



Technical Report HCSU-045

## ABUNDANCE AND DISTRIBUTION OF FERAL PIGS AT HAKALAU FOREST NATIONAL WILDLIFE REFUGE, 2010–2013

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## ABSTRACT

The Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex has intensively managed feral pigs (*Sus scrofa*) and monitored feral pig presence with surveys of all managed areas since 1988. Results of all available data regarding pig management activities through 2004 were compiled and analyzed, but no further analyses had been conducted since then. The objective of this report was to analyze recent feral ungulate surveys at the Hakalau Forest Unit to determine current pig abundance and distribution. Activity indices for feral pigs, consisting of the presence of fresh or intermediate sign at 422 stations, each with approximately 20 sample plots, were compiled for years 2010–2013. A calibrated model based on the number of pigs removed from one management unit and concurrent activity surveys was applied to estimate pig abundance in other management units. Although point estimates appeared to decrease from 489.1 ( $\pm 105.6$ ) in 2010 to 407.6 ( $\pm 88.0$ ) in 2013, 95% confidence intervals overlapped, indicating no significant change in pig abundance within all management units. Nonetheless, there were significant declines in pig abundance over the four-year period within management units 1, 6, and 7. Areas where pig abundance remained high include the southern portion of Unit 2. Results of these surveys will be useful for directing management actions towards specific management units.

## INTRODUCTION

The Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex has intensively managed feral pigs (*Sus scrofa*) and monitored feral pig presence with 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.* (2007). No further analyses had been conducted of pig monitoring data collected since 2004 when 39.95 km<sup>2</sup> of the refuge was pig-free (Figure 1). The abundance and distribution of feral pigs may have changed during this intervening period as a result of more recent management actions or other factors; hence, an analysis of recent data may provide an updated perspective and inform management decisions. The objective of this report is to analyze recent feral ungulate surveys at the Hakalau Forest Unit to determine current pig abundance and distribution.

## METHODS

Hess *et al.* (2007) reconstructed the standing population of feral pigs in a 22.13 km<sup>2</sup> management unit (Unit 2) of the Hakalau Forest Unit based on the number of pigs removed and their estimated ages for the period of 1988–2004. The ages of 623 pigs were estimated by tooth eruption and wear patterns (Matschke 1967). Dates of birth were back calculated by using the estimated age of each animal when it was removed (Anderson and Stone 1994). The ages of 11 additional pigs were estimated by the regression equation of mass and sex as described in Hess *et al.* (2007). Standing populations were estimated for each calendar year using estimated birth dates to determine how many animals had been born into the population and not removed, such that:

