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Changes in the soil micro-topography of two coastal hiking trails in south-western Australia

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ABSTRACT

Two coastal walk trails in south-western Australia were subjected to a specific soil erosion and microtopography assessment between 2004–2007. A point intercept (PIN) frame was used to evaluate change over time to the trail profile. Estimates of soil loss are quantified and discussed in relation to previous historical use and a lack of appropriate management intervention. The results show that soil erosion of up-slope areas and deposition in low lying areas is active on the sections of the Bald Head and Peak Head walk trails that received PIN frame treatments. The data show that a long-term data set is required to accurately analyse changes to soil microtopography and to show statistically significant differences in cross sectional area of trail profiles. It was also found that maintenance features alone do not guarantee the sustainability of a coastal walk trail. Appropriate planning, initial trail location and ongoing maintenance are essential components of a sustainable trail management program.

Keywords: Hiking trails, soil microtopography, soil erosion, sustainable trail management

INTRODUCTION

There is a need for clearly defined trail systems that contain the movement of visitors within natural and protected areas and to protect the surrounding environment from impacts such as uncontrolled trampling, soil degradation and wildlife disturbance (Newsome *et al.* 2002). Research into a wide range of cause and effect variables dealing with the environmental and use factors associated with recreational tourism has largely been focused around high use mountainous areas in Europe and the U.S. (see review by Sun & Walsh 1998). The main factors or environmental controls that affect walk trail degradation are slope, soil type and climate (Leung & Marion 1996). Other factors that impact on the condition of walk trails such as use levels and use type can be highly variable in the way impacts are evident, depending on the resistance and resilience of the host environment (Garland 1987; Parks & Wildlife Service Tasmania (PWST) 1994; Newsome *et al.* 2002). An understanding of the complexities of environmental controls and use factors, specific to the host environment is a crucial first step in the planning and management of trail systems in protected areas.

A number of trail assessment techniques have been developed that can be used to build a profile of trail conditions, which is useful for accurately directing maintenance efforts and estimating environmental sensitivity (Marion & Leung 2004). When used as baseline data, trail assessment information can form the basis of a monitoring program to assess the extent of change over time in response to management actions or ongoing use factors. Trail assessment techniques can also alert land managers to the nature of sensitive or resilient vegetation or soil associations within protected areas, aiding in the re-alignment or planning for the creation of new trails (Whinam *et al.* 2003).

Although much of the literature dealing with walk-trail-impacts focuses on mountainous environments (*e.g.*, Bayfield 1973; Coleman 1977; Cole 1983; Leung & Marion 1996; Jewell & Hammit 2000), the majority of the world's population lives in close proximity to coastal areas (Harvey & Caton 2003). Coastal areas usually have significantly different soil and vegetation types to those found in mountainous areas, while the environmental controls of slope and climate are ever present. In 2004, two walking trails on the south coast of Western Australia, the Bald Head and Peak Head trails in Torndirrup National Park were assessed using a modified version of Leung and Marion's (1999a) Trail Problem Assessment Method. Changes were made to the indicators used in the assessment to allow for the differences present in the coastal environment in relation to mountainous environments (Randall 2004). One of the benefits of analysing strip graphs produced as a result of the assessment was being able to locate severely degraded sections of trail that could be monitored by fixed point sampling techniques to show changes in soil micro-topography over time (Randall & Newsome, 2008).

Establishing a rate of change in soil loss for severely eroded sections of walk trail can provide useful knowledge for land managers undertaking sustainable trail management programs. Knowing the rate of change can help to enhance any understanding of the complex relationships between the walk trail's environmental and use factors. This information can aid in avoiding problem sections when aligning a new trail and the effective allocation of time and resources to deal with existing trail degradation. The Point Intercept Frame (PIN) has been used in the field of ecology to measure changes in vegetation community structure and is also an effective way of measuring changes in soil micro-topography (e.g., Phillips & Newsome 2002). Measurements that constitute the cross sectional profile of a walk trail can be repeated and compared against the initial baseline measurements to establish changes in the cross sectional area of trail soil. The objectives of this paper are therefore to:

- Provide an indication of soil erosion induced changes on severely degraded sections of trail previously identified by baseline assessment data;
- Make recommendations for these two trail sections for sustainable trail management.

THE STUDY AREA

Torndirrup National Park is located approximately 400 km south east of Perth and 10 km south of Albany. The area was set aside as a reserve in 1918 and elevated to National Park status in 1969 (Smith & Bamford 1991). The park is registered as part of the National Estate and comprises an 'A' class reserve (CALM 1992) (Figure 1). Located on the Flinders Peninsula, Princess Royal Harbour is located to the north and the Southern Ocean forms the parks southern border. The Bald Head and Peak Head trails are located at the eastern end of the park (Figures 2 and 3).

Climate

The study area is described as having a sub-Mediterranean climate with mild summers and cool wet winters. Air temperature is constantly moderated by the marine influence, ranging between a mean daily minimum and maximum air temperature of 10° and 20° C respectively. Annual mean rainfall is 1000 mm with the majority of rainfall between May and August (Smith & Bamford 1991; CALM 1995). Summer rainfall, however, is a common occurrence mostly as overnight drizzle in an easterly airstream but also as thunderstorms, the result of converging tropical cloud delivered to the region in a northerly airstream (Smith & Bamford 1991). More detailed rainfall data is supplied for the three year study period (Figure 4). The wind is a significant climatic factor that has the potential to erode exposed sandy soils and affect the behaviour of wild or prescribed fires in the parks (CALM 1995). North westerly to southerly winds are commonly associated with cold fronts between May and August. Strong and gusty south easterly to northerly winds are experienced September to December, with persistent easterlies in January and February (Smith & Bamford 1991).

Geology and soils

Torndirrup National Park is underlain by a combination of pre-cambrian granites, dolerite and banded gneisses that form rock outcrops, coastal cliffs and monadnocks. Subjected to a long history of weathering, the physiography is expressed as variations in topography soils and hydrology (Churchward *et al.* 1988). The weathering of basement rock has produced localised clay, gravel and a laterite profile more noticeable inland due to the dominance of a coastal mantle of limestone sands (CALM 1995). The coastal mantle exhibits a largely continuous ridge of Tamala limestone of Pleistocene age, overlain by younger sections of aeolian sands of Holocene age, now largely stabilised parabolic dunes. The surface soil is nutrient poor white to grey and yellow to brown fine to medium quartz sand with minor clay soils. There is some gravel or laterite development on the coastal strip occurring in association with exposed granite or gneiss monadnocks.

Coastal dune morphology

The granite and gneiss headlands that characterise the south coast are connected by shallow, curved sandy bays that have acted as the supply point for aeolian sand that has been transported inland during four major marine transgressions during the Pleistocene (Hodgkin & Hesp 1998). Ancient parabolic dune fields have generally accreted in low-lying areas but wind blown sand has also covered granite peaks and Tamala limestone along the coastline forming a belt some 2–3km in width (Churchward *et al.* 1988). The most recent marine transgression was during the Holocene, when sea levels reached about 1m higher than the present before receding approximately 4000 years ago. Coastal dunes are now mostly stabilised by vegetation but still vulnerable to erosion following disturbances such as fire, human activity and high winds associated with storm fronts (Beard 1979).

Vegetation

Approximately 88 plant families and 500 plant species are known to occur in Torndirrup National Park, representing 42% of plant families and 6% of plant species in Western Australia. The root rotting fungal diseases *Phytophthora cinnamomi, Phytophthora cryptogea, Armillaria luteobubalina and canker fungi* also occur (CALM 1995). Beard (1979) has described the dominant plant communities that occur in the immediate study areas as being, Shrubland and Rock Outcrop. Shrubland is further divided into two groups of heath found on the coastal strip in both areas (Table 1).

Visitor numbers

Statistics for Torndirrup National Park for the period 1993–2003 comprise 1,749,199 visits, which is 40% of the total numbers of visitors to six major National Parks in the Great Southern district. Data on trail usage from electronic pedestrian counters placed at selected positions at the beginning of the Bald Head and Peak Head trails, 1996–1999 show that the Bald Head Trail carries an average of 148 walkers per month and Peak Head 56 walkers per month.

METHODS

Using the data generated from the assessment of the chosen trails in the study area (Randall & Newsome, 2008), as well as observations made during field assessment, severely eroded trail sections were identified on the Bald Head and Peak Head trails in Torndirrup National Park. A point sampling technique using the PIN frame was applied to six static positions on both the Bald Head and Peak Head trails on: March, June and September of 2004, March 2005, September 2006 and May 2007. The PIN frame is an adjustable metal frame that holds 20 /1.5 m long pins (4 mm thick) which are centred vertically by the frame, sliding up and down between the upper and lower cross bar and used in this case to measure soil micro-topography. Two steel base plates (20 x 20 cm: 1 cm) support each leg of the PIN frame. In order to locate each base plate on a firm reference surface that was easily relocated over the duration of the study, 4 permanently located, painted hard wood stakes (5 x 5 cm: 30 cm) were driven into the ground under the inside corner of each base plate (rocky ground not suitable). A waterproof marker was used to mark the top of each stake through the alignment holes in each base plate corner (Figure 5).

This system allowed for an accurate realignment of the frame even if several stakes were removed from the site by walkers. However, to avoid this happening, the stakes were driven to ground level and covered with soil to disguise their location. The PIN frame locations on the trail were recorded with a measuring wheel. The distance between the upper, middle and lower sites (position on slope) were recorded, as was the overall length of the entire PIN frame treatment in relation to the trail inventory/assessment data (Randall & Newsome, 2008).

