Australasian Journal of Environmental Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tjem20

Patterns of road surface movement after three endurance horse-riding events in protected areas, south-east Queensland

R. Fairfax [a] , J. Neldner [a] , M. Ngugi [a] & R. Dowling [a]

[a] Queensland Herbarium, Department of Environment and Resource Management, Brisbane Botanic Gardens, Toowong

To cite this article: R. Fairfax, J. Neldner, M. Ngugi & R. Dowling (2012): Patterns of road surface movement after three endurance horse-riding events in protected areas, south-east Queensland, Australasian Journal of Environmental Management, 19:2, 122-132

To link to this article: http://dx.doi.org/10.1080/14486563.2012.664949

Australasian Journal of Environmental Management
Vol. 19, No. 2, June 2012, 122–132

Patterns of road surface movement after three endurance horse-riding events in protected areas, south-east Queensland

R. Fairfax, J. Neldner*, M. Ngugi and R. Dowling

Queensland Herbarium, Department of Environment and Resource Management, Brisbane Botanic Gardens, Toowong

Reviews of horse-riding impacts usually mention degradation of trails, watercourses and vegetation. These potential impacts are of current relevance within some south-east Queensland protected areas where the future of horse-riding is subject to studies on biophysical and social impacts. This study aimed to provide an indication of soil movement patterns on vehicular roads in response to three separate endurance riding events, which represent the most intense horse use of these roads with up to 300 passes in one day. A measure of the areal extent and depth of erosion was obtained from at least 16 sections of road at each event. Across the study, there was an average increase in eroded area of less than 2 per cent and decrease of erosion depth by less than 1 mm. Linear mixed effects modelling revealed that soil movement was weakly related to slope and field texture, where the steeper the slope and softer the surface the more movement. Soil movement could be predicted using pre-existing road characteristics alone and the number of horse passes was not significant in soil redistribution. While no other data on horse-related soil movement from such roads is known, this study supports the contention that harder surfaces (i.e. graded, built-up vehicular roads) would suffer less soil loss than other track types. There was no evidence to suggest that the combination of vehicle tracks and horse use compounded soil loss. Where other maintained vehicle tracks elsewhere within protected areas are like those studied here, it is expected that high-use horse-riding would have little impact on the road surface additional to other uses.

Keywords: Equus; erosion; National Park; protected area; track; trail

Introduction

Protected areas around the world are subject to various potentially compromising land uses. Contemporary examples from Australian protected areas include grazing (e.g. Mosley 2011), privatised built visitor accommodation (e.g. Queensland Government 2010), pipe and power-line easements (e.g. Johnstone 2009) and mining (Burke 2011; DEEDI 2011). Visitor use is also expected to increase across the park estate in Queensland (Auditor-General of Queensland 2010). Recreation and tourism use can have negative impacts on flora, fauna, water and soils (Kelly et al. 2003; Turton 2005; Pickering & Hill 2007). Issues include uncontrolled access, trampling, dispersal of weeds and pathogens, soil compaction and erosion; with impacts associated with different activities, including bushwalking, mountain bikes, trail bikes and horse-riding (Pickering et al. 2010).

---

*Corresponding author. Email: john.neldner@derm.qld.gov.au

ISSN 1448-6563 print/ISSN 2159-5356 online

http://dx.doi.org/10.1080/14486563.2012.664949
http://www.tandfonline.com

Australian reviews on biophysical impacts of horse-riding document studies relating to: trail widening; erosion and compaction; sedimentation and nutrification of creeks; the spread of weeds and pathogens; disruptions to the fungal mycelial network; and reductions in plant height and cover (Landsberg et al. 2001; Newsome et al. 2002; Beavis 2005; Newsome et al. 2008; Pickering 2008). However, all reviews variously refer to the dearth of information on such impacts; that existing studies may not necessarily apply elsewhere for a range of reasons, including differences in soil type, trail conditions and the frequency and intensity of use; and that described impacts are not necessarily related to horses alone. For example, although the combined literature suggests that horse-related erosion on well constructed and maintained roads (such as graded vehicular roads and fire breaks) would be less than on other types of trails, there is limited research on the topic (see also Pickering et al. 2010) and the need for such a targeted study has been described as urgent (Landsberg et al. 2001).