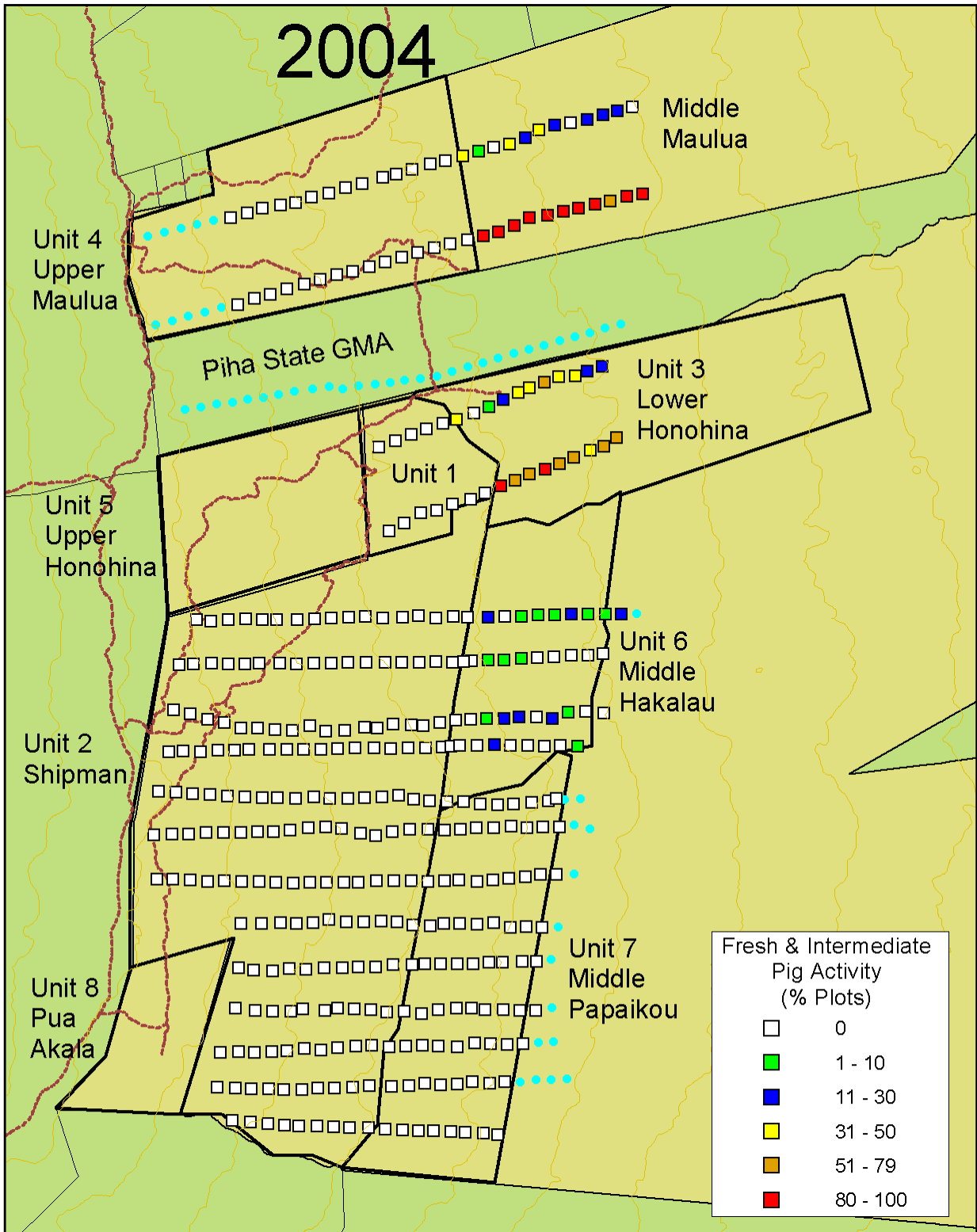


Figure 1. Ungulate management units at the Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, and the distribution of feral pigs as determined by activity surveys in 2004. Light blue circles are stations that were not sampled in 2004. The units are bisected by the Piha State Game Management Area (GMA).

The number of pigs alive in the last year of removals =  $Y_0$

$$\text{Pigs alive one year prior to last removal} = [Y_{-1} + (Y_0 \geq 1)] \quad (1)$$

$$\text{Pigs alive two years prior to last removal} = [Y_{-2} + (Y_{-1} \geq 1) + (Y_0 \geq 2)] \quad (2)$$

$$\text{Pigs alive three years prior to last removal} = [Y_{-3} + (Y_{-2} \geq 1) + (Y_{-1} \geq 2) + (Y_0 \geq 3)] \quad (3)$$

$$\text{Pigs alive four years prior to last removal} = [Y_{-4} + (Y_{-3} \geq 1) + (Y_{-2} \geq 2) + (Y_{-1} \geq 3) + (Y_0 \geq 4)] \quad (4)$$

Because age estimates were available for only 634 of the 757 pigs (83.75%) removed from Unit 2, the number of pigs in the reconstructed population was corrected for the proportion of aged pigs in each age category based on the available data. Unit 2 was pig free by 2004.

The known density of feral pigs from the reconstructed population and feral pig activity indices were used to develop predictive models of feral pig indices. These analyses were restricted to Unit 2 after a pig-proof fence enclosed the population in 1992. The estimated standing population at each time step was divided by the area of the unit to determine pig density, and density values were used as the response variable for regression analysis. The proportion of stations with fresh or intermediate pig sign and the proportion of stations with all sign were determined for each calendar year. Proportions were transformed to arcsine values (Sokal and Rohlf 1981) and used as predictor variables in linear regression following the approach of Anderson and Stone (1994).

