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VEGETATION AND NON-NATIVE UNGULATE MONITORING AT THE BIG ISLAND NATIONAL WILDLIFE REFUGE COMPLEX 2010–2014

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ABSTRACT

The Hakalau Forest Unit (HFU) of Big Island National Wildlife Refuge Complex (BINWRC) has intensively managed feral cattle (*Bos taurus*) and pigs (*Sus scrofa*) and monitored non-native ungulate presence and distribution during surveys of all managed areas since 1988. We: 1) provide results from recent ungulate surveys at HFU to determine current feral pig abundance and distribution; 2) present results of surveys of ungulate presence and distribution at the Kona Forest Unit (KFU); 3) present results of surveys of weed presence and cover at both refuge units; and 4) present baseline results from long-term vegetation monitoring plots at KFU. Overall pig abundance appears to have decreased at HFU, although not significantly, over the period from 2010 to 2014. Management units 2 and 4 contained the majority of pigs at HFU. Pig density outside of adjacent managed areas has declined significantly from 2010 to 2014 for unknown reasons. Ungulate sign occurred in > 50% of plots at KFU during the November 2012 and September 2013 surveys, but ungulate sign occurred in < 28% of plots during three other surveys. The ability to differentiate sign of ungulate species remains problematic at KFU. Changes in weed cover 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. Nonetheless, the distribution and cover of fireweed (*Senecio madagascariensis*) at KFU may have increased over the study period. Vegetation surveys documented baseline floristic composition and forest structure at KFU. It is not known if this current amount of emerging cover is sufficient for long-term self-sustaining forest canopy regeneration; however, numerous 'ōhi'a seedlings were found in the wet forest and mesic 'ōhi'a habitats, indicating an ample viable seed source and robust potential for forest regeneration.

INTRODUCTION

The Hakalau Forest Unit of Big Island National Wildlife Refuge Complex (BINWRC) has intensively managed feral cattle (*Bos taurus*) and pigs (*Sus scrofa*) and monitored non-native ungulate presence and distribution during surveys of all managed areas since 1988 (Stone *et al.* 1991). Results of all available data regarding feral pig management activities until 2004 were compiled and analyzed by Hess *et al.* (2007), and more recent surveys of feral pig abundance from 2010–2013 were analyzed and updated by Hess *et al.* (2013). Ungulate management and surveys of ungulate presence and distribution began at the Kona Forest Unit of BINWRC in 2013 after fence construction was completed, but have not been previously assessed.

To determine the current status of non-native ungulate distribution and abundance, and implications for vegetation so that management may be more effectively focused at BINWRC, here we: 1) analyze data and update results from recent ungulate surveys at the Hakalau Forest Unit to determine current feral pig abundance and distribution; 2) present results of surveys of ungulate presence and distribution at the Kona Forest Unit; 3) present results of surveys of weed presence and cover at both refuge units; and 4) present baseline results from long-term vegetation monitoring plots at the Kona Forest Unit, which will allow assessments of vegetation response to ungulate management in the future.

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-m² contiguous plots using field methods consistent with Stone *et al.* (1991). At HFU, 422 stations, each with approximately 20 sample plots, along 17 transects were surveyed during 2010–2014. At KFU, 147 stations, each with approximately 17 sample plots, along four transects were surveyed during 2013–2014. The presence and cover of weeds was also recorded in the same sample plots. 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 were trained in identifying and ageing ungulate sign by more experienced observers. Surveys were conducted at Hakalau Forest Unit during November 2010 and 2011, October 2012, March, May, September, and December of 2013, and March and June of 2014 (Table 1). Surveys were conducted at KFU during November 2012, March, June, and September of 2013, and March 2014 (Table 2). These data were joined to their spatial coordinates and plotted using ArcGIS 9.2 Geographic Information System. Locations were assigned to management units by UTM coordinates.

Baseline Vegetation Surveys at Kona Forest Unit

Baseline vegetation surveys were conducted from 24 April to 3 December 2013 within four of the six vegetation types at the Kona Forest Unit: 1) `ōhi`a (*Metrosideros polymorpha*) dominated wet forest with tree fern and native shrub/fern understory; 2) `ōhi`a dominated mesic forest with native shrub and exotic grass understory; 3) koa (*Acacia koa*)-`ōhi`a dominated mesic forest with native shrub and exotic grass understory; 4) dry subalpine woodland with native shrub understory. Five vegetation plots were replicated at random locations selected across a broad range of elevation within each of the vegetation types using ArcGIS 9.2 Geographic Information System (Figure 1). If a random location was unsuitable because of geological features, roads, or other reasons, another random location was selected. Plots 20 x 20 m in size were permanently marked with four 1.2-m tall PVC stakes and orange flags on stakes and nearby trees.

Vegetation composition and structure was measured for 13 life-form categories (bare ground, bryophyte, coarse woody debris, exotic fern, exotic grass, exotic herb, lichen, (leaf) litter, native fern, native woody plant, native grass or herb, rock, and scat) using the point-intercept method (Muller-Dombois and Ellenberg 1974). Life-form categories were selected to be comparable to previous vegetation surveys conducted at BINWRC (Hess *et al.* 2010). Point-intercept measurements were made at 1-m intervals along five north-south oriented lines spaced 5-m apart within plots. All plants that intercepted a pole at < 1, 1–2, or 2–3 m in height were identified to the lowest taxonomic level. Canopy cover was measured in increments of 5% along the same lines at 5-m intervals. Quadrats of 1 m² were used to enumerate the total number and lowest taxonomic level of seedlings, and amount of cover of ground vegetation in 1% increments at 5-m intervals along the same lines. Photographs were taken from the northeast pole of each plot facing the southwest pole to initiate a visual record of vegetation change.

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, during 2013 and 2014. The number of sampled transects and stations varied annually, and some stations were not sampled because they extended beyond management units.

Transect	Number of stations	Number of stations surveyed						Number of plots surveyed					
		Mar 2013	May 2013	Sep 2013	Dec 2013	Mar 2014	Jun 2014	Mar 2013	May 2013	Sep 2013	Dec 2013	Mar 2014	Jun 2014
1	21	18	10	10	0	9	18	372	185	190	0	173	371
1A	20	19	11	11	0	19	11	361	208	213	0	371	221
1B	17	0	7	8	0	7	9	0	140	150	0	142	179
2	20	10	18	0	18	10	18	193	328	0	313	194	358
3	20	10	18	10	8	10	18	191	387	216	145	200	318
4	20	11	8	18	8	11	11	197	151	373	125	204	160
5	26	16	9	9	8	16	16	340	159	163	126	310	281
6	27	24	17	17	8	17	25	462	313	334	147	349	500
7	27	24	17	18	24	17	8	670	337	342	443	348	160
7A	26	25	17	17	9	17	25	516	323	321	167	322	449
8	27	25	16	17	10	17	27	475	303	300	171	310	483
8A	26	24	26	26	21	26	0	446	493	514	402	494	0
9	27	13	25	25	26	25	0	256	491	506	464	431	0
10	28	0	18	27	28	27	11	0	367	513	554	530	217
11	28	0	27	11	26	26	11	0	548	216	519	536	234
13	31	0	20	30	30	30	20	0	390	588	600	551	370
14	31	0	20	19	30	28	20	0	372	401	578	538	392
Total	422	219	284	273	254	312	248	4149	5495	5340	4754	603	4693

Table 2. 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 2012–2014.

Transect	Number of stations	Number of stations surveyed					Number of plots surveyed				
		Nov 2012	Mar 2013	Jun 2013	Sep 2013	Mar 2014	Nov 2012	Mar 2013	Jun 2013	Sep 2013	Mar 2014
1	37	37	37	37	37	37	646	613	677	608	555
2	37	37	36	36	36	37	629	619	585	581	728
3	35	36	35	35	36	36	565	579	533	474	487
4	37	37	37	37	37	35	623	692	619	552	570
Total	146	147	145	145	146	145	2463	2503	2414	2215	2340

