An Assessment of Feral Horse Impacts on Treeless Drainage Lines in the Australian Alps

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CONTENTS

Introduction 3
1. Methods 4
2. Results 9
3. Discussion 14
4. References 24

Figures
Fig. 1 Study area and site locations 5
Fig. 2 Data variables relating to soils and stream stability 10
Fig. 3 Site scores for stream bank stability, longitudinal profile, and stream bed sediment 16
Fig. 4 Photo – horse damage 17
Fig. 5 Photo – horse damage 17
Fig. 6 Photo – Alpine water skink 18
Fig. 7 Photo – grazing effects 19
Fig. 8 Photos – vegetation differences – grazed / ungrazed 20
Fig. 9 Photo – feral horse camp 22

Tables
1. Distribution of study sites 6
2. General characteristics of the 185 drainage line sites 9
3. Analysis of horse impacts 12 -13
Introduction

The Australian Alps are a place of outstanding natural and cultural significance. Containing the highest points in the Great Dividing Range and spanning over 600 km from Mount Donna Buang in Victoria to Piccadilly Circus in the Australian Capital Territory (ACT), the Australian Alps cover an area of more than 1.6 million hectares. They encompass the headwaters of many major rivers in southeastern Australia and contain a diverse array of ecosystems that provide critical habitat for many threatened flora and fauna species. The significant value of the Australian Alps is reflected by their inclusion in Australia’s National Heritage List.

Feral horses have been present in the Australian Alps since the 1890s (Dyring, 1990). The environmental impacts of feral horses in the Australian Alps have been of concern since at least the 1950s (Costin 1954, 1957). Impacts on riparian and wetland ecosystems, especially those impacts associated with erosion and damage to streams, are of particular concern. Many of these ecosystems include the Commonwealth-listed Alpine Sphagnum Bogs and Associated Fens Endangered Ecological Community and synonymous communities listed under New South Wales and Victorian State legislation. These ecosystems also provide important habitat for a range of Commonwealth and/or State listed threatened species including the Alpine Water Skink, Guthega Skink, Alpine She-oak Skink and Alpine Bog Skink (Clemann et al. 2001; Clemann 2001; Meredith et al. 2003; Steane et al. 2005).

Streams, wetlands and adjacent riparian ecosystems are susceptible to damage through selective grazing, trampling, pugging, wallowing and crossing by feral horses and other hard- hoofed animals (Costin 1954; Whinam & Comfort 1996; Williams et al. 1997; Whinam & Chilcott 2002; McDougall 2007; Prober & Thiele 2007; Wild and Poll 2012). Impacts associated with feral horses include changes to soils, streams and vegetation (Dyring 1990); changes in stream structure and function, vegetation structure and composition (Prober & Thiele 2007; Wild and Poll 2012); and damage to peatland systems through track creation, compaction, trampling, pugging and stream bank slumping (Tolsma 2009).

Due to concerns about impacts on natural values, feral horse abundance across the Australian Alps has been monitored systematically since 2001. The feral horse population was reduced by large bushfires that affected much of the Australian Alps in 2002-2003 (Walter 2003). However, since then, the population has continued to grow, with the annual rate of increase for the Northern Kosciuszko area in New South Wales and the Southern Kosciuszko – Northern Victoria area estimated at 17% and 6% respectively (Cairns 2014).

Despite the long history of concern about impacts of feral horses and the substantial increase in horse abundance across the Australian Alps observed over the past decade, there has been little research to quantify the impacts of feral horses on natural values of the Australian Alps. Furthermore, those studies that have examined feral horse impacts have generally focused on localised areas. Such studies are very useful for understanding the nature of impacts at a site-scale, however for developing effective management strategies across the Australian Alps landscape, it is also important to understand how widespread these impacts are.

This study aims to address this knowledge gap. It compares various attributes of treeless drainage lines in sites with no sign of horse presence and sites that do show evidence of horse presence
(observations of horses, horse dung, prints or trails). To our knowledge, this is the first study that has assessed the environmental impacts of feral horses across the Australian Alps landscape.

**Methods**

**Study area**

The study area encompassed public land in the Australian Alps identified by local land management agency staff to be occupied by feral horses, as well as comparable areas of public land identified by local land management agency staff as areas in which horses do not occur. Parts of Kosciuszko National Park and Bago and Maragle State forests in New South Wales (NSW) are included, as well as the southern section of Namadgi National Park in the Australian Capital Territory (ACT), and areas of the Alpine National Park and Hotham Heights, Nunnet, Nunning and Wentworth State forests in Victoria (Fig. 1).

Horse-free areas in NSW are limited to the section of Kosciuszko National Park (KNP) between the Snowy Mountains Highway and the Alpine Way with the exception of the Snowy Plains area on the east of the park. This part of KNP occupies an area of about 220,000 ha and ranges in altitude from about 450 m to 2228 m (Mt Kosciuszko). Horse-free areas in Victoria are limited to a portion of the Bogong High Plains, Dargo High Plains and surrounding areas of state forest. Most of the ACT is horse-free, with horses occurring only on and near the NSW border (Fig.1).

