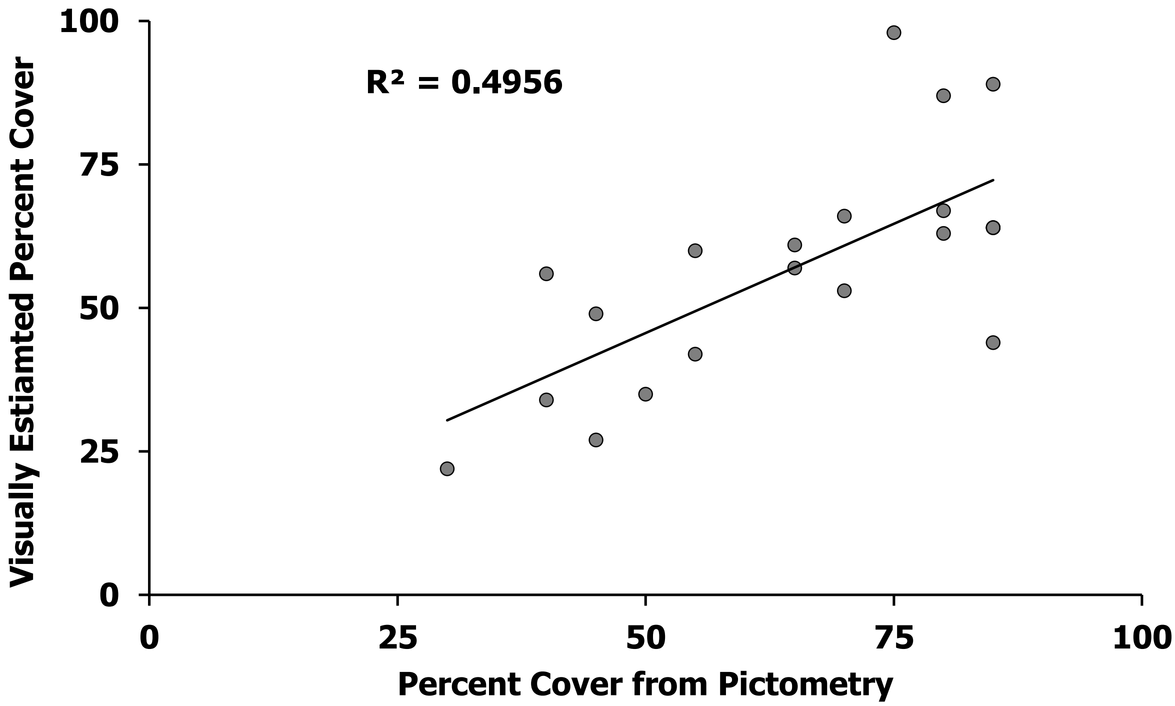

Figure 12. Relationship between two methods for estimating forest canopy cover at 20 vegetation plots in four vegetation types at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawaiʻi Island. Canopy cover was estimated visually at vegetation plots during 2013 (Leopold et al. 2015) and by using Pictometry aerial imagery from 2009. Values for transect estimates were averaged across all transect within each plot.

DISCUSSION

Removals of feral pigs at the Hakalau Unit of the Big Island National Wildlife Refuge Complex appear to have significantly decreased pig abundance over the study period from 2010–2015. Removals approached a particularly high proportion of pigs remaining in 2013–2015. Estimates from the last two surveys conducted in 2015 were exclusively less than estimates from surveys conducted in 2010 through early 2013. The greatest numbers of remaining feral pigs were in Management Unit 2 (Shipman) which was subdivided into three smaller management units in 2013 to further facilitate population reduction. Density changes in the unenclosed and unmanaged Lower Maulua unit reflect natural fluctuations in pig abundance and measurement error.

Because feral pig removals represented such a large proportion of population estimates or exceeded population estimates in several management units during some years, we suspect potential biases in survey methodology or ingress may have affected results, making interpretation difficult in smaller management units. Additionally, survey periods and snare removal efforts were concentrated among different time scales, i.e. some ungulate removals in a survey period could have actually occurred in previous months. Nonetheless, the overall total number of annual removals and population estimates are highly correlated in years 2012–2015, indicating that removals are likely to be affecting the abundance of feral pigs remaining at HFU.

Feral ungulates remained abundant at Kona Forest Unit, with ungulate sign recorded at nearly 92% of stations during surveys in 2014–2015. Although these data suggest some decrease in cattle abundance, this result may be due to unreliable differentiation of cattle and pig sign, particularly in later surveys. The ability to differentiate sign of ungulate species continued to remain problematic at KFU; species that browsed vegetation, rubbed on trees, or created wallows could not be reliably distinguished. Tracks were often indistinct. The most reliable species identifications came from fresh or intermediate scat. Measures of ungulate abundance at KFU should be considered relative for purposes of spatial and temporal comparisons only. Absolute measures of abundance will not be available until a calibrated model of reconstructed feral cattle and pig abundance has been validated.

