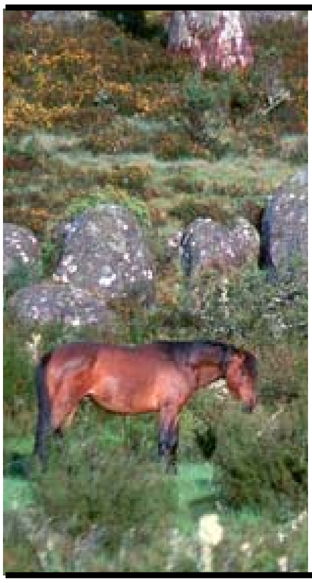

MONITORING THE IMPACT OF FERAL HORSES ON VEGETATION CONDITION USING REMOTELY SENSED fPAR: A CASE STUDY IN AUSTRALIA'S ALPINE PARKS

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ABSTRACT

Throughout the world, feral horses (*Equus caballus*) are causing environmental degradation and a decline in ecological integrity. Evidence from scientific monitoring is needed to inform the public debate and help land managers make informed decisions. We used field observations of vegetation condition at a network of sites in the Australian Alps where horses were present or absent. The data were combined with the remotely-sensed fraction of photosynthetic active radiation (fPAR) and topographic condition. Vegetation condition was assessed in the field by rangers using a modified version of the Landscape Function Analysis (LFA) index. We found significant differences in the LFA index between sites where horses were present or absent. Sites with presence of horses have 10 per cent lower fPAR than sites with absence of horses. The results also indicated a significant correlation between LFA and fPAR. Our analysis supports the hypothesis that feral horses have a negative impact on the condition of Australian alpine vegetation. This study provides a useful and relatively cost-effective method for monitoring the impact of feral horses on native vegetation, and can be used to support decision making and management interventions.

Key words: **Vegetation condition, Landscape Function Analysis, Propensity Score Matching, Australian Alps, fPAR, Decision tree, Recursive partitioning**

INTRODUCTION

Throughout the world, feral horses (*Equus caballus*) are causing environmental degradation and a decline in ecological integrity; defined in terms of the characteristic structure, composition and function of an ecosystem compared to the range of natural or historic conditions and disturbance regimes (Karr, 1996; Lindenmayer & Franklin, 2002; Parrish et al., 2003). Of particular concern is the extent to which feral horses degrade vegetation condition and associated ecosystem processes, which is a well-recognised conservation threat (Rogers, 1991). Feral horses have been shown to have negative impacts on the composition and structure of vegetation, and subsequently on landscape structure and ecological processes. For example, in the USA, Beever et al. (2008) identified positive associations between the presence of feral horses and soil compaction and subsequent increased runoff; reduced vegetation abundance; trampling and rubbing; removal of terminal meristems; and the distribution of nutrients. In Argentina, De Villalobos and Zalba (2010) found a negative association between total biomass and the presence of feral horses, and a positive association between the presence of forbs and bare soil and feral horses. However, effective control of feral horses remains a challenge due to various technical and social problems associated with the options available to land managers (Linklater et al., 2004; Nimmo & Miller, 2007; Reed, 2008).

In the face of the ecological impacts of feral horses, the impediments to management and the potential amplifying influences of climate change, improved information is essential for planning appropriate conservation responses. Field-based observations (i.e., *in-situ* techniques) are commonly used to assess the impacts of feral horses on natural ecosystems. However, to be effective for management, information is needed on a landscape-wide basis at short time periods. We suggest that remotely sensed satellite data can provide a cost-effective complementary source of information to assist land managers in monitoring the impacts of feral horses over regional extents and more frequently.

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Previous studies have used remotely sensed Normalized Difference Vegetation Index (NDVI) to study wildlife habitat condition, vegetation dynamics and associated population dynamics. Henderson and Dawson (2009) detected significantly low values of NDVI in sites with presence of feral goats in the Galapagos Islands, indicating that the presence of feral goats has a negative impact on vegetation. However, Pettorelly et al. (2005) and Zinner's (2002) results suggest that topography can be a confounding factor when investigating relationships between vegetation condition and the presence or absence of big herbivores. These studies have found that invasive herbivores have a negative impact on the condition of vegetation. However, a method to remotely monitor this impact has not been proposed. Here, we test a new approach to assessing the impact of feral horses on vegetation condition using as a case study Australia's alpine parks. The approach is tested at a network of sites where horses were present or absent, using field observations of vegetation condition, remotely sensed data, and topographic data.

The ecological communities of the Australian Alps bioregion contain a unique composition of plant species, 39 of which are listed as vulnerable and 16 as endangered, along with four endangered and one critically endangered ecological community (Australian Government, 2001a) under federal legislation (Australian Government, 2008). While more than 70 per cent of this bioregion is in protected areas, feral animals represent a major threat to listed species and communities (Australian Government, 2001b). Feral horses in the Australian Alps are a major conservation management problem and, among other things, have been found to have negative impacts on the structure of vegetation (Whinam et al., 1994; Whinam et al., 2001; McDougall et al., 2005).

The current population of feral horses in Australia is estimated to be the largest in the world at around 400,000 individuals, with Dawson and Miller (2008) estimating the horse population within a 180 km^2 area of the Australian Alps in 2009 to be around 7,679 horses with an annual rate of increase of about 22 per cent. Recent modelling for the Victorian East Alps estimates a population of 8,200 to 10,900 (Parks Victoria, 2013). Furthermore, climate change imposes additional pressures on the bioregion's vegetation with a projected increase in the frequency and intensity of extreme droughts and fire events (Worboys, 2003; Williams et al., 2008).