**Site selection**

The focus of the study was riparian areas and wetlands associated with treeless drainage lines. Study sites were located between 1040 m and 1920 m above sea level. Within the study area, all sites were selected randomly. For NSW and the ACT, GIS analysis of vegetation mapping from the Southern Comprehensive Regional Assessment (Thomas et al. 2000) and of peat-forming Bogs and Fens (Hope et al. 2012) was used to identify treeless vegetation coincident with drainage lines. For Victoria, GIS analysis of mapping of Ecological Vegetation Classes (DSE 2005) was used to identify suitable treeless sites. A GIS routine was used to allocate sites randomly ensuring a minimum distance of 2 km between sites within the areas identified as treeless vegetation areas coincident with drainage lines. Areas with cattle grazing licences that have been active in the last 5 years were excluded. In Bago and Maragle State forests, sites were located adjacent to existing randomly located plots established for monitoring the condition of Alpine Bogs. A total of 186 sites were assessed, with 129 of these showing signs of horse presence (Table 1).
Figure 1. Feral horse impact assessment study area and site locations.
Table 1. The distribution of study sites.

<table>
<thead>
<tr>
<th>Location</th>
<th>Horse-present</th>
<th>Horse-free</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kosciuszko National Park, NSW</td>
<td>56</td>
<td>27</td>
<td>83</td>
</tr>
<tr>
<td>Victoria (Alpine National Park &amp; State forest)</td>
<td>64</td>
<td>28</td>
<td>92</td>
</tr>
<tr>
<td>Bago &amp; Maragle State forest, NSW</td>
<td>7</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>ACT</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>129</td>
<td>57</td>
<td>186</td>
</tr>
</tbody>
</table>

Survey method
The survey method used in this study is an adaptation of a technique known as Ephemeral Drainage Line Assessment, developed to assess whether a drainage line is stable or actively eroding (Tongway and Ludwig, 2011). This technique assesses a range of attributes of a drainage line which may be combined to provide a single index of drainage line stability. In our study, the methods were modified with the assistance of David Tongway to better suit the ecosystems that were the subject of this study. In particular, erosion and depositional processes and the linearization of stream flow paths were emphasised. Additionally, the study included both ephemeral and perennial treeless drainage lines. Rather than combining scores to produce a single index of stability, we have treated each attribute separately to examine specific aspects of impacts caused by feral horses.

According to the original field procedure of Tongway and Ludwig (2011), entire stream beds are mapped from their source to confluence with a more major stream. In our study, mapping entire streams was neither feasible over the study area, nor relevant to the nature of horse impacts. At each of our sites, we assessed a randomly-located 20m wide x 50 m long strip of drainage line.

A GPS was used to locate the randomly allocated sites identified in the desk-top GIS routine. Not all of the sites identified could be accessed, or were not appropriate to sample due to errors in mapping, (e.g. no treeless drainage line at the site despite being indicated on map). The start of the 50 metre strip was located at the allocated random point and the drainage line site was deemed eligible provided that it was accessible and was a treeless drainage line.

If the 50 m length of drainage line comprised sections that differed in condition, for example where only a section of bank was actively eroding, the line was subdivided into sections which were as assessed separately.

To minimise the effects of variation among assessors, only two assessors undertook field assessment. One of these assessed all sites in NSW and ACT and the other assessed all Victorian sites. Both assessors worked together in the early stages of assessment in Victoria to ensure consistency in their interpretation of assessment categories. Photo-standards were also used to ensure standardisation among assessors.
Nine indicators were assessed on each 50 m length of drainage line or sub-section of drainage line where the site was sub-divided due to differing condition along the drainage line. All indicators assessed relate to soil and stream stability and vegetation cover, which in turn influence ecosystem function and habitat quality. The indicators were:

- Stream bank stability (5 categories);
- Pugging damage (4 categories);
- Longitudinal profile characteristics of a drainage line (4 categories);
- Sediment level on the stream bed (3 categories);
- Number of defined animal tracks or pads within 20 m of drainage system (4 categories);
- Level of impact of defined animal paths or pads on the vegetation (4 categories);
- Grazing disturbance on banks/in channel (4 categories);
- Projected foliage cover using a Braun-Blanquet scale (5 categories); and
- Proportion of projected foliage cover that is native using a Braun-Blanquet scale (5 categories).

The categories of each indicator were scored using a consecutive numbering system with a higher score implying better condition.

Photographs were taken of the start and end points of the 50 m site, and of each sub-section assessed. A description of the categories assessed for each variable is given in Appendix 1.

To assist with subsequent interpretation of results, observations relating to six site characteristics were also recorded for each site (i.e. 50 m section of drainage line). Characteristics recorded at the whole site level were:

- The width of the drainage system – that is the width of the area that would be inundated during flood events;
- The width of the stream channel;
- Altitude;
- Whether there is evidence of burnt stems from shrubs, or dead sphagnum indicating the site has been recently burnt (2003 and 2006 bushfires);
- Whether the site is the Alpine Sphagnum Bogs and Associated Fens endangered ecological community listed under the Commonwealth Environment and Biodiversity Conservation Protection Act 1999; and
- Evidence of other grazing and browsing mammal species (wombats, macropods and feral goats, rabbits, feral pigs and deer).

In addition, evidence of horse presence (animal seen, hoof print, dung) was recorded for each site.

Kosciuszko National Park and ACT sites were assessed between February and June 2011. Bago and Maragle State Forest sites were assessed in October 2011, and Victorian sites were assessed between February and June 2012. Horse presence was determined by direct observation of animals at the site, presence of horse pads, horse dung or horse prints within the 50 x 20 m site. In total, 186...
sites were sampled, with 92 located in Victoria, 90 in New South Wales and 4 in the Australian Capital Territory. Sixty-nine percent of sites showed evidence of horse presence (Table 1).