Changes in weed cover at HFU and KFU do not yet demonstrate any strong temporal pattern. Spatial patterns are more pronounced; however, some weed species may not be reliably represented due to observers' abilities to recognize less common weeds, particularly *Photinia* at HFU. The approach we used to minimize differences between observers was to present the maximum cover value at each sample station over several surveys. The identification of some weed species appears to be problematic for observers, and some inconsistencies between surveys have not yet been reconciled. More thorough training for plant species identification may be needed to ensure the reliability of observations. Several species of invasive plants currently have a limited distribution within the portions of KFU enclosed by fence: *Clidemia hirta, Psidium cattleianum,* and *Senecio madagascariensis.* Nonetheless, the distribution and cover of fireweed (*Senecio*) at KFU appears to have increased over the study period, but may have been due to seasonality (i.e., flowering) which made plants more obvious to observers.

Because the accuracy of canopy cover measurements reported in Leopold et al. (2015) seemed suspect, we wanted to determine if they corresponded to another independent method. Canopy cover estimates made visually from the ground generally agreed with estimates using aerial imagery from Pictometry; however, there were discrepancies between these two methods: 1) imagery allowed for more accurate cover estimates; 2) one observer evaluated all estimates from imagery, eliminating observer variability (as opposed to numerous observers estimating canopy cover along transects); 3) it was sometimes unclear as to whether open areas in Pictometry imagery contained understory cover ≥ 3 m in height included in transect estimates; 3) Pictometry imagery was from 2009, but canopy cover may have changed over the intervening five years due to tree falls caused by tree senescence, storms, or other factors. Although visual estimates of cover may contain observer variability and unknown bias, the method may be used for rapid assessment whereas Pictometry results can only be updated when new imagery becomes available. Nonetheless, Pictometry offers a particularly convenient means to monitor long-term changes in forest canopy cover, requiring no field work.

There are several ways that improved data collection during surveys can make analyses and findings more straightforward and reliable. More rigorous training is needed for survey participants in weed identification and scat differentiation, particularly at KFU, where scat and sometimes tracks are the only reliable way to identify sign of different ungulate species. Survey participants need to be dutiful in recording their observations. Weed data in particular appears to have been recorded inconsistently. Some observers did not have opportunities to see uncommon weed species such as *Photinia* prior to surveys. Observers were often trained only at HFU where they were unable to gain experience differentiating sign of feral cattle from feral pigs. Participants also often failed to indicate plots which were surveyed but contained no sign. These data had to be discarded. Data collection should also be streamlined to expedite analyses. Data from terminal parts of transects that cross fenced management units are difficult to assign to appropriate management units. These transect "tails" represent only a relatively small amount of data that need not be recorded. Data from uninterrupted segments of transects are sufficient for analyses.

ACKNOWLEDGMENTS

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APPENDIX I. DATA MANAGEMENT AND SUMMARIZATION INSTRUCTIONS

These instructions will guide users with some experience of using programs R or RStudio (preferred) for summarizing ungulate and weed data.

Appendix II: Ungulate Survey Data Sheet and Data Entry File Example

Appendix III: Hakalau Forest Unit Ungulate Survey Station UTM Coordinates

Appendix IV: Kona Forest Unit Ungulate Survey Station UTM Coordinates

Appendix V: R Script for Summarizing Ungulate Data

Appendix VI: Hakalau Forest Unit Weed Summary R Script

Appendix VII: Kona Forest Unit Weed Summary R Script

Appendix VIII. Minitab Regression File for Population Estimation

<u>Data entry</u>

Each station plot should receive its own row, i.e. 20 rows per station. Ensure that column headers maintain existing letter case, as R scripts are case sensitive. All records under column 'Ungulate_Sign' must be entered in capital letters. It is the column used for ungulate sign summaries and must include 'F, I, O, or X'; no blank entries.

Please see the KFU tab for entry examples of sign by multiple ungulate species. There is no script to separate cattle, pig, and donkey sign. Separating sign by species must be done manually before opening data in RStudio.

<u>R scripts</u>

Scripts are annotated for user ease. All scripts may be amended, although changes to associated files will also be necessary. Note that R language is case sensitive. File names cannot begin with numerical characters.

All files for summaries must be in one folder, i.e. quarterly survey data and UTM data. Files must be saved as .txt for input, and can be output as preferred file type in R script (.csv is current file type).

The working directory must be set using the filepath name to the proper folder.

At beginning of the script: 'ungulate_raw<-read.delim("KFU_pig_Jan2015_for analysis.txt"', insert file name of that to be summarized.

At the end of the script: 'write.csv(weed_sum, "Hakalau_weed_summary_quarterly2015-test.csv")' insert preferred file output name.

All UTM data should attach to transect and station summary data, although visually assessing data for errors in ArcGIS is prudent.

APPENDIX II. UNGULATE SURVEY DATA SHEET AND DATA ENTRY FILE EXAMPLE

All transects are marked with **blue** flagging.
Stations are marked with **pink** flagging, a consecutively numbered aluminum tag and are 200 meters apart
Orange flags mark 10 and 20 meters before and after each station
Each animal activity plot is 10m X 5m, continuous between each station, for a total of 20 plots between stations.
Use a new page for each station.
Write the station tag number in the station box and Ö off each 10 meter segment as they are finished.
Record animal sign as **F** = fresh, **I** = intermediate, **O** = old, using the Pig and Cattle criteria below.
For Cattle activity use **C** at the beginning of each entry followed by **F, I, or O**.
For Pig activity use **only F, I, or O**. P is not needed.
In the MISC box be sure to write the type of sign followed by **F, I or O.**
Weed Cover and Abundance: Record weed species and density. Blackberry (B) Holly (H) Photinia (Ph) Gorse (G) Poka (P): 1<5% (2.5 m^2); 2=6-25% (2.6-12.5m^2); 3=26-50%; 4=51-75%; 5>75%.