This study aimed to provide an indication of horse-related movement of soil on roads of the Horse Riding Trail Network of south-east Queensland (SEQ). The surface condition, including levels of soil movement, was assessed before and after three separate competitive endurance horse-riding events. These events represent the most intense horse use of these areas.

Methods

Study area

In SEQ, several state forests with long and continuous histories of recreational horse-riding were re-gazetted as national parks under the SEQ Forests Agreement 1999. Under the Queensland *Nature Conservation Act 1992*, horse-riding is not permitted within national parks, although the state government has also committed to no net loss of recreation, including horse-riding, in these areas. Thus, the SEQ Horse Riding Trail Network was created which consists of a Forest Reserve tenure (which permits horse-riding) covering roads within these areas. A code of conduct has been established for horse-riding on the Trail Network (Pickering 2008; DERM 2010a). To further inform future management of these areas, a monitoring program has been commissioned to investigate potential impacts of recreational horse-riding in forest reserves (DERM 2010b). This study observed soil surface conditions immediately before and after intense horse use.

Roads within Beerburrum West State Forest (26°57′S, 152°49′E) were used in the Murrumba Magic endurance riding events of 2 August 2009 and 7 August 2010. Both events started and finished with approximately 100 shod horses. Terrain is flat throughout (slope <3 per cent), soils are derived from decomposed quartzose sandstone and are predominantly sandy, although some artificially raised sections consisted of coarse aggregates (<20 mm). All surfaces are unsealed. Most of the road surface was bare, although limited grass cover occurred on the more irregularly used roads. Creek crossings were running during both events, although poorly drained areas of roads dry in 2009 were wet in 2010.

Sampling also occurred on the Lake Manchester Endurance Ride of 24–25 July 2010 which was held on the SEQ Trail Network adjacent to D'Aguilar National Park and on land managed by SEQ Water (27°27′S, 152°46′E). This event consisted of about 140 horses with some sites also sampling a training ride involving 30 horses. The roads were constructed on loamy clays or gravelly loams derived from meta-sediments. Most of the roads were bare with very few grass-covered sections. The trail also covered slopes ranging from flat to 28 per cent, and included both wet and dry creek crossings.

Roads of all courses had been graded and were mainly level in cross-section. They are primarily used by land managers' vehicles for access and, in some cases, as firebreaks. The roads are also used by trail bikes, bicycles, bushwalkers, dogs and horse riders, although the precise patterns of use by each is not known. Information from land managers suggest that horse use outside these events is in the order of a maximum of 20 per year at Lake Manchester, predominantly in the weeks prior to the event (IanWitheyman, Ranger, 2011, pers. comm., 24 March), and an estimated maximum of three to four groups of one or two horses per week only on the most well-used roads at the Murrumba location (Norm Taylor, Ranger-in-Charge, 2011, pers. comm., 24 March).

Sampling

Site selection aimed to capture the diversity of physical characteristics represented by the routes. Factors considered include adjoining vegetation types, creek crossings, ascents, descents and flat surfaces. Slope (per cent) was initially determined by intersecting a GIS coverage of the horse-trail network with a digital terrain model and subsequently confirmed in the field. Site locations were further refined during the pre-event measurements to represent different surface and road conditions. Variations in horse numbers were sampled by placing sites on parts of the course passed by horses once, twice, thrice or four times. The Murrumba Magic event of 2009 contained 18 sites, 17 of which were repeated in the 2010 event and 20 sites were conducted in Lake Manchester.

The 'variable interval cross-sectional area method', employed by Olive and Marion (2009) to measure soil loss, was adapted and used at each site. A straight transect line was drawn perpendicular to the road along which were placed as many complete contiguous square metre quadrats that could span the width of a road (3.3 on average across all sites). The precise quadrat location was recorded to enable resurvey of the quadrat post-event.