**Analysis**

On-ground assessment revealed that eleven sites located within the area assumed to be occupied by horses showed no evidence of horse presence (7.9%). This occurred because although the broad distribution of horses across the Australian Alps is reasonably well understood, that understanding is not sufficient to know with certainty which individual sites would have horses present and which ones would not. Hence, although sites were selected from areas believed to be occupied by horses and areas believed to be unoccupied by horses, our analyses compared sites where horse presence was confirmed during on-ground assessment with those sites where no evidence of horse presence was detected. No sites with evidence of horse presence were detected outside the broad area believed to be occupied by horses.

Prior to analysis, data were entered into a Microsoft Access database. Quality control checking of the data was carried out and all inconsistencies between data items and data errors were rectified. Data were collected from 186 sites. Although some horse sign was detected at one site in the Australian Capital Territory, it was not occupied by horses at the time of assessment as it had been subject to a recent horse removal program. Consequently, its status with respect to horse presence was ambiguous and this site was omitted from the analysis.

No adjustment for multiple comparisons was made. Adjustment methods reduce the type I error for null associations, but can increase the type II error for non-null associations. Many statisticians do not believe correction for multiple comparisons should be routinely done. There has been suggestion that correction for multiple comparisons is only required when joint hypothesis testing is being done (Rothman, Greenland and Lash, 2008). This was not our aim, and consequently we felt that correction for multiple comparisons was not necessary.

Comparisons among horse-present and horse-free sites with respect to the general site characteristics were carried out using two-sample t-test for continuous data and chi-square test for categorical data. If the categories were ordered, then a chi-square test for trend was performed. Also, if there were only two categories for a particular characteristic, then Fisher’s exact test was used instead of chi-square test.

When analyzing each of the nine indicators associated with the condition of a drainage line, an overall score for each site was obtained by computing the average of the score of each sub-section weighted by the proportion of the length of the section it accounted for.

A general linear model was used to compare horse-present and horse-free sites with respect to the overall score (outcome variable). To account for potential effects of altitude, fire status (burnt or not burnt) and State (Vic. or NSW/ACT) on each outcome variable, these three site characteristics were incorporated explicitly within the analysis. Nine sites for which information on fire status was not recorded were excluded from these analyses. When analysing the outcome variable associated with grazing disturbance on banks and in channel, a further 12 sites were excluded as information on this indicator had not been recorded. Hence, 176 sites were included in the analysis for all outcome variables except grazing disturbance on banks and in channel for which only 164 sites were analysed. Statistical tests performed were two-sided and a p-value of less than 0.05 was deemed to be statistically significant. The analysis was performed using the R statistical package (version 2.13.2).
Results

General site characteristics

A summary of general site characteristics for both horse-present and horse-free sites is given in Table 2a and 2b. On average, horse-present sites were 200m lower in altitude than horse-free sites (1379m and 1579m respectively, p <0.001, Table 2a and 2b).

Table 2a. General characteristics (measured as continuous variables) of the 185 drainage line sites (128 horse-present sites, 57 horse-free sites).

<table>
<thead>
<tr>
<th>Site characteristics</th>
<th>Horse-present (HP)</th>
<th>Horse-free (HF)</th>
<th>HP vs HF P</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage system width (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>42.4</td>
<td>46.4</td>
<td>0.53</td>
<td>43.6</td>
</tr>
<tr>
<td>SD</td>
<td>30.8</td>
<td>55.0</td>
<td></td>
<td>39.7</td>
</tr>
<tr>
<td>Stream channel width (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1.0</td>
<td>0.9</td>
<td>0.52</td>
<td>1.0</td>
</tr>
<tr>
<td>SD</td>
<td>1.1</td>
<td>1.1</td>
<td></td>
<td>1.1</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1379</td>
<td>1579</td>
<td>&lt;0.001</td>
<td>1441</td>
</tr>
<tr>
<td>SD</td>
<td>180</td>
<td>185</td>
<td></td>
<td>203</td>
</tr>
</tbody>
</table>

Table 2b. General characteristics (assessed as categorical variables) of the 185 drainage line sites (128 horse-present sites, 57 horse-free sites).

<table>
<thead>
<tr>
<th>Site characteristics</th>
<th>Category</th>
<th>Horse-present (HP)</th>
<th>Horse-free (HF)</th>
<th>HP vs HF P</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evidence of site having burned (unknown: 9)</td>
<td>yes</td>
<td>56</td>
<td>42</td>
<td>46.3</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>%</td>
<td>p</td>
<td>N</td>
</tr>
<tr>
<td>EPBC-listed community</td>
<td>yes</td>
<td>70</td>
<td>38</td>
<td>54.7</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>%</td>
<td>0.15</td>
<td>108</td>
</tr>
<tr>
<td>Sign of grazing/ browsing mammals other than horses detected</td>
<td>yes</td>
<td>38</td>
<td>25</td>
<td>30.0</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>%</td>
<td>0.07</td>
<td>63</td>
</tr>
</tbody>
</table>

The proportion of horse-present sites that showed evidence of recent fire was lower than that for horse-free sites (46% versus 76%, p<0.001). There were no significant differences among horse-present and horse-free sites with respect to the percentage of sites with evidence of wombats, macropods and feral goats, rabbits, feral pigs and deer; drainage system width; stream channel width or the percentage of sites that were classified as part of the Commonwealth-listed Alpine Sphagnum Bogs and Associated Fens Endangered Ecological Community.