Models were constructed with all combinations of predictors except where the same predictors appeared more than once (e.g., fresh sign with all sign), both with and without intercepts (i.e., constant proportion indices; Lancia *et al.* 1994). Interaction terms were not considered. Models were ranked with Akaike's Information Criterion corrected for small sample size (AICc; Burnham and Anderson 1998). Confidence intervals (95% CI) were determined for estimated regression equations of the highest ranked models. The regression equation of the highest ranked model was applied to predict the density of feral pigs in each of the other management units and other areas where activity indices were measured. Pig densities in unenclosed areas and estimated population sizes within enclosed units with 95% predictive confidence intervals were determined based on the estimated regression equation, its variance, and the area of each unit.

Activity indices for feral pigs, consisting of the presence of fresh or intermediate sign (Stone *et al.* 1991) at 422 stations, each with approximately 20 sample plots, were compiled for years 2010–2013. Surveys were conducted during November 2010 and 2011, October 2012, and March 2013 (Table 1). These data were joined to their spatial coordinates and plotted by year using ArcGIS 9.2 (ESRI 2006). Stations were assigned to management units by UTM (Universal Transverse Mercator) coordinate locations. The proportion of sample plots with fresh, intermediate, and both fresh and intermediate feral pig sign (hereafter all sign) was calculated for each survey within each management unit.



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 2010–2013. 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			
		2010	2011	2012	2013	2010	2011	2012	2013
1	21	20	0	18	18	466	0	354	372
1A	20	19	0	19	19	342	0	354	361
1B	17	17	0	16	0	289	0	321	0
2	20	18	0	18	10	362	0	310	193
3	20	18	0	16	10	316	0	318	191
4	20	18	0	19	11	331	0	374	197
5	26	24	0	24	16	444	0	486	340
6	27	19	0	24	24	382	0	466	462
7	27	0	0	26	24	0	0	513	340
7A	26	25	0	25	25	488	0	508	516
8	27	22	0	26	26	423	0	485	475
8A	26	25	0	25	25	487	0	486	446
9	27	25	0	24	24	477	0	445	489
10	28	28	19	27	27	570	381	556	537
11	28	22	17	27	26	436	329	503	501
13	31	27	20	20	19	512	360	399	355
14	31	25	19	19	17	476	386	389	317
Total	422	352	75	373	321	6801	1456	7267	6092

## RESULTS

The standing population of feral pigs in Unit 2 was reconstructed from 634 (83.75%) aged pigs of the 757 pigs removed from 1988–2004 (Figure 1). Sixteen different models of pig sign were all significantly and positively related to pig density (Hess *et al.* 2007). Models of feral pig activity with all sign, fresh sign, and intermediate sign, but without intercepts, were essentially equivalent among the highest ranked by AICc. The highest ranked model with an intercept was >2.6 AICc units lower than any of the three highest ranked models. Activity indices were variable at densities >8 pigs/km<sup>2</sup> (Figure 2). Year 1994 was a strong outlier in every model, having a high density of feral pigs with relatively low activity index values. A small number of pigs remained after most had been removed by the year 2000, resulting in four years with very low density. The resulting predictive equation was applied to estimate abundance in other management units:

$$\text{Density} = 20.665 \times \text{arcsine transformed (proportion of plots containing pig sign)} \quad (5)$$

