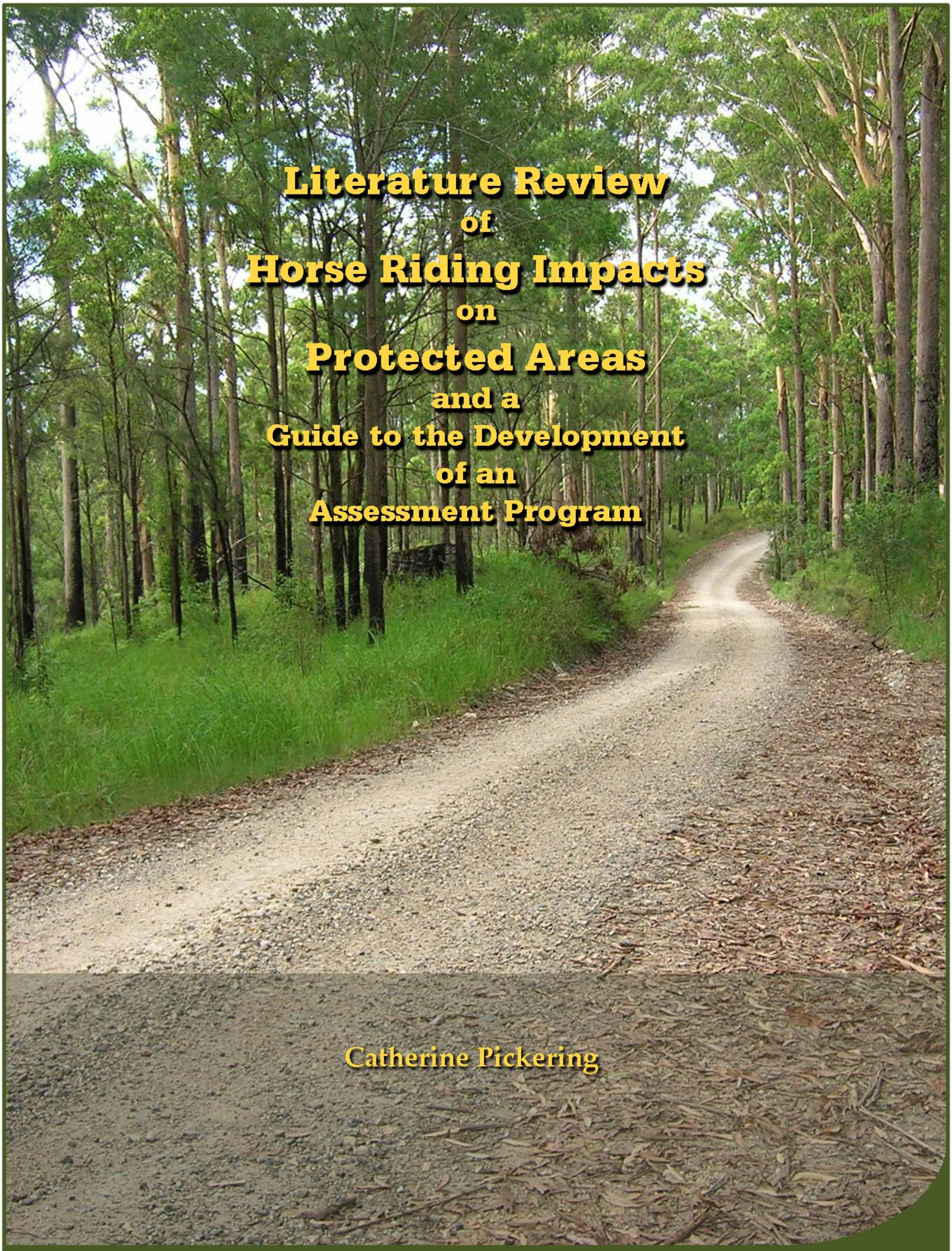

# Literature Review of Horse Riding Impacts on Protected Areas and a Guide to the Development of an Assessment Program

Catherine Pickering

Queensland Government
Environmental Protection Agency

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## Executive summary

This review has been prepared to guide the development of a program to assess the impacts of horse riding on designated trails traversing some proposed Southeast Queensland National Parks. The review finds:

1. Understanding patterns of visitation is very important when assessing social and environmental impacts of visitor use of protected areas. This includes determining how many visitors, when they come, where they go, and what they do in parks. This basic visitor information is critical for assessing where impacts are likely to occur and where monitoring points should be located.

2. Additional information on park users needs to be collected to better understand who is using the parks. This includes information on where the users are from (local, regional, international), demographics, market segmentation, visitor attitudes, expectations, experiences and visitor satisfaction. Information on the social component should not be limited to users of the parks, but also include the local and broader community. Although these aspects of social impact assessment are not addressed in detail in this report, it is recognised that there is a clear need to better understand how the change in the status of protected areas in Southeast Queensland associated with horse riding is perceived, understood and responded to by other visitors and users of these areas, by the relevant catchment communities and by the larger community of Southeast Queensland.

3. Horse riding has a range of biophysical impacts that can affect the amenity and environmental quality of protected areas. Biophysical impacts of horses riding that have been documented in Australia include reduction in the height, cover and biomass of native vegetation. These impacts combined with the potential for introducing exotic plant seed can result in changes in plant composition particularly on trail verges. Impacts of horse riding on soils include reductions in the surface profile of tracks, loss of soil, soil compaction and changes in hydrology. Direct and indirect impacts on aquatic ecosystems from horse riding are also predicted, including introduction of exotic species (aquatic and terrestrial weeds), increased turbidity associated with movement in water and soil erosion of banks, increased input of nutrients and sediments from soil erosion on banks, degraded water quality, compositional change of biota of water bodies and creek banks, potential for excessive algal growth and reduced ecological health of aquatic ecosystems.

4. Impacts from horse riding in Australia can be more severe than in other countries and/or continents due to the evolutionary history of Australian biota and soils. Because the flora has evolved in the absence of hard-hoofed grazing animals it is less resistant to trampling damage from hard hoofed animals such as horses. In addition the soils are often very low in nutrients. Also weeds and introduced pathogens can become a major threat.

5. Factors which can affect the severity of horse riding impacts and other recreational activities in parks need to be considered when developing assessment methods for biophysical impacts. These include: (1) the conservation value of the site, (2) likely resistance of the ecosystem to impacts, (3) likely recovery of the ecosystem from

impacts, (4) susceptibility of the site to erosion, (5) likely severity of direct impacts associated with horse riding, (6) likely severity of indirect effects associated with horse riding, (7) likely amount of use, (8) social issues associated with timing of use, (9) ecological issues associated with the timing of use, and (10) the total area likely to be directly affected by horse riding.

6. As the proposed horse riding activities in Southeast Queensland parks will be occurring on management trails, research on ways to assess trail impacts is described. Impacts include those associated with trail degradation including soil erosion, exposed roots, unplanned trails, increased width of trails, wet soil and running water on trails. Other impacts include those on aquatic systems, such as sedimentation, changes in nutrients, as well as ecological responses to physical and chemical changes in the ecosystems.

7. The benefits and limitations of potential assessment methods that are commonly used to assess vegetation and trail condition are described. This includes inventory methods, which often involve a point in time survey using qualitative measures of track condition. Inventory methods are suitable for use over large spatial areas and are suitable for identifying sites where more detailed monitoring and/or remedial action is required. Assessment of biophysical impacts could also involve monitoring, where standardised measures of relevant impact indicators are measured more than once, so that direct comparisons can be made between the current and past condition of a site. These types of monitoring methods are more time intensive than inventories, are less subject to observer bias and are more suitable for statistical analysis as they rely on quantitative measures of condition. Other research methods can be used to determine causation and thresholds of response to stresses associated with horse riding. These include using fully experimental approaches commonly used in recreation ecological research. An example of this would be multiple Before, After, Control, Impact (BACI) experiment comparing a number of reference and impacted sites before and after horse riding.

8. A suggested approach to assessment of indicators for horse riding trails in designated Southeast Queensland parks is provided including recommending that data on social impact assessment be collected in parallel with biophysical data. To fully assess potential environmental impacts a mixture of inventory, monitoring and recreation ecological research will be required.

# 1. Introduction

This scientific literature review was commissioned by the Terrestrial Policy Unit, of the Environment and Protection Agency, Queensland. It consists of a literature review to guide the development of a program to monitor and assess the impacts of horse riding on the proposed trail network in Southeast Queensland's protected areas. For the purposes of this review horse riding includes recreational use by individuals and groups, competitive use by endurance riders and trail competitions and commercial use for trail rides.

A comprehensive 20-year scientific monitoring program is to be undertaken to assess the impacts of horse riding in National Parks. This literature review provides information for the development of the proposed monitoring program. This literature review will:

- Discuss the clear need for visitor monitoring (numbers, locations, timing of visits activities etc)
- Discuss the need for other social impact assessment information
- Summarise documented impacts of horse-riding
- Describe why horse riding is of particular concern in Australian ecosystems
- Review factors that affect the severity of impacts
- Review research on track impacts and assessment
- Describe the types of assessment methods that may be appropriate
- Outline potential indicators for assessing horse riding impacts
- Describe indicators that could be used in Southeast Queensland.

# 2. Background

Horse riding is a popular activity in Australia including riding in State forests and some protected areas in Southeast Queensland (Newsome *et al*. 2002a, 2002b, 2008; Environmental Protection Agency 2008). As part of the Southeast Queensland Forests Agreements, approximately 406,000 ha of State forest will be transferred into national park (Environmental Protection Agency 2008). As some of these State forests have traditionally been used for horse riding, the Queensland Government proposes to continue to provide access for horse riding on some formed management roads through the proposed parks. Trails are proposed in some of the protected areas in the Tamborine, Nerang and Numinbah regions of the Gold Coast, in Brisbane Forest Park and in the Caboolture-Bellthorpe, Mapleton-Kenilworth and Noosa areas. In these areas, critical habitats may be fenced, track surfaces hardened, drainage improved, silt traps and other infrastructure developed, signage introduced and designated watering points provided where required. It is proposed that there will be restricted use of some trails and temporary closure of other trails where necessary. Funding of approximately $650,000 has been allocated for the provision of infrastructure within the trail networks (Environmental Protection Agency 2008).

Depending on the type and location of a trail there may be non-approved and approved multiple uses, including mountain bikes, walkers, motorbikes and four-wheel drive vehicles. Use of these trails will generally not require a permit, unless it is a commercial activity, an organised group activity or a competitive event, and on the spot fines will apply to riders off trail.

A code of practice for horse-riding is being developed to minimise riders' impacts on the park environment. It will apply to trails identified as the Southeast Queensland parks horse trail network. This code of practice is designed to prevent soil erosion, minimise trampling and grazing impacts, prevent the introduction and spread of noxious and exotic plants, protect waterways, protect significant and environmentally sensitive areas and species, protect cultural sites and minimise conflicts with other users.

Specifically riders are to minimise impacts on an area's natural or cultural resources by complying with the following provisions:

- On the identified horse trail network, ride only on formed management roads.
- Do not take shortcuts or form new trails.
- Obey notices and signs erected by the chief executive.
- Do not ride in groups with more than 15 horses without a permit.
- Obtain a permit under the *Nature Conservation Act 1992* before conducting large-scale organised riding events (e.g. group rides or competitive events).
- Only allow horses to cross watercourses at designated crossing points.
- Do not allow horses to enter or remain in or near natural watercourses. Do not wash horses in natural watercourses and use designated watering points to water horses, where provided.
- Do not mark trees or place any navigational marks or other signs in the area.
- Tether horses at hitching posts or staging areas only for short periods to minimise local impacts (erosion and compaction of soil or contamination of the site by accumulation of faeces and urine).
- Remove all litter brought into the area by the rider.
- Do not allow horses to remain in a forest reserve or protected area overnight.
- Riders should control their mounts so that they do not graze on any vegetation while in the area.
- The use of horse-drawn vehicles is not permitted.

In addition, the following guidelines complement the above provisions, and it is recommended that horse riders adopt these guidelines to further minimise their impact on these areas.