PIG AND CATTLE SIGN CRITERIA

FRESH: **(F)** UP TO 7 DAYS
INTERMEDIATE: **(I)** 8 DAYS TO ONE MONTH
OLD: **(O)** OVER ONE MONTH
ALWAYS LOOK FOR OTHER SIGN TO HELP IN DETERMINING AGE

DIGGING

FRESH: Fluffy soil, small soil clumps on rootlets, fresh dung or tracks nearby, uprooted plants green, litter distribution uneven or different from surroundings, dug area moist (weather dependent).
INTERMEDIATE: No seedlings or seedlings with cotyledons only, scattered litter, uprooted plants yellowing or w/brown tips.
OLD: Seedlings emerging, litter cover uniform and/or accumulating in pits, uprooted plants brown or rerooting, rootlets with soil (exposed).

SCAT

FRESH: Odor, steaming, mucous or shiny appearance, flies, fresh sign nearby.
INTERMEDIATE: Less odor, little or no insect activity, thin crust over cow pies, does not crumble when smashed.
OLD: Hardened, eroded, seedlings emerging, fungal or lichen growth on scat, grass shoots emerging.

PLANT FEEDING

FRESH: Damaged/uprooted plant material green, cut tips green, visible tooth marks, odor may be evident.
INTERMEDIATE: Discolored surfaces, cut tips browning/drying.
OLD: Dried/dead plant parts, plants regrowing, vertical plant growth from horizontal lying plants.
Pigs feed on hapu'u, fruits, tender shoots, fern rhizomes, lily bulbs.
Cattle feed on grasses, sedges, herbs and young woody plants, olapa bark and girdle ohia trees.

TRAILS AND TRACKS

FRESH: Green broken vegetation, fresh scats, tracks well defined, edges of prints not eroded, odor may be apparent.
INTERMEDIATE: Broken vegetation browning, trampled, tracks slightly eroded.
OLD: Untrampled look, seedlings emerging, vegetation regrowing, tracks very eroded.

WEATHER: CLEAR CLOUDY MIST LIGHT RAIN HEAVY RAIN

STATION #	WEED	DIGGING F-I-O	SCAT F-I-O	PLANTS F-I-O	TRACK/TRAIL F-I-O	NOTES
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						

Appendix 2 - Example Data Entry Files Hakalau and KFU - Microsoft Excel

	Transect	Station	Month_year	weather	plot	Ungulate_Sign	Spp.	Digging	Spp.	Scat	Spp.	Plants	Spp.	Trails/Tracks	Comments	RUBPAR	PSICAT	CLIHIR	SENMAD	INITIALS	DATE
2	3	15	Mar-14		12	I			C	I					F-1					EJA	18-Mar-14
3	3	16	Mar-14		1	F	P	F	C	O										SCH, MC	17-Mar-14
4	3	16	Mar-14		2	O			C	O										SCH, MC	17-Mar-14
5	3	16	Mar-14		3	X														SCH, MC	17-Mar-14
6	3	16	Mar-14		4	X														SCH, MC	17-Mar-14
7	3	16	Mar-14		5	X														SCH, MC	17-Mar-14
8	3	16	Mar-14		6	X														SCH, MC	17-Mar-14
9	3	16	Mar-14		7	O			C	O										SCH, MC	17-Mar-14
10	3	16	Mar-14		8	O			C	O										SCH, MC	17-Mar-14
11	3	16	Mar-14		9	I			C	I										SCH, MC	17-Mar-14
12	3	16	Mar-14		10	I	U	I												SCH, MC	17-Mar-14
13	3	17	Mar-14		1	O			C	O										SCH, MC	17-Mar-14
14	3	17	Mar-14		2	X														SCH, MC	17-Mar-14
15	3	17	Mar-14		3	X									3 COWS					SCH, MC	17-Mar-14
16	3	17	Mar-14		4	X														SCH, MC	17-Mar-14
17	3	17	Mar-14		5	O			C	O										SCH, MC	17-Mar-14
18	3	17	Mar-14		6	I			C	I										SCH, MC	17-Mar-14
19	3	17	Mar-14		7	I			C	I										SCH, MC	17-Mar-14
20	3	17	Mar-14		8	X														SCH, MC	17-Mar-14
21	3	17	Mar-14		9	O			C	O										SCH, MC	17-Mar-14
22	3	17	Mar-14		10	X														SCH, MC	17-Mar-14
23	3	17	Mar-14		11	I			C	I										SCH, MC	17-Mar-14