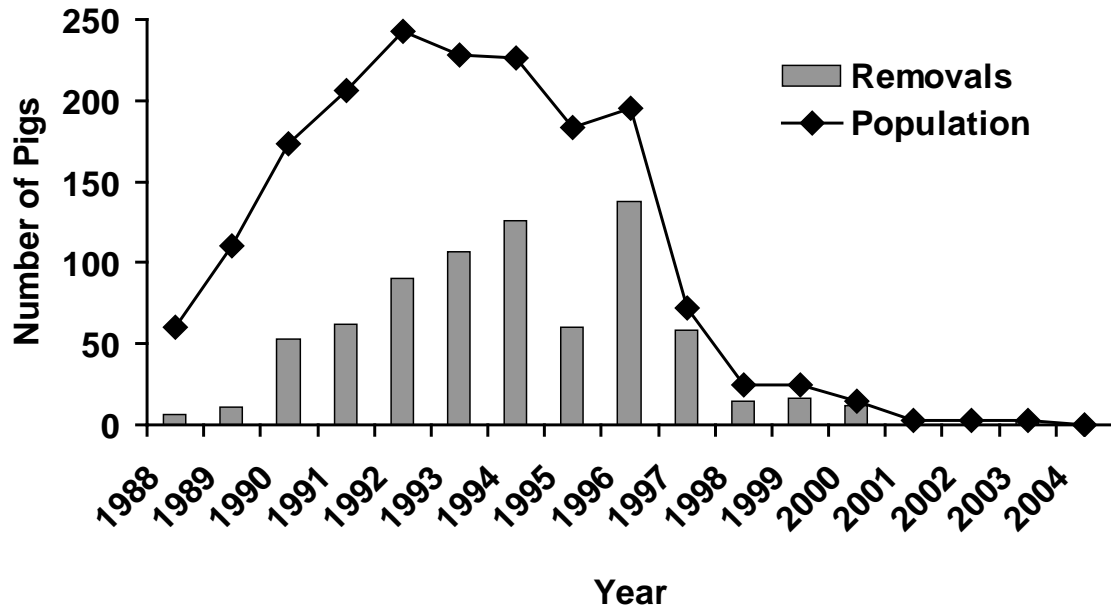


Figure 2. Number of feral pigs removed and the reconstructed population from a 22.13 km<sup>2</sup> management unit at Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 1988–2004.

When the model was applied to recent survey data, densities of feral pigs indicated ingress in several cases. The unmanaged area of Lower Maulua and units 1 and 5 had predicted densities of feral pigs in 2010 that were greater than the Unit 2 maximum of 12.1 pigs/km<sup>2</sup> (Table 2). While the model can reliably estimate that density was >12.1 pigs/km<sup>2</sup>, it cannot provide accurate density estimates beyond this number. Units 1, 6, and 7 density estimates for 2012–2013 are similar to those after intensive pig management during 2002–2004 (Hess *et al.* 2007), and current density estimates for these units are low. The spatial distribution of stations surveyed during 2010–2013 includes seven management units, and survey efforts varied annually (Figure 3). The proportion of plots with pig sign at each station is displayed in six categories: 0% sign (white); 1–10% (green); 11–30% (blue); 31–50% (yellow); 51–79% (orange); and 80–100% (red; Figure 4).

## DISCUSSION

Although recent surveys of ungulate sign suggest an overall decline in point estimates of pig abundance throughout all managed areas of the refuge over the period of 2010–2013, overlapping confidence intervals indicate that these estimates do not differ significantly. Nonetheless, there were significant declines in pig abundance over the four-year period within units 1, 6, and 7. Areas where pig abundance remained high included the southern portion of Unit 2, particularly in 2012 when an estimated 231.6 (±50.0) pigs inhabited the unit. Periodic surveys of unenclosed areas, such as Lower Maulua, would provide further understanding of fluctuations in estimated abundance resulting from limitations in the model to overcome variability in environmental factors such as recent precipitation and the inability to estimate densities outside the range of the data used to derive the model. The detection of changes in

Table 2. Estimated abundance of feral pigs ( $\pm 95\%$  confidence intervals) within eight enclosed management units and an unenclosed area of Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 2010–2013. Estimated abundance is based on index surveys calibrated with a model developed by Hess *et al.* (2007).