- Avoid riding during wet weather conditions.
- Use hardened water crossings, where possible.
- Be considerate of other park users.
- Avoid spreading weeds. The Environmental Protection Agency recommends that horse riders:

- Provide weed-free, good quality, processed feed to horses for at least 48 hours prior to entering a forest reserve or protected area;
- Ensure that horses' coats, hooves, equipment and floats are clean and free of seeds before park visits;
- Avoid riding through patches of weeds, especially if they are seeding;
- Report outbreaks of weeds along the trail to Queensland Parks and Wildlife (QPW) Rangers, particularly where the weed is of a type eaten by horses.

* Report damage or problems to QPW Rangers.
* Share these messages with other trail users.

## 3. Visitor monitoring, the first step [1]

The first step in assessing both social and environmental impacts of any type of recreational activity in protected areas, including horse-riders in Southeast Queensland parks, is to ensure that there is adequate visitor data for the park, including information on the frequency, timing and location of visitors (Eagles *et al*. 2002; Buckley 2003, 2004; Hadwen *et al*. 2007). Unfortunately, very few parks in Australia or overseas have an adequate level of detailed visitor data (Newsome *et al*. 2002a; Cole and Wright 2004; Leung and Monz 2006). At present, the extent to which visitor data collection occurs in most parks is variable and depends on the staff and financial resources of the park, its popularity and the degree to which visitation is seen as either a threat or an opportunity to meeting the management objectives for the park (Buckley 2003). Indeed, parks are generally very short on financial resources and are often under-staffed. In addition, staff can often lack the skills to design and implement visitor monitoring programs.

As part of any project assessing visitor impacts, park managers in Southeast Queensland will need, at a minimum, data on: (1) how many visitors use the area; (2) when do they come; (3) where do they go within the park; and (4) what activities do they undertake.

*How many visitors?*
Surprisingly few parks, including those in Queensland, have up to date, accurate records on visitor numbers whether measured as number of visitors (different people), number of visits (counts of separate visits) and/or as visitor day/nights (number of people in park each day summed for all days). In many cases this deficiency relates to institutionalised and/or logistic constraints on data collection, collation and analysis (Watson *et al.* 2000; Marion and Farrell 2002).

*When do they come?*
Knowledge of the temporal variability in visitor loads is important in the context of examining (and mitigating) visitor impacts. For example, protected areas with strongly seasonal visitation may suffer from acute impacts during peak visitation periods, yet there may be few impacts during low visitation periods. At even finer temporal resolutions, researchers have documented changes in visitor loads in relation

[1] This section is based on the paper Hadwen *et al*. (2007).

to days of the week and weather conditions (Ploner and Brandenberg 2004; Johnston and Growcock 2005).

*Where do they go?*
Whole-of-park level assessments do not provide adequate details of the importance (and consequences) of high and/or variable visitation (and associated impacts) to specific sites. By generalising visitation across the entire park, managers are left with insufficient information as to where impacts might be occurring and when, how often and why. Roads, trails, waterways and campsites (in addition to different management zones) focus visitors within key sites (Watson *et al*. 2000; Eagles *et al*. 2002). It is at these sites that visitor impacts are most likely to occur and, therefore, where they are most effectively monitored.

*What do they do?*
Whilst visitor numbers, timing and distributions can give an idea of the magnitude of visitation as an environmental pressure, information on the activities undertaken by visitors provides park managers with the information to design targeted monitoring programs. In the case of Southeast Queensland horse trails, information is needed on how many people use the trails, what type of activities they engage in (riding, walking, driving, riding a bicycle or horse) and when/how often they come. With this background information it is possible to start to determine how to monitor the impacts that visitors may have on the parks as well as start to assess social issues (Table 1).

**Table 1**. Different types of visitor monitoring data that could be collected. Modified from Newsome *et al*. (2002a).

| Focus | Data required | Potential uses of data | Monitoring techniques |
|---|---|---|---|
| Visitor numbers, timing, frequency | Visitor numbers, mode of entry and exit points, when arriving, departing, seasonal patterns in total usage | • Public accountability<br>• Planning - management | Automated counters, guesstimates, entrance records (ticket sales etc), manual counters, visitor books, tour records. |
| Visitor activities, locations | Sites visited, activities undertaken, site and activity based patterns of use, group sizes | • Planning – management (including frameworks)<br>• Resource allocation<br>• Routine management including ameliorating impacts | Questionnaires, telephone surveys, on site observations, personal interviews |
| Profiling (characteristics) | Demographic and socio-economic attributes of visitors. | • Marketing and interpretation<br>• Planning | Questionnaires, telephone surveys, personal interviews, focus groups. |
| Expectations and outcomes | Motivations, attitudes, preferences, expectations, satisfactions levels. | • Planning<br>• Marketing and interpretation<br>• Ameloriating impacts | Questionaries, telephone surveys, personal interviews, focus groups. |

## 4. More specific social impacts and monitoring requirements

This review principally focuses on the requirements for the collection of traditional visitor use data (see above) and then biophysical impacts and monitoring strategies (see below). However, there are important social dimensions of horse riding in parks in Southeast Queensland that are not fully addressed here as they lie beyond the scope of the current review.

A more detailed review of social factors is likely to be required as part of establishing an adequate monitoring program to cover social components of use of these areas and attitudes to use. What is clear already is that more detailed information about visitor use of the parks will be required to assess both social and biophysical impacts. This is likely to include information concerning motivations, attitudes, behaviour and satisfaction of other users on the horse riding trail network. Specific information could include determining user knowledge of the high impact potential of horse riding and even compliance with minimum impact codes including those for horse riding, attitudes of different user groups to the changes in status of the area and the use of trails for riding, information on conflict among and within different user groups, and levels of satisfaction with facilities including signage, trails, creek and river crossings, and the riding experience itself. Another important social component that will need to be addressed is the attitudes of the local and general community to the change in status and use of forest areas.

Further information on social issues related to use of protected areas including those that examine social aspects of protected areas as part of general park management are available in the following texts (Eagles *et al*. 2002; Newsome *et al*. 2002a; Bentrupperbäumer *et al*. 2005; Lockwood *et al*. 2006; Manning *et al*. 2006; Manning 2007, and in the references in Appendix 1, kindly provided by Joe Reser).

## 5. Documented biophysical impacts of horse-riding

Impacts of horse riding on trails and off trails have been studied in Australia and overseas (Liddle 1997; Landsberg *et al*. 2001; Newsome *et al*. 2002a, 2004, 2008) Tables 2 and 3 summarises many of these impacts. Australian research has been recently reviewed by Landsberg *et al.* (2001) and Newsome *et al.* (2002a, 2008). It has demonstrated that there is a range of impacts associated with horse riding. Impacts that are likely to be important in Southeast Queensland are summarised in Table 3. As horse riding will be on existing trails, impacts associated with trail use will be discussed. Further information about recent Australian research is available in Newsome *et al*. (2008).

Impacts from horse riding on trails are often due to the large ground pressure associated with horses which can alter track surfaces (Whinam and Comfort 1996; Liddle 1997; Newsome *et al*. 2004). The pressure and movement of horse’s hooves can result in areas of incision and compaction, as well as the breaking of soil surfaces, and displacement of sediments (Newsome *et al*. 2004). The extent to which the surface is affected depends on factors such as the type of material on the track (tar, rock, gravel, soil, sand, loam etc), how wet it is, and the type of usage (numbers of riders, gait of horse, shod or not, weight of horse and rider etc) (Liddle 1997; Newsome *et al*. 2004). Hardening of track surfaces is a common method of reducing the effect of trampling associated with activities such as horse riding. However, it can be expensive (construction and maintenance), may introduce foreign materials to a site, alter the visual amenity of the trail and change the hydrology of soils, streams and wetlands.

**Table 2**. Environmental impacts of horse riding on natural ecosystems (Modified from Liddle (1997); Landsberg *et al*. 2001; Newsome *et al*. (2002b, 2004, 2008)).

| **Soil** | **Vegetation** | **Water** | **Animals** |
|---|---|---|---|
| Soil compaction | Exposed roots | Introduction of exotic species | Increased noise |
| Loss of organic litter | Tree trunk damage | Increased turbidity and sedimentation | Increased vigilance and potential for displacement of grazing animals |
| Loss of soil | Loss of vegetation height and vigour | Increased input of nutrients | Damage to burrows |
| Change in hydrology of soils | Loss of ground cover | Increased levels of pathogens | |
| Alteration in microbial activity | Loss of fragile species | Degraded water quality | |
| Nutrient enrichment (manure, urine) | Loss of trees/shrubs | Reduced ecological health of aquatic ecosystems | |
| | Increase in resistant species | Compositional change in aquatic plant and animal communities | |
| | Introduction and spread of exotic plant species (invasive weeds) | Excessive algal growth | |
| | Introduction and spread of fungal pathogens | | |

**Table 3**. Australian research that has documented terrestrial environmental impacts from horse-riding. Modified from Newsome *et al*. (2002b) and Pickering and Hill (2007).

| **Impacts\Type of activities** | **Horse-riding research** |
|---|---|
| Vegetation clearing/damage | Whinam *et al*. 1994; Whinam and Comfort 1996; Landsberg *et al*. 2001; Turton, 2005 |
| - reduction in height | Gillieson *et al*. 1987; Newsome *et al*. 2002b; Phillips and Newsome 2002 |
| - reduced living biomass | Whinam *et al*. 1994 |
| - reduced cover | Whinam and Comfort 1996; Whinam *et al*. 1994; Newsome *et al*. 2002b |
| - change in litter | Whinam and Comfort 1996 |
| - changes in species composition | Weaver and Adams 1996; Phillips and Newsome 2002; Newsome *et al*. 2002b |
| - damage to trees (cutting etc), eating | |
| Degradation of existing trail networks | Royce 1983; Gillieson *et al*. 1987; Harris 1993; Whinam and Comfort 1996; |
| Reduction in surface profile | Whinam *et al*. 1994 |
| Soil loss | Whinam and Comfort 1996; Phillips and Newsome 2002; Newsome *et al*. 2002b |
| Nutrient addition | Whinam and Comfort 1996; Newsome *et al*. 2002b |
| Soil compaction/change in soil moisture | Newsome *et al*. 2002b |
| Change in hydrology | Landsberg *et al*. 2001 |
| Introduction/spread of weeds | Weaver and Adams 1996; Turton, 2005, Whinam *et al*., 1994, Landsberg *et al*., 2001, Newsome *et al*., 2002b, St John-Sweeting and Morris 1991, Royce 1983 |
| Spread of pathogens | Turton, 2005, Newsome *et al*., 2002b |

Direct alteration to the surface of trails can have flow on effects, with track widening, increased depth of track, exposure of tree roots, loss of vegetation on the side of trails and changes in hydrology along the trail and in adjacent areas (Figure 1, Harris 1993; Whinam and Comfort 1996; Newsome *et al*. 2002b, 2004). Trail widening can occur where other users (including other riders) form parallel trails to avoid boggy areas, or deeply incised trails. This is particularly common on unhardened trails, or narrow trails that experience high usage. Increased depth of trails occurs due to soil compaction and erosion, resulting in the main trail becoming lower than the surrounding ground (Whinam and Comfort 1996; Newsome *et al*. 2002b, 2004). Soil compaction and erosion reduces the capacity of plants to absorb nutrients and water from the soil, as well as reducing the structural capacity of the roots to support the plant. As a result trees and shrubs on trail verges can experience increased stress and even die. Loss of vegetation on the side of trails can also occur when parallel trails (ribboning) are made and/or when horses ride in a group rather than single file resulting in direct trampling damage to the aboveground parts of plants (Newsome *et al*. 2004). Changes in the hydrology of the trail can occur due to changes in the surface and depth of the trail, resulting in some areas becoming boggier (Whinam and Comfort 1996; Newsome *et al*. 2004).