Feral horse impacts on soils and stream stability

Following analyses adjusting for site altitude, recent fire status and State, significant differences among horse-present and horse-free areas were detected for all variables related to soil and stream...
stability ($P < 0.001$ for all, Fig. 2, Table 3). The average scores were lower for horse-present sites than for horse-free sites for each variable assessed. For all variables, lower scores mean poorer condition.

Figure 2. Distribution of data for variables relating to soils and stream stability for horse-free and horse-present sites. a. Stream bank stability, b. Pugging damage, c. Longitudinal profile of drainage line, d. Sediment level on stream bed, e. No. of defined animal paths or pads within 20 m of drainage system, f. Level of impact of defined animal tracks or pads, g. Grazing disturbance on banks/in channel. Lower scores signify poorer condition; red line indicates mean value.
**Feral horse impacts on vegetation**

Only two vegetation-related variables were assessed; projected foliage cover and the proportion of foliage cover that is native. No significant differences were detected among horse-present and horse-free areas for either of these variables (Table 3).

**Subgroup analysis excluding sites with signs of wombat, macropod and/or other exotic grazing and browsing mammals**

To remove the potential influence of wombats, macropods and exotic grazing and browsing mammals on soil, stream stability and vegetation cover, the data were re-analysed excluding sites where evidence of the presence of any of these species was detected. A total of 61 sites were excluded in this subgroup analysis (horse-present: 37, horse-free: 24). Thus, the number of sites that were available for analysis was 115 (Table 3). Our conclusions drawn from the analysis of the full data also applied to this subgroup analysis. Examination of the mean scores calculated for the full data set and this subgroup were very similar suggesting that the influence of other grazers and browsers may be minor.

**Subgroup analysis including only sites that were alpine bogs**

Because of their high conservation value, separate analyses were done considering only sites that were classified as alpine bogs. A total of 78 sites were analysed (horse-present: 46, horse-free: 32). When only data from sites that were alpine bogs were considered, our conclusions were the same as those drawn from the analysis of the full data set. In addition, we detected a statistically significant difference in projected foliage cover among horse-present and horse-free sites in this subgroup analysis (p = 0.03). However, the values in the 95% confidence interval for the estimated mean difference were so small that we concluded that the difference was negligible.
Table 3. Analysis of the impacts of feral horses on soils, stream stability and vegetation

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Analysis of the full data (N = 176)</th>
<th>Analysis excluding sites with signs of wombat, macropod and other exotic grazing and browsing mammals (N = 115)</th>
<th>Analysis including only sites that were alpine bogs (N = 78)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horse-present group mean score</td>
<td>Horse-free group mean score</td>
<td>Estimated mean difference (HP minus HF, 95% CI)</td>
</tr>
<tr>
<td>Soil and stream stability indicators</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream bank stability</td>
<td>3.3</td>
<td>4.8</td>
<td>-1.4 (-1.7, 1.1)</td>
</tr>
<tr>
<td>Pugging damage</td>
<td>2.4</td>
<td>4.0</td>
<td>-1.5 (-1.7, 1.2)</td>
</tr>
<tr>
<td>Longitudinal profile characteristics</td>
<td>2.6</td>
<td>4.0</td>
<td>-1.3 (-1.6, 1.0)</td>
</tr>
<tr>
<td>Sediment on stream bed</td>
<td>2.3</td>
<td>3.0</td>
<td>-0.6 (-0.8, 0.4)</td>
</tr>
<tr>
<td>No. defined animal paths or pads within 20m</td>
<td>1.5</td>
<td>3.8</td>
<td>-2.2 (-2.5, 2.0)</td>
</tr>
<tr>
<td>Level of impact of animal tracks or pads</td>
<td>2.4</td>
<td>3.8</td>
<td>-1.4 (-1.6, 1.2)</td>
</tr>
<tr>
<td>Indicator</td>
<td>Analysis of the full data (N = 176*)</td>
<td>Analysis excluding sites with signs of wombat, macropod and other exotic grazing and browsing mammals (N = 115)</td>
<td>Analysis including only sites that were alpine bogs (N = 78)</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------------------------</td>
<td>---------------------------------------------------------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Horse-present group mean score</td>
<td>Horse-free group mean score</td>
<td>Estimated mean difference (HP minus HF, 95% CI)</td>
</tr>
<tr>
<td>Grazing disturbance on banks and in channel</td>
<td>2.2</td>
<td>3.9</td>
<td>-1.5 (-1.8, -1.2)</td>
</tr>
<tr>
<td>Vegetation variables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projected foliage cover</td>
<td>4.9</td>
<td>5.0</td>
<td>-0.1 (-0.2, 0.03)</td>
</tr>
<tr>
<td>Proportion of foliage cover that is native vegetation</td>
<td>4.9</td>
<td>4.9</td>
<td>0.04 (-0.05, 0.1)</td>
</tr>
</tbody>
</table>

*for grazing disturbance on banks and in channel, N = 164
Discussion

Our study has shown clearly that feral horses are having adverse impacts on the condition of treeless drainage lines across the Australian Alps. Specifically, the condition of many of the variables we assessed was significantly worse in horse-present sites than in horse-free sites. This is consistent with the findings of other studies in the Australian Alps.