Management unit		Area km <sup>2</sup>	Pig abundance			
			2010	2011	2012	2013
Middle Honohina	Unit 1	2.21	33.4 ( $\pm 7.2$ )	6.5 ( $\pm 1.4$ )	6.2 ( $\pm 1.3$ )	18.1 ( $\pm 3.9$ )
Shipman	Unit 2	22.13	178.0 ( $\pm 38.4$ )	--	231.6 ( $\pm 50.0$ )	208.2 ( $\pm 45.0$ )
Lower Honohina	Unit 3	7.99	86.3 ( $\pm 18.6$ )	--	84.8 ( $\pm 18.3$ )	99.9 ( $\pm 21.6$ )
Upper Maulua	Unit 4	8.39	84.3 ( $\pm 18.2$ )	82.1 ( $\pm 17.1$ )	83.1 ( $\pm 17.9$ )	39.7 ( $\pm 8.6$ )
Upper Honohina	Unit 5	4.49	56.1 ( $\pm 12.1$ )	28.1 ( $\pm 6.1$ )	41.0 ( $\pm 8.8$ )	26.6 ( $\pm 5.7$ )
Middle Hakalau	Unit 6	5.23	15.6 ( $\pm 3.4$ )	--	6.7 ( $\pm 1.4$ )	4.0 ( $\pm 0.9$ )
Middle Papaikou	Unit 7	7.22	35.4 ( $\pm 7.6$ )	--	7.5 ( $\pm 1.6$ )	11.1 ( $\pm 2.4$ )
Pua Akala	Unit 8	2.30	--	--	--	--
Lower Maulua	Unenclosed	--	15.1/km <sup>2</sup> ( $\pm 3.3/\text{km}^2$ )	--	--	--
Total		59.96	489.1 ( $\pm 105.6$ )	--	461.0 ( $\pm 99.5$ )	407.6 ( $\pm 88.0$ )

the distribution and abundance of feral pigs at Hakalau Forest Unit necessitates surveys of ungulate sign on each transect at least once per year. Results of these surveys will be useful for directing management actions towards specific management units.

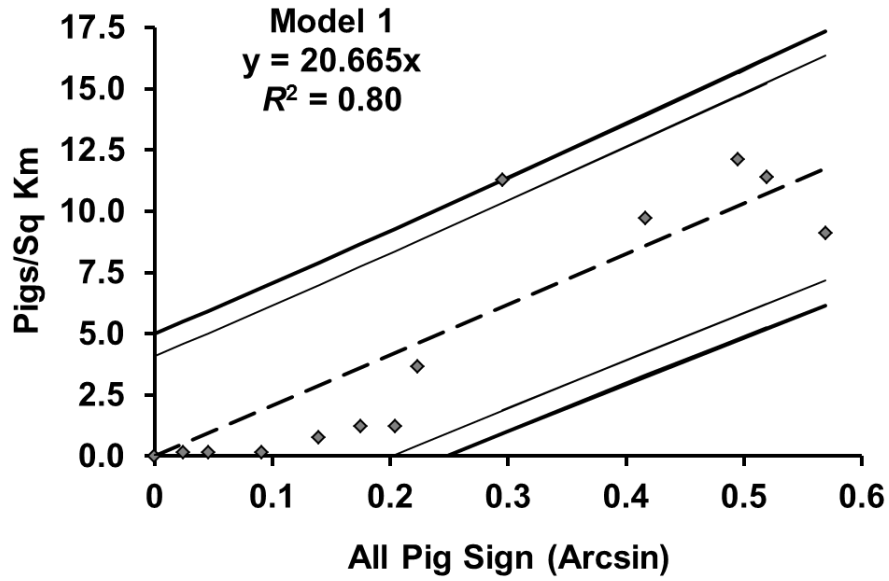


Figure 3. The highest-ranked predictive model for estimating feral pig density derived from a reconstructed population at Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 1992–2004. The dashed line represents the model, solid light lines represent 90% prediction confidence intervals (CI), and solid bold lines represent 95% prediction CI.