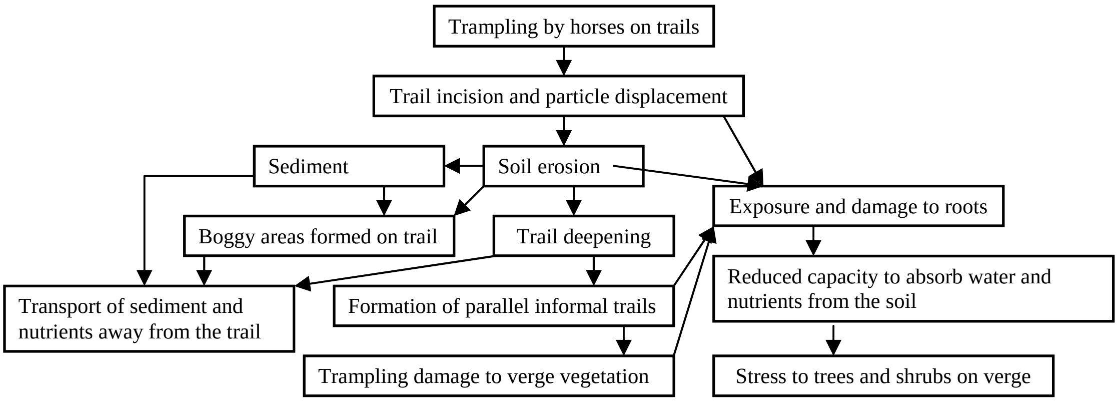


**Figure 1**. Cascade of possible terrestrial impacts from horse riding on tails.

Trampling damage is often particularly severe near watercourses (creeks, lakes, dams and wetlands), with a far greater potential for soil erosion, and trail incision (Liddle 1997; Newsome *et al*. 2004). Potential impacts at these sites include introduction of exotic species (aquatic and terrestrial weeds), increased turbidity associated with movement in water and soil erosion of banks, increased input of nutrients and sediments from soil erosion on banks, degraded water quality, compositional change of biota of water bodies and creek banks, potential for excessive algal growth and reduced ecological health of aquatic ecosystems (Liddle 1997; Newsome *et al*. 2002a). These environmental effects can also influence the visual amenity of aquatic sites and surrounding landscapes.

A second set of impacts due to horse riding on trails is associated with the release of manure and urine. Manure on or adjacent to trails can affect the visual amenity of the area for other users (Beeton 1999; Newsome *et al*. 2004). Horse riding can also result in nutrient 'hotspots' because of the high levels of nutrients (principally nitrogen) present in manure and urine (Drying 1990). Manure can also be a source of weed propagules (St John-Sweeting and Morris 1991, Appendix 2), as well as providing added nutrients for the weed seed to become established (Whinam *et al*. 1994; Torn 2007). Recent experimental trials in Finland found that trampling and manure from horses in combination resulted in more introduced species germinating and growing in forest sites than either on their own (Torn 2007). The introduction and establishment of potential environmental weeds into forests in Australia is a major issue for protected area managers (Pickering and Hill 2007).

Impacts of horse riding off trail are far greater due to direct trampling of vegetation (Whinam *et al*. 1994; Newsome *et al*. 2002a, 2002b, 2004). This can result in crushing, shearing and breaking of vegetation (Whinam *et al*. 1994). As a result there can be short and long term reduction in vegetation height and cover, loss of sensitive species, increase in more resistant species and introduction of seed from species not local to the area (including weeds) all of which will result in changes in plant species composition (Whinam *et al*. 1994; Newsome *et al*. 2002b). The consequences can be a change in the overall form of the vegetation with the loss of shrubs and soft herbs and the potential increase in grasses in the short term. Damage to vegetation along informal trails can be so great that it often results in the loss of all vegetation cover, with exposure of the litter and soil surface. As a result loss of litter, lichens and mosses as well as soil compaction and erosion can occur, with all the flow on effects discussed above. At tethering sites, damage to soils and vegetation is often concentrated. There is also an increased potential for direct damage to vegetation by horses rubbing, scraping and eating vegetation (Newsome *et al*. 2002b, 2004).

In addition to the environmental impacts of horse riding there are potential social issues (Beeton 1996; Newsome *et al*. 2002a). Depending on attitudes of different user groups and patterns of usage, there is a potential for conflict between horse-riders and other users (Beeton 1999, 2006; Newsome *et al*. 2002b). This can involve a reduced perception of 'naturalness' for other users, even when they do not see riders directly, but see the effects of riding use on sites. This type of conflict may be greater as it is the first time that horse riding will be permitted in parks in Southeast Queensland. Correspondingly, users of the current management trails may view horse riders as a traditional usage of these areas.

A different issue is the potential for conflict when user groups meet, which can result in crowding and displacement of groups and individuals. Visitor perceptions are always highly variable, with differences in expectations and differences in actual experience affecting visitor satisfaction (Beeton 1999, 2006; Dickson 2007). These and other social issues are important when assessing impacts and developing monitoring strategies.

## 6. Why horse riding impacts are of particular concern in Australia ecosystems

Australia's biota is of international significance due, at least in part, to its high levels of endemism (species that are only found in Australia, Department of the Environment, Sport and territories 1994). As a result of the long period of geographical isolation of the continent, 85% of vascular plant species and 82% of mammal species are endemic to Australia. Australia is one of the world's 15 mega diverse countries and contains several critical diversity hotspots including the south west of Western Australia, the Wet Tropics of Queensland and the Great Barrier Reef. The Southeast region of Queensland also has high biodiversity, with areas of such significance that they are world heritage listed (e.g. Gondwana Rainforests of Australia World Heritage Area).

One important way in which Australian flora and fauna differ from overseas, is that Australian species have evolved in the absence of large, hard hoofed herbivores such as horses, antelope, sheep, cattle or goats (Newsome *et al*. 2002b). Australian grasses, forbs and shrubs were therefore not subject to the types of grazing and trampling that plants native to the plains of North and South America, Europe and Africa have experienced. For example, many Australian native grasses are tussock species which can easily be uprooted by grazing animals such as horses, while inter-tussock spaces are important habitats for herbs that are easily damaged by trampling from hard hoofed animals such as horses.

A second issue is that Australian soils are often low in nutrients, particularly nitrogen and phosphorous (Newsome *et al*. 2002b). As a result Australian plants show many different adaptations to cope with low nutrient levels including sclerophyllous form (small leaves, short internodes, hard leaves with waxy layers), proteoid root mats (found in many Proteaceae species), nitrogen fixation (leguminous species including many shrubs and wattles and non-legumes such as she-oaks), and associations with a range of fungi (mychorrhiza) adapted to enhance the uptake of nutrients (Newsome *et al*. 2002b). Damage from horse riding to roots, combined with nutrient supplementation (manure, urine), can reduce the effectiveness of root based mechanisms for regulating nutrient uptake resulting in increased stress for many Australian plants. In some cases nutrient supplementation can even be toxic (Newsome *et al*. 2002b). The brittle nature of many Australian sclerophyllous shrubs also makes them more susceptible to trampling damage from horses (Whinam *et al*. 1994; Newsome *et al*. 2002b).

The third major way in which Australian ecosystems are likely to experience greater impacts from horses is by the introduction and dispersal of weeds and pathogens (St John-Sweeting and Morris 1991; Whinam *et al*. 1994; Weaver and Adams 1996; Newsome *et al*. 2002b). Due to Australia's long period of isolation, exotic weeds pose a significant threat to natural vegetation by competing with native species for light, space and nutrients, and by modifying natural ecosystem functioning (Williams and West 2000). Plant community composition and structure may change, affecting food resources and shelter for native fauna (Adair 1995). Therefore increasing the diversity and abundance of exotic species in protected areas is of concern. This has been acknowledged with environmental weeds (plants that invade natural ecosystems and can cause major modifications to indigenous species and ecosystem function) being recognised as major threats to conservation in Australia (Williams and West 2000; Williams *et al*. 2001).

Pathogens such as the root rot fungus (*Phytopthora cinnamomi*) also pose a major threat to Australia's biodiversity including in parks in Southeast Queensland. The severity of the threat has been recognised nationally and it is listed as a key threatening process by the Australian Government (Environment Australia 2001), and by the NSW government in the *Threatened Species Conservation Act 1995 (NSW).*

## 7. Ten factors that can affect the extent and significance of biophysical impacts of horse-riding in Southeast Queensland[2]

Peer reviewed scientific literature including Australia research has documented a range of factors that affect the severity of impacts and their relative importance for management (Table 4). Based on research into horse riding impacts, and more general recreational ecological research, it is possible to identify ten key factors that could influence the importance/extent of impacts from horse riding within Southeast Queensland (Figure 2). These factors allow protected area managers to identify where and when impacts are likely to be most severe, and also where and when monitoring is most likely to be required.

[2] This section is based on the paper 'Pickering, C.M. Ten factors that affect the severity of visitors in protected areas. *Ambio.'* That is currently under review by the journal as of June 2008.

**Table 4**. Recent Australian research into factors that affect the amount of damage from tourism and recreational activities. Modified from Pickering and Hill 2007.

| Factor associated with activity | Recent studies |
|---|---|
| - type of activity | Growcock 2005; Turton 2005 |
| - amount of use | Whinam *et al*. 1994; Goeft and Alder 2001; Landsberg *et al*. 2001; Newsome *et al*. 2002b; Phillips and Newsome 2002; Whinam and Chilcott 2003; Whinam *et al*. 2003; Talbot *et al*. 2003; Growcock 2005; Turton 2005. |
| - size of camping group | Smith and Newsome 2002; Growcock,2005 |
| - behaviour of user group | Turton *et al*. 2000; Newsome *et al*. 2002a, 2002b; Smith and Newsome 2002b; Growcock, 2005. |
| **Factors associated with environment** | |
| - resistances/resilience of vegetation | Whinam *et al*. 1994; Whinam and Comfort 1996; Turton *et al*. 2000; Bridle and Kirkpatrick 2003; Tablot *et al*. 2003; Whinam and Chilcott 2003; Whinam *et al*. 2003; Growcock *et al*. 2004; McDougall and Wright 2004; Growcock 2005. |
| - topography site | Goeft and Alder 2001; Whinam and Chilcott 2003; Whinam *et al*. 2003. |
| - soil characteristics including drainage | Whinam *et al*. 1994; Arrowsmith and Inbakaran 2001; Talbot *et al*. 2003; Whinam *et al*. 2003; Growcock *et al*. 2004. |
| - climatic zone | Whinam *et al*. 1994; Bridle and Kirkpatrick 2003; Talbot *et al*. 2003; Whinam and Chilcott 2003; Whinam *et al*. 2003; Growcock 2005; |
| - seasonality | Buckley 2004; DPIWE 2005; Turton 2005 |

***One: Conservation value of area.*** Some areas within a park, within Southeast Queensland and within Australia, are likely to have higher conservation value than others. Hence use of these areas for horse riding should be avoided. Identifying and protecting areas of high conservation value is well established internationally (IUCN categories of protected areas, world heritage listing, biosphere reserves; Lockwood *et al*. 2006), nationally (wilderness areas, threatened ecological communities, sites of national significance, national reserve system; Worboys *et al*. 2005), and within Queensland (conservation status of regional ecosystems, categories of parks: high profile, popular, explorer, self-reliant; Environmental Protection Agency 2001). Within a protected area, some areas and ecosystems are of greater value due to rarity, representiveness, biodiversity and the ecosystem services they provide to biota and to humans. The importance of these types of consideration is reflected in zoning systems within protected areas including the recognition of wilderness areas.

**Figure 2**. Ten factors to consider when assessing where horse riding likely to have most impact and hence where to concentrate monitoring.

| | **1. Conservation value of ecosystem** | **2. Resistance of ecosystem** | **3. Recovery of ecosystem** | **4. Susceptibility of site to erosion** | **5. Severity of direct impacts associated with specific activity** | **6. Severity of possible indirect impacts** | **7. Likely amount of visitor use** | **8. Timing of use - social** | **9. Timing of use - ecological** | **10. Total area likely to be directly effected** |
|---|---|---|---|---|---|---|---|---|---|---|
| Less impact likely | Low – already extensively modified ecosystems | High resistance (grasslands) | Faster (rainforest) | Low (rock or hardened soils) | Low impact (e.g. trampling) | Low (temporary changes in vegetation, displacement of wildlife, or predators) | Rare (limited use likely) | Constant low use | Drier, warmer seasons | Small (short, narrow track, single tethering sites, no focused events) |
| | | Medium resistance (herbfields etc) | | | Medium (Horse-riding) | | | | | |
| Greater impacts likely | High- Biodiversity hot spot, limited distribution, low dispersal potential, important source of colonists, breeding populations | Low resistance (wet trails, areas dominated by shrubs, waterways, wetlands) | Slower (cooler climatic zones) | High (deep humus soils, bog area) | High impact – (e.g. off-road cycles, 4WD) | High (e.g. spread of invasive plants) | Popular – many visitors on regular basis or very high usages at key times | Periods of very high usage | Wetter times, critical times for ecological events (e.g. flowering, seed set, breeding) | Large (long track, large tethering area, site of focused events) |

More specifically zoning systems involving the provision of different types of recreation opportunities and different levels of infrastructure to support such activities are used by park agencies around the world. One common method is the ROS system (Recreational Opportunity Settings) where sites within a park are allocated to different zones on the basis of the amount or level of site development, on site regulation, contacts between visitors, modification of the environment and ease of access (Newsome *et al*. 2002a; Worboys *et al*. 2005).