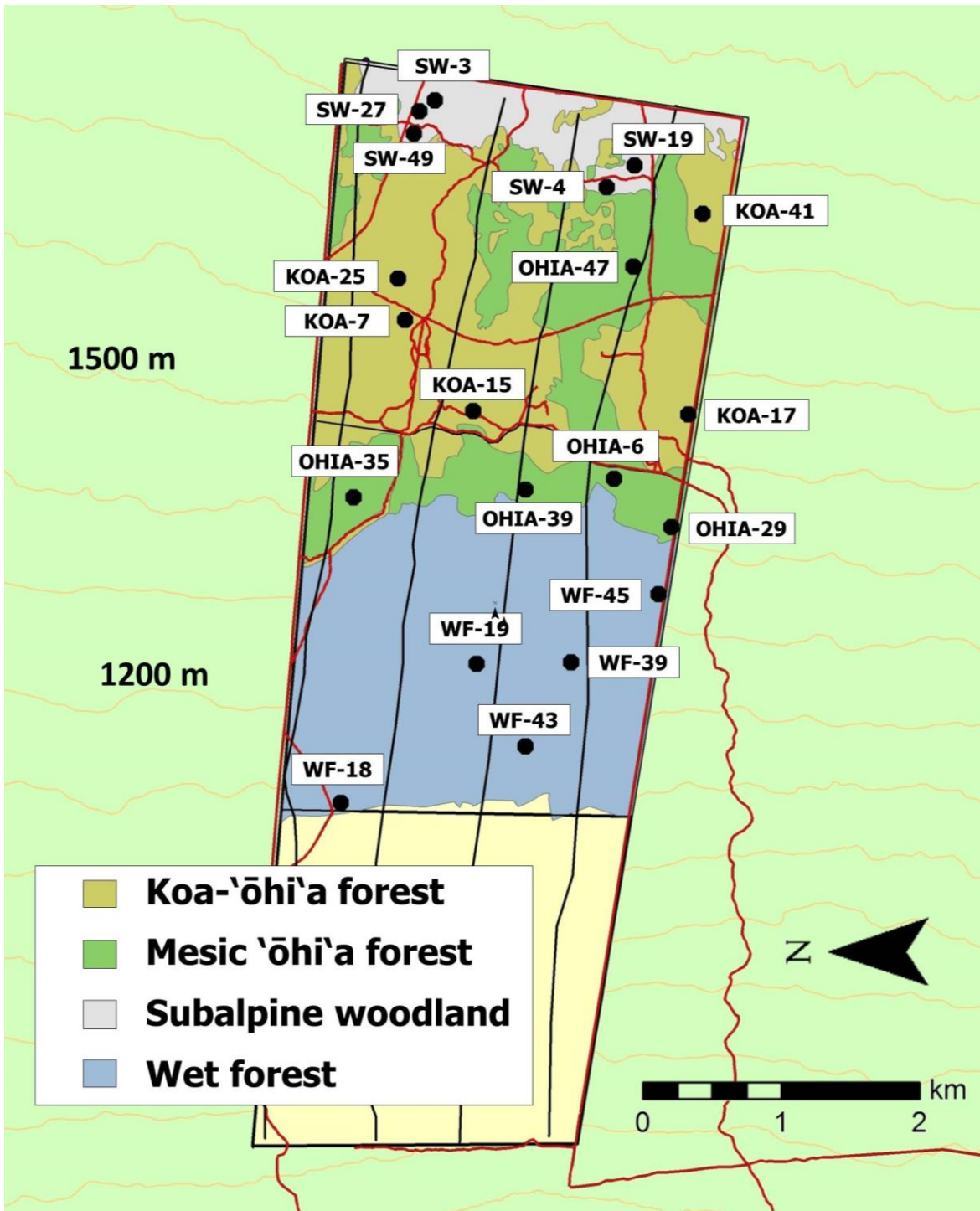


Figure 1. Locations of survey plots within four vegetation types at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island: Koa-ōhi'a forest (KOA), mesic ʻōhi'a forest (OHIA), subalpine woodland (SW), and wet forest (WF). Five vegetation plots were established within each vegetation type.

Analyses

Non-native ungulate presence and distribution data were analyzed to determine estimated abundance of feral pigs at HFU. The proportion of sample plots per station with fresh, intermediate, and both fresh and intermediate ungulate sign (hereafter all sign) was calculated for each survey within each management unit and plotted using ArcGIS 9.2 Geographic Information System. Feral pig abundance was estimated using the approach described by Anderson and Stone (1994), Hess *et al.* (2007), and Hess *et al.* (2013). A model of feral pig abundance developed by Hess *et al.* (2007) was used to determine population estimates in enclosed management units and densities in unenclosed areas from recent survey data. The proportion of sample plots per station with fresh, intermediate, and both fresh and intermediate cattle sign, pig sign, and all ungulate sign was also calculated for KFU. Abundance estimates could not be determined for KFU because a calibrated model of abundance had not yet been developed.

Observed weed cover was plotted for each survey using ArcGIS 9.2 Geographic Information System and the maximum value at each sample station was displayed for each weed species within calendar years to account for potential seasonal differences in cover. Analyses of baseline vegetation surveys at KFU included the proportion of species found in line-intercept surveys, and the mean cover values grouped by vegetation type, and native or exotic species and life form. Seedling count and canopy cover data were summarized at the lowest identifiable taxonomic level.

RESULTS

Ungulate Surveys

The percent of plots with fresh or intermediate feral pig sign in surveys from 2010 to March of 2013 at HFU ranged from 0.0–52.2%, whereas surveys since May of 2013 ranged from 0.0–36.5% (Table 3). The spatial distribution of stations surveyed from May of 2013 to June of 2014 includes seven management units, and efforts varied across surveys (Figure 2). The proportion of plots with pig sign at each station are displayed in six categories: 0% sign; 1–10%; 11–30%; 31–50%; 51–79%; 80–100%.

Although pig abundance since November of 2010 within managed areas of HFU has decreased, this trend is statistically non-significant (Figure 3). Two surveys, however, may have underestimated abundance: the May 2013 abundance estimate appears to be anomalously lower than other estimates perhaps due to environmental conditions of heavy rain; management units 1 and 3 were not surveyed in June of 2014, therefore an unknown number of pigs were not represented in the estimated total (Table 4). There has also been a significant decline in pig density in the unenclosed area of Lower Maulua from 15.1 (\pm 3.3) pigs/km² in November of 2010 to 6.6 (\pm 1.4) pigs/km² in March of 2014, reflecting population dynamics in adjacent unmanaged areas.

Table 3. Percent of plots with fresh or intermediate feral pig sign within seven enclosed management units and an unenclosed area of Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 2010–2014.

Management unit	Area km ²	Percent of plots with fresh or intermediate pig sign									
		2010	2011	2012	Mar 13	May 13	Sep 13	Dec 13	Mar 14	Jun 14	
Middle Honohina	Unit 1	2.21	52.2	2.5	2.2	18.0	4.4	36.5	30.6	12.0	--
Shipman	Unit 2	22.13	17.4	--	26.1	23.2	6.9	13.1	26.6	24.4	27.5
Lower Honohina	Unit 3	7.99	29.7	--	27.8	38.4	27.0	20.9	21.0	10.2	--
Upper Maulua	Unit 4	8.39	26.2	24.9	25.5	6.3	7.7	9.1	7.5	7.5	18.4
Upper Honohina	Unit 5	4.49	38.2	10.7	22.5	9.6	5.5	14.8	1.5	14.0	0.0
Middle Hakalau	Unit 6	5.23	2.5	--	3.9	0.2	0.6	2.0	0.0	0.0	0.6
Middle Papaikou	Unit 7	7.22	6.7	--	1.0	0.7	0.0	3.2	0.0	0.0	0.4
Pua 'Ākala	Unit 8	2.3	--	--	--	--	--	13.9	--	--	--
Lower Maulua	Unenclosed	--	44.7	--	--	--	--	--	--	9.9	--
Total	--	59.96	20.2	16.6	19.2	16.5	6.7	12.5	10.3	16.9	17.0

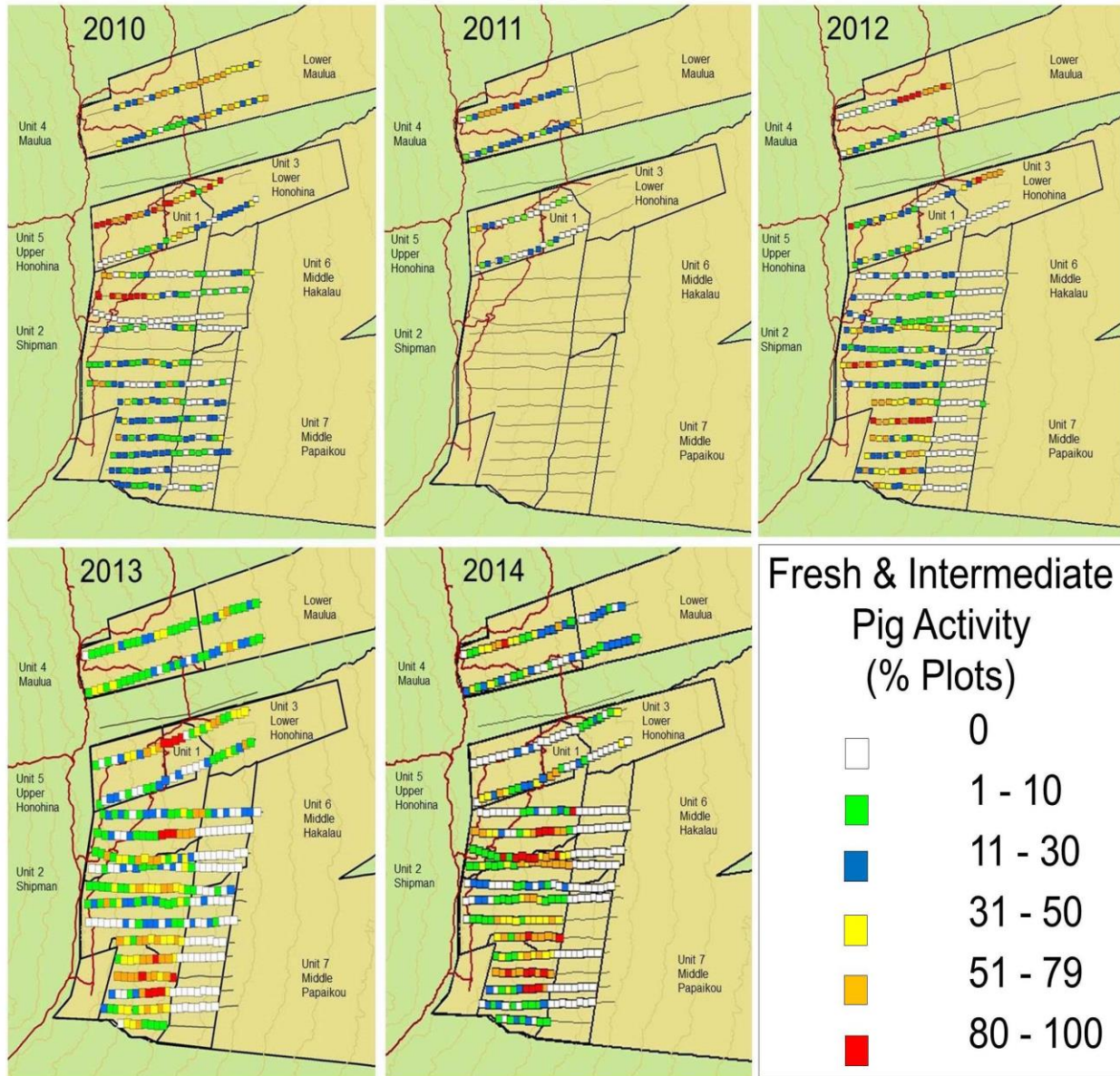


Figure 2. Pig sign from seven enclosed management units and unenclosed Lower Maulua of Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 2010–2014. Values presented are the maximum recorded from each sample station.