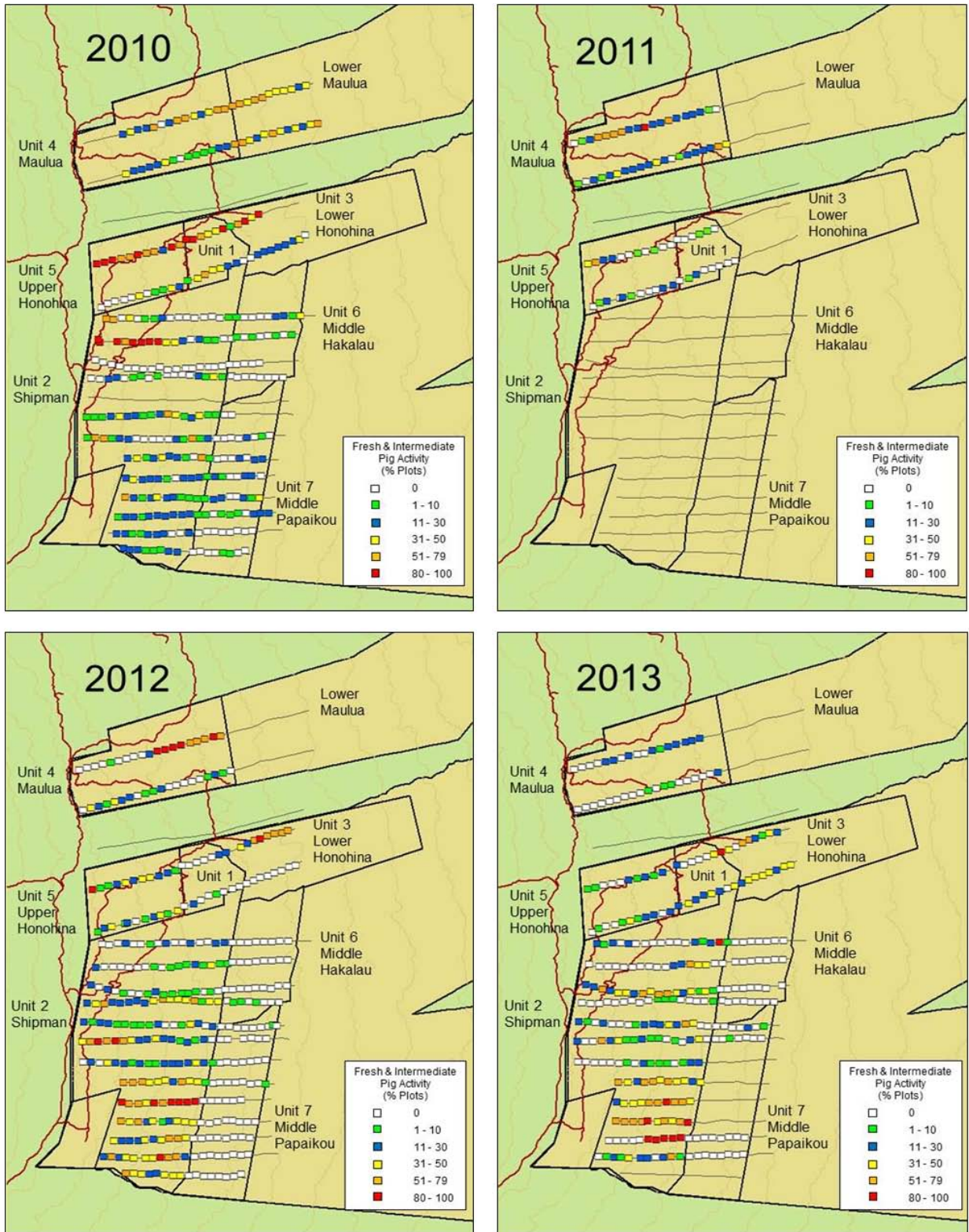


Figure 4. Surveys of feral ungulate sign at Hakalau Forest Unit of the Big Island National Wildlife Refuge Complex, Hawai'i Island, 2010–2013. Six categories indicate the proportion of plots where pig sign was detected at each station.

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