In 'primitive' sites there is no motorised access, sites are remote and natural, sites are larger, there are few social contacts among visitors, no visitor impacts are acceptable, there are no site developments or structures and there is no on-site regulation with reliance entirely on self-regulation (Newsome *et al*. 2002a; Worboys *et al*. 2005). In contrast, sites that are classed as 'developed' might have high levels of motorised use and parking, might have a natural landscape setting, but the site itself might be highly modified including the provision of roads and even resorts and other facilities. There is likely to be lots of contact among visitors, there are roads, tracks or developed sites, some impacts are evident and accepted, and obvious controls and signage are used to regulate visitor behaviour (Newsome *et al*. 2002a; Worboys *et al*. 2005).

In Southeast Queensland most horse riding trails are likely to be very similar to the 'roaded natural' class, where there is some motorised use, the site appears predominantly natural, there might be moderate contact among visitors on the trails, some impacts might be permitted at specific areas such as campsites or tethering areas, and there is moderate regulation via site design and signage.

***Two: Resistance of ecosystem and vegetation types.*** Resistance of vegetation to trampling including from horse riding is defined as the ability of the vegetation to withstand disturbance before damage occurs. Plants, vegetation communities and ecosystems vary in their resistance to use. Based on the increasing literature in recreation ecology it is possible to make some generalisation about the resistance of different ecosystems (e.g. rainforests vs coastal dunes), vegetation types (e.g. grasslands vs heathlands), and growth forms (e.g. shrubs vs herbs) to use (Whinam *et al*. 1994; Cole 1995; Liddle 1997; Newsome *et al*., 2002a; Hill and Pickering 2009). A common measure of the resistance of the site is the number of passes (by horses, bikes, cars or people) required to cause a 50% decline in vegetation cover (Liddle 1997). Based on a large number of studies of the resistance of vegetation to trampling it is apparent that some general principles apply (Table 5).

**Table 5**. Mean and range of resistance index (number of passes required to cause a 50% reduction in vegetation cover or biomass) for 55 different vegetation types. Modified from Hill and Pickering 2009. N = number of different vegetation communities assessed.

| **Catagory** | **N** | **Mean** | **Minimum** | **Maximum** |
|---|---|---|---|---|
| Climatic zones | | | | |
| Not specified | 1 | 273 | 273 | 273 |
| Alpine | 9 | 222 | 30 | 620 |
| Arctic | 2 | 200 | 200 | 200 |
| Montane | 6 | 148 | 25 | 520 |
| Subalpine | 11 | 235 | 20 | 1000 |
| **Subtropical** | **8** | **722** | **12** | **1475** |
| Temperate | 20 | 225 | 20 | 1445 |
| Life-form | | | | |
| Not specified | 3 | 881 | 273 | 1475 |
| Fern | 3 | 97 | 20 | 210 |
| Forb | 15 | 85 | 20 | 380 |
| Graminoid | 17 | 497 | 12 | 1445 |
| Grass-shrub | 1 | 160 | 160 | 160 |
| Shrub | 16 | 199 | 44 | 520 |
| Community type | | | | |
| Not specified | 4 | 198 | 60 | 316 |
| Forest understorey | 24 | 225 | 12 | 1475 |
| Grassland | 11 | 539 | 85 | 1412 |
| Heath | 7 | 140 | 75 | 200 |
| Herbfield | 5 | 115 | 30 | 400 |
| Sand-dune grassland | 3 | 866 | 288 | 1445 |
| Sand-dune heath | 2 | 301 | 258 | 344 |
| Total | 55 | 291 | 12 | 1475 |

Certain plant growth-forms appear more susceptible to damage by trampling, with forbs more sensitive then ferns, which are more sensitive than shrubs, which are more sensitive than graminoids (Yorks *et al*. 1997; Cole 2004a; Hill and Pickering 2009). Therefore communities dominated by more resistant growth forms – e.g. grasslands, are likely to be more resistant, than those where ferns, mosses and shrubs are important components of the vegetation. A common pattern of resistance is sand dune grasslands >grasslands >sand dune heaths >forest understorey >heaths~herbfields (Hill and Pickering 2009). For ecosystems, the pattern is dependent on factors such as the dominant types of vegetation, and also on the general abiotic environment including climate. As a result, for example, the order of resistance for ecosystems is subtropical>alpine~temperate~subalpine~arctic >montane. Although these general patterns apply there is considerable variation in resistance within each growth-form, climatic zone and vegetation type (Cole 1995a, 1995b, 2004a, 2004b; Hill and Pickering 2009). There is no absolute guarantee that in a particular plant community these judgements would apply. As a result there is often a need for site specific research using experimental trials to determine local levels of resistance.

Within Southeast Queensland the resistance of three vegetation communities to trampling by humans has been tested using the standardised experimental protocols that have been developed by Cole and Bayfield (1993). This study found that fern understoreys had low resistance to trampling intensity, with reductions in relative vegetation height and cover with as few as 10 passes by a person walking (Hill 2007; Hill and Pickering 2009). A tussock grass understorey showed moderate resistance with reduction in height at 25 passes and cover at 50 passes. A disturbed grassland community dominated by lawn grasses had the highest resistance, with reductions in vegetation height at 100-200 passes, but cover was affected by as few as 10 passes. The resistance indices (number of passes required to reduce vegetation cover by 50%) of these three communities were 210, 360 and 860 passes respectively. The number of passes by horses to result in a 50% reduction in vegetation cover would be much lower than these values reflecting the increased force per unit of a horse compared to a human.

If horse riding only occurs on trails, as would occur with compliance with the horse riding code, then there are unlikely to be trampling impacts on native vegetation. If off track riding occurs, the issues to do with the differences in the resistance and resilience of vegetation become an important consideration.

***Four: Susceptibility of site to erosion.*** One of the major types of damage associated with horse riding is increased soil erosion. This can occur on trails as well as during off trail use. As a generalisation steeper slopes are at higher risk of erosion. However, other factors such as the surface type and patterns of rainfall, can influence patterns of erosion. Generally areas with harder surfaces (rock, gravel and compacted soils) will experience less erosion than sandy or deep humus soils (Liddle 1997). Again information can be obtained from the recreation ecology literature, as well as more general research into disturbance and erosion. In studies comparing the impact of different types of activities, 4WD vehicles are likely to cause more erosion than horse riding, while horse-riding can cause more erosion than walking (Newsome *et al*. 2004). Again, this is partly a reflection of the physics of weight distribution over area (see below).

***Five: Severity of direct impacts.*** Different activities have different impacts on ecosystems. When assessing use of management trails in Southeast Queensland, an important issue is the average static pressure associated with different activities (Liddle 1997; Table 6). The total weight and area of ground contact varies among different recreation activities resulting in different total pressure patterns. Some activities have much higher pressure per area due to the high weight deployed over small areas. This applies particularly to horse riding, with a high total weight (approximately 613000 gm per horse) and low area of ground contact (whole foot = 478 $cm^2$, shoes only = 140 $cm^2$). As a result the ground pressure is very high (weight over an area), which can result in greater damage to tracks. However, the total area of usage (area of contact) is also important. Other factors that can vary with type of usage include noise generated, potential for spread of weeds and pathogens, etc (Liddle 1997, Newsome *et al*. 2004).

***Six: Severity of indirect impacts.*** Although considerable research has been conducted on direct impacts of different types of activities including horse riding, there is less research documenting the severity of some indirect impacts. However, indirect impacts can be more severe, occur over a wider area and be self-sustaining (ie. continue to cause damage even if the activity itself stops) than direct impacts (Buckley 2003; Pickering and Hill 2007). Two important indirect impacts are the spread of weeds and pathogens (St John-Sweeting and Morris 1991; Newsome *et al*. 2002b, 2004).

**Table 6**. Ground pressure associated with different recreation activities, vehicles and animals. Modified from Liddle (1997).

| **Activity, vehicle, animal** | **Pressure ($g\ cm^2$)** |
|---|---|
| Snowmobile | 7 |
| Human on snow skis | 28 |
| Human on snowshoes | 33 |
| Small personal-use three wheeler all terrain cycle | 100 |
| Four-wheeled, all terrain cycle | 100 |
| Human boots with whole sole in contact with ground - Woman | 160 |
| Human shoes | 180 |
| Human boots with whole sole in contact with ground - Man | 206 |
| Human bare-footed on hard ground | 297 |
| Human Vibram-soled boots on hard ground | 416 |
| Sheep | 690 |
| Vehicle - Caterpillar D-7 | 700 |
| Goat | 730 |
| Oryx | 860 |
| Sheep | 941 |
| Cattle | 980 |
| Four-wheel-drive Toyota, empty on ‘supa digger’ tyres on hard ground | 997 |
| Human Football boots (with studs) | 1000 |
| Eland | 1090 |
| **Horse and rider (whole foot)** | **1282** |
| Cow | 1467 |
| Saloon car and driver on hard ground | 1500 |
| Four-wheel-drive Toyota, empty on hard ground | 1550 |
| Four-wheel-drive Toyota, loaded 4 people and gear on hard ground | 1686 |
| Trail bike | 2008 |
| Jeep | 2240 |
| **Horse and rider (shoes only)** | **4380** |

Weeds are a major management issue for protected areas in Australia (Williams and West 2000; Williams *et al*. 2001; Pickering and Hill 2007). Over 192 significant weeds occur or have the potential to occur in Southeast Queensland (Thorp and Wilson 2008). Horses can contribute to the spread of these weeds by the introduction of weed propagules on hooves, in coats (Couvreur *et al*. 2004), on equipment, but most importantly in feed and manure (St John-Sweeting and Morris 1991; Whinam *et al*. 1994; Weaver and Adams

1996; Campbell and Gibson 2001; Newsome *et al*. 2002b, 2008; Cosyns and Hoffmann 2005; Wells and Lauenroth 2007). In one study of horses being transported between protected areas in Belgium, twenty species of plants were germinated in a glasshouse from material collected from the coats of horses (Couvreur *et al*. 2004, Appendix 2). Several studies have been conducted in Australia and overseas examining viable seed in the dung of horses (Appendix 2). From the studies examining horse dung collected from protected areas, one hundred and seventy-nine species germinated. For studies germinating seed in horse dung in Australia (including a pasture study), thirty-nine species have been identified. Many of these species are prominent weeds including species that occur in Australian protected areas (Williams and West 2000; Johnston and Pickering 2001; Bear *et al*. 2006).

In addition to being a source of seed, trampling by horses can favour weeds which often benefit from disturbance to existing vegetation (Whinam *et al*. 1994). In addition, nutrients in manure can also favour weed establishment, with the largest amounts of weeds established in areas both trampled and subject to manure (Torn 2007). Once established weeds are hard to control and can spread from tracks and tethering areas (Torn 2007; Newsome *et al*. 2008).