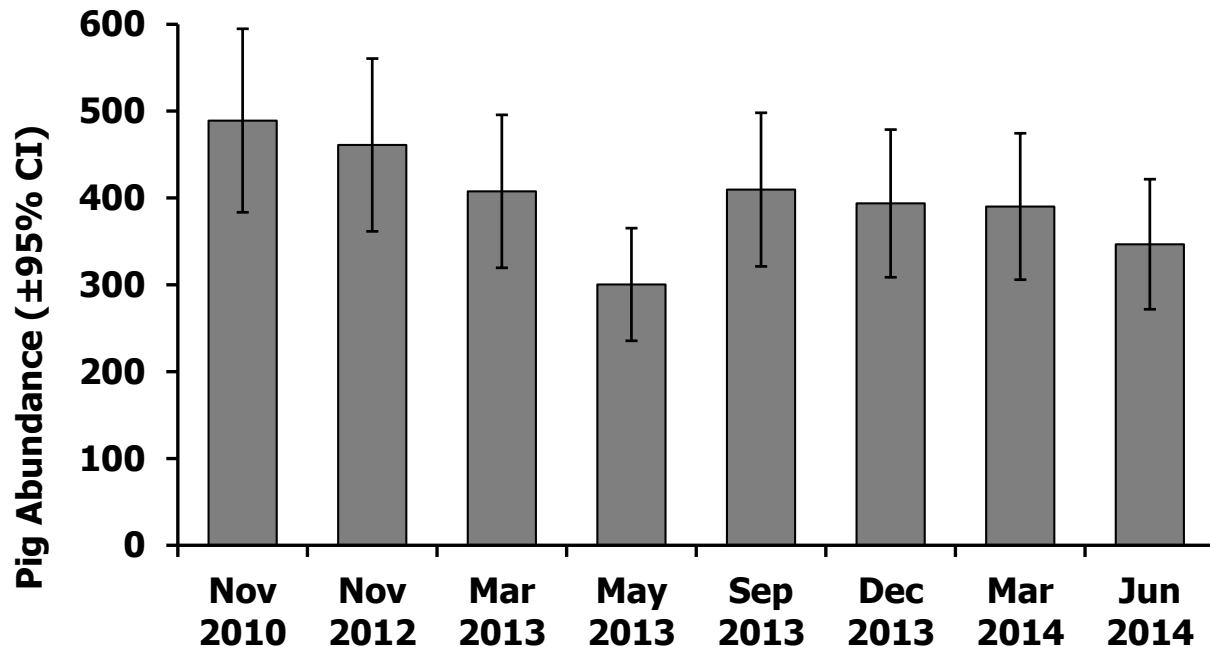


Figure 3. Estimated total abundance of feral pigs (\pm 95% confidence intervals) in seven enclosed management units of Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, November 2010–June 2014 based on index surveys calibrated with a model developed by Hess *et al.* (2007). Pig abundance was underestimated in June of 2014 because two management units were not surveyed. The May 2013 estimate is also anomalously low. Data for 2010 through March 2013 from Hess *et al.* (2013).

Four transects were surveyed at the KFU in November 2012; March, June, September of 2013; and March 2014. A total of 728 stations, and 11,935 sample plots were surveyed (Table 2). The percent of plots with fresh or intermediate feral ungulate sign including cattle, pig, sheep, and donkey, ranged from 9.2–70.7% (Table 5). It was not possible under many circumstances to discern between cattle and pig sign, other than scat. Feral cattle and pig sign was summarized separately; percent of plots with fresh or intermediate sign ranged from 8.4–41.4%, and 0.4–14.8%, respectively. Donkey sign was detected on 112 occasions, and sheep sign detected twice during 2012–2014. The spatial distribution of stations surveyed during 2012–2014 was consistent throughout both management units. Ungulate activity was generally lowest in subalpine woodland habitat at the highest elevations. Ungulate activity was greatest in the middle unit, with the greatest amount of sign detected during 2013 (Figure 4). Ungulate activity decreased from the highest cover category to more moderate cover during 2014. Feral cattle activity was consistently and frequently encountered throughout KFU, with less frequent detection on the upper portions of transects (Figure 5). Feral pig sign was more consistently encountered in the middle unit, although low-moderate densities were recorded throughout KFU (Figure 6).

Table 4. Estimated abundance of feral pigs (\pm 95% confidence intervals) within seven enclosed management units and an unenclosed area of Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, May 2013–June 2014 based on index surveys calibrated with a model developed by Hess *et al.* (2007).

Management unit		Area km ²	Pig abundance				
			May 2013	Sep 2013	Dec 2013	Mar 2014	Jun 2014
Middle Honohina	Unit 1	2.21	9.7 (\pm 2.1)	29.6 (\pm 6.4)	8 (\pm 1.7)	16.1 (\pm 3.5)	--
Shipman	Unit 2	22.13	121.4 (\pm 26.2)	169.7 (\pm 36.6)	247.8 (\pm 53.5)	236.5 (\pm 51.1)	252.2 (\pm 54.4)
Lower Honohina	Unit 3	7.99	90.2 (\pm 19.5)	78.4 (\pm 16.9)	78.4 (\pm 16.9)	53.7 (\pm 11.6)	--
Upper Maulua	Unit 4	8.39	48.9 (\pm 10.6)	53.1 (\pm 11.5)	48 (\pm 10.4)	48.2 (\pm 10.4)	76.8 (\pm 16.6)
Upper Honohina	Unit 5	4.49	21.9 (\pm 4.7)	36.7 (\pm 7.9)	11.5 (\pm 2.5)	35.6 (\pm 7.7)	0 (\pm 0)
Middle Hakalau	Unit 6	5.23	8.4 (\pm 1.8)	15.5 (\pm 3.3)	0 (\pm 0)	0 (\pm 0)	8.2 (\pm 1.8)
Middle Papaikou	Unit 7	7.22	0 (\pm 0)	26.7 (\pm 5.8)	0 (\pm 0)	0 (\pm 0)	9.4 (\pm 2.0)
Pua 'Ākala	Unit 8	2.30	--	--	--	--	--
Lower Maulua	Unenclosed	--	--	7.9 (\pm 1.7)/km ²	--	6.6 (\pm 1.4)/km ²	--
Total		59.96	300.4 (\pm 64.9)	409.6 (\pm 88.4)	393.7 (\pm 85.0)	390.2 (\pm 84.2)	346.7 (\pm 74.8)

Table 5. Percent of plots with fresh or intermediate feral ungulate sign within two enclosed management units of the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 2012–2014.

Type of sign	Survey date	Management Unit		
		Upper 7.79 km ²	Middle 7.53 km ²	Total 15.32 km ²
Feral cattle	Nov 2012	15.6	41.4	29.2
	Mar 2013	8.4	24.2	17.0
	Jun 2013	13.8	34.3	24.8
	Sep 2013	19.2	27.3	23.3
	Mar 2014	7.6	28.1	18.7
Feral pig	Nov 2012	1.4	14.8	8.5
	Mar 2013	3.9	5.6	4.8
	Jun 2013	0.9	3.3	2.2
	Sep 2013	0.4	7.7	4.1
	Mar 2014	0.5	14	7.8
All ungulate	Nov 2012	38.6	65	52.6
	Mar 2013	12	35.2	24.7
	Jun 2013	15.9	37.8	27.6
	Sep 2013	37.2	70.7	54.0
	Mar 2014	9.2	38.6	25.1

Weed Surveys

The maximum percent of weed cover from each station are displayed in six categories: 0% sign; < 5%; 5–25%; 26–50%; 51–75%; > 75%. Weed cover was surveyed for Florida blackberry (*Rubus argutus*), banana poka (*Passiflora mollissima*), photinia (*Photinia davidiana*), English holly (*Ilex aquafolium*), and gorse (*Ulex europaeus*). Florida blackberry was consistently detected throughout the upper units of HFU, with a high range of cover values (Figure 7). Banana poka was detected with moderate-high density coverage throughout the Maulua unit since 2012, and was also found consistently in units 1 and 5 (Figure 8). *Photinia* was found almost exclusively in units 1 and 5 since 2011 (Figure 9). English holly detections were limited to four transects in unit 2, with low density coverage at all detections (Figure 10). Gorse was detected in few locations throughout unit 2 in low densities (Figure 11).

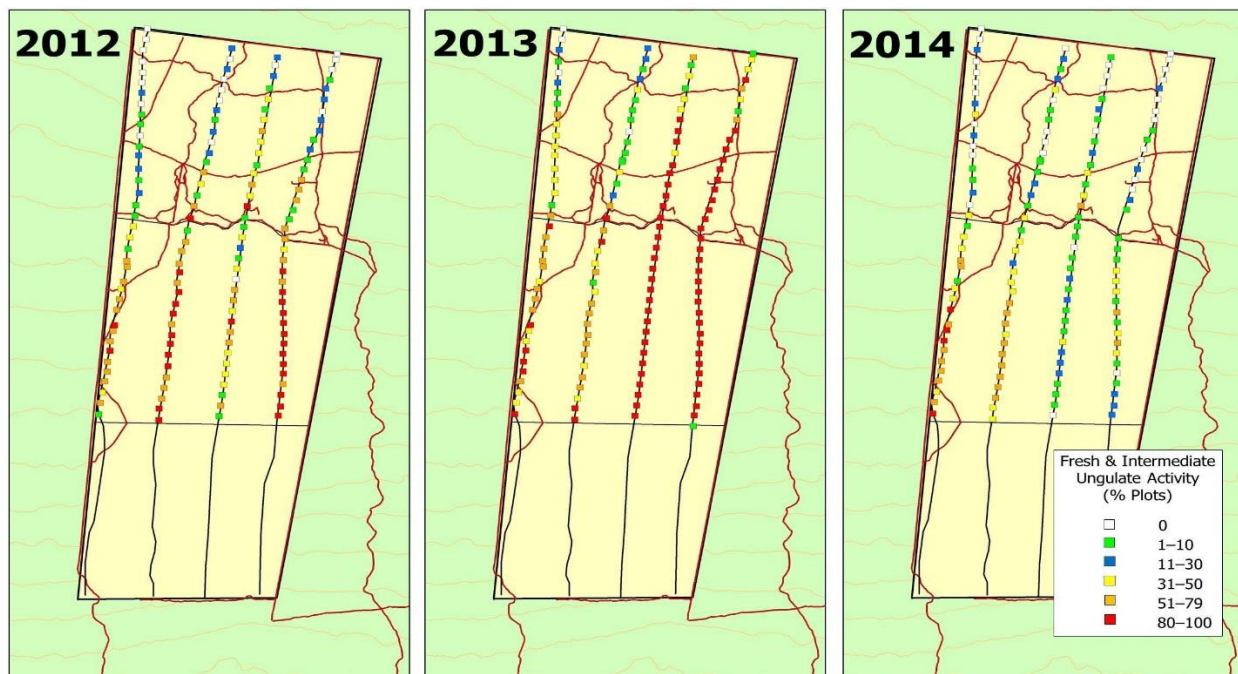


Figure 4. Ungulate sign at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 2012–2014.