To provide a suitable test of our approach, we investigated the following questions: (1) does vegetation condition of natural treeless drainage systems (riparian areas and wetlands) in the Australian Alps differ in areas with and without the presence of feral horses; (2) is there an interaction between the presence of horses and topography; and (3) can changes in vegetation condition (due to the presence of feral horses) be detected and monitored using remotely sensed data?

METHODS

Within our selected study region, we analysed three datasets at a network of field sites: (1) observations of horse presence and absence, (2) a Landscape Function Analysis (LFA) index was generated to provide an assessment of vegetation condition and (3) remotely sensed estimates of fraction of the photosynthetic active radiation (fPAR) were derived from a continental time series obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) product MOD13Q1. We used a set of statistical tests to balance and analyse the datasets. We balanced the landscape function analysis data using propensity score matching. We analysed the fPAR data using the 'breaks for additive and seasonal trend' (BFAST) model. Then, we used partitioning decision trees to explore (1) whether differences in the LFA index between sites were related to horse presence or site topographic attributes and (2) if there was a correlation between the LFA and fPAR. We also analysed if differences between sites with absence or presence of horses were statistically significant.

Study area

The study sites (n=171) were in the Australian Alps National Parks (35˚–38˚ S and 145˚–149˚ E) comprising an area of around 7,900 km^2 within New South Wales, Victoria and the Australian Capital Territory. The study sites were mostly located in subalpine areas (1,400 m to 1,900 m) with one site in alpine areas (> 1,900 m) (Green and Osborne, 1994). Ninety-one sites were in the state of Victoria, 76 in New South Wales and four in the Australian Capital Territory (Figure 1). The Australian Alps bioregion is dominated by a montane climate, with no dry season and a mild summer (Stern et al., 2000) with annual mean temperature 3 ^{o}C to 12 ^{o}C, mean minimum monthly temperature -7 ^{o}C to 0.4 ^{o}C, mean maximum monthly temperature 15.9 ^{o}C to 29.5 °C, mean annual rainfall 606 mm to 2,344 mm, minimum average monthly rainfall 44 mm to 126 mm, and mean maximum monthly rainfall 63 mm to 295 mm (NSW Government, 2013). Exploratory data analysis was undertaken to examine the pairwise correlation between all variables (see Supplementary Online Material).

Feral horse data and the Landscape Function Analysis

The Australian Alps Liaison Committee carried out an *in-situ* assessment to determine if natural treeless drainage systems (riparian areas and wetlands) were susceptible to the impacts of feral horses (Geoff Robertson pers. comm., June/July 2013). A total of 171 random points within treeless drainage systems were assessed between 2010 and 2012. Of these, 129 points were known to be occupied by feral horses. The feral horses occur within

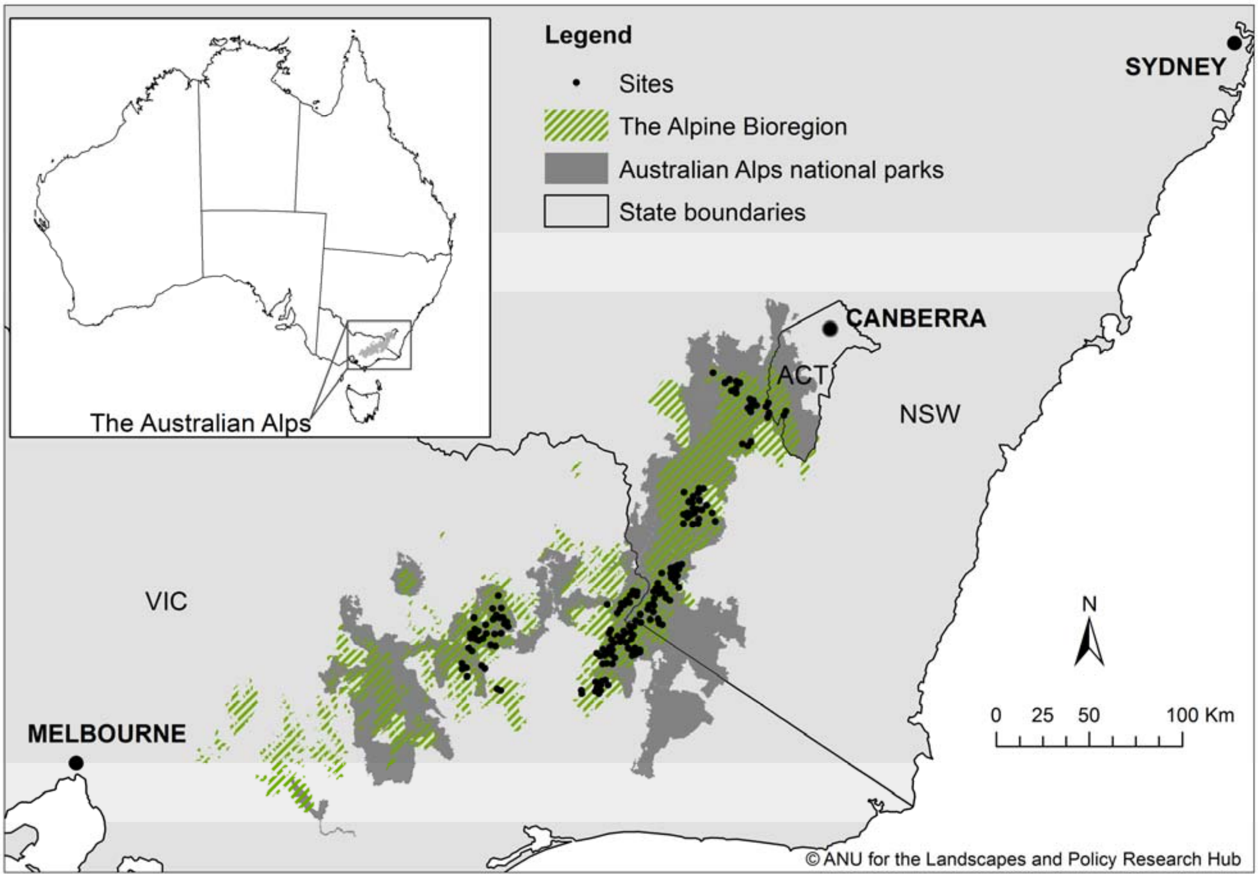

Figure 1. The Australian Alpine National Parks and the sites where the LFA index was assessed. Alpine National Parks - grey; Australian Alpine bioregion - hatched; VIC - Victoria; ACT - Australian Capital Territory; NSW - New South Wales.

more than 300,000 ha of Kosciuszko National Park and Bago and Maragle State Forests in New South Wales and around 330,000 ha of Victoria (Geoff Robertson pers. comm., June/July 2013).