Each pin was calibrated at 10 cm intervals, numbered and fitted with a directional cap for exact positioning during repeats. A spirit level was used to level the PIN frame with adjustments made via the swivel pin on each leg base. Figure 6 shows the PIN frame reading a cross sectional trail profile on the Bald Head trail

Measurements were taken by summing the 10 cm calibration marks on each pin, starting at the soil surface and completed by measuring the difference between the final calibration mark and the lower cross bar. For a complete description of the PIN frame and methods, see Phillips and Newsome (2002). Changes made to these methods for micro-topography included using twenty pins (full set) instead of 10 and replacing the 4 mm steel pins with 4 mm fibreglass pins which return to their original position if bent and do not rust over time. The formula for estimating changes to the cross sectional area is outlined below (Figure 7).

Each PIN frame was described as belonging to the upper, middle or lower slope 1 or 2, to provide a similarly positioned 'repeat' for each main location. The distance between each location (upper, middle and lower) was not evenly spaced due to the presence of exposed roots (Figure 8).

Estimating soil loss

Multiple cross trail measurements were collected in May 2007 to quantify the amount of soil lost (m^3) in the target sections subjected to the PIN frame treatment. The pin frame is capable of capturing data limited to the width of the frame itself (95 cm), and so has been used in this study to illustrate the nature of changing trail profiles. The PIN frame cannot quantify post construction soil loss in situations where the trail is wider than the frame. Additional cross trail measurements were necessary to quantify the soil loss on these wider trail sections, employing a method used by (Manning *et al.* 2006). This method requires the original off trail soil height be located on either side of the trail (Figure 9) and with tension exerted on a non elastic cord marked (in this case) every 10 cm. Measuring from the rope to the trail surface supplies one necessary component of the data needed to estimate average soil loss. The more frequent measurements one takes across a trail profile the greater the degree of confidence in the resulting estimation. The same formula described in Figure 8 was used to estimate the initial cross sectional area (CSA). Further formulae are needed to estimate the trail erosion volume, area of disturbance and the equivalent trail depth (see Appendix; Marion 2007, pers. comm[1]). Multiple cross trail measurements of this nature were only taken from upslope areas that exhibited a clear loss of soil as this technique has no capacity to quantify any increase in soil and was therefore confined to the middle and upper sections of the treatment. This method is much quicker to employ than the PIN frame but does not offer the same degree of accuracy for a repeat measure experiment.

Environmental parameters

A description of the vegetation height and dominant plant species was recorded for each location. Linear sections of the trail aspect in relation to north and slope angle were derived from the previous census data (Randall & Newsome, 2008) but were not standardised. Trail soil samples directly adjacent to each transect line (12 in total) were collected from each PIN location for water repellence testing (Hunt & Gilkes 1992). Samples were oven dried at 70°C overnight and then tested by applying a drop of

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distilled water ~ 6 mm diameter from a pipette held 2 cm above each soil sample. The time taken for penetration into the sample indicating the water repellence rating (*e.g.* ten seconds or less for distilled water indicated no repellence). If the drop penetration time was more than 10 seconds, the test progressed to using different strength solutions of ethanol (1–4M). The crucial drop penetration time of ethanol solution being five seconds or less (Table 2).

A two factor ANOVA was applied to the differences in the initial, second and final values of cross sectional area to establish any significant differences in the rate of erosion between the upper, middle and lower slope on and between treatments.

ENVIRONMENTAL CONDITIONS AND CHANGES TO SOIL MICROTOPOGRAPHY

The location of PIN frame measurements was determined from data generated from the trail assessment and field observations (Randall & Newsome, 2008). Results include environmental descriptions at PIN frame locations and water repellence determinations.

Bald Head trail

Figure 10 represents the location of the PIN frames on the Bald Head trail in relation to the census data. Slope values have not been standardised.

Environmental conditions

Trailside vegetation on the Bald Head trail was dense, grew close to the trail edge and formed a barrier that would have aided in dispersing the impact of wind driven rainfall. This trail was relatively narrow (60–120 cm) in contrast to the Peak Head trail, which was greater than 120 cm in width. Soil type was medium to fine pale grey quartz sand (standardised as white for the trail census), for the entire length of the PIN frame treatment. Water repellence testing indicated a drop penetration time of one second or less for all locations and therefore no water repellent soil for any PIN frame location on the Bald Head trail. General trail soil conditions for the PIN frame locations were firm underfoot for the upper and middle locations and loose for the lower locations.

A description of the trailside vegetation and results of water repellence testing for the Bald Head trail PIN frame locations in Torndirrup National Park are summarised below (Table 3).

The cross sectional profiles from the upper and middle PIN locations on the Bald Head trail show a trend of soil loss from the trail-side following initial baseline measurements and a mixture of staggered trail side losses and central gains between the 2004–05 measurements. The following measurement taken in May 2006 for all PIN locations shows a continuation of side losses to the left side of both upper and middle 1 profiles, with side gains most likely due to slumping of the uncontained right side of this hillside trail following an increased depth in these profiles.

The middle 2 profile shows a continuation of central gains consistent with previously measured profiles. The lower profiles also show staggered losses and gains but overall display gains between the March 2004 and final measurements in May 2007 (Figure 11).

Percentage change away from baseline measurements was less than 10% loss or gain for most of the profiles except for the upper 1 and lower 1 location (Figure 12), this is easily demonstrated in the upper 1 profile in Figure 12 which clearly shows an observable loss of over 33.7% for May 2006 (Figure 12), and similarly but to a lesser extent, a clear gain of just over 22.1% for the lower 1 profile while the lower 2 profile had an overall gain of 7.1% (Figure 12).

It is evident that the three monthly measurements taken in 2004 show little change to the profile, highlighting the need for long term studies in the order of years rather than months.

Peak Head trail

Figure 13 represents the location of the PIN frames on the Peak Head trail in relation to the trail assessment data (Randall & Newsome, 2008). Slope values have not been standardised.

Environmental conditions

The upper and middle sections of the Peak Head trail PIN frame locations are exposed to the predominant south-westerly/easterly winds experienced in the area from autumn to spring. Excessive width (>120 cm) is also evident in the upper and middle sections (Figure 13) with barrier vegetation being located too far from the trail-side to offer any protection from strong winds or as a means of raindrop interception. Soil type on the Peak Head trail was medium to fine quartz sand for the entire length of the PIN frame treatment. The upper 2 and both middle PIN locations exhibited soil colour that deviated from the usual pale grey (standardised as white for trail assessment), being darker and showing some iron oxide colouring (Munsell Soil Colour Chart 1994). Water repellence testing indicated slight water repellence for the middle PIN locations. All other PIN locations did not exhibit water repellent soil. General trail soil conditions were firm underfoot for the upper and middle and loose for the lower PIN locations. A description of the trail-side vegetation and results of water repellence testing for the Peak Head trail PIN frame locations in Torndirrup National Park are summarised below (Table 4).

The time series cross sectional trail profiles (Figure 14) for the upper PIN locations on the Peak Head trail shows a trend of staggered soil losses from one side of the trail profile with a build up on the opposite side, in contrast to the Bald Head trail which showed slumping and gradual inward collapse of the upper and middle profiles, the Peak Head upper and middle profiles appear to migrate to both the left and right side over time, this trail is very wide (> 120 cm) and uncontained by a steep trailside berm as is the Bald Head trail. Lower PIN locations show staggered losses and gains. Trail-side losses were not an obvious trend for any lower PIN location except for the lower 1 profile for the Peak head trail, between June 2004 and March 2005. This is most likely due to a peripheral spread of trail soil due to compaction from water (rainfall) and compaction from walkers.

The majority of the Peak Head PIN profiles were within a 10% margin of change away from baseline measurements taken in March 2004 (Figure 15) this range was also similar for the Bald head PIN profiles (Figure 12). A staggered process of losses and gains is clearly observable most likely due to varying rates of water movement on the trail tread due to trail topography and soil lost to deflation processes driven by exposure to the predominant winds. These two factors together with varying use levels (~53 walkers a month) would contribute to the staggered process seen in Figure 14. Lower 1 and 2 PIN locations for the Peak Head trail showed an overall gain of 30% and 7.8% respectively, with the loss of 8.2% for the lower 1 location in March 2005 most likely attributed to peripheral spread of the uncontained trail soil due to high localised rainfall (Figure 4) and compaction from walkers.

A two factor ANOVA was applied to the data to test for significant differences between the initial and final mean values of cross sectional area (cm^2) for the PIN locations situated on the upper, middle and lower slope over the course of the study (18th March 04–17th May 07). Locations named (1) were grouped as were locations named (2) to provide a 'repeat test'. The results show a significant difference ($P < 0.05$) between the majority of PIN locations and collectively, between the separate treatments: Bald Head and Peak Head trails. The only PIN locations that didn't display significant differences over time were the Bald Head middle 1 and middle 2 locations ($P > 0.05$) and the Peak Head lower 1 and lower 2 locations ($P > 0.05$).

ESTIMATION OF SOIL LOSS

One consideration for the multiple cross trail measurements was the frequency of the sampling interval between measurements. Lance *et al.* (1989), in their study on footpaths in the Cairngorm Mountains of Scotland, devised a method for statistically examining the variance between cross trail measurements to arrive at an optimal sampling interval. They found that over-sampling, while providing a high level of confidence and accuracy can be time consuming and costly and under-sampling can lead to an under-representation of the true conditions on the trail. It was decided to over-sample the Bald and Peak Head trails because they are relatively short sections and easily sampled. Bald Head (30m section) was sampled every six metres while the Peak Head trail (150m section) was sampled every 15 metres. Compared with the study by Lance *et al.* (1989) this sampling frequency represents almost double the number of points needed for a high level of confidence. See also Leung and Marion (1999b) for more details on this aspect of sampling.