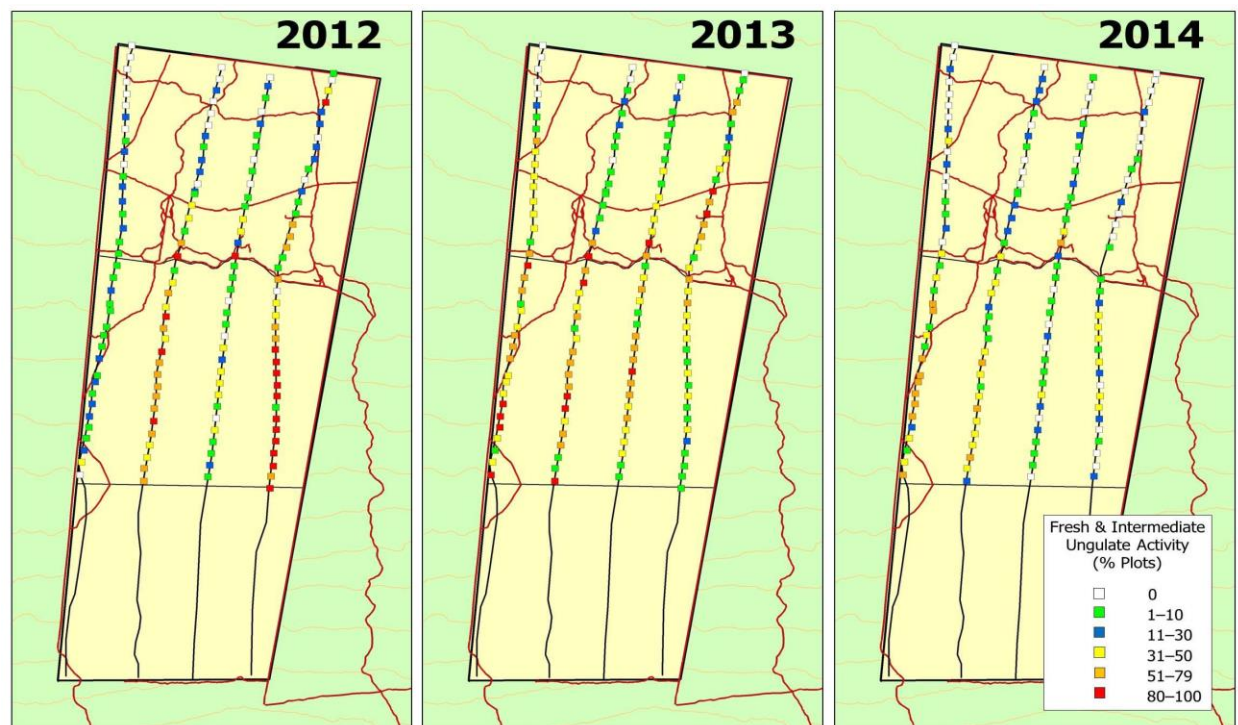


Figure 5. Feral cattle sign at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 2012–2014.

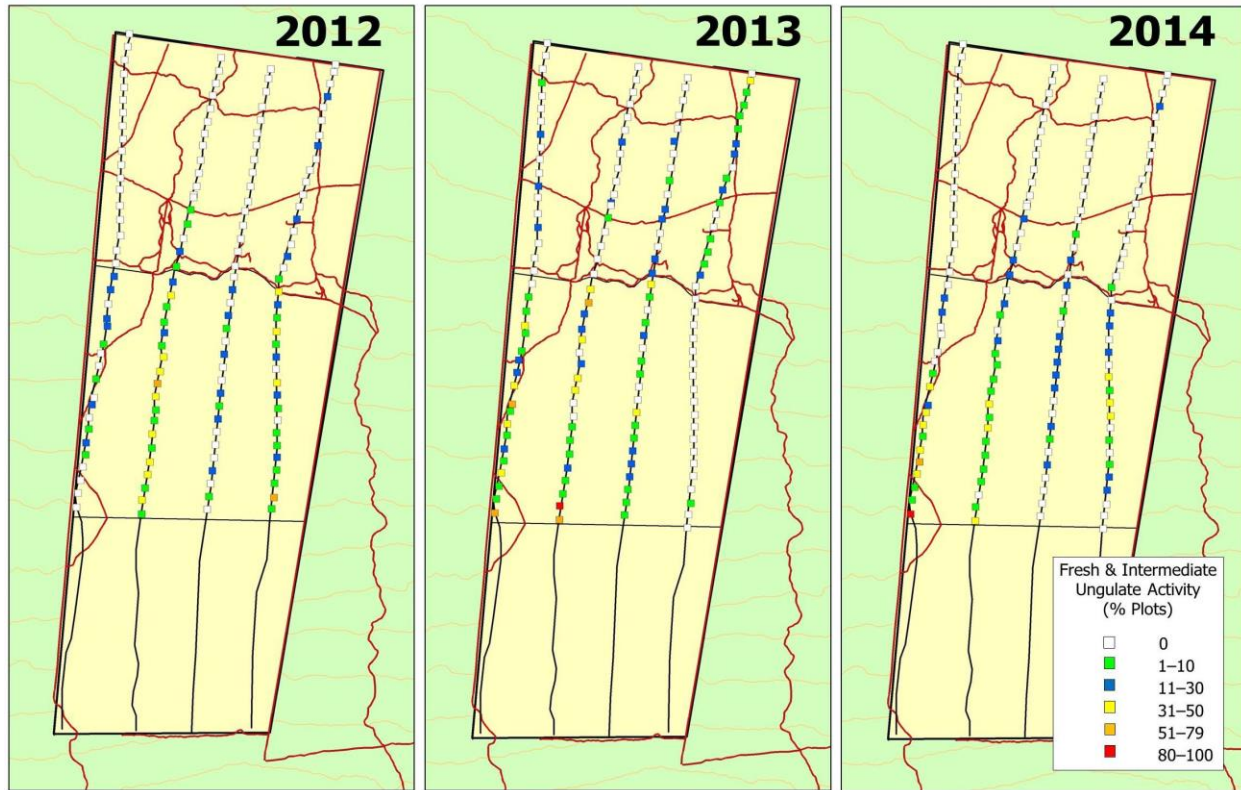


Figure 6. Feral pig sign at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 2012–2014.

At KFU, weed cover was recorded for five species: Koster's curse (*Clidemia hirta*), fireweed (*Senecio madagascariensis*), Florida blackberry (*Rubus argutus*), strawberry (*Fragaria vesca*), and strawberry guava (*Psidium cattleianum*). Koster's curse was consistently detected in the lower most portions of the middle unit (Figure 12) throughout KFU in 2012, and in the middle unit only during 2013–2014. Strawberry guava was detected in the middle unit 2012–2014, with high rates of cover during 2013 (Figure 13). Fireweed (*Senecio*) was detected primarily in the upper unit during each survey year, and cover has increased since the initial 2012 survey (Figure 14). English holly and strawberry were not detected at KFU during any survey. Florida blackberry was recorded three times during the 2012 survey.