The LFA index method applied at each site is an adaptation of the Landscape Function Analysis of Tongway and Hindley (2004). This is a monitoring procedure which uses visual indicators to assess the status of biotic and abiotic processes that retain water and nutrients. The visual indicators can be ranked from pristine to degraded, and when combined, they provide an overall estimate of the status of key soil properties using indices of soil stability, water infiltration and nutrient cycling. The modified LFA index included observations on the following variables: the number of defined animal tracks or pads within 20 m of a drainage system; the level of impact of defined animal tracks or pads; stream bank stability; longitudinal profile characteristics of a drainage line; sediment level on the stream bed; pugging damage (i.e. damage caused to grass by horses tearing up the soil structure); grazing disturbance on banks/in channel; percentage of vegetation cover; and percentage of the native foliage cover. The assessed features were combined into a single index for each site ranging from 0 to 100, representing degraded to pristine landscapes, respectively. As it was not feasible to map entire streams over the study area, a random 50 m length of drainage line was sampled at each location. If the 50 m length of drainage line possessed sections with different levels of impact, for example where a section of bank had collapsed, each section was assessed separately.

Remotely sensed fPAR

It has been well established that the remotely sensed Normalized Difference Vegetation Index (NDVI) is sensitive to changes in vegetation cover (Rouse et al., 1973; Holm et al., 1987; Reed, 2008). The NDVI is the normalised difference between the reflectance in the near infra-red and visible bands. As the NDVI increases, the proportion of green vegetation relative to soil cover increases. Radiation that is not reflected is intercepted. The greater the density of chlorophyll molecules in the vegetation, the greater the proportion of incoming radiation intercepted and available for photosynthesis (Berry et al., 2007). There is a linear relationship at time (*t*) between the proportion of photosynthetically active radiation that is intercepted by the green vegetation (fPAR), and the NDVI when $0 < \text{NDVI} < 1$ (Roderick et al., 2001).

Mean monthly estimates of fPAR data (250 m) were derived from MOD13Q1 NASA product (Schloss et al., 2002), resampled to a geographic projection and remapped to the Australian region using Berry and

Roderick's equations (Roderick et al., 2001; Berry & Roderick, 2002; Schloss et al., 2002; Berry et al., 2007; Paget & King, 2008) to isolate the turgor component, which represents the reflectance of radiation by the herbaceous vegetation within each pixel. The turgor component of the fPAR corresponds in this case to the productivity of native grasslands, which is the type of vegetation highly impacted by the presence of feral horses (Beever et al., 2008; de Villalobos & Zalba, 2010). The fPAR turgor values were extracted for the period 2000 to 2012 for 171 sites and the mean, maximum, minimum and coefficient of variation were calculated using the 'Raster' package (Hijmans & Etten, 2012) in R software (R Development Core Team, 2014) (Table 1). See Supplementary Online Material for detailed information about the formulae to obtain the fPAR proportions for different leaf functional types.

Breaks for additive and seasonal trend in vegetation

The break for additive and seasonal trend analysis (BFAST) (Verbesselt et al., 2010; Verbesselt et al., 2012) recognises seasonal trends in vegetation and detects anomalies in the seasonality that are commonly related to disturbances (Saatchi et al., 2013). We ran the 'BFAST' model (Verbesselt et al., 2010) in R software for each site and derived two indicators of change in the vegetation seasonality at the site level. The first indicator was the number of breaks in the fPAR seasonal component that were not related to seasonal changes (hereafter fPAR break index). The second indicator was the time, in months, taken for each site to recover to pre-break fPAR values (hereafter fPAR recovery index) (Table 1). Two examples of BFAST outcomes can be found in Figure 2, where the top panel shows a site (250 m pixel) with absence of horses and one abrupt change in 2009, as detected in the fPAR trend component. The bottom panel in Figure 2 shows a site with presence of feral horses and four abrupt changes are detected in the fPAR trend component.

Propensity score matching

The surveyed LFA data were not balanced, with just over twice as many sites where feral horses were present (n=116) as absent (n=55). Lack of balance is problematic when the objective is to test for differences between groups. To address this issue we used propensity score matching (Rosenbaum and Rubin, 1983) to balance the data. The propensity score matching for a site (*i*) is defined as the conditional probability of assignment to a particular treatment ($Ti = 1$) versus control ($Ti = 0$) given a set of observed covariates (Equation 1), where e = the propensity score, pr = the conditional probability and X = the background variables. The covariates were: LFA index; the mean, maximum, minimum and coefficient of variation of fPAR; slope; aspect; topographic position index; terrain ruggedness index; and roughness. The propensity score matching was then calculated using the nearest neighbour matching estimator without replacement using the 'Matching' package (Ho et al., 2006) and analysed using student's t-tests in R software.