Hakalau | KFU | Sheet3

APPENDIX III. HAKALAU FOREST UNIT UNGULATE SURVEY STATION UTM COORDINATES

Appendix 3 - Hakalau_stations_unit_UTM - Notepad

File Edit Format View Help

Tx_St	Transect	Station	X_UTM	Y_UTM	Lat	Long	UNIT_NO_1	Unit_Name
T10S1	10	1	255953	2194853	19.834512	-155.3301	5	Upper Honohina
T10S10	10	10	257650	2195323	19.838967	-155.31397	5	Upper Honohina
T10S11	10	11	257849	2195364	19.839361	-155.31208	5	Upper Honohina
T10S12	10	12	258024	2195508	19.840683	-155.31043	5	Upper Honohina
T10S13	10	13	258286	2195581	19.841375	-155.30794	1	Middle Honohina
T10S14	10	14	258460	2195674	19.842236	-155.30629	1	Middle Honohina
T10S15	10	15	258649	2195785	19.843262	-155.3045	1	Middle Honohina
T10S16	10	16	258828	2195819	19.843591	-155.3028	1	Middle Honohina
T10S17	10	17	259016	2195885	19.84421	-155.30101	1	Middle Honohina
T10S18	10	18	259210	2195947	19.844794	-155.29917	1	Middle Honohina
T10S19	10	19	259381	2196011	19.845392	-155.29755	1	Middle Honohina
T10S2	10	2	256112	2194950	19.835408	-155.3286	5	Upper Honohina
T10S20	10	20	259558	2196093	19.846155	-155.29587	3	Lower Honohina
T10S21	10	21	259723	2196159	19.846771	-155.2943	3	Lower Honohina
T10S22	10	22	259889	2196235	19.847478	-155.29273	3	Lower Honohina
T10S23	10	23	260065	2196286	19.84796	-155.29105	3	Lower Honohina
T10S24	10	24	260232	2196349	19.848549	-155.28947	3	Lower Honohina
T10S25	10	25	260399	2196421	19.84922	-155.28788	3	Lower Honohina
T10S26	10	26	260584	2196504	19.849992	-155.28613	3	Lower Honohina
T10S27	10	27	260737	2196553	19.850453	-155.28468	3	Lower Honohina
T10S3	10	3	256287	2195007	19.835944	-155.32694	5	Upper Honohina
T10S4	10	4	256499	2195045	19.836314	-155.32492	5	Upper Honohina
T10S5	10	5	256679	2195101	19.836842	-155.32321	5	Upper Honohina
T10S6	10	6	256878	2195139	19.837209	-155.32132	5	Upper Honohina
T10S7	10	7	257066	2195191	19.837702	-155.31953	5	Upper Honohina
T10S8	10	8	257260	2195233	19.838106	-155.31768	5	Upper Honohina
T10S9	10	9	257448	2195282	19.838571	-155.3159	5	Upper Honohina
T11S1	11	1	255834	2195927	19.844195	-155.33138	5	Upper Honohina
T11S10	11	10	257643	2196350	19.848239	-155.31418	5	Upper Honohina
T11S11	11	11	257836	2196415	19.84885	-155.31234	5	Upper Honohina
T11S12	11	12	257990	2196545	19.850043	-155.31089	1	Middle Honohina
T11S13	11	13	258166	2196544	19.850055	-155.30921	1	Middle Honohina
T11S14	11	14	258358	2196618	19.850747	-155.30739	1	Middle Honohina
T11S15	11	15	258537	2196687	19.851392	-155.30569	1	Middle Honohina
T11S16	11	16	258713	2196756	19.852037	-155.30402	1	Middle Honohina
T11S17	11	17	258898	2196814	19.852584	-155.30226	1	Middle Honohina
T11S18	11	18	259058	2196865	19.853064	-155.30074	3	Lower Honohina
T11S19	11	19	259246	2196934	19.85371	-155.29895	3	Lower Honohina
T11S2	11	2	256027	2195981	19.844706	-155.32955	5	Upper Honohina
T11S20	11	20	259418	2197010	19.854418	-155.29732	3	Lower Honohina
T11S21	11	21	259583	2197092	19.855178	-155.29576	3	Lower Honohina
T11S22	11	22	259757	2197171	19.855913	-155.29411	3	Lower Honohina
T11S23	11	23	259885	2197222	19.856389	-155.29289	3	Lower Honohina
T11S24	11	24	260055	2197287	19.856997	-155.29128	3	Lower Honohina