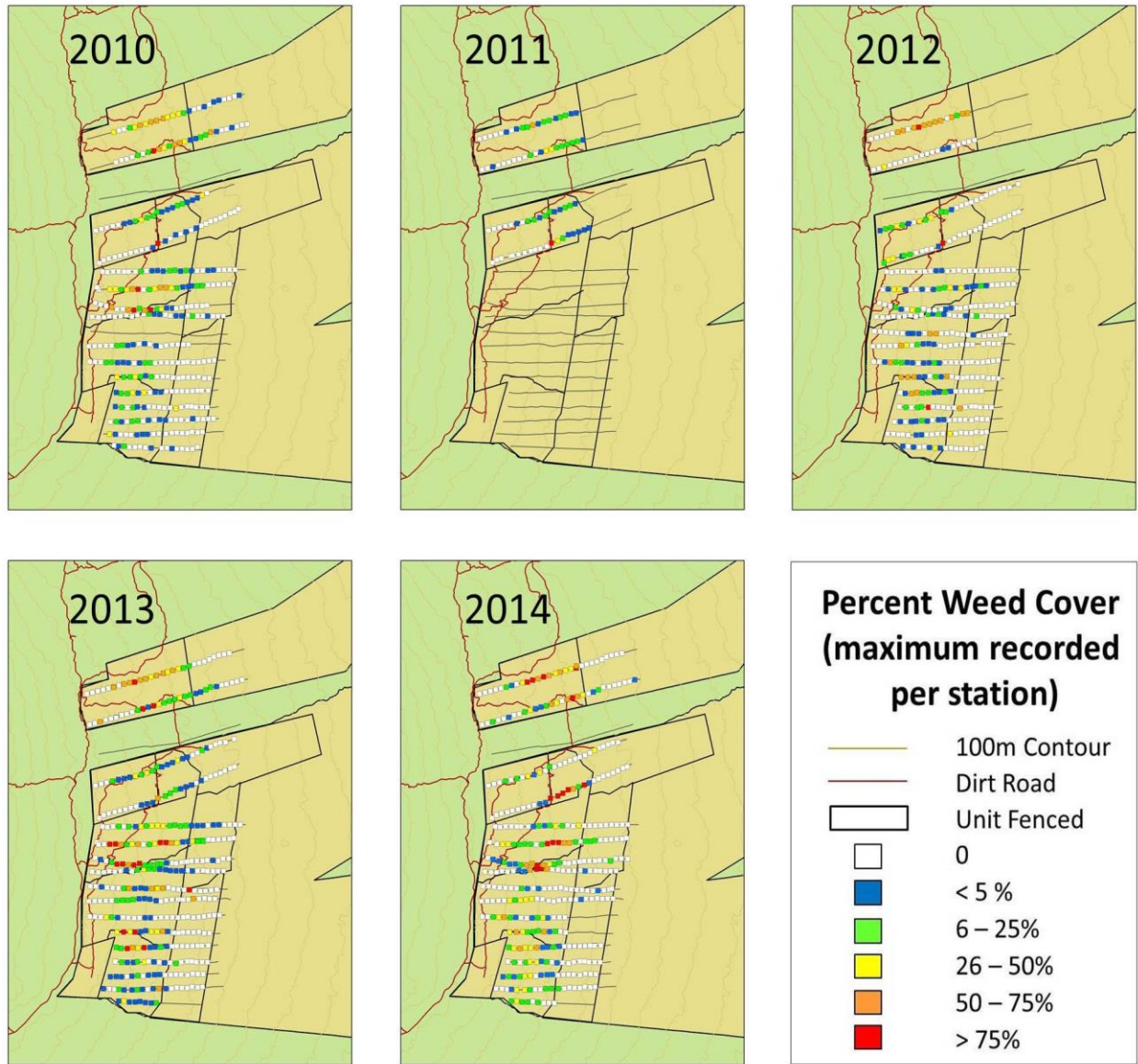


Figure 7. Percent cover of Florida blackberry (*Rubus argutus*) from 2010–2014 at the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island. Values presented are the maximum recorded from each sample station.

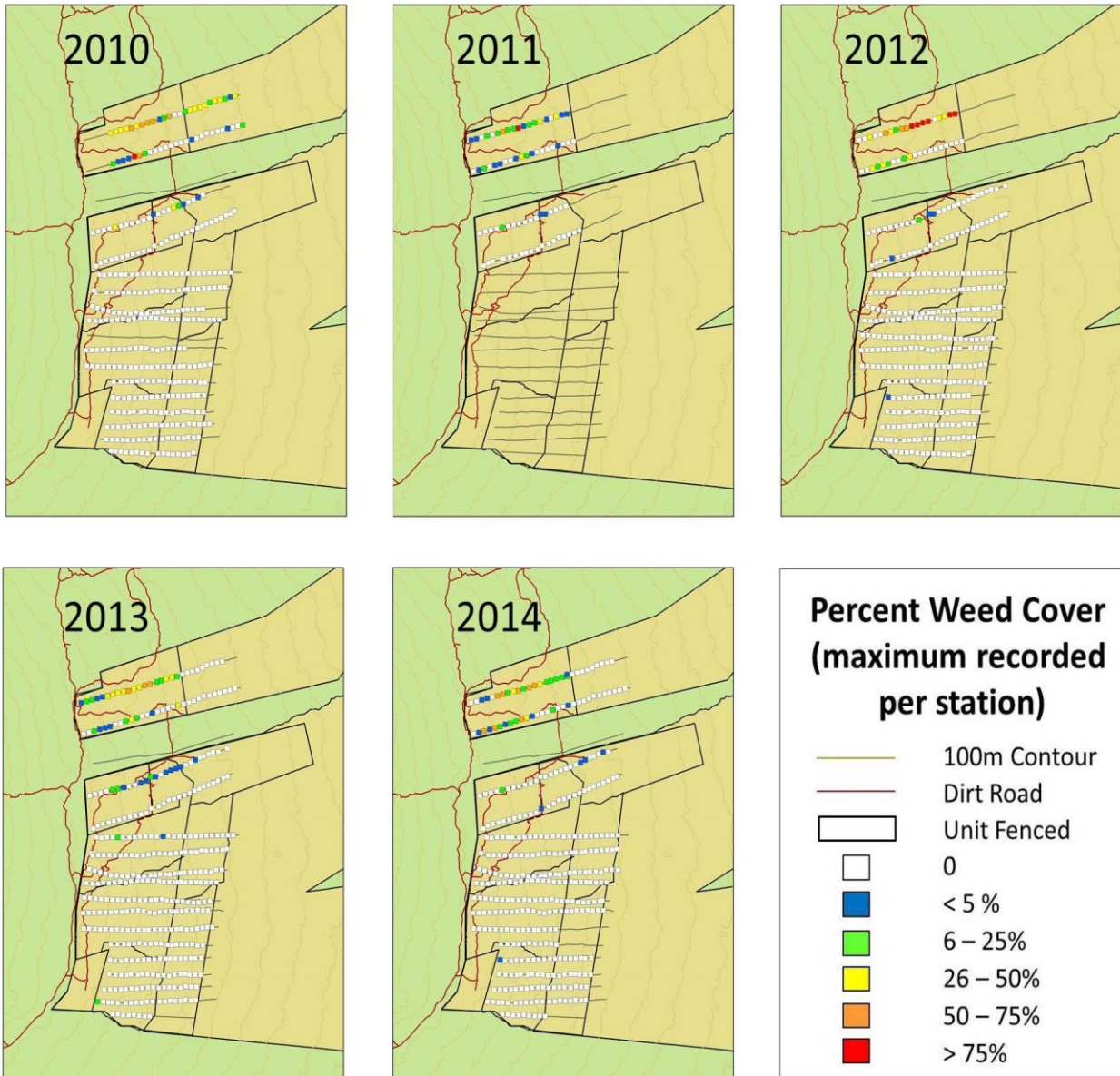


Figure 8. Percent cover of banana poka (*Passiflora mollissima*) from 2010–2014 at the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island. Values presented are the maximum recorded from each sample station.

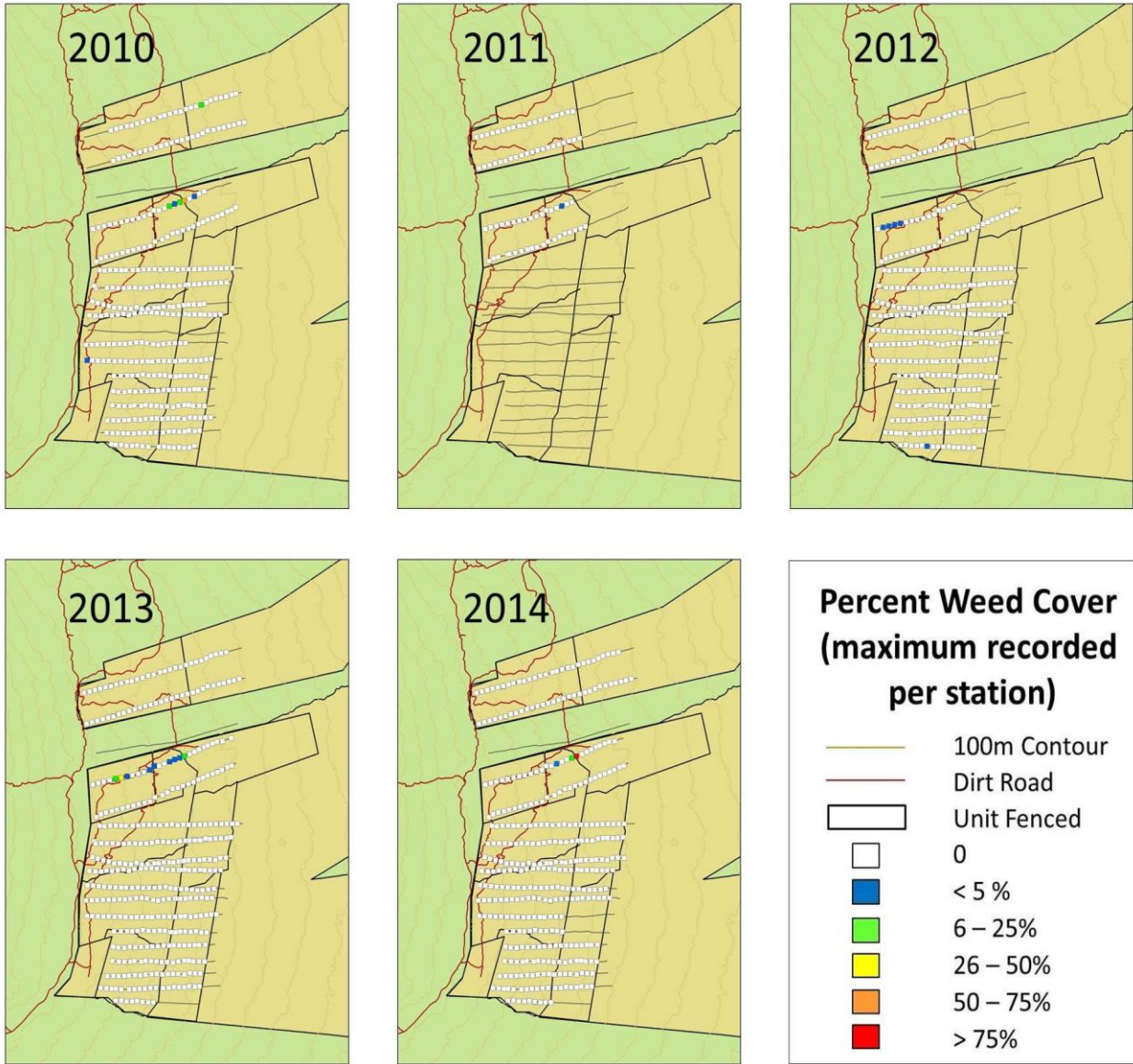


Figure 9. Percent cover of photinia (*Photinia davidiana*) from 2010–2014 at the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island. Values presented are the maximum recorded from each sample station.