The Bald Head trail has an area of disturbance that only slightly exceeds its length due to its narrow nature when compared to the Peak Head trail and is an average width of 1.5m (Table 5). The area of disturbance represents that m^2 portion of the trail which has suffered from erosion and a lowering of the profile. Trail erosion volume is still strikingly significant at 19.2m^3 and equates to a loss of 0.64m^3 per linear metre. The equivalent average trail depth is much deeper than the Peak Head trail at 42.6 cm. The Peak Head trail was originally a vehicle access trail to several local fishing spots. This is all too obvious from the area of disturbance which is more than twice the linear length of the actual trail. Trail erosion volume equates to an average of 78.2 m^3 or 0.52 m^3 per linear metre of trail over the assessed section. The equivalent trail depth is an average of 23.5 cm at an average trail width of 2.21 m. This trails history as an unplanned vehicle trail accounts for the massive soil loss and increased width, especially in upper sections as middle and lower sections have been naturally revegetated but still show signs of the former road edges.

SIGNIFICANCE OF THE FINDINGS FOR SUSTAINABLE TRAIL MANAGEMENT

Changing trail conditions

The results show that soil erosion of up-slope areas and deposition in low lying areas is active on the sections of the Bald Head and Peak Head walk trails that received PIN frame treatments. Statistical analysis shows significant differences ($P < 0.05$) in the changes to cross sectional area (cm^2) for the majority of the upper middle and lower slopes. Similarly, significant differences ($P < 0.05$) in the changes to cross sectional area when comparing the separate treatments, e.g., Bald Head and Peak Head PIN locations. The initial analysis of this data done at 174 days showed insignificant differences ($P > 0.05$). Liddle (1997) stated that long term data sets were preferable when dealing with trail erosion studies so it was decided to extend the measurements for a three year period.

Observable differences in erosion on slope locations and between trails during the initial period (2004) were small, but were clearly evident as severe degradation from a historical perspective. The only PIN locations not showing significant differences ($P > 0.05$) were the middle 1 and middle 2 locations on the Bald Head trail and lower 1 and 2 locations on the Peak Head trail. What this means is that the rate of change for these two locations was similar over the course of the study. Rainfall in the April and June period of 2005 was relatively high and could account for the rapid shift in percentage change seen on both PIN sites at this time (Figures 4, 13 and 15).

An analysis of the micro-topography graphs for both upper and middle PIN sites of both trails (Figures 12 and 15) show a staggered process of soil loss on the steep and deeply incised trail sides, in combination with a build up of soil on the central trail tread. The side losses are most likely a combination of rainfall and deflation as it can be assumed that walkers are confining themselves to the trail centre on such steep sided trails. Increases in trail soil evident on the sides of the Bald Head trail can not be attributed to a build up of soil and are most likely due to a gradual slumping and inward collapse of these high sided and deeply incised upper and middle sections (Figure 16). The left side of the trail is the upslope side of a steep hill and is virtually walled in by a densely vegetated fixed dune. The right side of the trail berm is sparsely vegetated and accessible offering walkers a more uniform surface to travel which could contribute to inward slumping from use factors.

Use factors such as boot imprints and scuffing can create an uneven soil surface, which enhances trail soil erosion following further rainfall, especially on dry soil. Soil losses are then evident in the trail centre. Deeply incised trails such as the upper and middle sections of the Bald Head trail were observed to undergo a gradual bank collapse towards the trail centre, while the deposited soil on lower sections of trail, being unconfined by trail-side berms or vegetation was spread peripherally.An analysis of percentage change in cross sectional area from baseline measurements illustrates the staggered nature of soil losses and gains generally within ~ 10% of baseline measurements that occurred over the time period, March 2004 to May 2007

The September 2004–March 2005 loss seen on the lower 1 PIN location for the Peak Head trail (Figure 15) is counter intuitive and is most likely due to compaction and disturbance by water (rainfall) and walkers. This lower area, unconfined by trailside berms, was observed to be comprised of loose sand during the summer months, which became firm and easy to walk on during periods of soil wetness which enhances compaction. Soil displacement from use factors was also obvious on loose sand, as deep boot imprints and compaction from walkers caused a peripheral spread of sand on lower slope areas.

Environmental factors

A thunderstorm (17.4 mm, Figure 17) immediately prior to the PIN measurements taken on June 2004 for the Peak Head trail was observed to cause major soil movement and build up on the trail centre despite the damp nature of the soil profile due to previous rainfall. This section of the Peak Head trail is categorised as being excessively wide > 120 cm and displays slightly water repellent soil (Figure 14, Table 4), and it is likely that the observed rainfall was collected and channelled by the excessively wide section. Trail soil movement due to thunderstorm activity was not evident on the Bald Head trail PIN site measured on the following day (June 2004) probably due to the narrow trail and the presence of trail-side vegetation which would reduce the impact of raindrops.

A source of variation in erosion rates on the Peak Head trail is most probably due to differences in the distribution of many roots and ineffective water-bars that occur on an excessively wide trail that has been subject to ongoing erosion due to its past history as a 4WD track prior to the 1990's. It is evident that these roots, ineffective water-bars and the steep grade of the trail can concentrate the flow of surface water leading to enhanced erosion at the base of drop offs created by roots and water bars (Figure 17)

The presence of slightly water repellent soils on both middle PIN locations for the Peak Head trail may also be facilitating erosion during heavy rainfall. Water repellence can be due to the presence of organic material (Table 4), hydrophobic residues concentrated in the upper soil profile by scrub fires and possibly fungal hyphae (Jungerius & van der Meulen 1988). Rainfall in study area has been below average. The yearly average rainfall figures (1000 mm) for Denmark (CALM 1995), show that a shortfall of ~ 100 mm was required to make up the average rainfall usually experienced between March and August 2004. September 2004 was an unusually dry month for the region with a short fall of ~ 60 mm from the yearly average.

Reasons why water bars on the Peak Head trail are not arresting the erosion problems are twofold. Firstly, water bars are inappropriate for such a steep slope (Randall 2004). The trail should ideally be re-routed to avoid a direct descent down this steep decline. Failing this a zig-zag or switchback trail and a series of steps or a boardwalk would help to reduce erosion. Secondly, no ongoing maintenance exists to clear built-up trail sediment or debris. This has led to a total redundancy of these maintenance features, their effectiveness currently rivalled by the numerous tree roots acting as surrogate water bars (Randall 2004). The increased width and large volume of trail soil lost on the Peak Head trail is representative of its prior history as an unplanned vehicle trail and the current walk trail should never have been located on this degraded section as it represents an ongoing burden for trail managers. In contrast, the Bald Head trail couldn't be located in any other position as it exists on the apex of a ridge that traverses the Flinders Peninsula and this means that the only option for this trail is to mitigate the trail erosion problems. This could be done by installing and servicing maintenance features such as water-bars, steps and boardwalks; a program which has in fact been implemented during the course of this study.

CONCLUSION

Overall, the results of the PIN frame experiment have shown that firstly a long-term data set is required to accurately analyse changes to soil microtopography and to show statistically significant differences in cross sectional area of trail profiles. Secondly, the fact that maintenance features alone cannot guarantee the sustainability of a coastal walk trail confirms that appropriate planning, initial trail location and ongoing maintenance is an essential part of a sustainable trail management program.

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Table 1

Vegetation communities of fixed dunes and granite monadnocks in the study area. *(Source: Beard 1979.)*

Vegetation Community	Characteristics	
Shrubland	Scrub Heath	Occurs on inland coastal strip Dominant trees < 4m *Agonis flexuosa* and *Eucalyptus angulosa* in association with a Proteaceous upper layer of tall shrubs and a Myrtaceous lower layer. Other spp. Include *Adenanthos sericeus, Templetonia retusa* and *Hardenbergia comptoniana*
	Heath	Closed lower layer of dwarf shrubs < 60cm Species diverse, often Myrtaceous dominant, independent or in association with scrub heath with scattered shrubs of *A. flexuosa* and *E. angulosa* occurring as stunted ecotypes. Other spp.include *Hakea prostrata, Scaevalla crasifalia, Loxocarya cinerea* and *adenanthos obovatus*
Rock Outcrop		Mosses, grasses and scattered shrubs *Anthocercis viscose, Agonis marginata, Hakea elliptica* and *Dryandra formosa*

Table 2

Method for testing the water repellence of soil.

Drop penetration time:	Class	Rating
Distilled water (10s or less)	Not significant	0
Ethanol solutions (5s or less)		
1M	Slight repellence	1
2M	Moderate	2
3M	Severe	3
4M	Very severe	4

Table 3

Summary of vegetation type and soil water repellence testing, Bald Head PIN sites.

Vegetation	Veg. Height (m)	PIN Location	Rating	Pen. time (s)	Soil Colour
Adenanthos sericeus *Eucalyptus angulosa* *Eremophila calohabdos* *Loxocarya cinerea*	0.6–1m	upper 1	not repellent	1	10 YR 7/1 pale grey
Adenanthos obovatus *Eremophila calohabdos* *Loxocarya cinerea*	0.3–0.5m	upper 2	not repellent	1	10 YR 7/1
Scaevola crassifolia *Olearia axillaris* *Acacia decipiens*	0.5m	middle 1	not repellent	1	10 YR 7/1
Scaevola crassifolia *Olearia axillaris* *Loxocarya cinerea*	0.5m	middle 2	not repellent	1	10 YR 7/1
Templetonia retusa *Eucalyptus angulosa* *Loxocarya cinerea* *Hardenbergia comptoniana* *Acacia decipiens*	0.5–1m	lower 1	not repellent	1	10 YR 7/1
Olearia axillaris *Adenanthos obovatus* *Eucalyptus angulosa* *Loxocarya cinerea*	1m	lower 2	not repellent	1	10 YR 7/1

Table 4

Summary of vegetation type and soil water repellence testing, Peak Head PIN site.