In a study of four small catchments covering approximately 500 ha in the Snowy Mountains of New South Wales, Dyring (1990) found that trampling by feral horses creates extensive track networks leading to higher levels of soil compaction and erosion, reduced plant species richness and changes in vegetation structure, as well as damage to streambanks. Other studies using exclosure plots at Native Cat Flat and Cowombat Flat in Victoria have also demonstrated that feral horses degrade streams, streambanks and vegetation. Outside exclosure plots, stream incision and channelling, soil compaction, bank disturbance and erosion are higher, vegetation cover is lower and vegetation structure is less complex than inside exclosures (Prober and Thiele, 2007; Wild and Poll, 2012).

Both of these studies were relatively localised. Prior to our study, the only work to document feral horse impacts across a large area of the Australian Alps landscape was that of Tolsma (2009), who assessed the status of 424 alpine mossbeds across the Victorian Alps. While he considered a broader range of impacts than just those caused by feral horses, he recorded pugging, trampling or wallowing by feral horses at 97% of alpine mossbeds in the Eastern Alps unit of the Victoria’s Alpine National Park (the area of the Alps where the majority of feral horses occur in Victoria). Our work builds on these earlier studies, and although not the first study to demonstrate impacts of feral horses on Australian alpine ecosystems, it is the first study to investigate this issue across the Australian Alps landscape.

Feral horses are widespread across the Australian Alps (Dawson, 2009), with the current range estimated to cover around 756,600 ha (Cairns, 2014). However, within that range, around 195,000 ha is steep or rocky terrain that may not be widely-utilised by feral horses. Even if we discount this steep and rocky terrain, feral horses occur across a large portion of the Alps landscape. Our study has demonstrated that feral horses are having a significant impact on the condition of drainage lines across this range. Almost all sites assessed within the broad horse distribution showed evidence of horse presence, and all of the sites in poorest condition were occupied by horses. This is illustrated by the maps in Figure 3, which show site condition with respect to three of the variables we assessed. Signs of horse impact were evident even in the most isolated sites. For example, in the Suggan Buggan Range east of the Ingeegoodbee River in the Pilot Wilderness, even the headwaters of the creeks in sites not usually characterised as horse habitat are affected by feral horses (Fig. 4). To access one site, horses have travelled for approximately 2 km through dense post-fire regrowth and away from an area that would appear to be better habitat. This suggests that even the most isolated areas are at risk of degradation by feral horses.

We note that on average, horse-present sites were 200m lower in altitude than horse-free sites (1379m and 1579m respectively, p < 0.001, Table 2a and 2b). This is a consequence of
horse distribution across the Australian Alps. The horse-free area in NSW is largely an elevated plateau dissected by steep valleys located between the Alpine Way and the Snowy Mountains Highway. Similarly in Victoria, the horse-free area was on part of the Bogong High Plains. At higher altitudes, greater levels of precipitation and snow create greater potential for erosion, while the shorter growing season for plants will result in slower recovery rates after disturbance than at lower altitudes. Consequently, we do not believe that the difference in altitude biases our results in favour of detecting impacts of feral horses on vegetation, soil or streams. Rather, we believe it masks detection of any effects.

We assessed variables related to soil and stream stability and to vegetation. All soil and stream stability variables assessed in this study were significantly worse in horse-present sites than horse-free sites. Impacts from feral animals such as pigs or rabbits, or from native animals such as wombats appeared to be minor.

Horse-present sites have higher levels of streambank disturbance, bank collapse and sedimentation than horse-free sites. Some sites were highly-impacted, with heavily grazed vegetation, pugging damage, large areas of exposed soil and stream bank collapse. Other sites showed only minor levels of impact; however this situation can change rapidly. At one site assessed in 2010 as part of a trial to develop our assessment method, there was very little evidence of feral horse impacts. By the time this site was re-assessed in 2011, feral horses had created a new stream crossing, damaging the streambank and exposing areas of bare soil. Similarly, at a location within 2 km of Mt Kosciuszko, where a population of around 15 – 20 feral horses has recently established, drainage lines are already showing signs of damage from feral horses (GR pers. obs.).

A consequence of reduced streambank stability is increased levels of erosion resulting in higher levels of sediment on the stream bed. When horses sink into saturated soils, damage to the streambank can result in dislodgement of large clods of soil into the stream (Fig. 5). Water flow disaggregates the soil, with the larger particles remaining visible on the stream bed and the finer particles transported down-stream. We found that on average, about 28 metres of the streambed in each 50 m site had a moderate to high sediment load in horse-present sites. In contrast, all of the horse-free sites showed very little sign of erosion, probably due to protection of the streambank soil provided by fringing vegetation.

Erosion has long been recognised as a significant threat to alpine and sub-alpine ecosystems in the Australian Alps. This was clearly demonstrated by investigations into the effects of stock grazing in the Australian Alps last century (Costin 1954). Erosion results in net export of soil and nutrients away from a site or landscape, reducing ecosystem function and productivity (Ludwig et al. 1997). It also results in sedimentation of streambeds and degradation of aquatic habitat. In-stream sediment can affect aquatic fauna in creeks and rivers. For example, Verkaik et al. (2014) suggest changes in aquatic macroinvertebrate fauna composition in creeks in Victoria after fires in 2006 are “probably caused by increases in erosion, sediment transport, nutrients and organic matter”. Erosion and sedimentation caused by feral horses may have similar effects on aquatic fauna.
Figure 3. Maps showing scores for each site relating to (a) stream bank stability, (b) longitudinal profile and (c) sediment on the stream bed. Circles represent horse-present sites and triangles represent horse-free sites. The colour of the symbols relates to the condition of each variable, grading from red (poorer condition) to green (better condition).
Figure 4. Horse damage on an isolated headwater in the Suggan Buggan Range.