$$e(x)_i = pr(T_i = 1|X = x_i)$$

Table 1. The list and description of the variables used in the analysis

Type of	Variable	Description
Ecosystem function indices	Coefficient of variation of fPAR	CV=⍰⍰⍰⍰⍰⍰ (⍰⍰⍰⍰ 2000−2012) divided by ⍰⍰⍰⍰ (⍰⍰⍰⍰ 2000−2012)
	Maximum of fPAR	Maximum fPAR value for the period 2000-2012
	Mean of fPAR	Mean fPAR value for the period 2000-2012
	Minimum of fPAR	Minimum fPAR value for the period 2000-2012
	fPAR break index	Number of breaks in the fPAR seasonal trend that are not related to seasonal changes. Modelled using BFAST.
	fPAR recovery index	Number of months to reach fPAR pre-disturbance values. Modelled using BFAST.
	Landscape function index	The assessed features in the survey were combined into the landscape function index for each site ranging from 0 to 100, representing degraded to pristine landscapes, respectively.
Terrain indices	Roughness	The difference between the maximum and the minimum value of a cell and its 8 surrounding cells.
	Slope	Radians.
	Topographic position index	The difference between the elevation value of a cell and the mean value of its 8 surrounding cells.
	Terrain ruggedness index	The mean of the absolute differences between the value of a cell and the value of its 8 surrounding cells.
	Aspect	Radians.

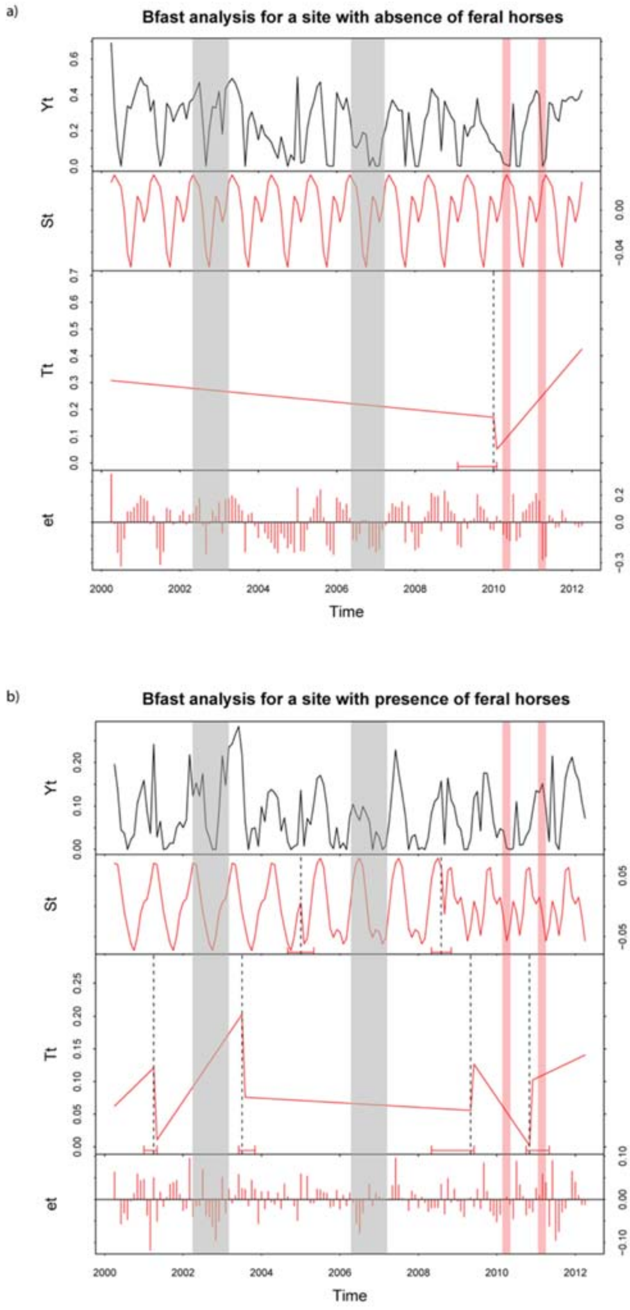

Figure 2. The observed fPAR (Yt), fitted seasonal (St), trend (Tt) and residuals (et) (i.e. estimated noise) components for a fPAR time series at two sites in the Australian Alps over the period 2000-2012. The top panel a) shows a site with absence of horses and one abrupt change (----) is detected in the trend component of the fPAR time series, associated with the drought in 2009. The bottom panel b) shows a site with presence of feral horses and four abrupt changes are detected in the fPAR trend component. The time (----), corresponding confidence interval (red horizontal lines at the bottom of dashed lines), direction and magnitude of abrupt change and slope of the gradual change are shown in the estimated trend component (red lines). The two severe droughts of the decade are shown in the grey bands, and dates when the LFA index was assessed are shown in the red bands across all estimates.

Decision tree analysis

We used decision tree analysis to investigate the relationships between the presence of horses, LFA index and fPAR values at the sites. Decision tree analysis is a multivariate analytical approach that allows sites to be grouped based on their similarity as measured by a set of variables (Hothorn et al., 2006). We calculated two models. The response variable in both models was the LFA index. The explanatory variables in the first model were the following topographic attributes: slope; topographic position index; roughness and aspect (see Table 1 for a description of the variables). The aim of the first model was to examine the interactions between the LFA index, the presence of horses and topography. To further analyse the level of significance in the interactions between presence of feral horses and topography we ran a variation of the first model, changing the α parameter to α=0.10; details provided in the Supporting Information. The second model used a set of explanatory variables derived from the fPAR time series data: mean and coefficient of variation of fPAR, fPAR Break Index; and fPAR Recovery Index. The aim of the second model is to examine whether there is an interaction between the LFA index and fPAR derivatives. We used only explanatory variables for which the correlation coefficient was lower than 0.5 (see Figure A1 in the Supplementary Online Material). We specified that the splits in the trees must not exceed α = 0.05 and the Nodes should contain at least 10 observations. The decision tree analysis was performed using the 'Party' package (Hothorn et al., 2006) in R software.