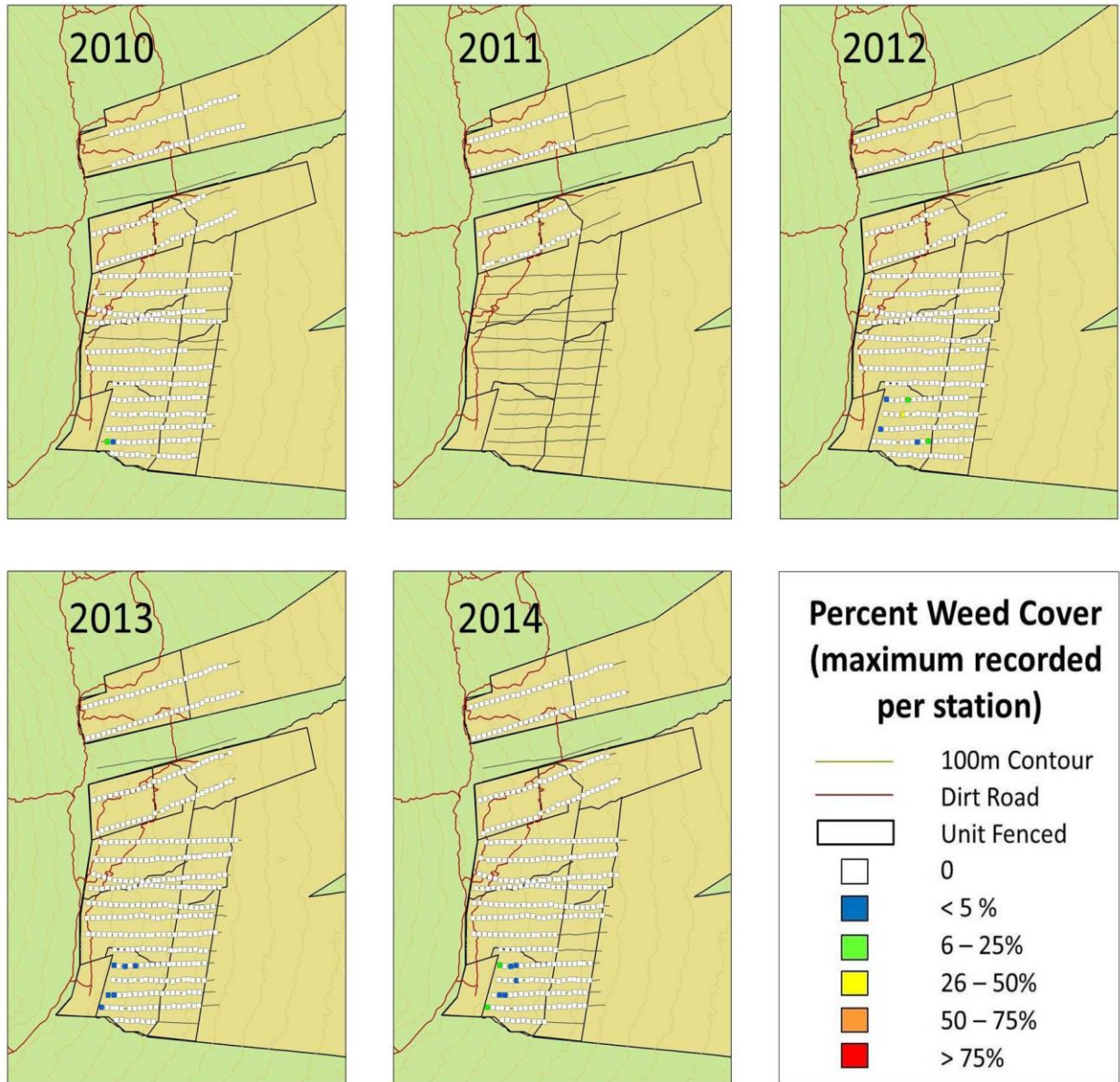


Figure 10. Percent cover of English holly (*Ilex aquafolium*) from 2010–2014 at the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island. Values presented are the maximum recorded from each sample station.

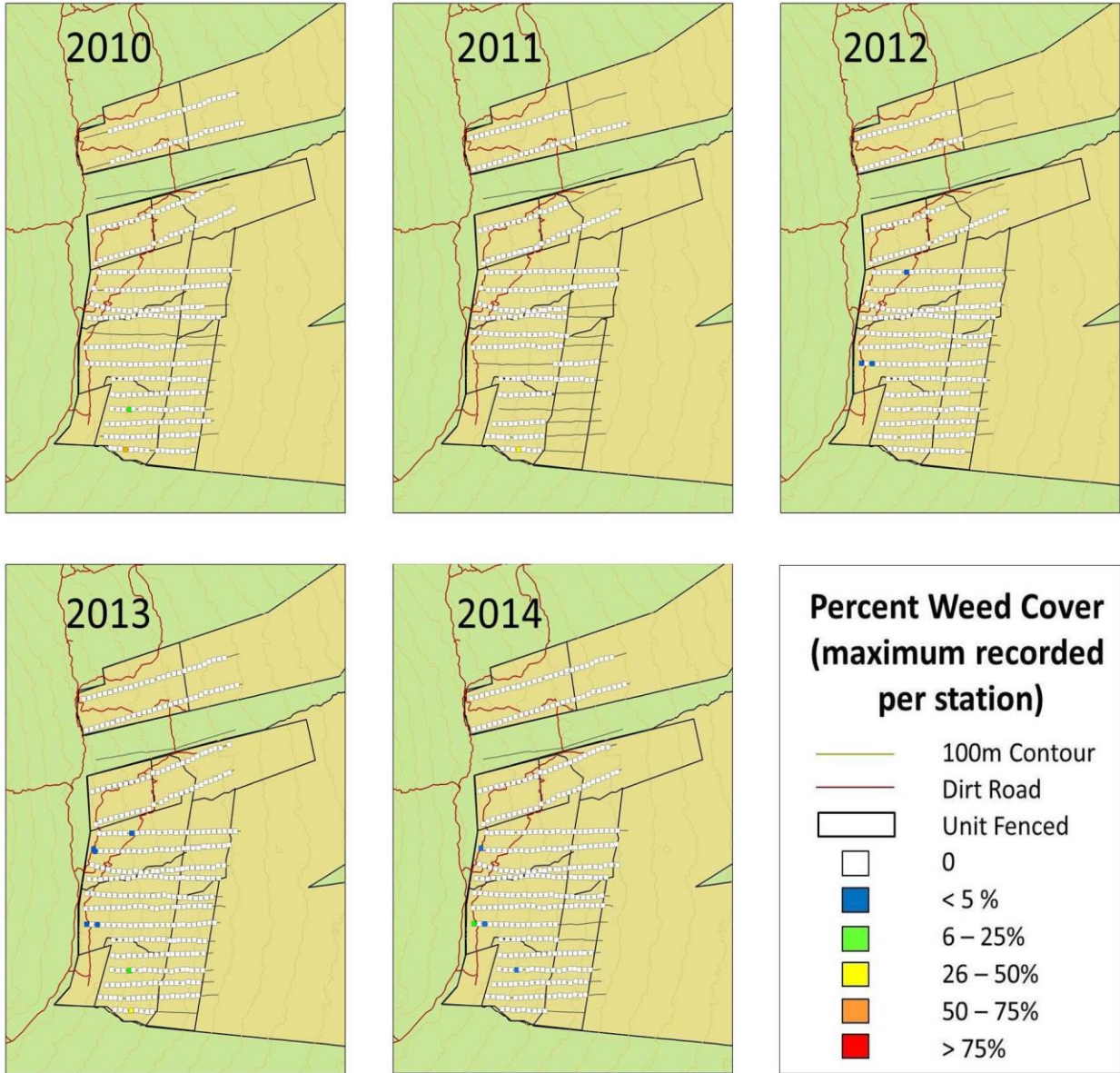


Figure 11. Percent cover of gorse (*Ulex europaeus*) from 2010–2014 at the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island. Values presented are the maximum recorded from each sample station.

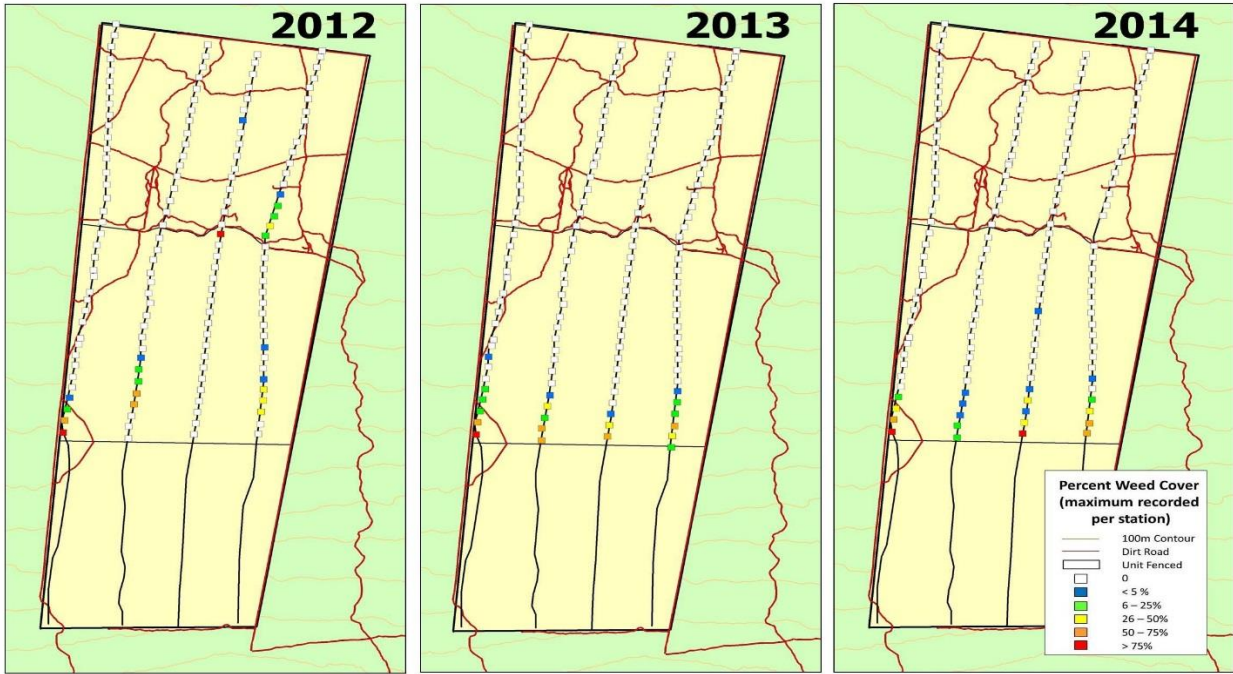


Figure 12. Percent cover of Koster's curse (*Clidemia hirta*) from 2012–2014 at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island. Values presented are the maximum recorded from each sample station.