The following information was recorded from each quadrat the day before and day after the events with the exception of one two-day hiatus: the number of partial and whole horse prints; the number of horses that traversed a site and a photograph. The following was also estimated by at least the same two observers before and after each event: per cent area affected by four and two-wheeled vehicles, exposed roots, leaf litter, bare ground, coarse substrate fraction ($>$20 mm diameter), coarse woody debris ($>$10 cm diameter), living vegetation and horse manure. Erosion before the event ('pre-erosion') was also measured and defined as the proportion of quadrat area where the soil surface undercut an assumed level surface. For example, if a quadrat contained a wheel rut 15 cm wide, then 15 per cent of that quadrat had an eroded surface. Erosion after the event is defined as the corresponding value post-event ('erosion'), with the absolute difference between the two defined as 'soil movement'. A measure of erosion depth was also obtained by measuring the deepest point below mean ground surface along the transect line for each quadrat, both before and after the event ('pre-incision depth' and 'incision depth').

In the above example, if the wheel rut prior to the event was 2 cm deep, the pre-incision depth is 2 cm. 'Change in depth' is the difference between these two values either side of the event. Field texture was also described and based on the 'condition of the soil surface when dry' at the time of the event (McDonald & Isbell 2009, p.189). ‘Field texture’ of each quadrat was accordingly assigned ‘loose’, ‘soft’, ‘firm’ or ‘hard’, reflecting a gradient from sand to clay.

Footprints and tyre marks of each user at the initial monitoring were infrequent excepting vehicles and trail bikes. The majority of quadrats were not traversed by users other than horses between the events and subsequent monitoring.

Statistical analysis

Two sites adjoined creek crossings and were deleted from the analysis as they were affected by wash pushed up by vehicles. Linear mixed effects models were used to predict both ‘erosion’ and ‘soil movement’ on all remaining quadrats using the following variables: the number of horse passes; ‘pre-erosion’; bare ground; the presence of vehicular tyre tracks; per cent slope; and field texture. Linear mixed effects models were also constructed to predict ‘incision depth’ and ‘change in depth’ using ‘pre-incision depth’, the number of horse passes, bare ground, the presence of vehicular tyre tracks, per cent slope and field texture.

The number of horse prints was not used as a predictor because it did not accurately represent the number of horses (on softer surfaces prints made from the first passes were subsequently obliterated by later passes and on some harder surfaces prints were not visible). Leaf litter was not used as it was significantly correlated with bare ground. Field texture was given a continuous value reflecting an estimated average indentation depth of hoof prints in that substrate at that time, whereby: ‘hard’ = 0; ‘firm’ = 2; ‘soft’ = 4; and ‘loose’ = 8. The cover of coarse woody debris, stones and vegetation were all minimal, did not significantly change between times, and were not considered further. Horse manure was rarely present and was not considered separately for analytical purposes.

The values of ‘soil movement’ and ‘change in depth’ were normally distributed amongst the quadrats and no transformations were employed. Linear mixed effects models (e.g. Buckley et al. 2003; Oberg & Mahoney 2007) were used to explore the individual and collective influence of all predictive variables. Pseudo-replication of quadrats was accounted for by treating the site as a random effect. Preliminary modelling revealed no difference between the 2009 and 2010 events at Murrumba; thus, these Murrumba events were combined and analysed separately from the Manchester event. Models were re-run after progressively deleting the most insignificant multiple-interaction until only significant interactions and their constituent individual variables remained. Where a model contained more than one predictive variable, a more parsimonious model was constructed using only the single-most significant variable (the ‘parsimonious model’). All models were re-run using the per cent cover of vehicle tyre tracks in lieu of the presence of vehicles, both with and without trail bikes.

Results

Variables describing the study sites are summarised in Table 1. Vehicle tyre tracks were evident on 51 per cent of quadrats before the events, and prints and/or manure on 51 per cent after the events. Across the study there was a significant positive correlation between quadrats with hoof prints and the presence of tyre tracks ($p < 0.02$), i.e. horses tended to use the same portion of the road as vehicles. The per cent cover of tyre tracks, with or without trail bikes, did not improve the models.