Brumbies, alpine region, Kosciuszko National Park
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RESULTS

Our results suggest that the presence of feral horses is correlated with the condition of natural treeless drainage systems (riparian areas and wetlands) in the Australian Alps. Decision tree models can be interpreted using 'if-then' rules (Markham et al., 2013). The decision tree for the first model is shown in Figure 3. In the first model, if the site was characterised by the absence of horses (Node 2 in Figure 3), then the LFA index presents values close to 100, representing a site with vegetation in good condition. If the site was characterised by the presence of feral horses (Node 3), then the LFA index was low, showing a mean of 50 (black line in Node 3's boxplot in Figure 3), representing sites with poor vegetation condition. There were no interactions between the presence or absence of feral horses and the terrain attributes at the P = 0.05 level. However, if feral horses are absent there was an interaction with a terrain attribute at the P = 0.06 level (see Figure A2 in the Supplementary Online Material).

The second decision tree model suggests that changes in vegetation condition at the landscape scale can be detected using remotely sensed data of 250 m pixel resolution. The second decision tree model, which did not include presence/absence of feral horses as a covariate, is shown in Figure 4. The two variables that were found to be most important in accounting for the variability of the LFA index were the mean fPAR and the fPAR break index. If the mean fPAR was lower than or equal to 0.12, the sites were allocated in Node 2 (see Figure 4) characterised by low LFA index (mean ~ 50), indicating sites in poor vegetation condition. If the mean fPAR was greater than 0.12, then the second most important variable was the fPAR break index (Node 3). If the number of breaks in the fPAR break index, which represent the seasonal component of vegetation, were lower than or equal to one, the sites were allocated to Node 4; which corresponds to high values and low variability of the LFA index (see Node 4 in Figure 4). Node 4 represents sites with the best vegetation

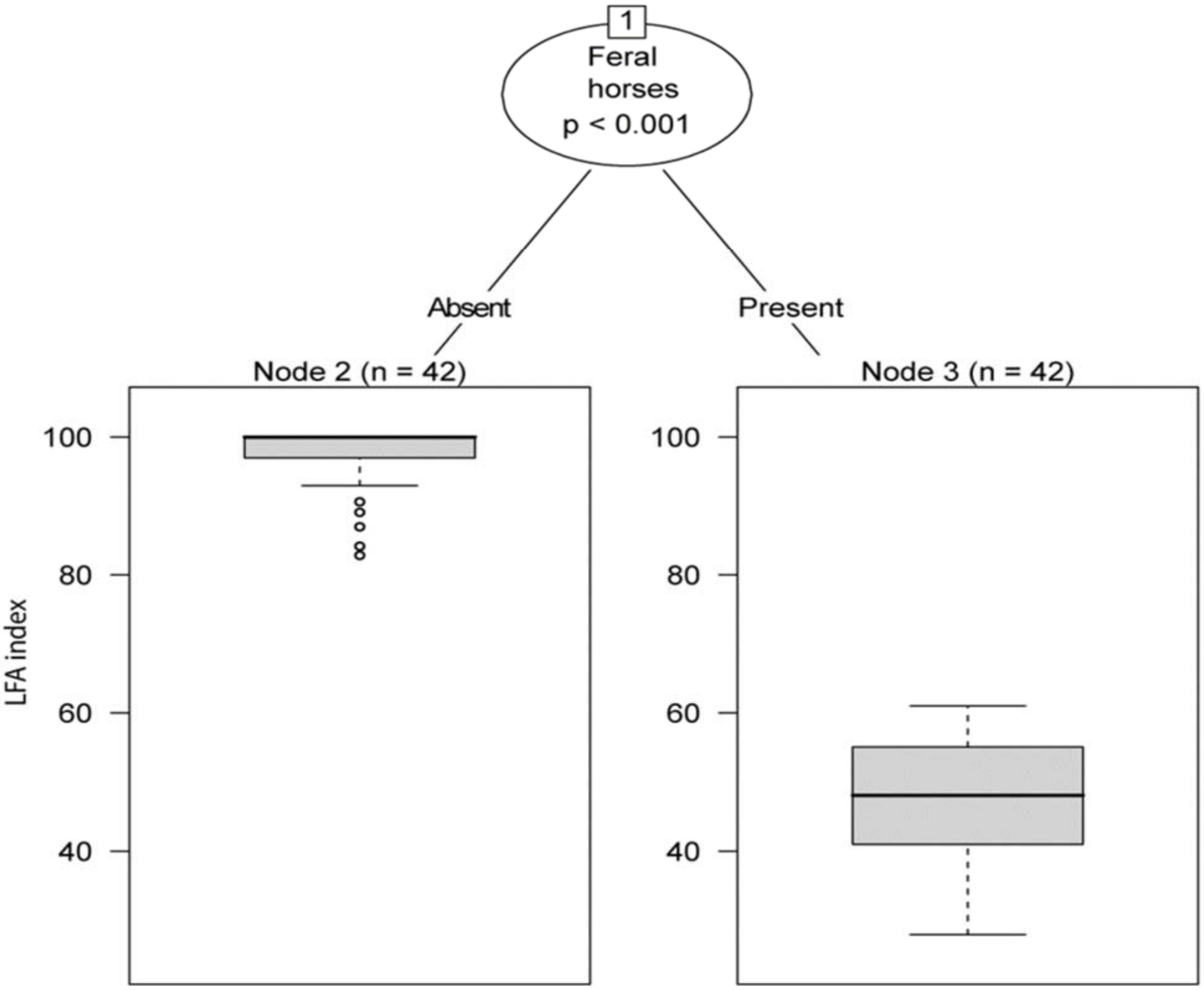


Figure 3. Decision tree model and the interaction between variables to explain the LFA index. The model uses the presence or absence of feral horses and terrain attributes to explain the LFA index (boxplots).