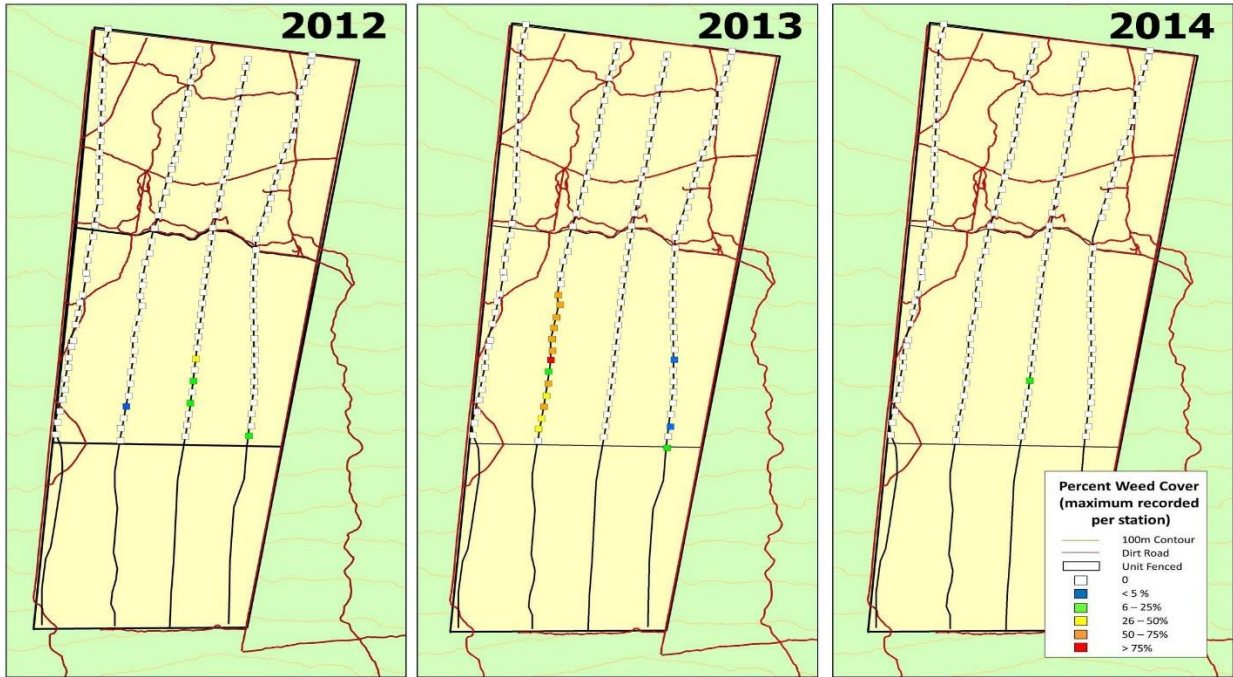


Figure 13. Percent cover of strawberry guava (*Psidium cattleianum*) from 2012–2014 at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island. Values presented are the maximum recorded from each sample station.

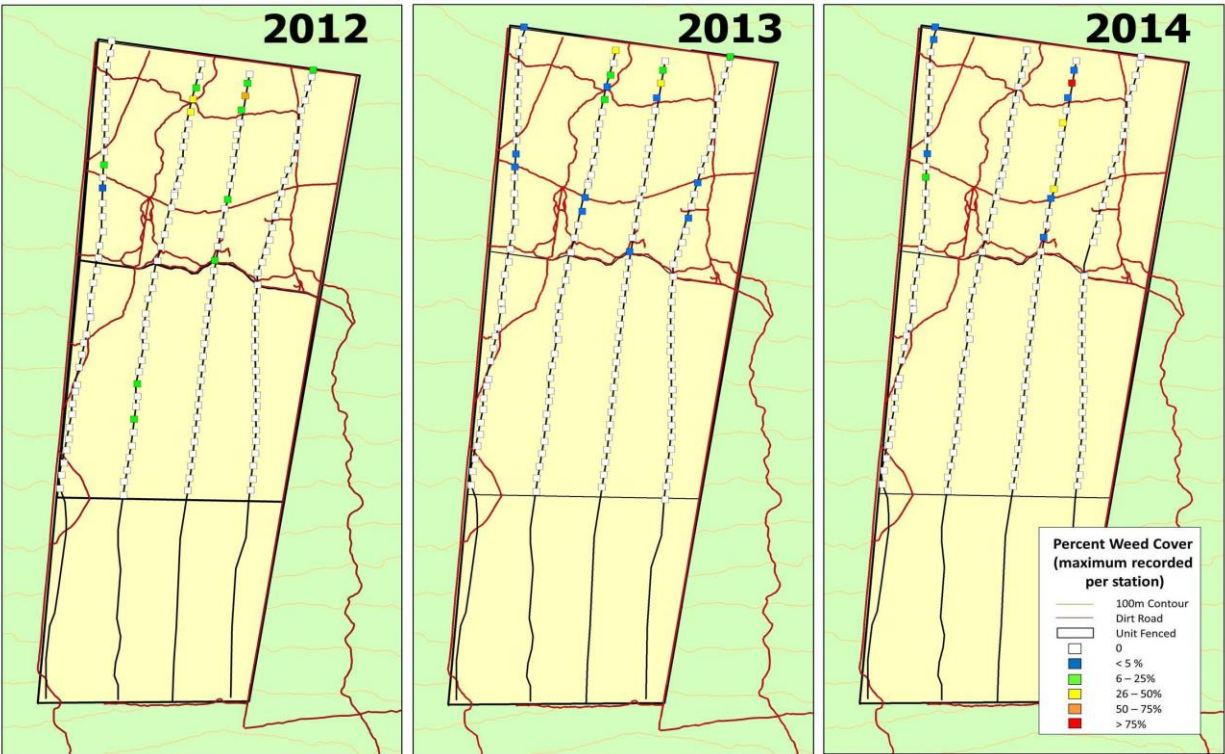


Figure 14. Percent cover of fireweed (*Senecio madagascariensis*) from 2012–2014 at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island. Values presented are the maximum recorded from each sample station.

Baseline Vegetation Surveys at Kona Forest Unit

A total of five vegetation plots within four habitat types were surveyed at KFU (Figure 1). Within the koa-`ōhi`a forest, 25 transects and 118 quadrats were surveyed; 23 transects and 116 quadrats within mesic `ōhi`a forest; 24 transects and 120 quadrats within subalpine woodland; and 23 transects and 122 quadrats within wet forest. Thirteen life form categories were recorded including: bare ground, bryophyte, coarse woody debris, exotic fern, exotic grass, exotic herb, lichen, (leaf) litter, native fern, native woody plant, native grass or herb, rock, and scat.

In point-intercept data ≤ 1 m in height, exotic grasses comprised the greatest proportion of ground cover in all habitat types except subalpine woodland, where leaf litter was the dominant ground cover (Table 6). The majority of vegetation intercepted above 1 m in height was of native woody species, but coarse woody debris was encountered occasionally (Table 7). Point-intercept methods provided higher proportion values of cover categories compared to cover estimates within quadrats, except in wet forest vegetation. Quadrat data confirmed similar patterns as point-intercept data; koa-`ōhi`a forest, mesic `ōhi`a forest, and wet forest had high proportions of exotic grass, ranging from 63–88% cover (Table 8). Leaf litter was high across all vegetation types, especially within subalpine woodland. Within the koa-`ōhi`a habitat categories of exotic grass and litter, on average, covered over 25% of the ground layer. Lichen, litter, and native woody plant were $> 25\%$ of ground cover in both the mesic `ōhi`a forest and subalpine woodland. Wet forest habitat was dominated by bare ground, exotic grass, and litter.

Table 6. Proportion of functional groups encountered from point-intercept data at ≤ 1 m height at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island in 2013. All plants encountered were recorded at each point. A total of 95 transects were surveyed across 20 vegetation plots.

Functional group	Habitat type			
	Koa-`ōhi`a forest	Mesic `ōhi`a forest	Subalpine woodland	Wet forest
Bare ground	0.01	0.21	0.12	0.38
Bryophyte	0.23	0.18	0.23	0.04
Coarse woody debris	0.15	0.17	0.19	0.14
Exotic fern	0.00	0.00	0.00	0.00
Exotic grass	0.88	0.84	0.08	0.63
Exotic erb	0.01	0.02	0.01	0.01
Lichen	0.01	0.00	0.26	0.00
Litter	0.58	0.65	0.70	0.43
Native fern	0.05	0.11	0.00	0.11
Native woody plant	0.09	0.03	0.31	0.01
Native grass/herb	0.00	0.01	0.16	0.01
Rock	0.01	0.02	0.38	0.02
Scat	0.00	0.00	0.00	0.01

Native fern was highest within the mesic `ōhi`a and wet forests, at 0.11 each (Table 6). `Ōhi`a was the predominant species of seedling in all habitat types except subalpine woodland, and mesic `ōhi`a forest where *Vaccinium* was predominant (Table 9). The greatest number of seedlings occurred in mesic `ōhi`a forest and wet forest; the fewest seedlings occurred in subalpine woodland and koa-`ōhi`a forest. Canopy cover data were summarized by species, and species presence within each vegetation type presented (Appendix I).