APPENDIX IV. KONA FOREST UNIT UNGULATE SURVEY STATION UTM COORDINATES

Appendix 4 - KFU_transect_waypoints - Notepad

File Edit Format View Help

Tx_St	PROJECTION	ZONE	X_UTM	Y_UTM	TRANSECT	STATION	Lat	Long
T1S2	UTM/UPS	05Q	207858	2146222	1	2	19.38896672	-155.7813696
T1S3	UTM/UPS	05Q	207708	2146239	1	3	19.38909833	-155.782799
T1S4	UTM/UPS	05Q	207557	2146274	1	4	19.38939226	-155.7842407
T1S5	UTM/UPS	05Q	207393	2146281	1	5	19.38943154	-155.7858018
T1S6	UTM/UPS	05Q	207237	2146280	1	6	19.38939976	-155.7872856
T1S7	UTM/UPS	05Q	207092	2146291	1	7	19.38947789	-155.7886665
T1S8	UTM/UPS	05Q	206946	2146291	1	8	19.38945657	-155.7900553
T1S9	UTM/UPS	05Q	206791	2146297	1	9	19.38948809	-155.7915306
T1S10	UTM/UPS	05Q	206637	2146290	1	10	19.3894024	-155.7929944
T1S11	UTM/UPS	05Q	206502	2146306	1	11	19.38952708	-155.7942811
T1S12	UTM/UPS	05Q	206341	2146311	1	12	19.38954866	-155.7958133
T1S13	UTM/UPS	05Q	206186	2146321	1	13	19.38961623	-155.7972892
T1S14	UTM/UPS	05Q	206058	2146327	1	14	19.38965164	-155.7985077
T1S15	UTM/UPS	05Q	205868	2146327	1	15	19.3896238	-155.800315
T1S16	UTM/UPS	05Q	205706	2146326	1	16	19.38959102	-155.8018558
T1S17	UTM/UPS	05Q	205524	2146321	1	17	19.38951919	-155.8035863
T1S18	UTM/UPS	05Q	205351	2146363	1	18	19.3898729	-155.8052384
T1S19	UTM/UPS	05Q	205204	2146373	1	19	19.38994158	-155.8066382
T1S20	UTM/UPS	05Q	205050	2146392	1	20	19.39009045	-155.808106
T1S21	UTM/UPS	05Q	204896	2146434	1	21	19.39044691	-155.8095774
T1S22	UTM/UPS	05Q	204732	2146458	1	22	19.39063942	-155.8111411
T1S23	UTM/UPS	05Q	204561	2146473	1	23	19.39074964	-155.81277
T1S24	UTM/UPS	05Q	204474	2146467	1	24	19.39068268	-155.8135966
T1S25	UTM/UPS	05Q	204264	2146512	1	25	19.39105792	-155.8156011
T1S26	UTM/UPS	5Q	204161	2146543	1	26	19.39132255	-155.8165857
T1S27	UTM/UPS	5Q	204016	2146563	1	27	19.39148169	-155.8179681
T1S28	UTM/UPS	5Q	203862	2146596	1	28	19.39175684	-155.819438
T1S29	UTM/UPS	05Q	203647	2146619	1	29	19.3919327	-155.8214867
T1S30	UTM/UPS	5Q	203565	2146641	1	30	19.39211916	-155.8222701
T1S31	UTM/UPS	5Q	203416	2146674	1	31	19.39239501	-155.8236926
T1S32	UTM/UPS	5Q	203285	2146677	1	32	19.39240272	-155.8249391
T1S33	UTM/UPS	5Q	203126	2146708	1	33	19.39265901	-155.8264564
T1S34	UTM/UPS	5Q	202985	2146714	1	34	19.3926923	-155.8277985
T1S35	UTM/UPS	5Q	202848	2146742	1	35	19.39292475	-155.8291061
T1S36	UTM/UPS	5Q	202692	2146769	1	36	19.39314534	-155.8305942
T1S37	UTM/UPS	5Q	202543	2146796	1	37	19.39336697	-155.8320157
T1S38	UTM/UPS	5Q	202378	2146815	1	38	19.39351399	-155.8335882
T1S39	UTM/UPS	5Q	202216	2146761	1	39	19.39300254	-155.8351207
T1S40	UTM/UPS	5Q	202013	2146743	1	40	19.39280993	-155.8370488
T1S41	UTM/UPS	5Q	201867	2146738	1	41	19.39274311	-155.8384368
T1S42	UTM/UPS	5Q	201727	2146763	1	42	19.39294795	-155.8397724
T1S43	UTM/UPS	5Q	201583	2146787	1	43	19.39314317	-155.8411459
T1S44	UTM/UPS	5Q	201427	2146791	1	44	19.39315606	-155.8426304
T1S45	UTM/UPS	5Q	201340	2146811	1	45	19.39332363	-155.8434611