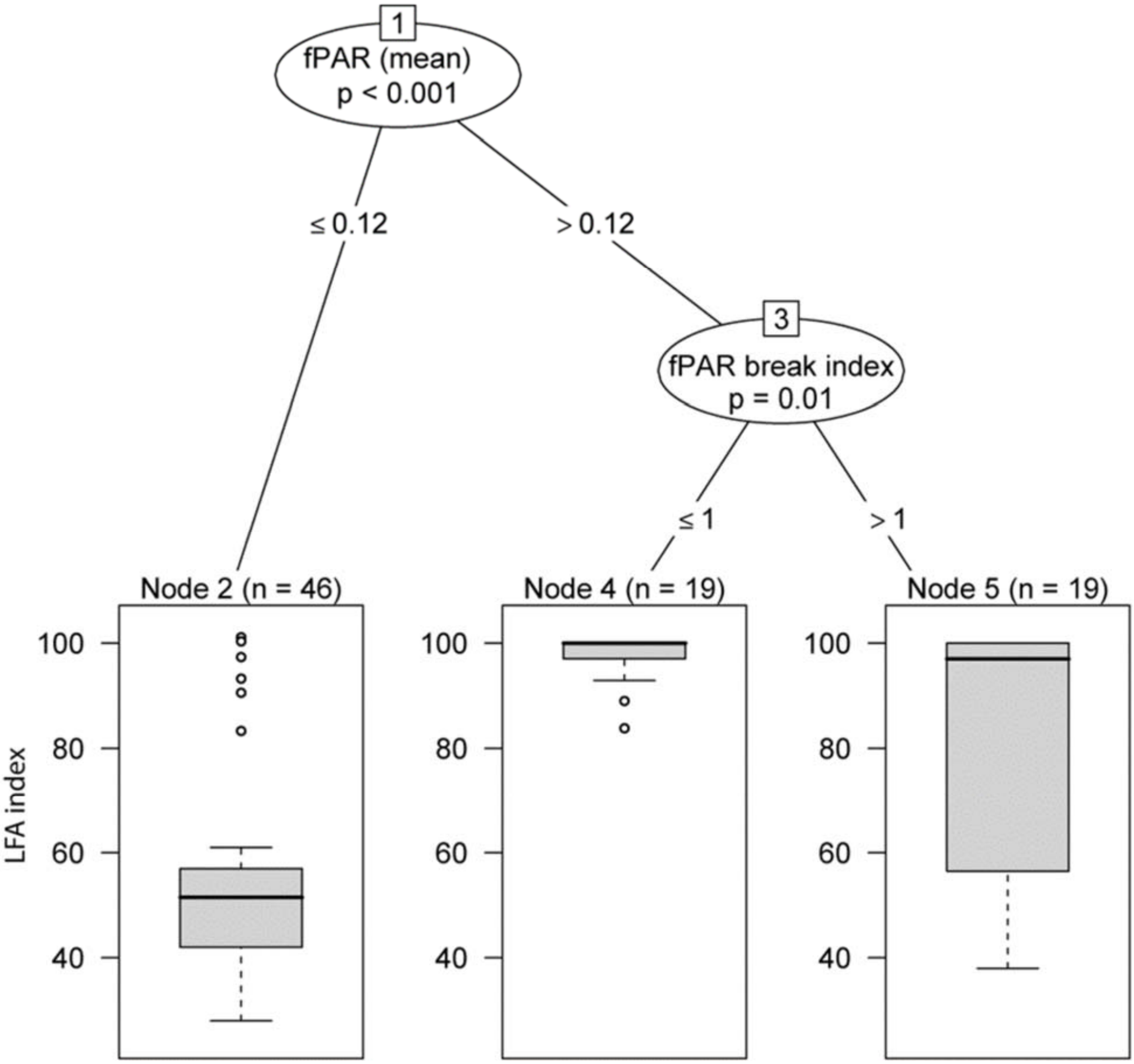


Figure 4. Decision tree model and the interaction between variables to explain the LFA index. The model uses the presence or absence of feral horses and ecosystem function attributes to explain the LFA index (boxplots)

condition. If the number of breaks in the fPAR seasonal component (Node 3 in Figure 4) were greater than one, then the sites were allocated to Node 5, characterised by sites with relatively high vegetation condition but high variability (see Node 5 in Figure 4).

These results aligned with the differences we found between sites with absence or presence of feral horses (see Table 2). The statistical analysis showed that the control group, which were sites characterised by the absence of feral horses, was statistically different to the treatment group (sites where horses were present) for four of the five fPAR variables, in addition to the Landscape function index, and the topographic variables of roughness and slope (Table 2). Sites characterised by the presence of feral horses presented less 20 per cent fPAR-maximum values than sites with absence of feral horses. The treatment groups also presented less 10 per cent fPAR-mean values, more breaks in the fPAR seasonal component (as modelled using the BFAST algorithm) and the LFA index values were two-fold the values for sites with absence of horses. The difference we found between the number of breaks in the fPAR seasonal component in sites with and without feral horses (Table 2) implies that sites with absence of feral horses are significantly less variable and had a lower number of breaks (disturbances) in the fPAR seasonal component.