Horse riding therefore poses a risk for the introduction of weed species along the horse trails in Southeast Queensland. For example of the 14 significant grass weeds for south eastern Queensland (Thorp and Wilson 2008), all can be dispersed by seed, all can be found in pastures and many also occur on road verges. Hence they have the potential to appear in horse feed and dung. Several of them could also be spread on the fur of horses, on riders or on riding equipment. For example, Mossman River grass (*Cenchrus echinatus*) has burrs that attach to fur, African lovegrass (*Eragrostis curvula*) has seed that can be dispersed on the mud of cars and in animal fur, olive hymenachne (*Hymenachne amplexicaulis),* a weed of national significance, can be dispersed in stock feed, fountain grass (*Pennisetum setaceum*) can be dispersed on clothing, giant Parramatta grass (*Sporobolus fertilis*) and giant rat's tail grass (*Sporobolus pyramidalis*) have seed that can become attached to machinery, and seed that can attach to fur and hair, while grader grass (*Themeda quadrivalvis*) can be dispersed by animals, mud and on graders (hence the common name) (Thorp and Wilson 2008 and references there in).

For Southeast Queensland horse trails, the potential for long distance dispersal (introduction into a park) and short distance dispersal (within the park) of weed species by horses is clearly of concern. Adherence to the horse riding code should reduce the risk of introducing seeds and reduce damage to vegetation that may favour the establishment of weeds. Assessment of the seed load on horses (coat, equipment), in feed, and in manure would help quantify the risk of long and short term dispersal of weeds from riding in parks. To assess the relative risk from horses, research on seed introduction via car and bike wheels as well as on walkers shoes could also be conducted.

The spread of pathogens by visitors into and within protected areas has been documented (Newsome *et al*. 2002a, 2002b, 2008; Pickering and Hill 2007), with the spread of root rotting fungi of most concern in Australia (Newsome *et al*. 2002a, 2002b, 2008;

Pickering and Hill 2007). Horse riding, along with other activities such as mountain biking, walking and 4WD driving has the potential to introduce pathogens into parks and to enhance their spread within a park (Newsome *et al*. 2002a, 2002b, 2008; Pickering and Hill 2007). Again sampling along trails and sampling material from different user groups could help quantify this risk in Southeast Queensland.

**Seven: Likely amount of use.** Generally more use results in more impact. Therefore information on how many people use a trail is very important when assessing their impacts. The common model of the relationship between increasing use and damage, is curvilinear, where proportionally more damage occurs at lower levels of use, that is the first foot fall (or hoof fall) causes proportionally more damage than the 10th or the 100th (Newsome *et al*. 2004; Cole 2004a). However, recent research indicates that, in more resistant vegetation communities, the relationship is closer to linear, that is, each foot fall/ hoof fall causes the same amount of damage (Hill 2007).

Another factor that affects the relationship between amount of use and amount of damage is the behaviour of users. Users vary in their behaviour, including the extent to which they follow minimum impact behaviour (Worboys *et al*. 2005; Littlefair and Buckley In Press). As a result different users do not cause equivalent levels of damage, with some people causing far more damage than others (Growcock 2005; Littlefair and Buckley In Press). This can involve moving off formal designated trails, deliberate damage to trees, leaving of refuse and use of fires in areas where banned (Growcock 2005; Littlefair and Buckley In Press). As a result effective management of these visitors should be a priority, as reducing activities that have impacts can have a disproportionate benefit, both environmentally and socially.

***Eight: Timing of use - social*.** Visitor use is rarely constant. Rather use of many protected areas tends to be spasmodic with long periods of low usage, and then short periods of high usage, often during public holidays (Pickering and Buckley 2003). This pattern is found in boat usage on Moreton Bay, people swimming in lakes on Fraser Island, and people walking to the summit of Australia's highest mountain, Mt Kosciuszko. As a result, managing visitor usage is typically concerned with managing peak usage. At peak times facilities can often be overwhelmed with overflow from carparks, tracks, toilets, view points, rubbish bins and drinking or washing facilities. As a result some visitors may engage in behaviour that otherwise they would be less likely to. This includes defecating or urinating away from toilets, leaving litter beside full rubbish bins, parking on verges, camping beyond designated campsites, ribboning on tracks and riding off trails. As a result far more environmental damage can occur during peak usage than would be indicated by total annual usage figures. This highlights the importance of knowing precisely when and how often most people are using the horse riding trails in parks in Southeast Queensland.

The second aspect of peak usage of concern for park managers is interactions among visitors and its potential effect on visitor satisfaction (Beeton 1999, 2006; Newsome *et al*. 2002a; Worboys *et al*. 2005). The visitor experience involved in accessing a protected area with low usage can be very different to that in high use areas, even though the facilities provided by the park and the environment itself are similar. At periods of peak usage there is far greater potential for user conflict, and a perception of crowding among visitors. In effect more people are competing for what can be perceived to be limited resources (car park, toilet, access to track, tethering areas and watering points). However, perceptions of crowding can be surprising. On the summit of Mt Kosciuszko visitors during the peak period of usage expected a 'wilderness' experiences, and were satisfied with their experience, even though they were often sharing the area with hundreds of other people (Dickson 2007).

***Nine: timing of use – ecological.*** A second aspect of the timing of use that can affect the severity of impacts, is that the resilience and resistance of an ecosystem can vary over time. The most obvious example of this is where there is greater damage to vegetation and soils when conditions are wet than when dry. Soil erosion, ribboning, compaction and so on can all be greater on a wet track than on a dry track, although more damage might also occur to a track after prolonged drought than during an 'ordinary' season. Other seasonal factors are also important including whether damage occurs during critical periods of growth and reproduction for plants and animals. For example noise from visitors and their activities can have greater effects on animal behaviour when the animals are calling for mates, or mating or taking care of young (Liddle 1997). Correspondingly, trampling damage during flowering and fruiting periods for plants can have greater impact than during non-reproductive periods (Liddle 1997).

***Ten: Total area likely to be affected.*** Generally the smaller the total area used and/or damaged the better. However, some activities and facilities provided are likely to have larger ecological footprints on a site than others. An example of this is the extent of trails within a protected area. First, the total area of a trail is often not taken into account, although it might have a larger total footprint than other types of infrastructure such as a carpark because trails are long and narrow. Secondly, because trails are prone to linear disturbances they can actually have a greater impact on a site or ecosystem than would occur for the same area in a more compact form. Trails can fragment habitats, alter water flows in areas beyond the immediate site, affect animal movements and facilitate the introduction of feral animals and plants. Trails also provide access to a wider area of the park and hence an increased potential for any indirect flow on effects (see Part 4).

## 8. Research on trail impacts and assessment[3]

Horse riding will be restricted to management trails in Southeast Queensland. Therefore assessing impacts of horses will involve assessing the condition of the trails used for riding and off trail effects e.g. on water bodies. The range of impacts of riders on trails has already been discussed above. Here more general issues to do with trail impacts and assessment are discussed.

[3] This section is based on the CRC for Sustainable Tourism draft report on 'Review of Impacts and Assessment of Walking Tracks in Protected Areas' by Wendy Hill and Catherine Pickering

Trails are a fundamental part of most park infrastructure, providing recreation opportunities and access, as well as ensuring resource protection by concentrating human movements and activities. Managed trails contribute to the sustainable visitor use of protected areas as they protect the environment by controlling the wider effects of erosion, damage to flora, fauna and ecosystems, damage to places of heritage and cultural signficance, and by reducing visual impact and social intrusion. They are among the most common types of infrastructure provided by park agencies. Although the area of trails can be small, impacts on degraded trail networks can be locally severe and often have larger scale ecological and social effects (Leung and Marion 2000; Cole 2004a; Marion *et al*. 2006).

In areas accessible by road, engineered trails are often provided with surfaces hardened with gravel and stone, cement pavers, bitumen or wooden planks (Cole 2004a). In more remote areas, hardened trails are neither appropriate nor feasible. In backcountry and wilderness areas there can be extensive systems of unhardened trails, many of which have developed from former grazing trails, off road vehicle trails and the like (Cole 2004a). The majority of tracks through wilderness areas of the US were not specifically designed for heavy use and were not located in areas resistant to heavy use (Marion 2007). This may also be the case in Australia.

On well-constructed and maintained hardened trails, impacts are often limited to those resulting from construction and maintenance. However, on unhardened or under hardened trails, overuse or poor design and inadequate maintenance can contribute to ongoing deterioration of the surface, which vastly increases the area of impact beyond that arising from initial track construction (Cole 2004a). Cole (1983) states that in the US wilderness areas, more money is spent on mitigating trail impacts than on any other form of visitor impact. Impacts in recent decades have been exacerbated by an increase in the number of people accessing wilderness areas via track networks (Marion *et al*. 2006). The deterioration of trails is associated with four key issues for protected area managers (Cole 2004a; Marion *et al*. 2006).

1. Deteriorating tracks can cause ongoing ecological damage to valuable and vulnerable protected habitats. In particular, soil erosion (track deepening), track widening and the proliferation of unplanned tracks can damage ecological systems and reduce the condition which then affects the natural, social and economic values of the protected area.
2. Mitigating impacts and rehabilitating degraded areas is expensive.
3. There are safety issues arising from visitors using eroded and/or muddy tracks.
4. Degraded overused tracks reduce the quality of the visitor experience and thus reduce the tourism value of the protected area.

Data on trail condition can be used to: (1) compile detailed trail profiles; (2) identify trail problems so that maintenance can be undertaken strategically; (3) determine trends in condition over time; and (4) demonstrate whether management action and interventions have been effective e.g. by designing adaptive management systems (Leung and Marion 2000; Cole 2004a).

*Trail erosion and widening*

Erosion is the most significant form of trail degradation and may be ecologically irreversible once soil is removed off-trail and into adjacent areas where it can smother vegetation or enter water bodies where it can remain suspended or settle out and harm aquatic life (Liddle 1997; Jewell and Hammitt 2000; Cole 2004a). The resulting rutted trails then intercept and transport greater volumes of water, accelerating soil erosion and alter natural patterns of water runoff. The loss of soil and organic litter and exposure of roots and rock can retard the recovery of vegetation. On highly overused trails on erodable soils or in wet areas so much soil is lost that the surface can be metres below the surrounding ground (Leung and Marion 2000). Soil eroded from trails can expose tree roots, creating a rutted and uneven surface with safety issues for users (See Part 4).

Obtaining accurate and precise measures of soil erosion along trails is challenging. Researchers have developed numerous methods including rapid qualitative estimates based on use of condition classes and rapid quantitative assessment based on measuring maximum incision (trail depth) post construction or current incision (Marion and Leung 2000). Intensive sampling methods have also been developed that measure the cross sectional area of trail ruts to estimate soil loss across path transects. These methods detect subtle changes but are time consuming and only provide specific data on localised trail conditions (Cole 1991).

Trail widening is another impact related to both overuse and prevailing environmental conditions – particularly rainfall and soil type. In wet conditions excessive muddiness forces users to spread out laterally to avoid wet muddy areas. This increases the width of the trail through formation of multiple, braided or parallel trails (Leung and Marion 2000; Marion 2007). To examine trail widening, researchers measure several indicators of trail width, including the width free of vegetation, width of vegetation visibly affected by trampling and/or erosion and width free of both vegetation and organic litter (Marion and Leung 2000; Dixon *et al*. 2004).

*Unplanned trails*

A significant ecological impact of trail use is the proliferation of user-created trails as horse riders go off formal trail and into areas used for tethering. This increases the spatial extent of existing impacts. Most impacts to soil and vegetation occur with low initial use, although in vegetation types sensitive to change permanent trails can develop rapidly (Cole and Bayfield 1993; Leung and Marion 2000).

Assessment techniques have been developed to document the extent of informal trails that have developed along trail systems (Marion *et al*. 2006). Aerial photographs have been used to assess this on a regional scale and this can be an efficient method if suitable coverage is available over a sufficient period of time (Jewell and Hammitt 2000). This method has potentially significant limitations and when interpreting aerial photographs, the distinction between trampled, dying, dead or damaged vegetation and eroded segments is far from obvious (Jewell and Hammitt 2000). Furthermore, the financial commitment and high level of training necessary to interpret photos raises serious concern about its utility. However, in combination with other methods, aerial photography and Geographic Information Systems may enhance the data that managers use to make trail resource decisions (Jewell and Hammitt 2000).

*Social impacts from deteriorated trails*

Deteriorated trails have undesirable social consequences. For example, eroded and/or muddy trails reduce the quality of the recreational experience through loss of visual appeal, increased evidence of human disturbance, perceived crowding and user conflicts (for example encounters between walkers and bike riders) (Parks and Wildlife Service 1994). Also, the functionality of the resource is decreased with increased travel difficulty and visitor safety problems (Leung and Marion 2000) (Table 7).