Vegetation	Veg. Height (m)	PIN Location	Rating	Pen. time (s)	Soil Colour
Agonis flexuosa *Hakea prostrata* *Hibbertia cuneiformis* *Olearia axillaris* *Petrophile* sp.	2m	upper 1	not repellent	1	10 YR 7/1 pale grey
Agonis flexuosa *Acacia decipiens*	1.5m	upper 2	not repellent	3	10 YR 5/3 brown
Agonis flexuosa *Dryandra formosa*	1.5m	middle 1	slight repellence	3 (1M -eth.)	10 YR 4/1 dark-grey
Agonis flexuosa *Banksia grandis*	2m	middle 2	slight repellence	2 (1M -eth.)	10 YR 4/4 dark/grey-brown
Agonis flexuosa *Hibbertia cuneiformis*	2–3m	lower 1	not repellent	1	10 YR 7/1
Agonis flexuosa *Vegetatio*n *Agonis flexuosa*	2–3m	lower 2	not repellent	1	10 YR 7/1

Table 5

Estimation of soil loss and disturbance on the Bald Head and Peak Head trail sections.

Trails Treatment length	Bald Head 30m	Peak Head 150m
Area of disturbance (av. m^2)	45	332.7
Trail erosion volume (av. m^3)	19.2	78.2
Equivalent trail depth (av. cm)	42.6	23.5

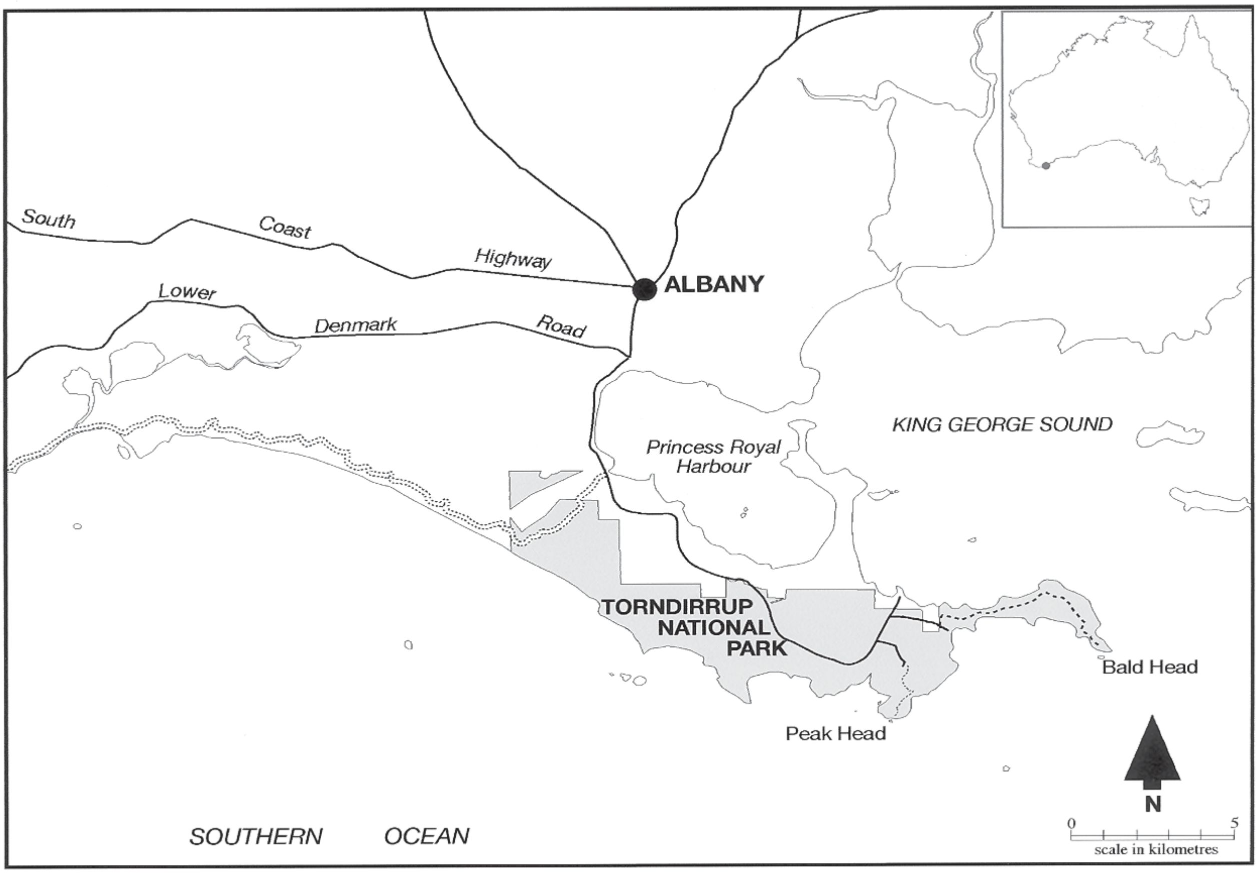

Figure 1. Study area, Torndirrup National Park on the South Coast of Western Australia, Albany region. (Source: Rossow 2004.)

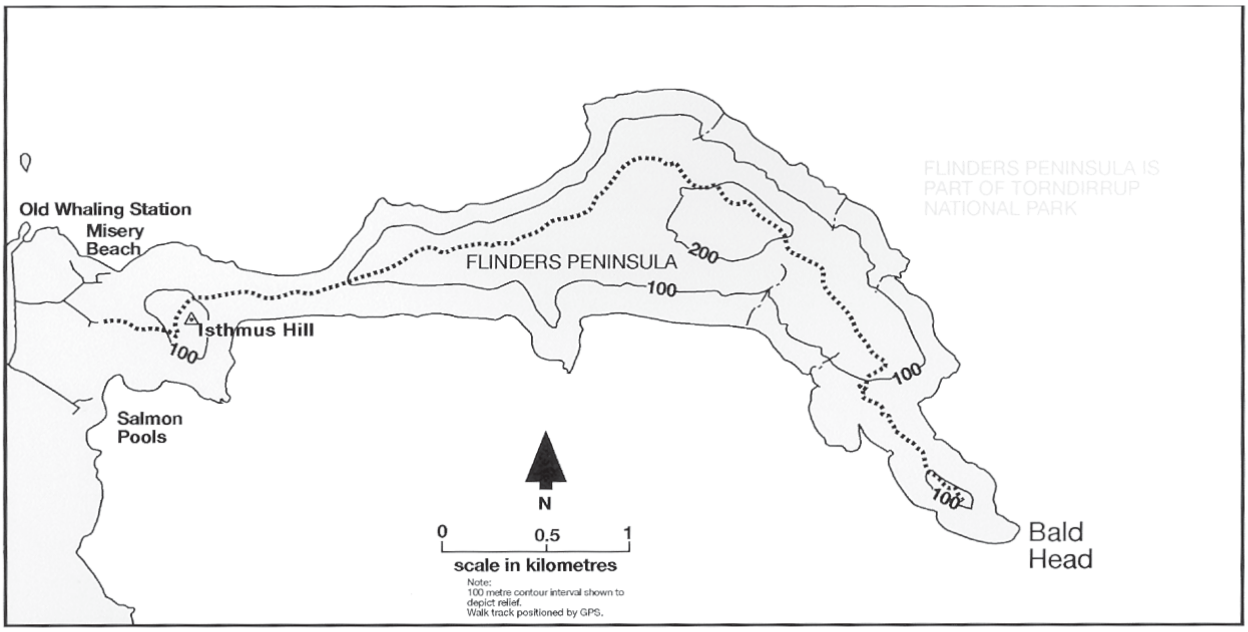

Figure 2. The Bald Head trail on the Flinders Peninsula in Torndirrup National Park, trail length 6552.8 m. (Source: Rossow 2004.)

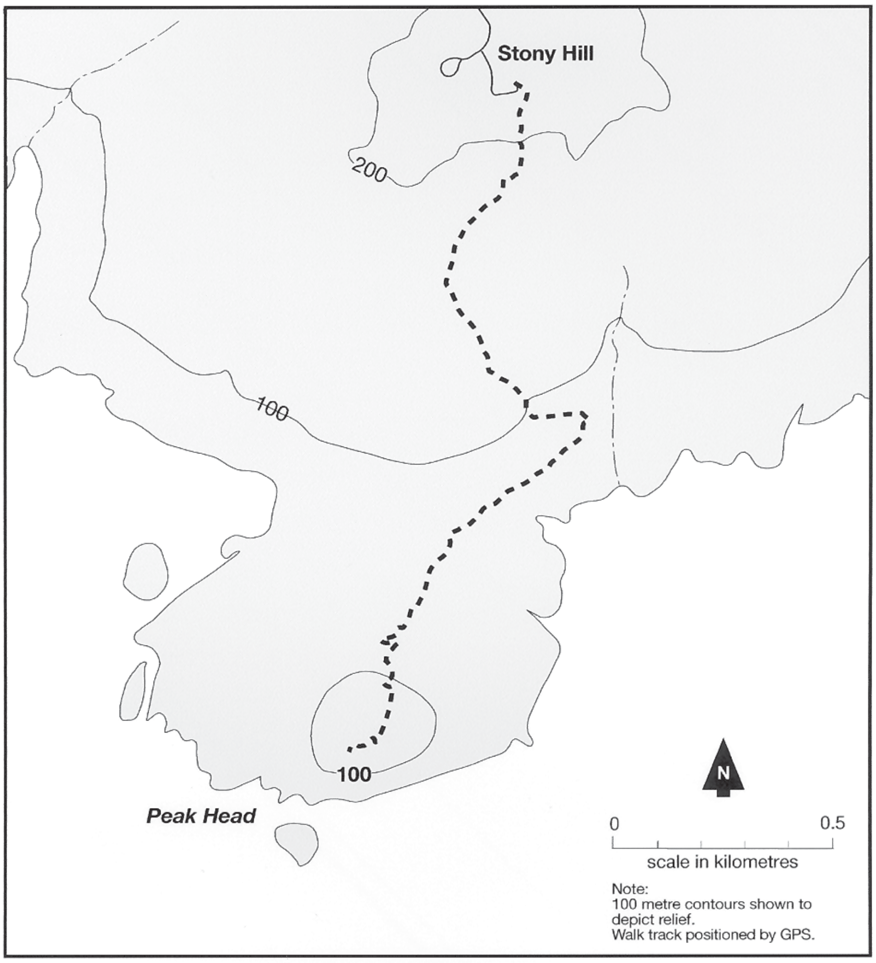

Figure 3. The Peak Head trail on the Flinders Peninsula in Torndirrup National Park, trail length 6552.8 m. (Source: Rossow 2004.)