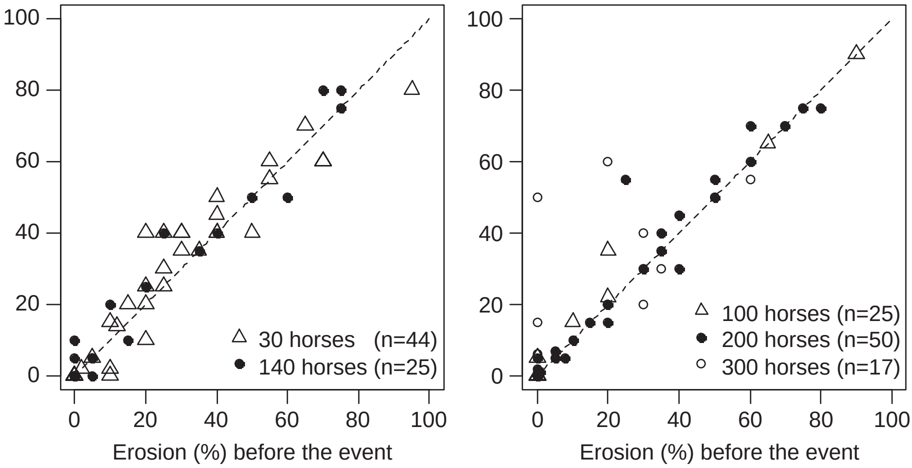

Figure 1. 'Erosion' before and after the event for each location
Note: 'Soil movement' is represented by the distance that points lie from the centre line. The number of horses and number of quadrats is also presented.

No roots became exposed as a result of the horse-riding events. Across the study, horse manure was present in 6 per cent of quadrats and, where present, typically covered less than 2 per cent of the quadrat area. Bare ground slightly increased at the expense of leaf litter and vegetation cover.

Erosion values and incision depths per quadrat were very similar before and after each event indicating that there was little effect of horse-riding on soil movement (Figures 1 and 2).

Seventy-nine per cent of quadrats demonstrated negligible soil movement (within 5 per cent of the original value), with 6 per cent showing gains of between 5 and 10 per cent, 5 per cent showing gains >10 per cent, 4 per cent showing losses of between 5 and 10 per cent, and 6 per cent losses >10 per cent (Figure 1). Across the

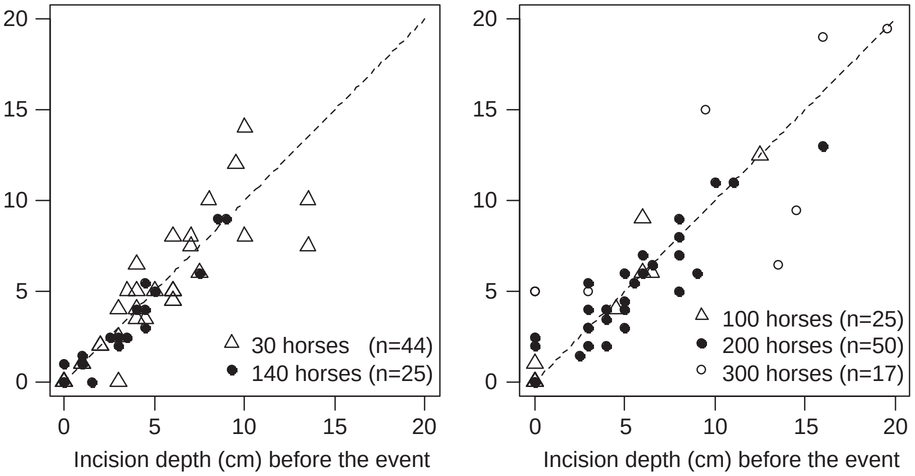

Figure 2. 'Incision depth' before and after the event for each location
Note: 'Change in depth' is represented by the distance that points lie from the centre line.

study there was an average increase in eroded area of <2 per cent and decrease of erosion depth by <1 mm. However, such values and those presented in Table 1 and Figures 1 and 2 do not account for the influence of predictive variables. To that end, models predicting 'erosion' and 'soil movement' for each location were constructed (Table 2) and are discussed below.

Lake Manchester

The extent of 'erosion' at the Lake Manchester sites prior to the event was the most significant variable in predicting 'erosion' after the event ($p < 0.001$), with slope an additional term in the model ($p < 0.05$, Table 2). The relationship between slope and soil movement is positive; that is, the higher the slope, the greater the movement, and slope alone was the best predictor of 'soil movement'. 'Incision depth' was highly correlated with its pre-event measurement and unrelated to any other variables. On average, 'incision depth' decreased after the event by 1.1 mm. The change in incision depth could not be predicted (Table 2).