## 9. Which type of assessment approach is appropriate for assessing environmental impacts of horse-riding?

It is clear from the above review that: (1) horse riding can have a range of negative social and biophysical impacts on the park environment; (2) these impacts are predicted to be more severe in Australia than in some overseas regions; (3) because horse riding in Southeast Queensland trails network will be limited to hardened, often mixed use trails, many impacts will be associated with trails; (4) other impacts, particularly arising from weeds, pathogens, and nutrient accessions to waterways, may be more severe and self-sustaining and may affect biota and ecosystems some distance away from the immediate area of the trails.

**Table 7**. Environmental and social impacts of track degradation associated with use for horse riding (modified from Leung and Marion (2000) and Newsome *et al*. (2008).

| Impact | Environmental | Social |
|---|---|---|
| Soil erosion | Soil and nutrient loss, water turbidity, alteration of water runoff | Increased travel difficulty, reduction of visual appeal, safety |
| Exposed roots | Damage to trees/shrubs. Reduce vigour, intolerance to drought | Reduction of visual appeal, safety |
| Unplanned tracks | Vegetation loss, habitat fragmentation | Evidence of human degradation, reduction of visual appeal, safety |
| Increased/excessive width | Vegetation loss, exposed soil | Reduction of visual appeal, safety |
| Wet soil | Soil compaction, increased water run off | Increased travel difficulty, reduction of visual appeal, safety |
| Running water | Accelerated erosion | Increased travel difficulty, reduction of visual appeal, safety |

Before discussing indicators for assessing these potential impacts of horse riding in Southeast Queensland parks it is important to clarify the objectives of different assessment methods that can be used in parks (Hadwen *et al*. 2008). In reality, the approach taken to assessing impacts is dependent on the objectives of the study and the resources available. When the resources available are limited, assessments tend to involve basic inventories. This is the common type of assessment conducted by park agencies. Figure 3 presents the various approaches that could be undertaken to investigate environmental impacts. Inventories may require less detailed measurement than monitoring. As inventory sampling is often conducted by the same people over a short period of time, they can use qualitative measures of track condition. Inventory types of methods can be used over a larger number/distance/type of tracks as less time may be required for sampling at any given point on a track. However, it is important to be aware that many of the methods used for inventories have a subjective component.

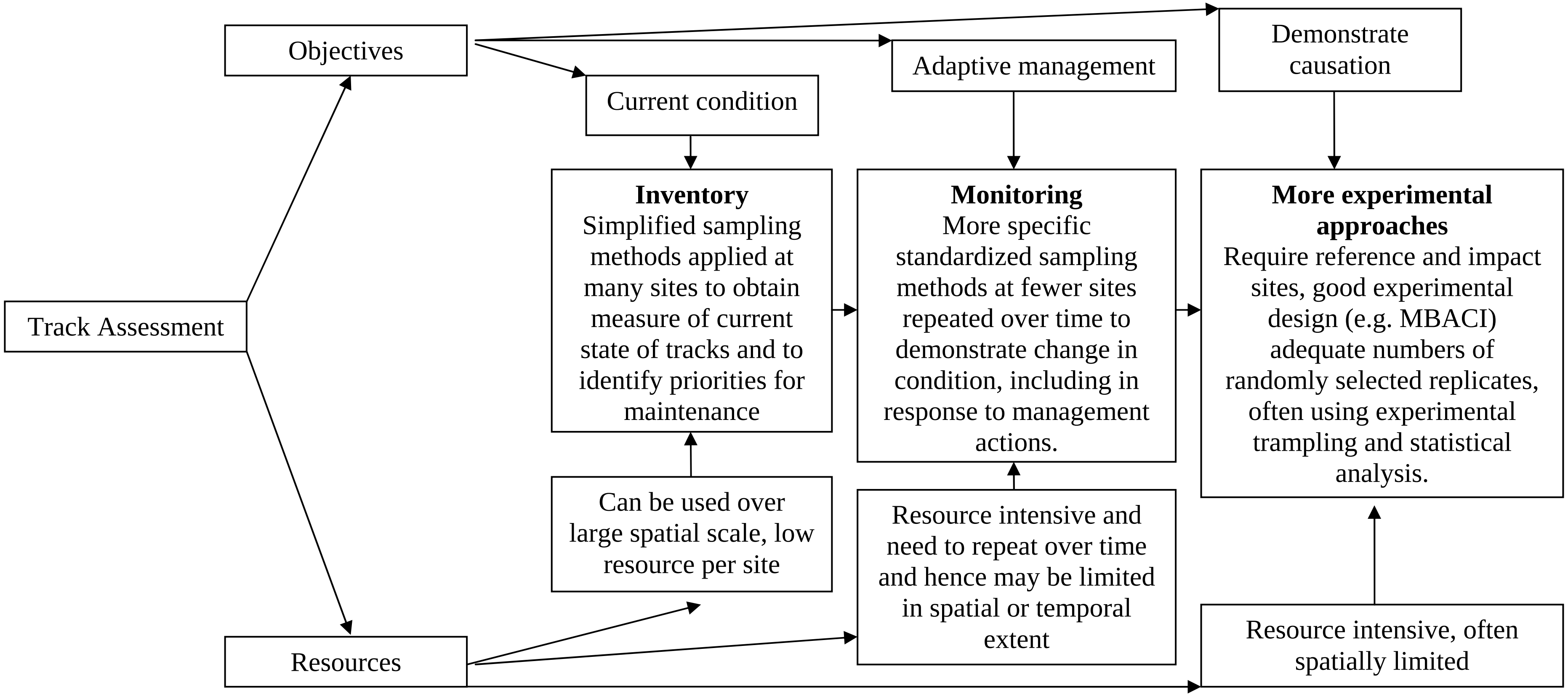


**Figure 3. Schematic representation of the relationship among different approaches for environmental impact assessments.**

Condition class methods are an example of the type of method suitable for conducting inventories. Tracks used by horse riders are divided into relatively homogenous sections in terms of environmental conditions, and assessments are made for each section using pre-defined condition classes by field staff who asses the entire track system. Bratton *et al*. (1979) estimated the proportions of entire track sections that were subject to various depths of erosion. Dixon *et al*. (2004) rated track sections for width, erosion, depth and a number of other parameters. Nepal (2003) assigned an aggregate assessment to each track section based on condition classes defined by Cole (1983). Category class descriptions are determined by disturbance of vegetation and litter, width of track, depth of soil erosion, presence of wet soil and running water, root exposure, and presence of multiple tracks.

The second main type of impact assessment involves monitoring defined here as the standardised measurement of relevant impact indicators over time (Figure 3). As the aim of the method is to detect a change in condition over time, it is important in designing a monitoring program that the methods used can be applied consistently over time, often by different people. Therefore, some types of methods used for inventories may not be appropriate for a monitoring program. Some broad scale categories used in inventories, for example, can be subject to observer bias, particularly when undertaken at different times or by different people. As a result monitoring programs tend to use quantitative measures of specific indicators at fixed sites.

The relationship between use related factors (type of and amount of use), environmental factors and impacts can be assessed based on data resulting from a well designed monitoring program (Cole 2004b). Data collected by monitoring specific types of biophysical response to horse riding along trails can assist managers in understanding the track degradation process and identify factors that might be manipulated to facilitate sustainable track use (Cole 2004b; Marion 2007). It can also be used to support an adaptive management program designed to determine if a particular management response (hardening of track, increased permitted use, change in type of activities permitted and closure of a track) has the desired outcome. The point sampling method has been widely used for track monitoring, particularly in the US as it allows for relatively rapid assessment of average track condition and estimates of spatial variation in track condition relative to environmental conditions (Cole 1991; Leung and Marion 2000; Dixon *et al*. 2004; Marion 2007).

Point sampling is based on measuring track condition at numerous points along tracks using either systematic sampling at fixed intervals or stratified sampling where environmental factors (vegetation type, slope, substrate) and use factors (amount and type of use) are accounted for in the sampling design. Sampling points can be permanent or non-permanent. Design and maintenance factors are also recorded. Variations of this method (using permanently located transects) were used to assess the walking track system in the Tasmanian Wilderness World Heritage Area (Dixon *et al*. 2004).

Some of the types of impact indicators often recorded during point monitoring include: (1) soil erosion; (2) track width; (3) informal/unplanned tracks, (4) changes in vegetation on verges (increase in weeds, decrease in native vegetation cover). These indicators can provide useful estimates of system wide track condition. Soil erosion (track depth) is seen as a very important indicator of the severity of declines in track condition and can be estimated in a number of ways including maximum incision post construction, current maximum incision and cross sectional area of the trail. Track width is measured as width of bare ground and width affected by trampling. Changes in vegetation can be measured using quadrats or point quadrat sampling on verges and in adjacent areas. Long term vegetation monitoring requires quadrat locations to be permanently marked and georeferenced using GPS (global positioning system). Within quadrats, plants can be identified to species level and assessed for cover to enable subsequent estimates of differences in relative cover and species richness. However, such sampling methods can be time consuming and require expertise in plant identification.

These types of indicators can also be used in a quasi-experimental approach to compare impacted and non-impacted sites (eg tracks and adjacent areas), or to compare tracks before and after specific levels and/or types of use or along gradients of increasing use by horse riders (Buckley 2003; Arthington *et al*. 2006). These types of methods are good and have provided useful information for research and management (Buckley 2003; Cole 2004b; Newsome *et al*. 2008; Hadwen *et al*. 2008). However, they can suffer from issues regarding the need to quantify levels of use and, where multiple types of use occur (e.g. walking and horse riding), from the difficulties of separating out the effects of different types of use as well as the impacts of interactions among users.

A fully experimental approach using a Before, After, Control, Impact method (BACI) or MABACI (multiple site BACI) can be applied to both test for causation and determine the effect of different levels of use (Buckley 2003). This type of approach is resource intensive but has provided valuable information on the resistance and resilience of various vegetation communities to trampling including from horse riding (Cole and Bayfield 1993; Cole 1995a, 1995b, 2004a; Newsome *et al*. 2002b, 2008). It also allows data to be collected about a particular type of use and the use's impacts on a site or system such as a water body. One method involves determining the number of experimental passes required to halve the vegetation cover on experimental plots (Liddle 1997). The types of impacts commonly measured are change in plant species composition, plant species richness, biomass, vegetation height and cover as well as soil erosion and compaction (Liddle 1997; Cole 1995a,b, 1995b, 2004a). Experimental trampling trials show that proportionally more vegetation damage (reduction in vegetation height and cover) occurs at low levels of use and correspondingly, that as trampling intensity increases rate of vegetation damage decreases (Cole 1995a, 1995b, 2004a; Cole and Monz 2002).

## 10. So what could be assessed in Southeast Queensland, why and how?

Depending on the approach taken to the assessment of horse riding impacts, a range of variables can be measured (Buckley 2003; Newsome *et al*. 2002a, 2002b, 2008; Table 8). These include biophysical variables such as measures of track condition, vegetation based variables which may be measured on tracks (exposure of roots), on verges (presence of weed species, reduced vegetation cover) or off track in areas where horses may stray (vegetation composition, height, biomass and condition). Indicators on the impact of horse riding on aquatic ecosystems are also required. These could use indicator and designs similar to those used for healthy waterways. Visitor data needs to be collected, including who visits, when and how often, where do they go and what do they do (Newsome *et al*. 2002a; Hadwen *et al*. 2008). Information also needs to be collected about the attitudes and levels of visitor satisfaction (Newsome *et al*. 2002a). The exact type of variable used will in part depend on the approach taken to assessment (inventory, monitoring and/or recreational ecology research among others), and which types of impacts are likely to be seen as of greatest concern in Southeast Queensland (damage to tracks, spread of weeds, impacts on aquatic systems, attitudes of different user groups, community perceptions). Additional information on design and indicators is available in a range of environmental monitoring and social impact assessment texts and journals. In addition the members of the scientific committee have considerable expertise in many of these areas that can be used to supplement the more territorial biophysical approaches outlined here.