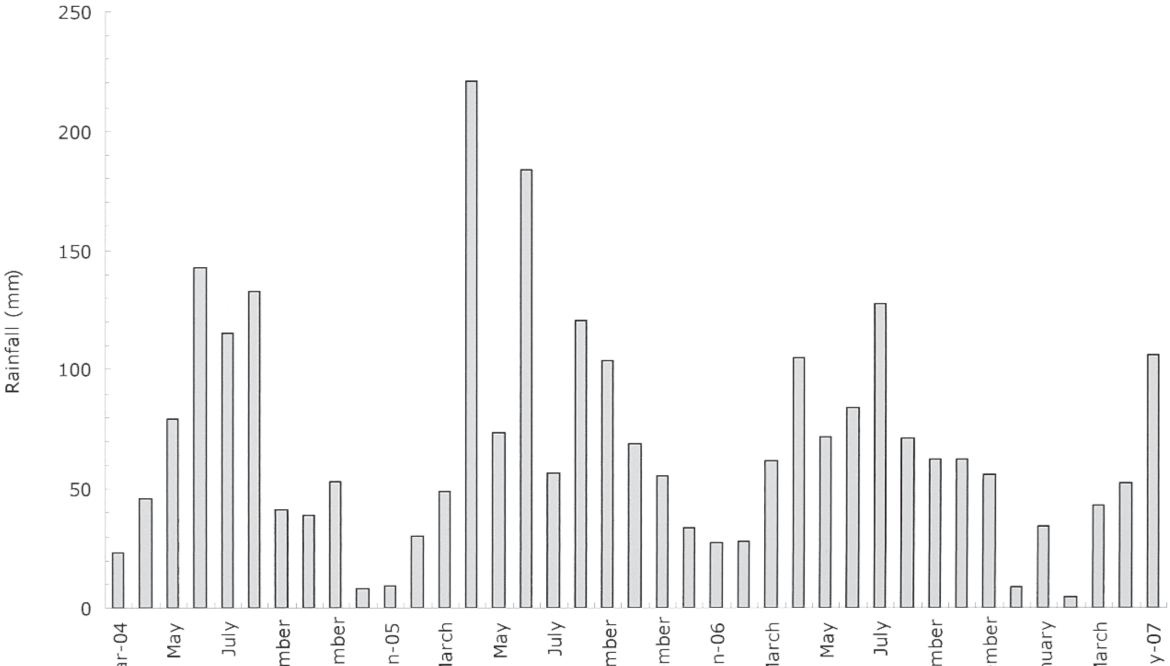

Figure 4. Rainfall displayed as monthly averages over the course of data collection, from Little Grove rain gauge (3 km from study site) in Albany. (Source: BOM 2007.)

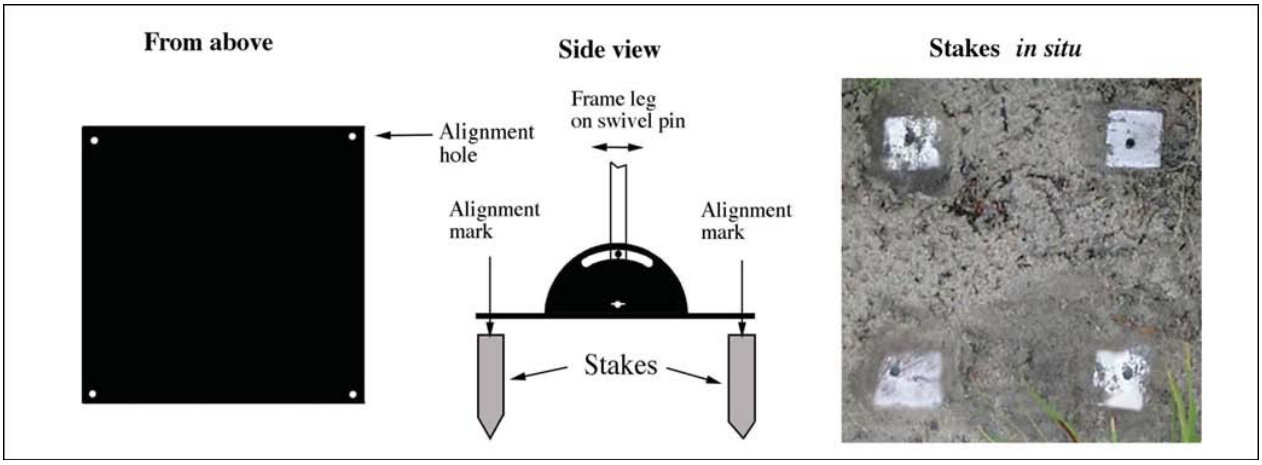

Figure 5. PIN frame base plate stakes, used for accurate relocation of the frame showing relocation points (black dots), used for realignment. Image shows 4 stakes for 1 side of the frame (e.g., 8 in total for each location).

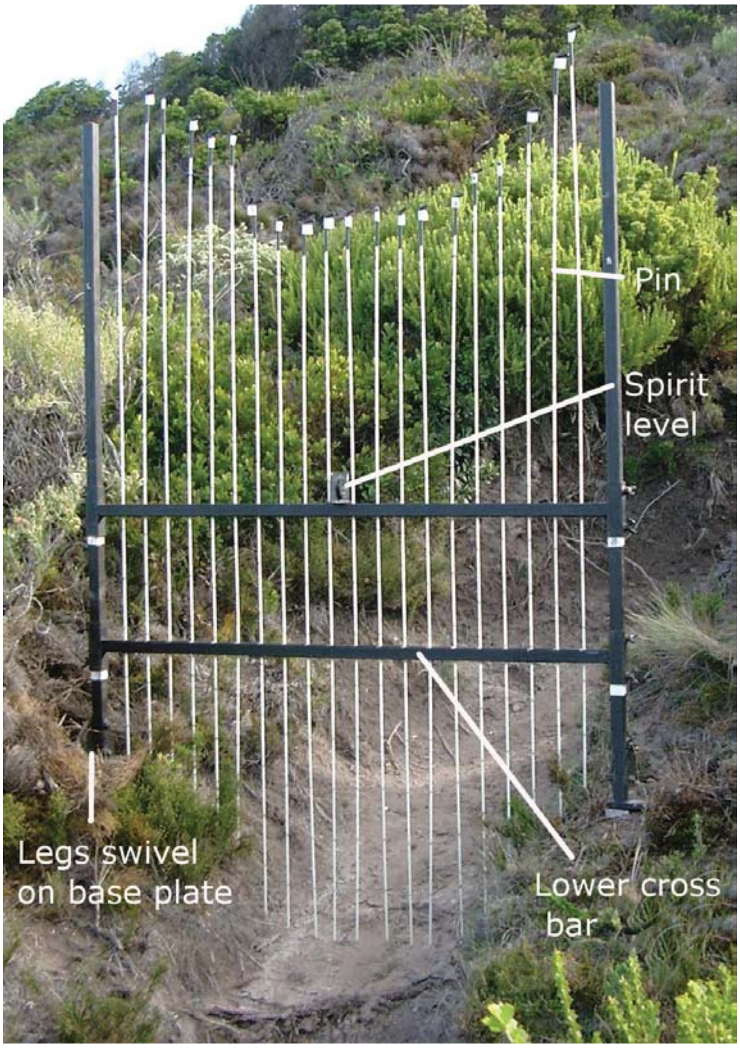

Figure 6. PIN frame erected in situ (Bald Head trail) showing the pins reading the cross sectional trail profile.