Murrumba

The extent of pre-event erosion was also the strongest influence on 'erosion' at Murrumba, with field texture also weakly influential. In this trend, the looser the soil surface, the greater the soil movement. Surface condition was the best predictor of 'soil movement' and was influential in predicting 'incision depth'. Like Lake Manchester, incision depth pre-event was the most significant variable for predicting incision depth post-event. The latter variable was also the greatest predictor of 'change in depth', which increased, on average, by 7 mm on each quadrat. Over two-thirds of quadrats exhibited no change. Despite the extent or presence of tyre tracks being irrelevant for predicting incision depth across the sites, the greatest measured incision depth (80 mm) occurred on a muddy wheel rut incised by vehicles. The greatest change in depth ($+70$ mm) occurred in an adjacent rut at the same site.

For both locations, no other variables, either separately or in interaction, satisfactorily predicted soil movement. The number of horse passes at Lake Manchester was weakly significant ($p > 0.09$) although did not warrant inclusion in the final model (Figure 1).

Discussion

A strength of this study is that a wide range of horse passes was observed (30–300) and that this level of use greatly exceeds typical monthly horse use on the Horse Trail Network. While the study did not include control sites, soil movement over the course of the endurance rides can reasonably be attributed to horses. Despite the roads being previously used by vehicles (both four- and two-wheeled), and a strong correlation between vehicle and horse use of the same quadrats, prior vehicle use (either its presence or quadrat area affected) was not a significant predictor of any response variable across the study. It is likely that vehicle use subsequent to the events and any compounding interaction between horse and vehicle use on the same road surface after events would be minor. Indeed, typical vehicle use of these roads probably has a far greater impact on the road surface and soil movement than the endurance rides.

Table 1. Characteristics of the event locations and the average values and net changes in five variables

Event	% Slope (no. quadrats)	Field texture (no. quadrats)	No. horses (no. quadrats)	% Leaf litter (Δ)	% Bare ground (Δ)	% Vehicle tracks (Δ)	% Soil movement (Δ)	Incision depth (mm) (Δ)
Lake Manchester	<2 (18), 4–6 (20), 8–9 (14), 15–28 (17)	Soft (4), Firm (14), Hard (51)	30 (44), 140 (25)	33 (−0.8)	53.3 (−1.6)	6 (−5)	21.3 (−1.2)	3.26 (−0.12)
Murrumba 2009	<1 (41), 3 (2)	Loose (7), Soft (16), Firm (19), Hard (1)	100 (12), 200 (20), 300 (11)	17.9 (−2.1)	63.7 (−2.9)	13.2 (−5.4)	15.8 (−1.4)	3.78 (0.16)
Murrumba 2010	<1 (49)	Loose (7), Soft (15), Firm (20), Hard (7)	100 (13), 200 (30), 300 (6)	19.1 (−1.4)	65.6 (−3.7)	11.9 (−6.2)	15.5 (−2.2)	2.57 (0.21)