Figure 5. A clod of soil excised from the bank as a result of feral horse activity along the Little Thredbo River (NSW).
Reduced stability of streambanks, erosion of soil and modification of vegetation structure have significant implications for biodiversity conservation. These processes degrade habitats that are critical for conservation of a wide range of threatened flora and fauna that occur in the Australian Alps. Consequently, impacts of feral horses are identified as a major threat to a number of threatened species listed under New South Wales, Victorian and Commonwealth threatened species legislation. For example, damage to streambank integrity can threaten survival of the threatened Alpine Spiny Crayfish *Euastacus crassus* (Horwitz 1990 In DSE 2003a). Similarly, the Alpine Water Skink *Eulamprus kosciuskoii* (Fig. 6) is listed under the Victorian *Flora and Fauna Guarantee Act 1988*. This species occurs in *Sphagnum* mossbeds and adjacent wet heath along drainage lines in the Australian Alps (DSE, 2003b; Steane et al., 2005). Grazing or trampling of this habitat by feral horses is a recognised threat to this and other species (e.g. Alpine Bog Skink *Pseudemoia cryodroma*, Alpine She-oak Skink *Cyclodomorphus praealtus* and Alpine Tree Frog *Litoria verreauxii alpina* that use similar habitat (DSE 2003b). These and other impacts have led to the listing of “Degradation and loss of habitats caused by feral Horses (*Equus caballus*)” as a potentially threatening process under the Victorian *Flora and Fauna Guarantee Act 1988*.

Figure 6. The Alpine Water Skink *Eulamprus kosciuskoii* an endangered species whose habitat is threatened by feral horses (Nick Clemann).

The most critical impact of feral horses in the Alps is the damage they cause to Alpine Sphagnum Bogs and Associated Fens. This is an endangered ecological community listed under the Commonwealth *Environment and Biodiversity Conservation Protection Act 1999*. This is synonymous with the Alpine Bog Community and the Fen (Bog Pool) Community listed as threatened under the Victorian *Flora and Fauna Guarantee Act 1988* and the Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions, listed as an endangered ecological community under the New South Wales *Threatened Species Conservation Act 1995*.

The impacts of feral horses are considered one of the greatest threats to the Alpine Sphagnum Bogs and Associated Fens Endangered Ecological Community (Department of
Environment, 2014). Horses enter bogs and fens to access water and to feed on more palatable species that occur within these systems. Such species include Carex gaudichaudiana which is highly-palatable (Costin, 1954; Wahren et al. 2001). Grazed Carex leaves were observed at a number of sites (e.g. see Fig. 7) within horse-present areas, whereas signs of grazing on Carex were not evident in horse-free areas. As a result of entering bogs, feral horses pug soils and trample plants, causing higher levels of water turbidity, damaging the Sphagnum and other vegetation, exposing peat soils, creating channels and altering water flow that may result in increased drying of bogs and fens (Whinam & Chilcott 2002).

![Figure 7. Grazed Carex gaudichaudiana and pugging of soil by feral horses in a fen on Currango Plain (NSW).](image)

When we considered only sites that were classified as Alpine Sphagnum Bogs and Associated Fens, all of the effects detected for drainage lines across the broader landscape were evident. We also detected a difference in projected foliage cover among horse-free and horse-present sites, with slightly lower projected foliage cover in bogs in horse-present areas than in horse-free areas. However, the values in the 95% confidence interval for the estimated mean difference were so small that we concluded that the difference was negligible.

While most soil and stream stability variables assessed differed significantly among horse-free and horse-present sites, we did not detect significant differences in projected foliage cover. This may be a consequence of natural variation in vegetation communities across the landscape. Our sites span a range of vegetation communities that differ in composition and
structure. We did not make detailed assessment of species composition or structural measures such as height. It is possible that these attributes do vary among horse-present and horse-free sites. Although we did not measure vegetation structure, we did photograph each site. For grassy sites, vegetation appeared to be lower in horse-present sites than horse-free sites, perhaps as a consequence of horses grazing palatable grasses and other plants (e.g. Fig. 8). This difference was less apparent for sites with dense shrubby vegetation.

![Image](image_url)

**Figure 8.** An example of commonly observed differences in vegetation structure between horse-free (upper photo) and horse-present sites (lower photo).

Differences in vegetation structure resulting from horse grazing has been demonstrated in other studies using exclosure experiments in various locations and ecosystems around the world (e.g. Turner 1987; Beever & Brussard 2000; De Stoppelaire *et al.* 2004). Importantly, impacts of feral horse grazing on vegetation structure have also been demonstrated in the
Australian Alps through the exclosure plot experiments established at Native Cat Flat and Cowombat Flat. At these sites, vegetation inside horse exclosures comprises a dense sward of sedges and grasses, whereas outside the exclosure plots, vegetation is typically a low herbfield turf (Prober and Theile 2007; Wild and Poll 2012). To understand of impacts of feral horses on vegetation composition and structure across the Australian Alps, targeted assessments of these attributes would be required.