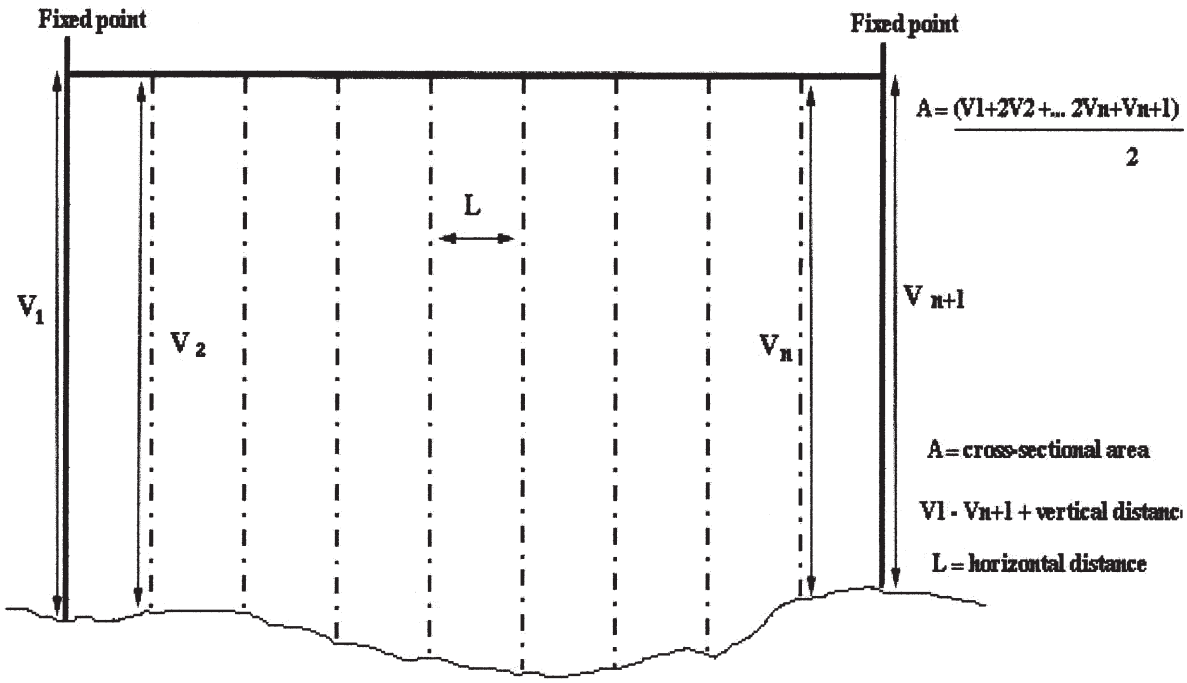

Figure 7. Each PIN frame was described as belonging to the upper, middle or lower slope 1 or 2, to provide a repeat for each location. The distance between each location was not evenly spaced as exposed roots precluded this. Figure 9, indicates the manner in which PIN frames were located.

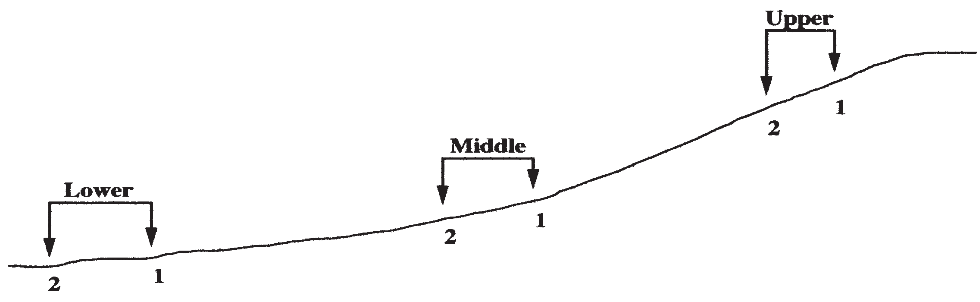

Figure 8. PIN frame locations described as belonging to the upper, middle or lower slope, each 'repeat' measurement site was given a number describing its position in relation to the top of the slope (1 or 2)

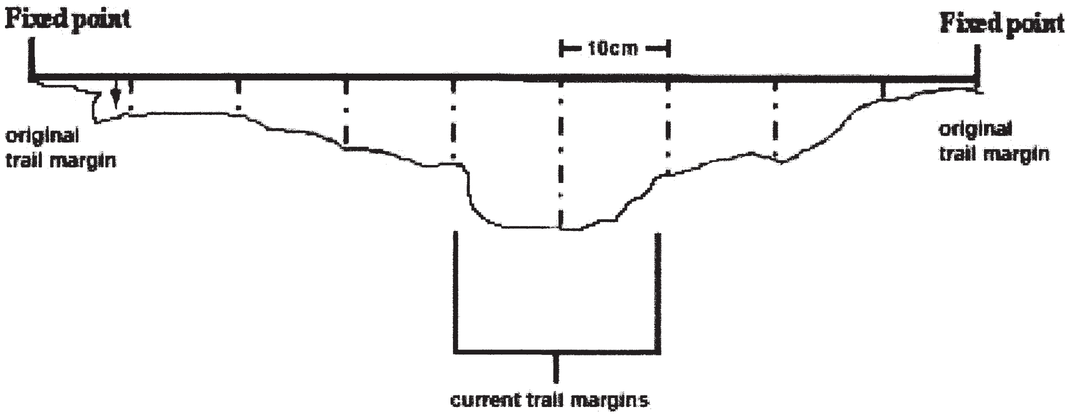

Figure 9 Illustration of how cross trail rope measurements effectively locate and measure the original trail width and depth with a series of rope to soil measurements.

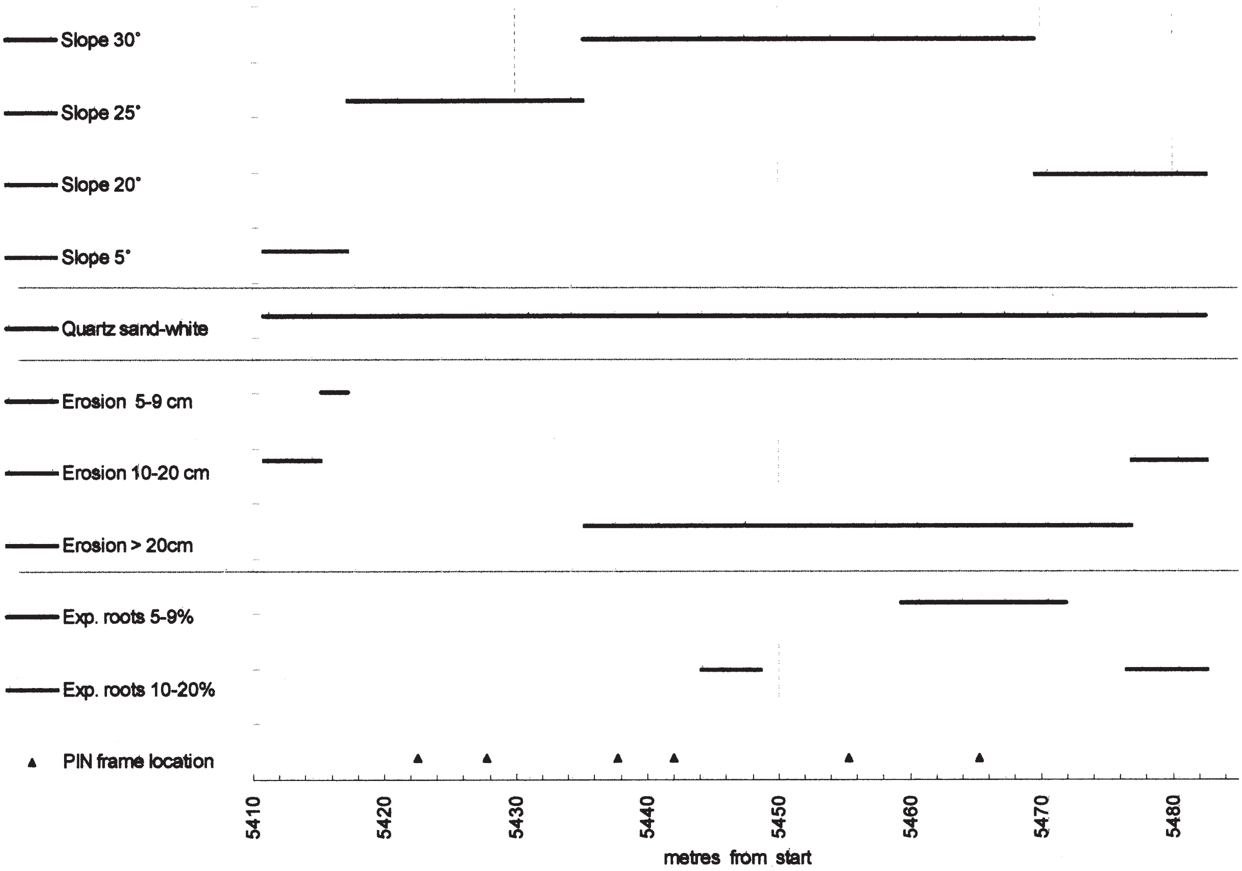

Figure 10 Pin Frame locations in relation to the trail assessment data showing slope (absolute values), soil type, erosion depth, root exposure and PIN frame location for the Bald Head trail in Torndirrup National Park.