**Table 8**. Some types of variables that can be used to form inventory categories, or directly measured for monitoring horse riding impacts on existing management trails. (Modified from Newsome *et al*. 2008; Hadwen *et al*. 2008)

| Biophysical variables | Vegetation based variables | Visitor data | Social condition variables |
|---|---|---|---|
| Increased amount of bare ground | Reduction in height and vegetation cover on verges | Who visits | User conflicts on multi-use trails |
| Soil compaction | Presence of weeds on trails and verges | When visitation occurs | Unsafe or difficult travelling conditions |
| Soil erosion | Increase in width of verge (area of altered vegetation adjacent to trail) | Activities undertaken | Manure on trails |
| Increased trail width | Increase in resistant species in verge and adjacent areas | Location of activities | Visitor expectations |
| Wet muddy trails | Evidence of dieback on verges | | Visitor satisfaction |
| Increased surface run-off | Root exposure | | |

Assessing the impacts of horse riding in Southeast Queensland is likely to require a mixture of inventory, monitoring and experimental approaches, and hence a mixture of observational, quantitative, qualitative and experimental data of visitors, tracks, and impacts. Both monitoring and full experimental methods are likely to be required as part of the assessment program, particularly if thresholds of concern or other types of ecological thresholds are to be identified and used to trigger management actions by park agencies.

1. Visitors
Visitor monitoring data is required for horse riding and other usages of the protected areas. This information should always be collected as part of the day-to-day running of parks in Australia and is critically important when assessing impacts of recreational usage.

2. Track management
For much of the day-to-day management of the trail network, an inventory or monitoring based approach may provide the best strategy for assessing the condition of tracks, location of sites for repair, and to assess the success of adaptive management strategies.

3. Impacts
At least some of the assessment of the impacts of horse riding will require an experimental approach using recreation ecology research methods in order to provide an acceptable level of evidence (Buckley 2003). Much of the criticism of the information used as a basis for changes in management of horse riding in other protected areas in Australia (Beavis 2000) has focused around the following issues.

*a. Lack of site specific data.* This deficiency arises because factors such as the nature of the use (timing, intensity, frequency), the type of facilities (hardened tracks or off-track, type of track, slope, substrate), and ecosystem (vegetation growth form, ecosystem type) can all influence the type, degree and extent of impacts. With increasing research experience in recreation ecology in Australia it will be possible to make more and more specific predictions/generalisations about impacts at forest sites. Site specific recreation ecology research, therefore, undertaken in local sites under local conditions will improve understanding of impacts by scientists, park management and the public.

*b. Type of approach.* Criticism has been made of some of the approaches used to assess impacts. This includes issues to do with the capacity of the study to determine causation. As a result, where it is necessary to directly test causation, an experimental approach, potentially involving a BACI (Before, After, Control, Impact) or similar design and appropriate (often repeated measures ANOVA with block design) should be used.

*c. Multi-use.* On multi-use trails it can be difficult to separate out impacts caused by different activities. A quasi-experimental or full experimental approach in some sites may be required to quantify/demonstrate differences in impacts.

*d. Significance of indirect impacts.* As horse riding appears to have a greater potential for introducing non-local seeds including weeds, and for altering habitats in ways that then benefit such ruderal species, additional research examining this issue is required.

This impact is one that is particularly controversial, despite a general acceptance of the threat that weeds can pose in parks.

## 11. Conclusions

Horse riding has a range of social and environmental impacts on parks. These impacts need to be assessed and managed in Southeast Queensland. Due to many distinctive features of the Australian biota, impacts from riding are particularly severe in Australian forest ecosystems and possible also in aquatic ecosystems, and hence need to be carefully managed. The assessment approach taken in Southeast Queensland needs to take into account the range of factors that can influence the significance/extent of impacts, and the resources available to park staff for assessing impacts. The management agency also needs to provide information to the community about the methodology and results of this research.

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## Appendix 1. Potential sources of information regarding social aspects of impact assessment. (References kindly provided by Joe Reser).


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**Appendix 2: One hundred and eighty-nine species that have seed that was either found on the coat of horses, or germinated from horse dung.** GH = from samples germinated in glasshouse. Field = germinated from manure in the field.

| | Coat | Horse dung | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | Couvreur *et al*. 2004 | Cosyns & Hoffmann 2005 | Campbell & Gibson 2001 | Wells & Lauenroth 2007 | Weaver & Adams 1996 | | | Whinam *et al*. 1994 | | St John-Sweeting and Morris 1991 | |
| Location of study | Belgium | Belgium | Illinois USA | Colorado USA | Victoria, Australia | | | Tasmania, Australia | | Victoria, Australia | |
| Sampled from | Parks | Parks | Parks | Parks | Kinglake NP | Otway NP | Alpine NP | Central Plateau, Park | | Pasture | Total All studies |
| Germinated | GH | GH | GH | GH | GH | GH | GH | Field | GH | GH | |
| Species germinated | 20 | 72 | 73 | 20 | 24 | 11 | 11 | 6 | 10 | 6 | 189 |
| *Acetosella vulgaris* | | | | | | | | | 1 | | 1 |
| *Agrimonia* sp. *(eupatoria?)* | | | 1 | | | | | | | | 1 |
| *Agrostis capillaris* | 1 | 1 | | | 1 | | | | | | 3 |
| *Agrostis stolonifera* | | 1 | | | | | | | | | 1 |
| *Aira caryophyllea* | | | | | | | | 1 | 1 | | 2 |
| *Aira praecox* | | 1 | | | | | | | | | 1 |
| *Amaranthus retroflexus* | | | | 1 | | | | | | | 1 |
| *Amaranthus spinosus?* | | | 1 | | | | | | | | 1 |
| *Ambrosia artemisiifolia* | | | 1 | | | | | | | | 1 |
| *Anthriscus caucalis?* | | 1 | | | | | | | | | 1 |
| *Anthriscus sylvestris?* | 1 | | | | | | | | | | 1 |
| *Arenaria serpyllifolia* | | 1 | | | | | | | | | 1 |
| *Arvena fatua* | | | | | 1 | | | | | | 1 |
| *Asphodelus fistulosus* | | | | | | | | | | 1 | 1 |
| *Aster pilosus?* | | | 1 | | | | | | | | 1 |
| *Avena barbata* | | | | | 1 | | | | | | 1 |
| *Avena sativa* | | | | 1 | | | | | | | 1 |

| | Coat | Horse dung | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | Couvreur *et al.* 2004 | Cosyns & Hoffmann 2005 | Campbell & Gibson 2001 | | Wells & Lauenroth 2007 | Weaver & Adams 1996 | | | Whinam *et al.* 1994 | | St John-Sweeting and Morris 1991 | |
| Location of study | Belgium | Belgium | Illinois USA | | Colorado USA | Victoria, Australia | | | Tasmania, Australia | | Victoria, Australia | |
| Sampled from | Parks | Parks | Parks | | Parks | Kinglake NP | Otway NP | Alpine NP | Central Plateau, Park | | Pasture | Total All studies |
| *Avena* sp. | | | 1 | | | | | | | | | 1 |
| *Betula fontinalis* | | | | | 1 | | | | | | | 1 |
| *Boehmeria cylindrica* | | | 1 | | | | | | | | | 1 |
| *Briza minor* | | | | | | 1 | | | | | | 1 |
| *Bromus diandrus* | | | | | | 1 | | | 1 | 1 | | 3 |
| *Bromus inermis* | | | | | 1 | | | | | | | 1 |
| *Bromus mollus* | | | | | | | | | 1 | 1 | | 2 |
| *Bromus rubens* | | | | | | 1 | | | | | | 1 |
| *Bromus* sp. | | | 1 | | | | | | | | | 1 |
| *Bromus tectorum* | | | | | 1 | | | | | | | 1 |
| *Calamagrostis epigejos* | | 1 | | | | | | | | | | 1 |
| *Callitriche heterophylla* | | | 1 | | | | | | | | | 1 |
| *Capsella bursa-pastoris* | | | | | 1 | | | | | | | 1 |
| *Cardamine hirsuta* | | 1 | 1 | | | | | | | | | 2 |
| *Carex arenaria* | | 1 | | | | | | | | | | 1 |
| *Carex blanda* | | | 1 | | | | | | | | | 1 |
| *Carex cephalophora* | | | 1 | | | | | | | | | 1 |
| *Carex flacca* | | 1 | | | | | | | | | | 1 |
| *Carex* sp. | | | 1 | 1 | | | | | | | | 1 |
| *Cenchrus* sp. | | | | | | 1 | | | | | | 1 |
| *Centaurium erythraea* | | 1 | | | | | | | | | | 1 |
| *Centaurium littorale* | | 1 | | | | | | | | | | 1 |
| *Cerastium fontanum* | | 1 | | | | | | | | | | 1 |
| *Cerastium glomeratum* | | | 1 | | | 1 | | 1 | | | | 3 |

| Reference | Coat: Couvreur *et al.* 2004 | Horse dung: Cosyns & Hoffmann 2005 | Campbell & Gibson 2001 | Wells & Lauenroth 2007 | Weaver & Adams 1996 | | | Whinam *et al.* 1994 | St John-Sweeting and Morris 1991 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Location of study | Belgium | Belgium | Illinois USA | Colorado USA | Victoria, Australia | | | Tasmania, Australia | Victoria, Australia | |
| Sampled from | Parks | Parks | Parks | Parks | Kinglake NP | Otway NP | Alpine NP | Central Plateau, Park | Pasture | Total All studies |
| *Chenopodium ambrosioides* | | | 1 | | | | | | | 1 |
| *Chrysothamnus nauseosus* | | | | 1 | | | | | | 1 |
| *Conyza canadensis* | | 1 | | | | | | | | 1 |
| *Crepis capillaris* | | 1 | | | | | | | | 1 |
| *Cyperus ovularis* | | | 1 | | | | | | | 1 |
| *Dactylis glomerata* | | | | 1 | | | | 1 | | 2 |
| *Daucus carota* | | | 1 | | | | | | | 1 |
| *Dichanthelium boscii* | | | 1 | | | | | | | 1 |
| *Dichanthelium dichotomum* | | | 1 | | | | | | | 1 |
| *Digitaria ischaemum* | | | 1 | | | | | | | 1 |
| *Digitaria sanguinalis* | | | 1 | | | | | | | 1 |
| *Eclipta prostrata* | | | 1 | | | | | | | 1 |
| *Eleocharis obtusa* | | | 1 | | | | | | | 1 |
| *Eleusine indica* | | | 1 | | | | | | | 1 |
| *Epilobium ciliatum* | | 1 | | | | | | | | 1 |
| *Epilobium hirsutum* | | 1 | | | | | | | | 1 |
| *Epilobium roseum* | | 1 | | | | | | | | 1 |
| *Epilobium* sp. | 1 | 1 | | | | | | | | 2 |
| *Erigeron anuus* | | | 1 | | | | | | | 1 |
| *Erigeron philadelphicus* | | | 1 | | | | | | | 1 |
| *Erigeron* sp. | | | 1 | | | | | | | 1 |
| *Erigeron strigosus* | | | 1 | | | | | | | 1 |
| *Erodium* | | 1 | | | | | | | | 1 |