Damage caused by feral horses is widespread across the Australian Alps. Our study focused only on treeless drainage lines (including Alpine *Sphagnum* bogs and associated fens). However, feral horses occur at virtually all elevations and of the Australian Alps (Walter 2002) and utilise a range of habitats and ecosystems, with evidence of their impacts evident in many areas. Dyring (1990) reported that feral horses created extensive track networks, with associated soil compaction, vegetation disturbance and soil erosion across each of her study areas. These included not only drainage lines, but also grassland, heath, wet forest and sub-alpine woodland. We have observed extensive track networks in many areas additional to Dyring’s sites.

Bishwokarma et al. (2014) undertook Landscape Function Analysis inside and outside exclosure plots established in 1984 in White Cypress Pine (*Callitris glaucophylla*) -White Box (*Eucalyptus albens*) woodlands of the lower Snowy River Valley of NSW. They found that variables associated with soil stability (erosion), water infiltration and nutrient cycling were lower in plots accessible to grazers than areas inside exclosure plots. They suggested these differences were due to activity of herbivores, particularly grazing and trampling by feral horses, as although other herbivores utilised their study site, signs of species other than feral horses were rare.

Further impacts are observed at sites where horses congregate regularly (sometimes called horse camps). Such sites are common in open grassy woodland areas of the Eastern Alps in Victoria (e.g. Fig. 9). At these sites, impacts of feral horses are pronounced. The vegetation is often damaged by trampling, ground cover is sparse, soil compaction is evident and there are extensive areas of bare ground (DB pers. obs.). Although no comprehensive assessment has been undertaken to quantify the magnitude and extent of these impacts across the alps, the signs of damage to soil and vegetation are obvious and it is clear that feral horses are affecting many areas of the alps.

Additional evidence of broader impacts comes from the work of Porfirio et al. (2014), who used remotely-sensed data to assess the fraction of photosynthetically active radiation that is intercepted by the green vegetation [(fPAR) in the 250 x 250 m area surrounding 171 of our study sites across the Australian Alps. The fPAR score is directly associated with vegetation cover; lower scores mean lower vegetation cover. They found that fPAR scores were lower in horse-present areas than in horse-free areas. Their results complement ours by demonstrating that impacts of feral horses extend well-beyond the narrow riparian zone we assessed, and affect the broader vegetation in the landscape surrounding our sites. Consequently, impacts of feral horses present significant implications for land management and biodiversity conservation not only for drainage lines and mossbed systems, but also for a wide range of habitats and ecosystems across the alps.
Not only are impacts widespread, the threats posed by feral horses to ecosystems of the alps are likely to increase. Feral horse abundance is increasing (Cairns, 2014). Given the current impacts of feral horses in the Australian Alps, increasing horse abundance may place further pressure on ecosystems that are already at risk from the effects of climate change. Alpine and sub-alpine communities and species have been identified as among those most at risk from climate change (Basher et al. 1998, Pittock 2003, Steffen et al. 2009). Among these is the Alpine Sphagnum Bogs and Associated Fens endangered ecological community, listed under the Commonwealth *Environment and Biodiversity Conservation Protection Act 1999*. White (2009) examined the impacts of climate change on this community in the Victorian alps. She found that climate change and grazing and trampling by mammals (including horses) were among the greatest threats to this ecosystem. While it may not be possible to alleviate the direct threats of climate change, reducing other pressures may enhance the resilience of vulnerable ecosystems to the effects of climate change (Steffan et al. 2009).

White (2009) argues that the resilience of alpine bogs could be enhanced by maintaining their structural integrity. Our results and those of others demonstrate clearly that feral horses damage the structural integrity of mossbeds and drainage lines in the alps, and consequently, degrade habitat of many species of plant and animal that depend on these habitats. Reducing the damage caused by feral horses may thus reduce the vulnerability of sensitive alpine communities and species to the pressures of climate change.

Reduction in the level damage caused by feral horses across the Australian Alps will not occur without management intervention to prevent further impacts and allow for recovery. In addition, while reducing pressure from feral horses may assist recovery, active rehabilitation may also be needed in some areas.
Whilst we have demonstrated that feral horses impact upon the condition of treeless drainage lines across the alps, other work demonstrates that recovery from these impacts is possible. The exclosure plot studies at Native Cat Flat and Cowombat Flat in Victoria were established in 1999. Assessments at the time of establishment indicated no initial bias in the allocation of plots to fenced or unfenced treatments (Prober and Thiele 1999). Over the time since the establishment of that study, there has been improvement in the condition of the streambank and greater vegetation growth inside fenced plots when compared to unfenced plots (Prober and Thiele, 2007; Wild and Poll, 2012).

Recovery of alpine ecosystems from the impacts of feral horses may not be rapid in all areas or habitats. For example, after more than a century, the practice of seasonal livestock grazing and burning in Kosciuszko National Park ceased in 1974. Whilst there has been recovery in the condition of bogs, this has taken many decades, and for sites that have been severely disturbed, “subclimax conditions may persist indefinitely” (Wimbush and Costin, 1979b). Further grazing research in the Australian Alps showed that recovery of the herbaceous inter-tussock flora took more than 20 years in the absence of grazing, with no recovery at all in sites that continued to be grazed (Williams et al 2014, Wimbush and Costin, 1979a).