Table 2. Models predicting soil movement and the strength of their fixed effects

Location	Response	Model terms	Estimate (se)	*t*-value	*p*-value	AIC
Lake Manchester (n = 69)	'Erosion'	~pre-erosion	0.948 (0.03)	30.94	<0.001***	458.3
		+% slope	0.222 (0.105)	2.112	0.0498*	
		intercept	0.569 (1.244)	0.457	0.649	
	'Erosion' (parsimonious)	~pre-erosion	0.963 (0.03)	31.69	<0.001***	458
		intercept	2.139 (1.07)	1.989	0.052	
	'Soil movement'	~% slope	0.178 (0.101)	1.759	0.096	454
		intercept	−0.191 (1.150)	−0.166	0.869	
	'Incision depth'	~pre-incision depth	0.909 (0.046)	19.73	<0.001***	247.2
		intercept	0.173 (0.22)	−0.788	0.435	
	'Change in depth'	~pre-incision depth	0.091 (0.046)	1.971	0.054	247.2
		intercept	−0.173 (0.22)	−0.788	0.435	
Murrumba (n = 92)	'Erosion'	~pre-erosion	0.977 (0.037)	26.27	<0.001***	649.6
		+field texture	0.793 (0.386)	2.054	0.045*	
		intercept	−0.405 (1.626)	−0.249	0.804	
	'Erosion' (parsimonious)	~pre-erosion	0.988 (0.038)	26.11	<0.001***	651.6
		intercept	2.073 (1.127)	1.84	0.071	
	'Soil movement'	~field texture	0.760 (0.382)	1.99	0.051	643.2
		intercept	−0.649 (1.575)	−0.412	0.682	
	'Incision depth'	~pre-incision depth	0.693 (0.087)	7.959	<0.001***	373.7
		+field texture	0.167 (0.082)	2.037	0.046*	
		+pre-incision depth * field texture	0.045 (0.02)	2.177	0.034*	
		intercept	0.004 (0.324)	0.013	0.990	
	'Incision depth' (parsimonious)	~pre-incision depth	0.887 (0.038)	23.219	<0.001***	378.0
		intercept	0.522 (0.203)	2.589	0.012	
	'Change in depth'	~pre-incision depth	0.307 (0.087)	3.53	0.001***	373.7
		+field texture	−0.167 (0.820)	−2.037	0.046*	
		+pre-incision depth * field texture	−0.044 (0.020)	−2.772	0.034*	
		intercept	−0.004 (0.324)	−0.013	0.99	
	'Change in depth' (parsimonious)	~pre-incision depth	0.113 (0.038)	2.959	0.004***	378
		intercept	−0.522 (0.202)	−2.589	0.012	

Note: Where the final model includes more than one term, the most parsimonious model is also presented. Aikake's information criterion (AIC; Akaike 1974) represents a measure of model fit weighted against the number of explanatory variables, where a lower value reflects a better fit. * represents 95 per cent confidence that a variable is not influential by chance and *** represents >99 per cent confidence

Accurate measurement of erosion is difficult (Stroosnijder 2005), especially where there is a small amount of movement over a short timeframe. In this study, potential error exists with the estimations of areas affected; however, the significant predicting factors are intuitive, match field observations elsewhere within the courses, and are concordant with other studies (see below). The degree of soil movement was equally positive and negative, and it is therefore likely that observational error is represented by the spread around the trend, rather than the slope of the relationship or intercept on the y-axis (Figures 1 and 2). As expected, pre-existing erosion and incision depth measurements are influential on the corresponding post-event situation, partly because they were used to calculate the response variables and partly because they reflect a pre-existing propensity to be prone to soil redistribution. Regardless, the result that the slope of the road is positively influential in soil movement is commensurate with that of Upitis (1980) and Royce (1983) (cited in Beavis 2005 and Newsome et al. 2008 respectively). This study also supports the point made by Newsome et al. (2004) that softer less cohesive soils are more susceptible to erosion (e.g. the sandier, softer sites of this study); and the observations of Wilson and Seney (1994), where soil texture in combination with slope and wetness helped explain erosion in relation to road users. The quadrats with the greatest erosional loss were adjacent to creek crossings, which supports Pickering (2008) that creek crossings are particularly susceptible to horse-related erosion, and is consistent with other studies of horse-related erosion (e.g. Deluca et al. 1998). The most comprehensive modelling exercise in relation to soil loss on tracks in relation to different user groups also found that soil texture, slope and level of use were all significant predictors (Olive & Marion 2009).

Other studies have measured ‘incision depth’ or equivalent in relation to impacts of horses (Winnam et al. 1994; Winnam & Comfort 1996; Phillips & Newsome 2002; Olive & Marion 2009). While none of these studies is directly comparable, it is worth noting that all demonstrated larger soil losses than the current study (given fewer passes in Winnam et al. 1994 than this study). The negligible losses and gains observed here are also compatible with the conclusion of Landsberg et al. (2001) and Newsome et al. (2008), which predict greater impacts off-road, and support the conclusion of Winnam and Comfort (1996) who recommend hardening trail surfaces to minimise soil loss.

Although not tested here, personal observations also support the notion that on-road impacts are lesser than off-road. Isolated off-road trails were made to circumvent puddles or negotiate creek crossings during the Murrumba events. In such places, deep incisions in the soil and damage to vegetation were observed. All reviews on impacts of horse-riding highlight the sensitivity of waterways to horse use. Management strategies used to address such matters have been summarised in Newsome et al. (2008), the issue is specifically addressed in the code of conduct for horse riders on Forest Reserves (DERM 2010a) and, in a more recent example, horse camps have been relocated from around waterways in the Kosciuszko National Park (ABC News 2011).