| | Coat | Horse dung | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Reference | Couvreur *et al*. 2004 | Cosyns & Hoffmann 2005 | Campbell & Gibson 2001 | Wells & Lauenroth 2007 | Weaver & Adams 1996 | | | Whinam *et al*. 1994 | St John-Sweeting and Morris 1991 | |
| Location of study | Belgium | Belgium | Illinois USA | Colorado USA | Victoria, Australia | | | Tasmania, Australia | Victoria, Australia | |
| Sampled from *cicutarium+lebelii* | Parks | Parks | Parks | Parks | Kinglake NP | Otway NP | Alpine NP | Central Plateau, Park | Pasture | Total All studies |
| *Eupatorium cannabinum* | | 1 | | | | | | | | 1 |
| *Fageria vesca* | | | | 1 | | | | | | 1 |
| *Festuca arundinacea* | | | 1 | | | | | | | 1 |
| *Festuca filiformis* | | 1 | | | | | | | | 1 |
| *Festuca rubra* | | 1 | | | | | | | | 1 |
| *Galium aparine* | | 1 | | | 1 | | | | | 2 |
| *Galium mollugo* | | 1 | | | | | | | | 1 |
| *Galium palustre* | | 1 | | | | | | | | 1 |
| *Galium uliginosum* | | 1 | | | | | | | | 1 |
| *Galium verum* | | 1 | | | | | | | | 1 |
| *Geranium molle* | | 1 | | | | | | | | 1 |
| *Gnaphalium uliginosum* | 1 | 1 | | | | | | | | 2 |
| *Holcus lanatus* | 1 | 1 | | | 1 | 1 | 1 | 1 | | 6 |
| *Hordeum* sp. | | | | | | 1 | | | | 1 |
| *Hydrocotyle* sp. | | | | | 1 | | | | | 1 |
| *Hydrocotyle vulgaris* | | 1 | | | | | | | | 1 |
| *Hypericum perforatum* | 1 | | | | | | | | | 1 |
| *Iva annua* | | | 1 | | | | | | | 1 |
| *Juncus articulatus* | | 1 | | | | | | | | 1 |
| *Juncus balticus* | | | | 1 | | | | | | 1 |
| *Juncus bufonius* | 1 | 1 | | | 1 | | | | | 3 |
| *Juncus confuses* | | | | 1 | | | | | | 1 |
| *Juncus marginatus* | | | 1 | | | | | | | 1 |

| | Coat | Horse dung | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Reference | Couvreur *et al*. 2004 | Cosyns & Hoffmann 2005 | Campbell & Gibson 2001 | Wells & Lauenroth 2007 | Weaver & Adams 1996 | | | Whinam *et al*. 1994 | St John-Sweeting and Morris 1991 | |
| Location of study | Belgium | Belgium | Illinois USA | Colorado USA | Victoria, Australia | | | Tasmania, Australia | Victoria, Australia | |
| Sampled from | Parks | Parks | Parks | Parks | Kinglake NP | Otway NP | Alpine NP | Central Plateau, Park | Pasture | Total All studies |
| *Juncus* sp. | | | | 1 | | | | | | 1 |
| *Juncus tenuis* | | | 1 | | | | | | | 1 |
| *Kummerowia striata* | | | 1 | | | | | | | 1 |
| *Leersia virginica* | | | 1 | | | | | | | 1 |
| *Lepidium virginicum* | | | 1 | | | | | | | 1 |
| *Leucospora multifida* | | | 1 | | | | | | | 1 |
| *Lindernia dubia* | | | 1 | | | | | | | 1 |
| *Lobelia inflata* | | | 1 | | | | | | | 1 |
| *Lolium perenne* | 1 | | | | 1 | | | 1 | | 3 |
| *Lolium rigidum* | | | | | | | 1 | | | 1 |
| *Ludwigia altermifolia* | | | 1 | | | | | | | 1 |
| *Luzula campestris* | | 1 | | | | | | | | 1 |
| *Lycopus europaeus* | | 1 | | | | | | | | 1 |
| *Lysimachia vulgaris* | | 1 | | | | | | | | 1 |
| *Lythrum salicaria* | 1 | 1 | | | | | | | | 2 |
| *Malva parviflora* | | | | | | | | | 1 | 1 |
| *Marrubium vulgare* | | | | | | | | | 1 | 1 |
| *Matricaria chamomilla* | | | 1 | | | | | | | 1 |
| *Medicago lupulina* | | 1 | | | | | | | | 1 |
| *Medicago minima* | | | | | 1 | | | | | 1 |
| *Medicago polymorpha* | | | | | 1 | 1 | | | 1 | 3 |
| *Medicago truncatula* | | | | | 1 | 1 | 1 | | | 3 |
| *Melilotus indicus* | | | | | 1 | | | | | 1 |
| *Melilotus* sp. | | | 1 | | | | | | | 1 |

| | Coat | Horse dung | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Reference | Couvreur *et al.* 2004 | Cosyns & Hoffmann 2005 | Campbell & Gibson 2001 | Wells & Lauenroth 2007 | Weaver & Adams 1996 | | | Whinam *et al.* 1994 | St John-Sweeting and Morris 1991 | |
| Location of study | Belgium | Belgium | Illinois USA | Colorado USA | Victoria, Australia | | | Tasmania, Australia | Victoria, Australia | |
| Sampled from | Parks | Parks | Parks | Parks | Kinglake NP | Otway NP | Alpine NP | Central Plateau, Park | Pasture | Total All studies |
| *Mentha aquatica* | | 1 | | | | | | | | 1 |
| *Mollugo verticillatus* | | | 1 | | | | | | | 1 |
| *Myosurus minimus* | | | 1 | | | | | | | 1 |
| *Oenothera glazioviana* | | 1 | | | | | | | | 1 |
| *Oxalis* sp. | | | | | 1 | 1 | 1 | | | 3 |
| *Oxalis stricta* | | | 1 | | | | | | | 1 |
| *Panicum* sp. | | | 1 | | | | | | | 1 |
| *Pascopyrum smithii* | | | | 1 | | | | | | 1 |
| *Pentaphylloides floribunda* | | | | 1 | | | | | | 1 |
| *Penthorum sedoides* | | | 1 | | | | | | | 1 |
| *Phacelia tanacetifolia* | 1 | | | | | | | | | 1 |
| *Phalaris paradoxa* | | | | | 1 | | 1 | | | 2 |
| *Phleum pratense* | | 1 | | | | | | | | 1 |
| *Pilea pumila* | | | 1 | | | | | | | 1 |
| *Plantago coronopus* | | 1 | | | | | | | | 1 |
| *Plantago lanceolata* | | 1 | 1 | | 1 | | | 1 | 1 | 5 |
| *Plantago major* | 1 | 1 | 1 | | | | | | | 3 |
| *Plantago rugelii* | | | 1 | | | | | | | 1 |
| *Plantago virginica* | | | 1 | | | | | | | 1 |
| *Poa annua* | | 1 | 1 | | | 1 | 1 | | | 4 |
| *Poa pratensis* | 1 | 1 | | 1 | | | | | | 3 |
| *Poa* sp. | | | 1 | 1 | | | | | | 1 |
| *Poa trivalis* | 1 | 1 | | | | | | | | 2 |
| *Polygonum arenastrum* | | | | 1 | | | | | | 1 |

| | Coat | Horse dung | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Reference | Couvreur *et al*. 2004 | Cosyns & Hoffmann 2005 | Campbell & Gibson 2001 | Wells & Lauenroth 2007 | Weaver & Adams 1996 | | | Whinam *et al*. 1994 | St John-Sweeting and Morris 1991 | |
| Location of study | Belgium | Belgium | Illinois USA | Colorado USA | Victoria, Australia | | | Tasmania, Australia | Victoria, Australia | |
| Sampled from | Parks | Parks | Parks | Parks | Kinglake NP | Otway NP | Alpine NP | Central Plateau, Park | Pasture | Total All studies |
| *Polygonum avicluare* | | | 1 | | | | | | | 1 |
| *Polygonum cespitosum* | | | 1 | | | | | | | 1 |
| *Polygonum convolvus* | | | 1 | | | | | | | 1 |
| *Potentilla reptans* | | 1 | | | | | | | | 1 |
| *Protulaca oleracea* | | | 1 | | | | | | | 1 |
| *Prunella vulgaris* | | 1 | 1 | | | | | | | 2 |
| *Ranunculus abortivus* | | | 1 | | | | | | | 1 |
| *Ranunculus repens* | | 1 | | | | | | | | 1 |
| *Ranunculus sceleratus* | | 1 | | | | | | | | 1 |
| *Rubus caesius* | | 1 | | | | | | | | 1 |
| *Rumex acetosella* | | 1 | | | | | | | | 1 |
| *Rumex conglomeratus* | | 1 | | | | | | | | 1 |
| *Rumex crispus* | | 1 | 1 | | | | | | | 2 |
| *Rumex obtusifolius* | 1 | | 1 | | | | | | | 2 |
| *Rumex* sp. | | | | | | 1 | 1 | | | 2 |
| *Rununculus sceleratus* | | | 1 | | | | | | | 1 |
| *Sagina procumbens+apetala* | | 1 | | | | | | | | 1 |
| *Salix nigra* | | | 1 | | | | | | | 1 |
| *Samolus valerandi* | | 1 | | | | | | | | 1 |
| *Scirpus setaceus* | | 1 | | | | | | | | 1 |
| *Sedum acre* | | 1 | | | | | | | | 1 |
| *Senecio glabellus* | | | 1 | | | | | | | 1 |
| *Senecio jacobaea* | 1 | 1 | | | | | | | | 2 |
| *Senecio sylvaticus* | | 1 | | | | | | | | 1 |

| | Coat | Horse dung | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | Couvreur *et al.* 2004 | Cosyns & Hoffmann 2005 | Campbell & Gibson 2001 | Wells & Lauenroth 2007 | Weaver & Adams 1996 | | | Whinam *et al.* 1994 | | St John-Sweeting and Morris 1991 | |
| Location of study | Belgium | Belgium | Illinois USA | Colorado USA | Victoria, Australia | | | Tasmania, Australia | | Victoria, Australia | |
| Sampled from | Parks | Parks | Parks | Parks | Kinglake NP | Otway NP | Alpine NP | Central Plateau, Park | | Pasture | Total All studies |
| *Senecio vulgaris* | 1 | | | | | | | | | | 1 |
| *Setaria viridis* | | | | 1 | | | | | | | 1 |
| *Solanum dulcamara* | | 1 | | | | | | | | | 1 |
| *Solanum nigrum* | | 1 | | | | | | | | | 1 |
| *Solidago canadensis* | | | 1 | | | | | | | | 1 |
| *Solidago ulmifolia* | | | 1 | | | | | | | | 1 |
| *Sonchus oleraceus* | 1 | 1 | | | | | | | | | 2 |
| *Spergularia rubra* | | | | 1 | | | | | | | 1 |
| *Stellaria media* | | 1 | | | 1 | 1 | 1 | | | | 4 |
| *Tanacetum vulgare* | 1 | | | | | | | | | | 1 |
| *Taraxacum officinale* | | | 1 | | | | | | | | 1 |
| *Trifolium arvense* | | | | | 1 | 1 | 1 | | | | 3 |
| *Trifolium balansae* | | | | | | | | | | 1 | 1 |
| *Trifolium brachycalycinum* | | | | | | | | | | 1 | 1 |
| *Trifolium campestre* | | 1 | | | | | | | | | 1 |
| *Trifolium dubium* | | 1 | | | | | | | | | 1 |
| *Trifolium glomeratum* | | | | | | 1 | | | | | 1 |
| *Trifolium pratense* | | | 1 | | | | | | | | 1 |
| *Trifolium repens* | 1 | 1 | 1 | | 1 | | 1 | 1 | 1 | | 7 |
| *Trifolium subterraneum* | | | | | 1 | 1 | | | | | 2 |
| *Urtica dioica* | 1 | 1 | | | | | | | | | 2 |
| *Verbascum thapsus* | | | 1 | | | | | | | | 1 |
| *Verbena urticifolia* | | | 1 | | | | | | | | 1 |
| *Veronica arvensis* | | | 1 | | | | | | | | 1 |

| | Coat | Horse dung | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Reference | Couvreur *et al.* 2004 | Cosyns & Hoffmann 2005 | Campbell & Gibson 2001 | Wells & Lauenroth 2007 | Weaver & Adams 1996 | | | Whinam *et al.* 1994 | St John-Sweeting and Morris 1991 | |
| Location of study | Belgium | Belgium | Illinois USA | Colorado USA | Victoria, Australia | | | Tasmania, Australia | Victoria, Australia | |
| Sampled from | Parks | Parks | Parks | Parks | Kinglake NP | Otway NP | Alpine NP | Central Plateau, Park | Pasture | Total All studies |
| *Veronica chamaedrys+arvensis* | | 1 | | | | | | | | 1 |
| *Veronica officinalis* | | 1 | | | | | | | | 1 |
| *Veronica perigrina* | | | 1 | | | | | | | 1 |
| *Veronica serpyllifolia* | | 1 | | | | | | | | 1 |
| *Vulpia bromoides* | | | | | | | | 1 | 1 | 2 |
| *Woodsia obtusa* | | | 1 | | | | | | | 1 |