APPENDIX V. R SCRIPT FOR SUMMARIZING UNGULATE DATA

Appendix 5 - Summarize_ungulate_data_R_script - Notepad

File Edit Format View Help

```
#Summarize ungulate data

setwd("C:\\Users\\ccornett\\Desktop\\Veg & Ungulates\\")  #sroutes to folder with data files, waypoint files, and saved summary files

UTMdata<-read.delim("Hakalau_stations_unit_UTM.txt",as.is=T) #read-in UTM data; change for KFU summaries
ungulate_raw<-read.delim("Hakalau ungulate surveys Sep2014.txt",as.is=T)  #data file for summary
ungulate_raw$ID <- paste0("T",ungulate_raw$Transect,"S",ungulate_raw$Station, "X", ungulate_raw$Month_year) #make unique station ID
stations <- unique(ungulate_raw$ID)


ungulate_sum <- NULL
for (i in (1:length(stations))){
  current <- stations[i] #current is station being assessed
  tmp <- ungulate_raw[which(ungulate_raw$ID==current),] #tmp=all plots (rows of data) from given T and ST', ' gives all columns
  Transect <- tmp$Transect[1]
  station <- tmp$Station[1]
  MonthYear <- tmp$Month_year[1]
  Nplots <- nrow(tmp)
  sign_X <- sum(tmp$Ungulate_Sign=="X")
  sign_F <- sum(tmp$Ungulate_Sign=="F")
  sign_I <- sum(tmp$Ungulate_Sign=="I")
  sign_O <- sum(tmp$Ungulate_Sign=="O")
  proportion_FI <- (sign_F+sign_I)/Nplots
  dig_F <- sum(tmp$Digging=="F")
  dig_I <- sum(tmp$Digging=="I")
  dig_O <- sum(tmp$Digging=="O")
  scat_F <- sum(tmp$Scat=="F")
  scat_I <- sum(tmp$Scat=="I")
  scat_O <- sum(tmp$Scat=="O")
  plant_F <- sum(tmp$Plants=="F")
  plant_I <- sum(tmp$Plants=="I")
  plant_O <- sum(tmp$Plants=="O")
  track_F <- sum(tmp$Trails.Tracks=="F")
  track_I <- sum(tmp$Trails.Tracks=="I")
  track_O <- sum(tmp$Trails.Tracks=="O")

  ungulate_sum<-rbind(ungulate_sum,c(Transect, station, MonthYear, Nplots,sign_X,sign_F,sign_I,sign_O,proportion_FI,dig_F,dig_I,dig_O,scat_F,scat_I,scat_O,plant_F,plant_I,p
}  #sums all plot data by station

ungulate_sum<-as.data.frame(cbind(stations,ungulate_sum))

colnames(ungulate_sum)<-c("stationID", "Transect","station", "MonthYear", "Nplots","sign_X","sign_F","sign_I","sign_O","proportion_FI","dig_F","dig_I","dig_O","scat_F","sca
UTMx <- UTMdata$X_UTM[match(paste0("T",ungulate_sum$Transect,"S",ungulate_sum$station),UTMdata$Tx_St)]
UTMy <- UTMdata$Y_UTM[match(paste0("T",ungulate_sum$Transect,"S",ungulate_sum$station),UTMdata$Tx_St)]  #matches UTM data with unique station

ungulate_sum$UTMx <- UTMx
ungulate_sum$UTMy <- UTMy

write.csv(ungulate_sum,"HF_test.csv")  #change file name accordingly for output
```

Ln 44, Col 82

APPENDIX VI. HAKALAU FOREST UNIT WEED SUMMARY R SCRIPT

Appendix 6 - Hakalau_weed_summary_R_script - Notepad

File Edit Format View Help

```
#Summarize weed data

setwd("C:\\Users\\ccornett\\Desktop\\Veg & Ungulates\\") #Set working directory to the folder with all files for the analysis

UTMdata<-read.delim("Hakalau_stations_unit_UTM.txt",as.is=T) #read-in UTM data; change for KFU summaries
weed_raw<-read.delim("Hakalau ungulate surveys Sep2014.txt",as.is=T) #insert input file name accordingly
weed_raw$ID <- paste0("T",weed_raw$Transect,"S",weed_raw$Station, "X", weed_raw$Month_year) #makes unique station ID
stations <- unique(weed_raw$ID)
weed_raw[is.na(weed_raw)]<-0 #is.na returns a True/False matrix for anything NA value. Reassigned NA to value of 0 for calculations
percentKey <- as.data.frame(cbind(rbind(0,1,2,3,4,5),rbind(0,2.5,15.5,38,63,88)))


weed_sum <- NULL
for (i in (1:length(stations))){
  current <- stations[i] #current is station being assessed
  tmp <- weed_raw[which(weed_raw$ID==current),] #tmp=all plots (rows of data) from given T and ST', ' gives all columns
  Transect <- tmp$Transect[1]
  station <- tmp$Station[1]
  MonthYear <- tmp$Month_year[1]
  Nplots <- nrow(tmp)

  RUBARGcount <- sum(tmp$RUBARG>0)
  RUBARGprop <- RUBARGcount/Nplots #proportion plots with any sign
  RUBARGmax <- max(tmp$RUBARG, na.rm=T)
  RUBARGavg <- mean(percentKey[match(tmp$RUBARG,percentKey[,1]),2]) #match matches category value of RUBARG to percentKey and outputs midpoint value and returns the mean

  PASMOScount <- sum(tmp$PASMOS>0)
  PASMOSprop <- PASMOScount/Nplots #proportion plots with any sign
  PASMOSmax <- max(tmp$PASMOS, na.rm=T)
  PASMOSavg <- mean(percentKey[match(tmp$PASMOS,percentKey[,1]),2])

  PHODAVcount <- sum(tmp$PHODAV>0)
  PHODAVprop <- PHODAVcount/Nplots #proportion plots with any sign
  PHODAVmax <- max(tmp$PHODAV, na.rm=T)
  PHODAVavg <- mean(percentKey[match(tmp$PHODAV,percentKey[,1]),2])

  ILEAQUcount <- sum(tmp$ILEAQU>0)
  ILEAQUprop <- ILEAQUcount/Nplots #proportion plots with any sign
  ILEAQUmax <- max(tmp$ILEAQU, na.rm=T)
  ILEAQUavg <- mean(percentKey[match(tmp$ILEAQU,percentKey[,1]),2])

  ULEEURcount <- sum(tmp$ULEEUR>0)
  ULEEURprop <- ULEEURcount/Nplots #proportion plots with any sign
  ULEEURmax <- max(tmp$ULEEUR, na.rm=T)
  ULEEURavg <- mean(percentKey[match(tmp$ULEEUR,percentKey[,1]),2])

  weed_sum <- rbind(weed_sum,c(Transect, station, MonthYear, Nplots, RUBARGcount, RUBARGprop, RUBARGmax, RUBARGavg, PASMOScount, PASMOSprop, PASMOSmax, PASMOSavg, PHODAVcou

}  #weed values summed across all plots per station
```