Conclusion

This study demonstrated that after three major horse-riding events on dirt roads built for vehicles, the majority of sampled areas exhibited no change in the areal extent of eroded area or depth of erosion. Where soil movement was observed, it was positively related to slope or a softer substrate. The number of horses was not significant in soil redistribution. If other maintained vehicle tracks elsewhere within protected areas are like those studied here, high-use horse-riding events would be expected to have little impact on erosion *per se* additional to other road uses. Sites adjacent to sandy creek crossings (and from personal observations) were found to be the most affected, and any efforts to manage road users for soil movement should target such areas.

Acknowledgements

The authors thank David Somerville and Marty Branigan for assistance and advice with the Lake Manchester Endurance Ride, and Greg Jarrad for assistance with the Murrumba routes. Vehicle access was provided by SEQ Water, Queensland Parks and Wildlife Service, and Forestry Plantations Queensland. Don Butler created the slope coverage and, with Melinda Laidlaw, provided valuable assistance with the analysis. Thanks also to Tim Ryan for assistance with field work and identification of regional ecosystems. Bernie Powell and Calvin Rose provided advice on the sampling methodology. Bernie Powell and Gordon Guymer provided valuable comments on the draft manuscript. The manuscript was also considerably improved by the comments of two reviewers, to whom we are grateful.

References

ABC News 2011, 'Snowy horse camps get revamp', viewed 18 March 2011, <http://www.abc.net.au/news/stories/2011/03/02/>.

Akaike, H 1974, 'A new look at the statistical model identification', *IEEE Transactions on Automatic Control*, vol. 19, pp. 716–723.

Auditor-General of Queensland 2010, *Auditor-General's Report to Parliament No. 9 for 2010: Sustainable management of national parks and protected areas*, Queensland Audit Office, Brisbane.

Beavis, S 2005, 'Biophysical impacts of recreational horse riding in multi-use National Parks and reserves', *Australasian Journal of Environmental Management*, vol. 12, pp. 109–116.

Buckley, YM, Briesse, DT & Rees, M 2003, 'Demography and management of the invasive plant species *Hypericum perforatum*. I. Using multi-level mixed-effects models for characterizing growth, survival and fecundity in a long-term data set', *Journal of Applied Ecology*, vol. 40, pp. 481–493.

Burke, J 2011, SA 'Government considers Arkaroola mining ban', viewed 23 March 2011, <http://www.miningaustralia.com.au/news/sa-govt-considers-arkaroola-mining-ban--1>.

Deluca, TH, Petterson, IV, Freimund, WA & Cole, DN 1998, 'Influence of llamas, horses, and hikers on soil erosion from established recreation trails in western Montana, USA', *Environmental Management*, vol. 22, pp. 255–262.

DEEDI (Department of Employment, Economic Development and Innovation) 2011, Queensland (DEEDI), viewed 20 October 2011, <http://www.deedi.qld.gov.au/cg/coordinator-general-projects.html>.

DERM (Department of Environment and Resource Management) 2010a, *Code of conduct for recreational horse riding on multi-use trails in designated state forests, forest reserves and protected areas: Information Sheet, Parks and Forest Management*, DERM, Queensland, viewed 21 March 2011, <http://www.derm.qld.gov.au/parks_and_forests/activities_in_parks_and_forests/seq_horse_riding_trail_network/pdf/horse-riding-code-conduct.pdf>.

DERM (Department of Environment and Resource Management) 2010b, *Scientific monitoring program for the south east Queensland Horse Riding Trail Network*, DERM, Queensland, viewed 21 March 2011, <http://www.derm.qld.gov.au/parks_and_forests/activities_in_parks_and_forests/seq_horse_riding_trail_network/pdf/scientific_monitoring_program_horse_trail_network.pdf>.

Johnstone, C 2009, 'Desalination on Bribie? Bribie Island or Marcoola; desalination site kept secret', 4 November 2009, *Courier Mail*, viewed 21 February 2012, <http://www.couriermail.com.au/news/queensland/bribie-island-or-marcoola-desalination-site-kept-secret/story-e6freoof-1225794078489>.