DISCUSSION

The statistical analysis we used provided a robust basis for our results. Unbalanced data are common in ecology due to the difficulty and cost of large-scale, long term experiments. Propensity score matching has only

Table 2. The mean, P values and magnitude of the effect of the variables tested for sites with absence and presence of feral horses in the Australian Alps

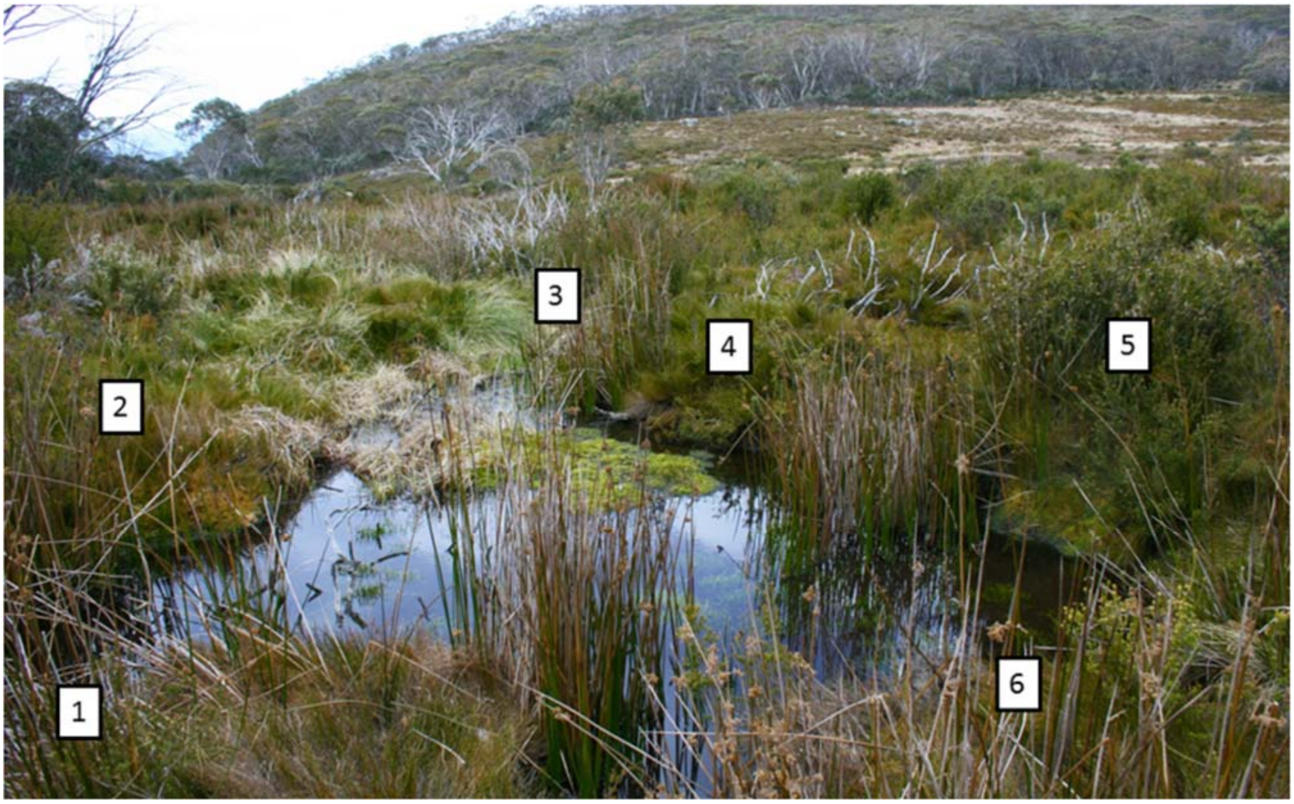
Type of indicator	Variable	Absence of feral horses (mean)	Presence of feral horses (mean)	P value	Magnitude of the effect
Ecosystem function indices	Coefficient of variation of fPAR	0.704	0.742	0.002	-0.04
	Maximum of fPAR	0.50	0.30	< 0.001	0.20
	Mean of fPAR	0.19	0.09	< 0.001	0.10
	Minimum of fPAR	0	0	Na	0.00
	fPAR break index	1.81	2.976	0.001	-1.17
	fPAR recovery index	11.976	15.214	0.495	-3.24
	Landscape function index	97.357	46.976	< 0.001	50.38
Terrain indices	Roughness	1607.071	1360.398	< 0.001	246.67
	Slope	0.125	0.095	0.039	0.03
	Topographic position index	-1.591	-4.915	0.274	3.32
	Terrain ruggedness index	27.588	22.412	0.073	5.18
	Aspect	3	3.318	0.386	-0.32

recently been used in ecological studies to deal with unbalanced data and has proved to be an effective tool for dealing with this issue (Bottrill et al., 2011). Here, it proved to be useful in helping to obtain two balanced and comparable groups of sites with absence and presence of feral horses.

Our study is, to the extent of our knowledge, the first that has used BFAST to generate fPAR derivatives to explore the link between feral herbivore impacts on the phenology of vegetation. The BFAST analysis provided an indicator of vegetation phenology associated with the seasonal component of the fPAR. The number of breaks in the seasonal component of the fPAR is quite different from the fPAR coefficient of variation as the latter does not account for the seasonality in the phenology of vegetation. The studied period, 2000-2012, had two severe droughts as determined by the Australian Bureau of Meteorology, one in 2003 and another in 2006. So, we were expecting high variability in terms of fPAR phenology over the 12-year period, represented by the coefficient of variation. However, this new technique enabled us to find that sites with absence of feral horses had, on average, more fPAR-mean and fPAR-maximum values (higher productivity) and a lower number of breaks in their seasonal component than sites with presence of horses (see Table 2).

Our results confirm that vegetation condition can be detected using remotely sensed data at 250 m pixel resolution. The second decision tree model indicated that the mean fPAR and the number of breaks in the fPAR seasonal component are the most important variables ($P < 0.05$) in explaining LFA index values. An increase in the number of breaks in the fPAR seasonal component correlated with sites in poor condition, as measured by the LFA index. One explanation is that the presence of feral horses adds pressure to the landscape so that it is more vulnerable to abrupt changes in the vegetation phenology when compared to sites with absence of horses. Therefore, the vegetation would change more often than would occur from seasonal variation alone. The results of the two decision tree models suggest that the presence of horses is correlated with sites that have poorer and more variable vegetation condition as represented by the LFA index.