Although previous studies have demonstrated the potential for recovery, this has been at relatively localised scales. Further research to better-understand the capacity for recovery of ecosystems of the Australian Alps from the impacts of feral horses at broader scales would greatly improve understanding of the value of management strategies aimed at reducing the abundance of feral horses. The increasing application of adaptive management principles within land management agencies provides an opportunity to couple management programs (including current approaches such as trapping and mustering) with well-designed monitoring to investigate this issue thoroughly.
References


**Appendix 1**

**Description of assessment categories for each of the indicators assessed for each site (or sub-section of site line where sites were subdivided)**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Assessment Categories and Scores</th>
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</table>
| Stream bank stability | 1. Drainage line walls nearly vertical and greater than 30 cm high. Signs of active erosion include side-wall caving, shearing and mass wasting. Extensive slumping of bank into stream: point bars on inside edge of stream bends.  
                             2. Drainage line walls also near vertical but < 30 cm high sheared face: signs of soil loss from the bank into the stream bed are less severe: slight undercutting of walls on the outside of bends, and significant slumping visible along drainage line walls.  
                             3. Drainage line wall angles moderate with bank edges typically not vertical, but clear evidence of soil disturbance (such as pugging, compaction) or soil loss.  
                             4. Drainage line wall angles low to moderate and clearly shedding small amounts of sediment; width greater than depth. Maybe some low, small sediment deposits at base of side walls.  
                             5. Indications of spontaneous restoration (from fire). Little if any evidence of soil disturbance or loss visible. Drainage line walls strongly vegetated by a range of life-forms. Drainage line has obviously been stable for a considerable period of time: |
| Pugging damage      | 1. Extensive soil disturbance by deep pugging > 25/m².  
                             2. Significant soil disturbance by pugging, moderately deep, 10-25/m².  
                             3. Noticeable soil disturbance by pugging, < 10 per m², and shallow.  
                             4. No soil disturbance visible or very shallow and less than 5/m². |
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Assessment Categories and Scores</th>
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</thead>
<tbody>
<tr>
<td>Longitudinal profile characteristics of a drainage line</td>
<td>1. Drainage line significantly broadened by extensive bank slumping: sometimes connected to bare areas such as horse-wallows. Resource flow is from bank to stream, often via incised horse tracks and slumping. Flood plain may be laterally draining rapidly into the stream.</td>
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<td></td>
<td>2. Drainage line channel being straightened by bank slumping to form a pediment; point bars visible on inside of bank curves. Floodplain draining into channel very slowly and carrying sediment.</td>
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<tr>
<td></td>
<td>3. Drainage line channel has meandering bed shape, without point bars, few if any slumped pediments. Floodplain draining into channel very slowly</td>
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<td></td>
<td>4. Drainage line channel well vegetated between non-cascading chain of ponds (when not flowing), or gently meandering continuous stream (wet), or diffuse flow between dense vegetation elements. This type of channel is closely connected to its floodplain and gentle over-bank water extension may occur at moderate flow rates.</td>
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<tr>
<td>Sediment level on the stream bed</td>
<td>1. Displaced soil material from bank in the form of clods or “islands”, readily mobilised by downstream flow. Very low soil cohesion provided by bank vegetation.</td>
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<td></td>
<td>2. Materials on the drainage line floor are comprised of eroded and/or slumped bank material. Bank vegetation providing soil coherence in displaced material; low but noticeable potential for downstream movement.</td>
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<td></td>
<td>3. Materials on the drainage line floor show few if any signs of transport due to strong coherence provided by dense fringing plant root systems: low potential to be transported downstream. Bed is characterized by cohesive fine sediment/organic matter floors or cobbles, no signs of downstream sediment movement</td>
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<tr>
<td>Number of defined animal paths or pads within 20 m of drainage system</td>
<td>1. Multiple animal paths, or path(s) cross stream.</td>
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<td></td>
<td>2. Four or more animal paths on either side, but not crossing.</td>
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<tr>
<td></td>
<td>3. Less than four animal paths on either side, but not crossing.</td>
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<tr>
<td></td>
<td>4. No animal paths within 20 m on either side of stream for the 50 m transect.</td>
</tr>
<tr>
<td>Indicator</td>
<td>Assessment Categories and Scores</td>
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| **Level of impact of defined animal tracks or pads** | 1. Animal paths bare of vegetation and potentially incised into soil, sometimes eroded down to a rocky or gravelly base.  
2. Animal paths clearly visible and with some vegetation death: >25% soil exposed but not gravel or stone.  
3. Animal paths only lightly trampled, soil exposed less than 25%. Little or no vegetation death  
4. No animal paths tracks visible. |
| **Grazing disturbance on banks/in channel** | 1. Heavily grazed close cropped vegetation less than 4 cm high.  
2. Moderate grazing – average height of vegetation 5 cm or higher. Obvious “squared ends” on grazed plants.  
3. Low levels of grazing impacts, such as pulled grass tillers or light grazing evident.  
4. No grazing evident. |
| **Projected foliage cover** | 1. < 5% projected foliage cover (PFC)  
2. 5–25% PFC  
3. 25-50% PFC  
4. 50–75% PFC  
5. 75–100% PFC |
| **Proportion of foliage cover that is native vegetation** | 1. < 5% native projected foliage cover (PFC)  
2. 5–25% native PFC  
3. 25-50% native PFC  
4. 50–75% native PFC  
5. 75–100% native PFC |