Kelly, CL, Pickering, CM & Buckley, RC 2003, 'Impacts of tourism on threatened plant taxa and communities in Australia', *Ecological Management and Restoration*, vol. 4, pp. 37–44.

Landsberg, J, Logan, B & Shorthouse, D 2001, 'Horse riding in urban conservation areas: reviewing scientific evidence to guide management', *Ecological Management and Restoration*, vol. 2, pp. 36–46.

Mosley, G 2011, 'High country ought stay a cattle no-go zone', 8 March 2011, *Sydney Morning Herald*, viewed 21 February 2012, <http://www.smh.com.au/opinion/high-country-ought-stay-a-cattle-nogo-zone-20110307-1bka1.html>.

McDonald, RC & Isbell, RF 2009, 'Soil profile', in National Committee on Soil and Terrain, *Australian soil and land survey field handbook* (3rd edn), CSIRO Publishing, Melbourne.

Newsome, D, Cole, DN & Marion, JL 2004, 'Environmental impacts associated with recreational horse-riding', in R. Buckley (ed.), *Environmental impacts of ecotourism*, CABI Publishing, Wallingford, UK, pp. 61–82.

Newsome, D, Milewski, A, Phillips, N & Annear, R 2002, 'Effects of horse riding on national parks and other natural ecosystems in Australia: implications for management', *Journal of Ecotourism*, vol. 1, pp. 52–74.

Newsome, D, Smith, A & Moore, SA 2008, 'Horse riding in protected areas: a critical review and implications for research and management', *Current Issues in Tourism*, vol. 11, pp. 144–166.

Oberg, AL & Mahoney, DW 2007, 'Linear mixed effects models', in WT Ambrosius (ed.), *Topics in biostatistics*, Humana Press, Totowa, NJ.

Olive, ND & Marion, JL 2009, 'The influence of use-related, environmental, and managerial factors on soil loss from recreational trails', *Journal of Environmental Management*, vol. 90, pp. 1483–1493.

Phillips, N & Newsome, D 2002, 'Understanding the impacts of recreation in Australian protected areas: quantifying damage caused by horse riding in D'Entrecasteaux National Park, Western Australia', *Pacific Conservation Biology*, vol. 7, pp. 256–273.

Pickering, CM 2008, *Literature review of horse riding impacts on protected areas and a guide to the development of an assessment program*, Environmental Protection Agency, Brisbane, viewed 9 March 2012, <http://www.derm.qld.gov.au/register/p02813aa.pdf>.

Pickering, CM & Hill, W 2007, 'Impacts of recreation and tourism on plant biodiversity and vegetation in protected areas in Australia', *Journal of Environmental Management*, vol. 85, pp. 791–800.

Pickering, CM, Hill, W, Newsome, D & Leung, Y 2010, 'Comparing hiking, mountain biking and horse riding impacts on vegetation and soils in Australia and the United States of America', *Journal of Environmental Management*, vol. 91, pp. 551–562.

Queensland Government 2010, *Tourism action plan to 2012. List of actions*, Queensland Government, Brisbane.

Stroosnidjer, L 2005, 'Measurement of erosion: is it possible?', *Catena*, vol. 64, pp. 162–173.

Turton, SM 2005, 'Managing environmental impacts of recreation and tourism in rainforests of the wet tropics of Queensland World Heritage Area', *Geographical Research*, vol. 43, pp. 140–151.

Whinam, J, Cannell, EJ, Kirkpatrick, JB & Comfort, M 1994, 'Studies on the potential impact of recreational horseriding on some alpine environments of the Central Plateau, Tasmania', *Journal of Environmental Management*, vol. 40, pp. 103–117.

Whinam, J & Comfort, M 1996, 'The impact of commercial horse riding on sub-alpine environments on Cradle Mountain, Tasmania, Australia', *Journal of Environmental Management*, vol. 47, pp. 61–70.

Wilson, JP & Seney, JP 1994, 'Erosional impact of hikers, horses, motorcycles, and off-road bicycles on mountain trails in Montana', *Mountain Research and Development*, vol. 14, pp. 77–88.