Table 7. Proportion of functional groups encountered from point-intercept data at 1–2 m and 2–3 m height the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island in 2013. All plants encountered were recorded at each point. A total of 95 transects were surveyed across 20 vegetation plots.

Functional group	Habitat type			
	Koa-`ōhi`a forest	Mesic `ōhi`a forest	Subalpine woodland	Wet forest
Bare ground	0.0	0.0	0.0	0.0
Bryophyte	< 0.01	0.0	0.0	0.0
Coarse woody debris	0.02	0.01	0.05	0.03
Exotic fern	0.0	0.0	0.0	0.0
Exotic grass	0.0	0.0	0.0	0.0
Exotic herb	0.0	0.0	0.0	0.0
Lichen	0.0	0.0	0.0	0.0
Litter	0.0	0.0	0.0	0.0
Native fern	< 0.01	0.0	0.0	0.02
Native woody plant	0.09	0.05	0.20	0.02
Native grass/herb	0.0	0.0	0.0	0.0
Rock	0.0	0.0	0.0	0.0
Scat	0.0	0.0	0.0	0.0

Table 8. Percent of ground covered at ≤ 1 m height by functional group from quadrat data collected within vegetation plots at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island in 2013.

Functional group	Habitat type			
	Koa-`ōhi`a forest	Mesic `ōhi`a forest	Subalpine woodland	Wet forest
Bare ground	0.1	14.2	8.7	33.5
Bryophyte	18.9	14.6	15.9	5.6
Coarse woody debris	9.5	12.5	7.4	16.1
Exotic fern	0.0	< 0.01	0.0	0.0
Exotic grass	75.2	61.2	5.4	69.1
Exotic herb	1.4	0.6	0.2	3.4
Lichen	0.6	0.9	17.3	0.8
Litter	19.9	29.7	58.6	23.5
Native fern	5.0	12.7	0.1	9.6
Native woody plant	3.8	4.1	30.9	1.9
Native grass/herb	0.1	0.2	11.4	0.5
Rock	0.7	1.2	36.8	1.8
Scat	0.1	0.3	0.1	0.2

Table 9. Total number of seedlings counted within quadrats of each habitat type at the Kona Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island in 2013. The shrub `ōhelo kau la`au (*Vaccinium calycinum*) was included because it is an important forest species.

Seedling species	Habitat type			
	Koa-`ōhi`a forest	Mesic `ōhi`a forest	Subalpine woodland	Wet forest
<i>Cheirodendron trigynum</i>	3	42	0	38
<i>Metrosideros polymorpha</i>	79	127	55	347
<i>Vaccinium calycinum</i>	68	300	0	51
Other	4	36	77	38
Total	154	505	132	474

DISCUSSION

Overall pig abundance appears to have decreased at HFU, although not significantly, over the period from 2010 to 2014. Management units 6 and 7 have remained pig-free or nearly pig-free over this entire period with perhaps a small number of pigs that have periodically entered these units. Units 1 and 5 also appear to have contained a small number of pigs or may have been nearly pig-free. Units 2 and 4 contained the majority of pigs at HFU, likely due to the large size of these units. Pig density outside of adjacent managed areas has declined significantly from 2010 to 2014 for unknown reasons, but may possibly include movement away from these areas rather than a large-scale landscape decline in abundance. Annual abundance patterns from survey data do not appear to track the peak period for lactating sows at HFU, from April to June, when the greatest number of young pigs should be expected (Hess *et al.* 2007).

At KFU, ungulate sign was encountered at 128 of 147 stations in 2012, 143 of 146 stations during 2013, and 123 of 145 surveyed stations in 2014. Ungulate sign occurred in > 50% of plots during the November 2012 and September 2013 surveys, but ungulate sign occurred in < 28% of plots during the other three surveys. The ability to differentiate sign of ungulate species remains problematic at KFU; species that have browsed vegetation, rubbed on trees, or created wallows cannot be reliably distinguished. Tracks may often be indistinct. The most reliable species identifications come 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.

The specific alien plants surveyed at HFU were determined by the refuge both in part due to current presence on the refuge, and documented spread throughout HFU and other mesic forest environments on Hawai`i Island. Florida blackberry is considered a primary species of concern by BINWRC (USFWS 2010) and is an invasive weed within the Ola`a Unit of Hawai`i Volcanoes National Park (Loh and Tunison 1999). The rapid growth and ability to exclude light from forest understory plants (LaRosa 1999) has made banana poka a focus for removal efforts at HFU. Jacobi and Price (2007) found photinia to be spreading within the Nauhi Unit of HFU and accelerated efforts to remove photinia are ongoing. At peak infestation, English holly cover was estimated at 500 acres within HFU and the refuge has since treated over 100 acres. Gorse is considered a primary fuel source for fires within and surrounding HFU, and treatment of gorse continues year-round at BINWRC (USFWS 2010).

While alien plants are not yet controlled at KFU, alien plant control is outlined within the BINWRC Comprehensive Conservation Plan (CCP) Action summary (USFWS 2010, p. 69). Koster's curse is ranked as a top threat within Haleakala National Park, HI and is quick to revegetate disturbed areas (DeWalt 2006). Strawberry guava is among the most destructive of alien species found within wet and mesic forests throughout Hawai`i (Uowolo and Denslow 2008) and is of important management concern for BINWRC (USFWS 2010). Florida blackberry was also identified as a management concern for KFU (USFWS 2010). Strawberry is considered invasive, although it is naturalized (Wagner et al. 1999), but not listed as a priority species of concern within the BINWRC CCP. Fireweed has a relatively new presence within the upper unit at KFU, although, it is a strong concern given that fireweed is a dominant invader within similar habitat structure at Pōhakuloa Training Area (Kellner et al. 2011).

Changes in weed cover 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. 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 it remains to be seen if this was due to seasonality (i.e., flowering) which made plants more obvious to observers or a longer-term trend in abundance.

Vegetation surveys have documented baseline floristic composition and forest structure at KFU. Exotic grasses comprised the most important component of ground cover in all areas of KFU except in subalpine woodland habitat. Exotic grass ranged from 63–88% of ground cover in other habitats. Native ferns at KFU comprised < 13% of cover at the level of ≤ 1 m in height and averaged 11% cover within mesic `ōhi`a and wet forest within, but < 5% of cover in koa-`ōhi`a dominated mesic forest and subalpine woodland habitats. Native ferns, a potentially important indicator of overall native vegetation recovery, strongly increased in cover over a 16-year period at HFU after ungulate management (Hess *et al.* 2007). Native woody plants comprised a low amount of cover ($\leq 9\%$) at the 1–3 m height level in koa-`ōhi`a dominated mesic forest, mesic `ōhi`a, and wet forest. It is not known if this current amount of emerging cover is sufficient for long-term self-sustaining regeneration of forest canopy, or if these

environments are in the process of becoming less forested over time. Nonetheless, nurse logs were widely available and numerous `ōhi`a seedlings were found in the wet forest and mesic `ōhi`a habitats, indicating sufficient growth substrate and an ample viable seed source supporting the potential for robust forest regeneration. Continued vegetation monitoring and modeling of forest dynamics should provide a useful predictive assessment of forest trajectory.

Management Implications

This research 1) allows the effectiveness of ungulate management regimes to be evaluated and refined; 2) determines if the intensity of ungulate control efforts are adequate to expediently reduce and eradicate non-native ungulate populations; and 3) provides a baseline for determining the response of plant communities to ungulate removal by implementing vegetation monitoring, thereby informing managers to what extent they may need to take additional actions to assist in the recovery of native plant communities to benefit wildlife habitat, or to proactively control invasive plant species before they become problematic. As these surveys continue, the change in vegetation cover will inform habitat recovery assessments and corresponding ungulate management efforts.

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APPENDIX I

Appendix I. Life form and species > 3 m in height encountered during canopy cover estimates within each of four vegetation types at the Kona Forest Unit of the Big Island National Wildlife Refuge during vegetation plot surveys in 2013.

Life form	Species	Habitat type			
		Koa-'ōhi'a forest	Mesic 'ōhi'a forest	Wet Forest	Subalpine woodland
Canopy tree	<i>Acacia koa</i>	X	X	X	
Canopy tree	<i>Broussaisia arguta</i>		X	X	
Canopy tree	<i>Cheirodendron trigynum</i>	X	X	X	
Understory fern	<i>Cibotium</i> spp.	X	X	X	
Understory tree	<i>Coprosma</i> spp.	X	X	X	X
Coarse woody debris	Multiple species	X		X	
Understory tree	<i>Ilex anomala</i>	X	X	X	
Understory tree	<i>Melicope</i> spp.	X	X	X	
Canopy tree	<i>Metrosideros polymorpha</i>	X	X	X	X
Understory shrub	<i>Myoporum sandwicense</i>	X			
Understory tree	<i>Myrsine lessertiana</i>	X	X	X	
Canopy tree	<i>Nestegis sandwicensis</i>			X	
Understory tree	<i>Perrottetia sandwicensis</i>			X	
Understory shrub	<i>Pipturus albidus</i>			X	
Understory tree	<i>Pittosporum hosmeri</i>		X		
Understory tree	<i>Psychotria hawaiiensis</i>			X	
Understory shrub	<i>Leptecophylla tameiameiae</i>		X		X
Understory shrub	<i>Vaccinium calycinum</i>	X	X	X	