Native alpine wetland damaged by feral horses' incursion © Suzie Gaynor



The characteristics of an alpine wetland in good vegetation condition: (1) Raised water table supporting sphagnum bog community and surrounding heathlands. (2) Dense and diverse vegetation cover protects the soil from erosion from adverse weather and protects soil carbon. (3) Ginini sphagnum bog and associated fens, a nationally threatened ecological community. (4) Sphagnum bog hummocks, habitat of the endangered Corroboree frog (Pseudophryne pengilleyi). (5) Dense heath vegetation, habitat for birds, amphibians, reptiles and mammals. And (6) high quality erosion free mountain water; protected from evaporation; with vegetation buffeting and slowing water flow regimes in serious storms. © ACT Government

The LFA index was strongly related to the presence and absence of feral horses and only weakly to the topographic attributes. However, in the models where feral horses were absent, we found an interaction with a terrain attribute at marginal significance level (see Figure A2 in the Supplementary Online Material). These results therefore suggest that topography, as represented by the terrain indices we used, is not a significant factor in determining either LFA index or the presence and absence of horses (Figure 3). This statistical result supports our hypothesis that feral horses impact on alpine vegetation.

CONCLUSION

Public opinion about the impact of feral horses on native vegetation is polarised. There are people who revere them because of their beauty, sense of freedom and historical bond to humans; and those who are concerned about their growing numbers and destructive impact on natural alpine vegetation (Forum, 2013). Our results provide further evidence that feral horses have a negative impact on Australian alpine and sub-alpine vegetation condition. Therefore, management of feral horse populations in Australia is an important conservation problem. Monitoring the impact of feral horses on native vegetation will remain an ongoing challenge for land managers in many regions of the world. Given the extensive landscapes that must be surveyed and analysed, cost-effective approaches are needed. Our results suggest that existing remotely sensed satellite data can provide useful information about feral horse impacts on vegetation condition. The approach we have presented provides a useful and relatively cost-effective method for monitoring the impact of feral horses on native vegetation in support of decision making and management interventions. This method could be used to map the extent of feral horse impact on alpine and sub-alpine vegetation using satellite data at various pixel resolutions (i.e. Landsat at 30 metres pixel, Aster at 15 metres pixel) to increase model accuracy.

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Brendan Mackey is Director of the Griffith Climate Change Response Program at Griffith University, Queensland, Australia. His research is currently focussed on the interactions between climate change, biodiversity and land use, and approaches to helping improve environment and conservation regulatory and management frameworks.

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RESUMEN

La presencia de caballos salvajes cuasa degradación ambiental y pone en riesgo la integridad de sistemas ecológicos. Nueva evidencia científica es necesaria para informar al debate público y asistir a las personas encargadas del manejo de parques en la toma de decisiones. En este studio usamos observaciones sobre la condición de la vegetación hechas en el campo. Estas observaciones fueron tomadas en la zona Alpina Australiana, en sitios caracterizados por tener presencia y ausencia de caballos salvajes. Estas observaciones fueron combinadas con datos de sensores remotos, más precisamente datos de la fracción de la vegetación fotositéticamente activa (fPAR), así también con datos de topografía del terreno. La condición de la vegetación fue estimada en el campo usando una técnica llamada analisis de función del paisaje, del inglés Landscape Function Analysis (LFA). La técnica LFA genera un índice que fue cotejado con los datos de fPAR derivados de sensors remotos. Nuestros resultados indican que existe una diferencia significativa en el índice LFA entre sitios con o sin presencia de caballos salvajes. Los sitios con presencia de caballos salvajes, muestran valores de alrededor de 10 por ciento menos fPAR que los sitios sin caballos salvajes. Los resultados también indican que existe una correlación entre el índice de LFA y los datos de fPAR. Nuestro análisis apoya la hipótesis que los caballos salvajes generan un impacto negativo en la vegetación alpina en Australia. Este studio provee un método útil y relativamente económico para monitorear el impacto de los caballos salvajes en la vegetación nativa alpina. Este método puede ser usado para la toma de decisiones y para intervenciones de manejo del paisaje.

RÉSUMÉ

A travers le monde, les chevaux sauvages (*Equus caballus)* provoquent une dégradation de l'environnement et un déclin de l'intégrité écologique. L'analyse scientifique de cette dégradation peut fournir les informations nécessaires pour alimenter les débats publics et assister les gestionnaires des terres dans leurs prises de décisions. Nous avons réalisé des observations de l'état de la végétation sur de nombreux sites des Alpes australiennes où des chevaux sont présents ou absents. Les données ont été combinées avec la fraction détectée à distance du rayonnement photosynthétiquement actif (fRPA), et l'état topographique. L'état de la végétation a été évalué sur le terrain par les gardes forestiers en utilisant une version modifiée de l'Analyse de la Fonction des Paysages (LFA). Des différences significatives sont apparues dans l'indice LFA entre les sites selon la présence ou non de chevaux. Le fFAR des sites ayant une présence de chevaux est inférieur de 10% par rapport aux sites où les chevaux sont absents. Les résultats indiquent également une corrélation significative entre LFA et fPAR. Notre analyse confirme l'hypothèse selon laquelle les chevaux sauvages ont un impact négatif sur l'état de la végétation alpine australienne. Cette étude fournit une méthode utile et relativement peu onéreuse pour surveiller l'impact des chevaux sauvages sur la végétation indigène, et peut être utilisée pour soutenir la prise de décision et décider de la nécessité d'une intervention.