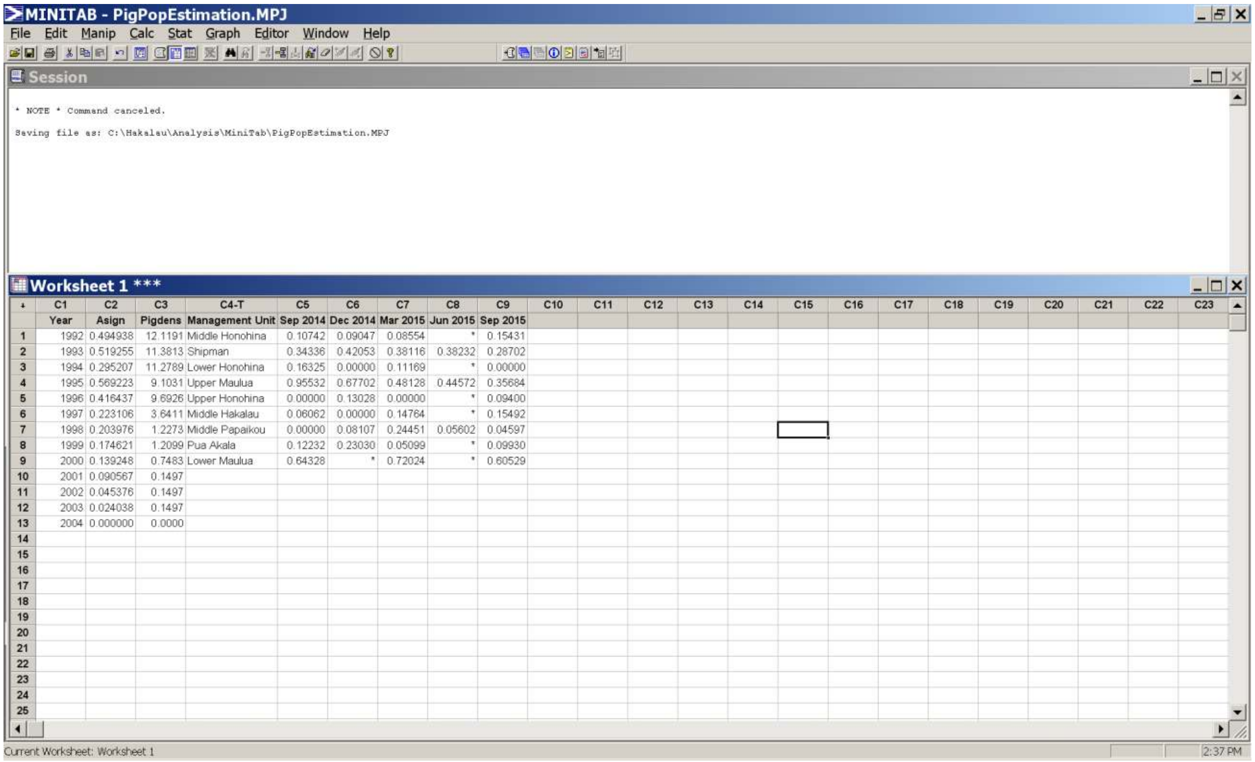
APPENDIX VII. KONA FOREST UNIT WEED SUMMARY R SCRIPT

Appendix 7 - KFU_weed_summary_Rscript - Notepad

File Edit Format View Help

```
#Sumarize weed data

setwd("C:\\Users\\ccornett\\Desktop\\Veg & Ungulates\\")  #Set working directory to the folder with all files for the analysis

UTMdata<-read.delim("KFU_transect_waypoints.txt",as.is=T) #read-in UTM data; change for KFU summaries
weed_raw<-read.delim("KFU_Jan2015_for analysis.txt",as.is=T) #insert input file name accordingly
weed_raw$ID <- paste0("T",weed_raw$Transect,"S",weed_raw$Station, "X", weed_raw$Month_year) #makes unique station ID
stations <- unique(weed_raw$ID)
weed_raw[is.na(weed_raw)]<-0 #is.na returns a True/False matrix for anything NA value. Reassigned NA to value of 0 for calculations
percentKey <- as.data.frame(cbind(rbind(0,1,2,3,4,5),rbind(0,2.5,15.5,38,63,88)))


weed_sum <- NULL
for (i in (1:length(stations))){
  current <- stations[i] #current is station being assessed
  tmp <- weed_raw[which(weed_raw$ID==current),] #tmp=all plots (rows of data) from given T and ST', ' gives all columns
  Transect <- tmp$Transect[1]
  station <- tmp$Station[1]
  MonthYear <- tmp$Month_year[1]
  Nplots <- nrow(tmp)

  RUBPARcount <- sum(tmp$RUBPAR>0)
  RUBPARprop <- RUBPARcount/Nplots #proportion plots with any sign
  RUBPARmax <- max(tmp$RUBPAR, na.rm=T)
  RUBPARavg <- mean(percentKey[match(tmp$RUBARG,percentKey[,1]),2]) #match matches category value of RUBARG to percentKey and outputs midpoint value and returns the mean


  SENMADcount <- sum(tmp$SENMAD>0)
  SENMADprop <- SENMADcount/Nplots #proportion plots with any sign
  SENMADmax <- max(tmp$SENMAD, na.rm=T)
  SENMADavg <- mean(percentKey[match(tmp$SENMAD,percentKey[,1]),2])

  PSICATcount <- sum(tmp$PSICAT>0)
  PSICATprop <- PSICATcount/Nplots #proportion plots with any sign
  PSICATmax <- max(tmp$PSICAT, na.rm=T)
  PSICATavg <- mean(percentKey[match(tmp$PSICAT,percentKey[,1]),2])


  CLIHIRcount <- sum(tmp$CLIHIR>0)
  CLIHIRprop <- CLIHIRcount/Nplots #proportion plots with any sign
  CLIHIRmax <- max(tmp$CLIHIR, na.rm=T)  #maximum cover encountered within the station
  CLIHIRavg <- mean(percentKey[match(tmp$CLIHIR,percentKey[,1]),2])

  weed_sum <- rbind(weed_sum,c(Transect, station, MonthYear, Nplots, RUBPARcount, RUBPARprop, RUBPARmax, RUBPARavg, PSICATcount, PSICATprop, PSICATmax, PSICATavg, SENMADcou

}  #weed values summed across all plots per station


weed_sum <- as.data.frame(cbind(stations,weed_sum))
```