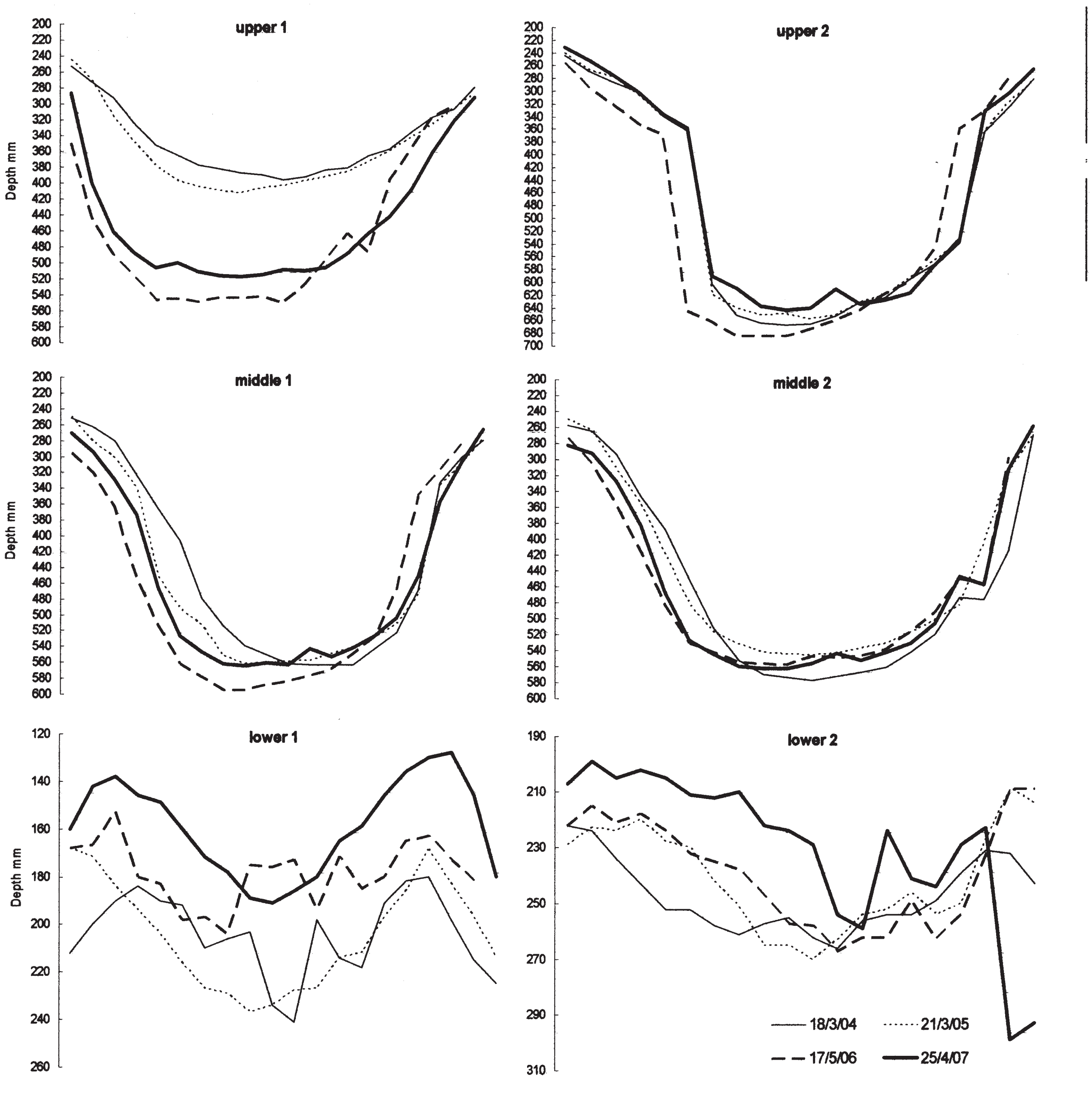

Figure 11 Six cross sectional trail profiles measured as a time series for the Bald Head Trail in Torndirrup National Park. Graphs show a yearly progression and omit two extra readings in 2004 to avoid clutter. Width measures 95cm for each trail profile

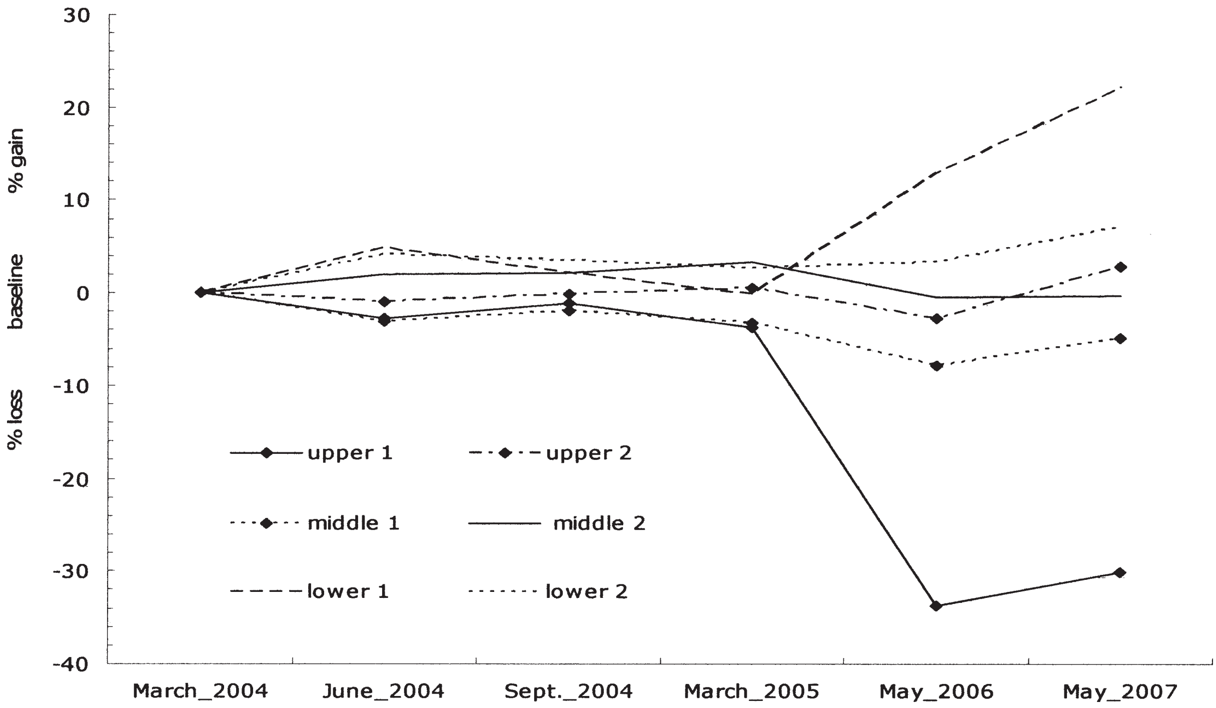

Figure 12 Percentage change away from baseline measurements for cross sectional trail profiles on the Bald Head trail including extra readings for 2004.

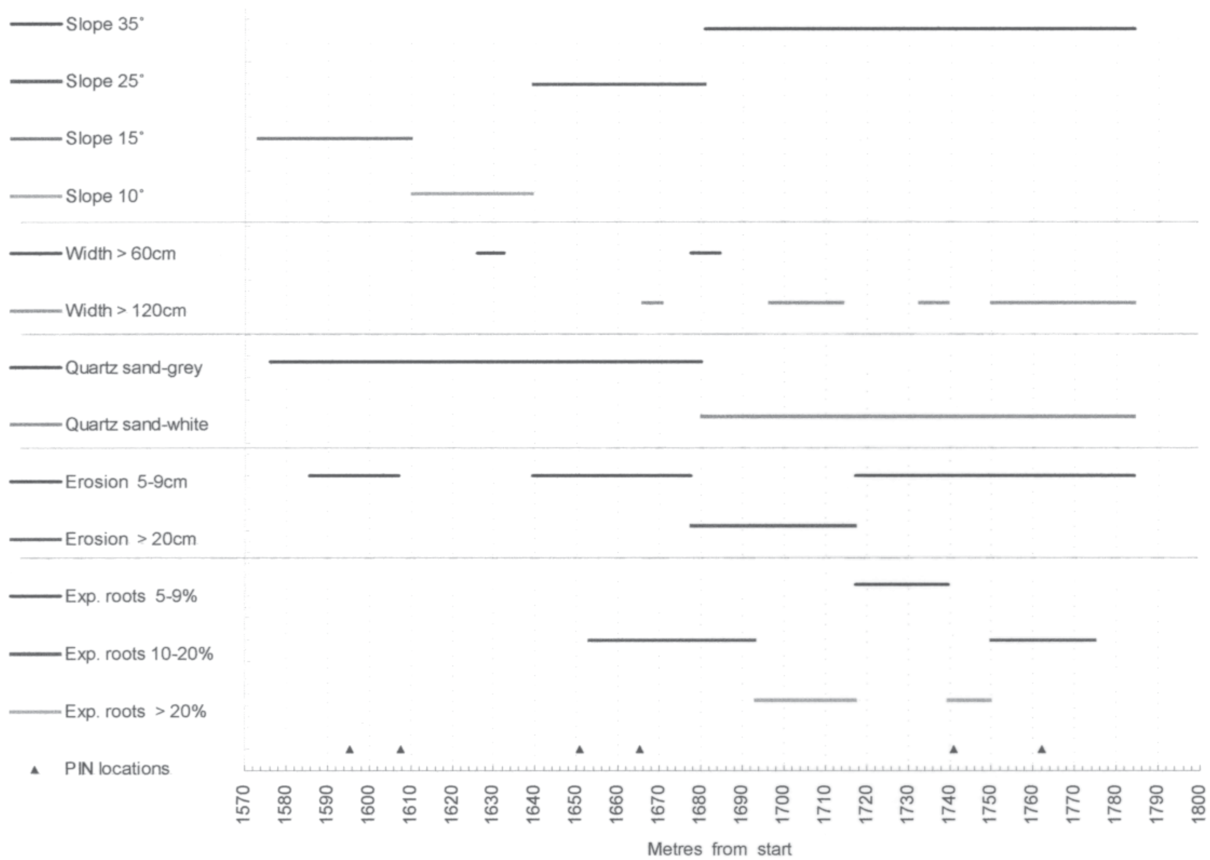

Figure 13 Pin Frame locations in relation to the trail assessment data showing slope (absolute values), soil type, erosion depth, root exposure and PIN frame locations for the Peak Head trail in Torndirrup National Park.

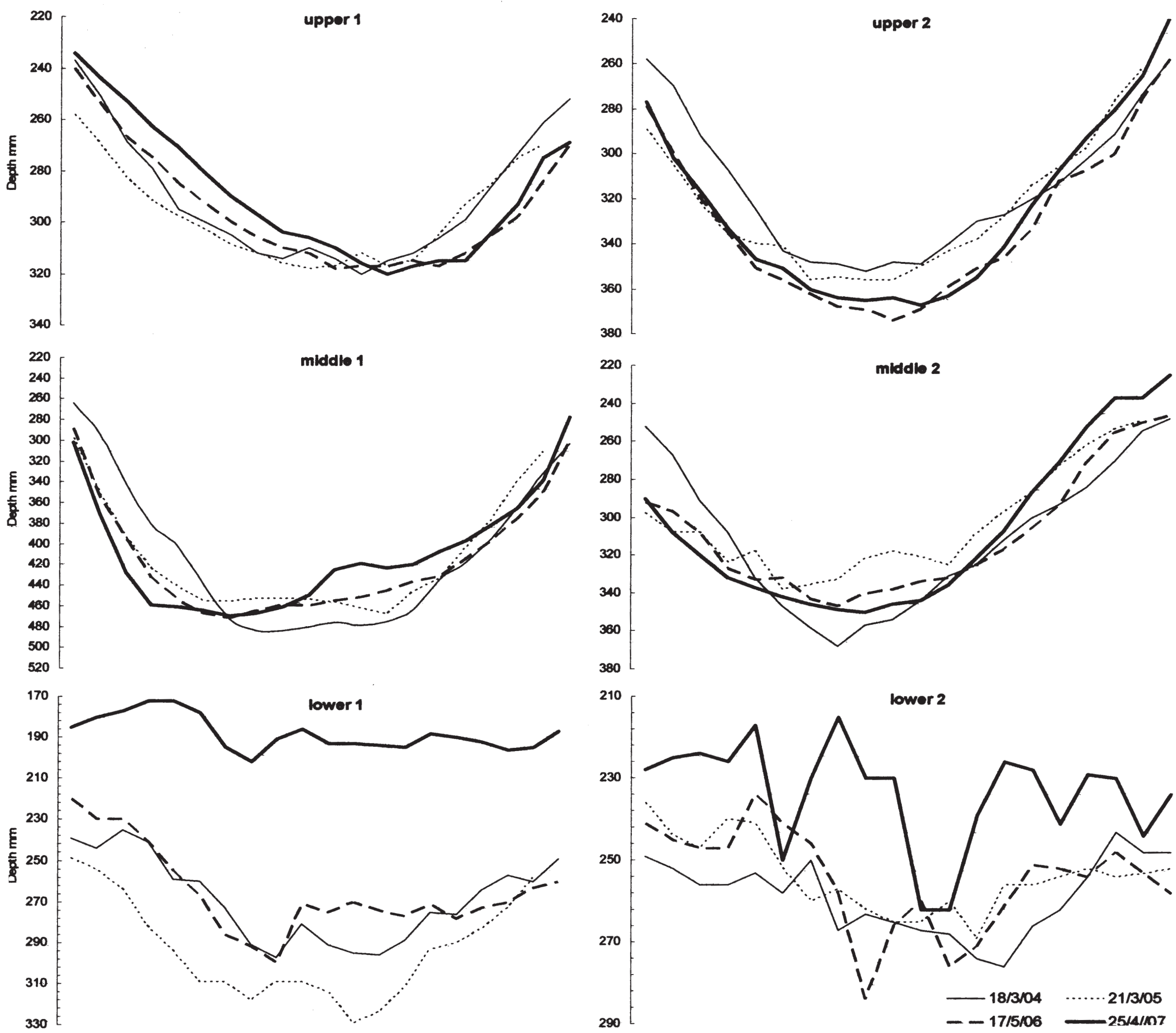

Figure 14 Cross sectional trail profiles measured as a time series for the Peak Head Trail in Torndirrup National Park. Graphs show yearly progress and omit two extra readings in 2004. Width measures 95 cm for each trail profile.

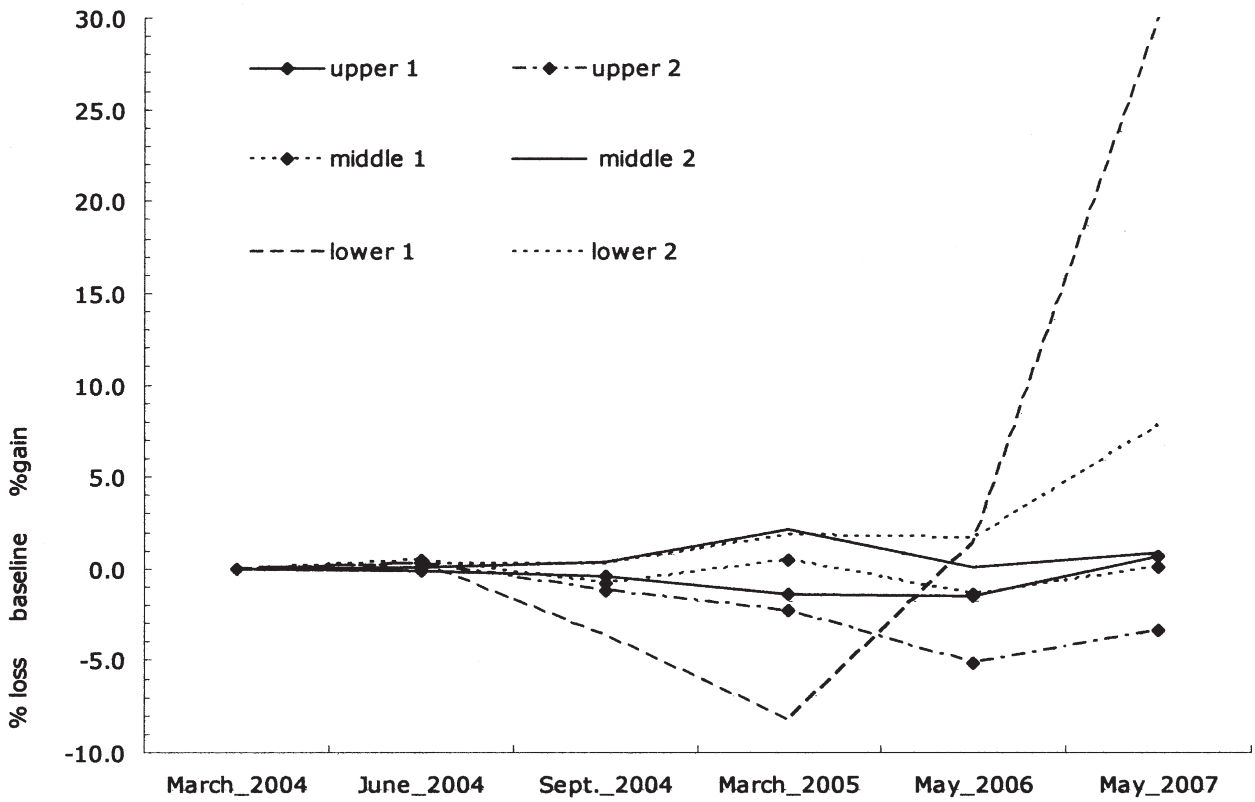

Figure 15 Percentage change away from baseline measurements for cross sectional trail profiles on the Peak Head trail including extra readings for 2004.

Figure 16 Bald Head trail PIN frame middle section showing a deeply incised trail set into a hillside, up-slope section to the left and an uncontained berm to the right which is leading to trail slumping on both sides as soil is moved along the trail centre (see Figure 12).

Figure 17 Ineffective water bars on the Peak Head trail, suffering from a lack of maintenance action are rivalled by the numerous exposed tree roots on this severely degraded trail (slope 25°).

APPENDIX

Calculation example—Bald Head Trail

	start	sample	sample	sample	end	
	0 m	10.6 m	25.09 m	41.48 m	49.97 m	means
tread width (cm)		53.3	55.8	60.9		56.6
CSA-w (cm)		0	64	91.4		51.8
CSA (cm^2)		0	238	267		168.3
trail impact width (cm)		53.3	64	91.4		65.59

Area of Disturbance = (mean trail impact width) (trail length)
= (65.59cm) (42.97m) (m/100cm)
= 28.2m^2

Trail Erosion Volume = (Mean Cross Section Area) (trail length)
= (168.3cm^2) (42.97m) (m^2/100cm^2)
= 0.72m^3

Equivalent Trail Depth = (Trail Erosion Volume) / (Area of Disturbance)
= (0.72m^3) / (28.2m^2) (100cm / m)
= 2.6cm

Definition of terms- trail impact calculation

Trail Length	The trail is the measurement unit. The length is measured with the measuring wheel. The number of sample points will be based on the length.
Mean Tread Width	The average of the tread width (TW) measurements. Tread width is defined in the trail measurement procedure manual.
CSA-width	The width of the trail at any CSA (cross section area) sample point. The width is the number of CSA transect points times the interval (typically 10cm). For simplicity the right most interval is treated as a full interval. This width is larger than the tread width by the amount of the trail side slopes.
Trail Impact Width	The CSA-width or, if zero, the tread width.
Mean Trail Impact Width	The average of the trail impact width measurements at the sample points.
CSA	The cross section area at a sample point measured per the trail measurement procedure manual. In some cases the erosion is small so a CSA is not measured.
Mean CSA	The average of the CSA measured at the sample points. The mean includes a zero value for CSA for sample points where CSA was not measured (because the CSA was too small).
Area of Disturbance	The mean trail impact width times the trail length.
Trail Erosion Volume	The mean CSA times the trail length. This calculation assumes all eroded soil leaves the trail; none is re-deposited on the trail.
Equivalent Trail Depth	The trail erosion volume divided by the area of disturbance. This is the trail depth that would give the same volume of trail erosion as a trail of this length and mean trail width. This depth is the “squared off “depth for the trail.

Source of methodology: J Marion 2007, Unit Leader/Scientist USDI, US Geological Survey Virginia Tech/Dept of Forestry, Patuxent Wildlife Research Center, Blacksburg, Virginia.