Appendix VIII. Minitab Regression File for Population Estimation



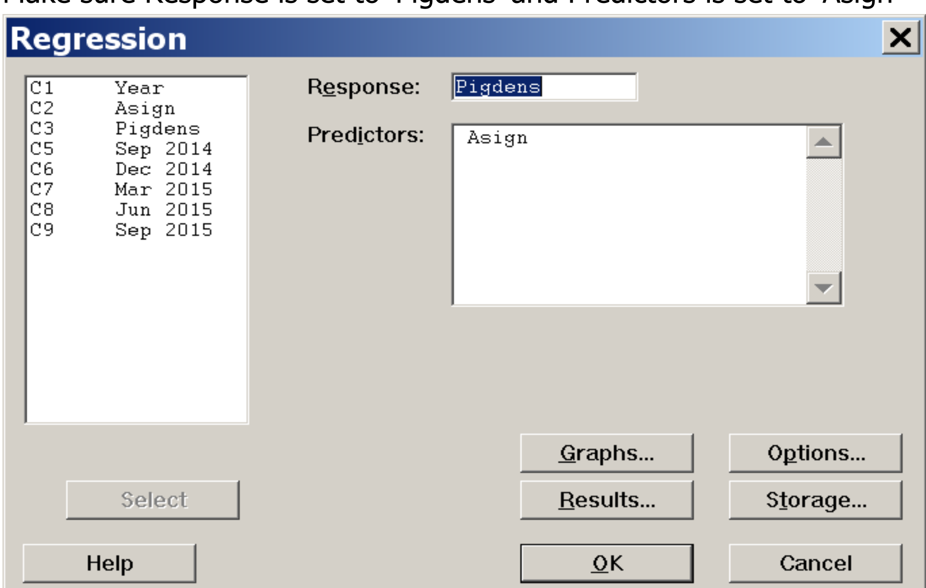
	C1	C2	C3	C4-T	C5	C6	C7	C8	C9
	Year	Asign	Pigdens	Management Unit	Sep 2014	Dec 2014	Mar 2015	Jun 2015	Sep 2015
1	1992	0.494938	12.1191	Middle Honohina	0.10742	0.09047	0.08554	*	0.15431
2	1993	0.519255	11.3813	Shipman	0.34336	0.42053	0.38116	0.38232	0.28702
3	1994	0.295207	11.2789	Lower Honohina	0.16325	0.00000	0.11169	*	0.00000
4	1995	0.569223	9.1031	Upper Maulua	0.95532	0.67702	0.48128	0.44572	0.35684
5	1996	0.416437	9.6926	Upper Honohina	0.00000	0.13028	0.00000	*	0.09400
6	1997	0.223106	3.6411	Middle Hakalau	0.06062	0.00000	0.14764	*	0.15492
7	1998	0.203976	1.2273	Middle Papaikou	0.00000	0.08107	0.24451	0.05602	0.04597
8	1999	0.174621	1.2099	Pua Akala	0.12232	0.23030	0.05099	*	0.09930
9	2000	0.139248	0.7483	Lower Maulua	0.64328	*	0.72024	*	0.60529
10	2001	0.090567	0.1497						
11	2002	0.045376	0.1497						
12	2003	0.024038	0.1497						
13	2004	0.000000	0.0000						

Open Minitab project: PigPopEstimation.MPJ

Add arcsine transformed proportion values to the next available column

Select: Stat> Regression > Regression from the dropdown menu

Make sure Response is set to 'Pigdens' and Predictors is set to 'Asign'



Set ‘Prediction intervals for new observations:’ to the name of your new data column

Set confidence level to ‘95’

Check boxes for Confidence limits and Prediction limits

Density values and confidence limits will be displayed as ‘new obs’ in the session window