2 Recreational Walking

Chapter Summary
The various categories of recreational walking are described in this chapter, including devotional trails and formal and informal trails, and the numbers involved in the activity are estimated. Trampling impacts on vegetation, soil, and water quality, and the resultant footpath erosion are discussed and evaluated, including the impacts of hiking poles. The ways to assess the trampling patterns caused are summarised, including experimental trampling. The effects of recreational walking, including dog walking, on wildlife, especially on birds, through flight and behaviour changes, are evaluated. Techniques for managing the footpath surface are described such as creating more resistant surfaces, such as using geotextiles, surface nettings, chemical binders and surface glues, mulch mats, aggregate paths, and boardwalks. Vegetation reinstatement using transplanting techniques and seeding is evaluated, and an example of management experiments are described and evaluated from the Three Peaks project (Yorkshire Dales, UK).

2.1 Introduction

There are several ways of categorising recreation walkers. For example, the typologies of walkers used by Natural England, who fund and maintain the English National Trails, were as follows: they categorised 33% of the trail users as dedicated users (completing the trail in one go or in different sections over time) (Edwards 2007), and the remaining 67% were split into three categories: (a) Amblers (people on trips of one hour or less), accounting for 6% of users; (b) Ramblers (who typically walk between one and four hours), accounting for 44% of users; and (c) Scramblers (full-day walkers and anyone walking over four hours), accounting for 50% of users. The latter category included hiking, hiking to a summit, backpacking, backpacking to a summit, mountain climbing, and rock climbing. However, the link between scrambling, mountain climbing, and rock climbing demonstrates a conceptualisation of certain forms of walking with other activities that cannot be considered walking, although all the three terms do require walking as part of the preparatory phase of the recreational activity. We will consider scrambling in the chapter on gorge walking and canyoning and rock climbing in a separate chapter. It has been suggested that hill-walking in exotic places has been "redefined as trekking" (Beedie and Hudson 2003). In the USA, the UK, and Canada, hiking refers to walking outdoors on a trail or off-trail for recreational purposes. The terms rambling and fell-walking are used as a synonym in the UK and Northern England, respectively. In Australia bushwalking refers to both off-trail and on-trail hiking in natural areas, but bushwacking is used specifically for hiking through dense forest where the vegetation needs to be wacked or slashed using a machete in order to prog-

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ress. In New Zealand a long, vigorous walk or hike is called tramping. Backpacking is where multi-day hikes take place, with the hikers carrying their food supplies and overnight camping equipment. This can be part of long-distance hikes along National Trails in England and Wales, the Kungsleden in Sweden, and the National Recreational Trail (NRT) system in the USA. The latter are often called thru' trails and thru'-hiking entails hiking the entire length of a long-distance trail from one terminus to the other terminus within the span of one hiking season. The numbers attempting this type of hike have greatly increased, and the number of thru' hikers on the Pacific Crest Trail has been restricted to 50/day starting at the monument at the Mexican border. In a similar way reflecting the popularity of these types of hikes, the Appalachian Trail Conservancy has begun to charge for a thru'-hiking permit to pass through the Great Smoky Mountains National Park. The US NRTs were first designated as part of the National Trails System Act in 1968, and the first was inaugurated in 1971. They have to be over 100 miles long, and there are nearly 1300 NRTs, in all states, with over 26,000 miles of trails. The National Trails include the 1200-mile Ice Age National Science Trail established in 1980 which traces the last ice sheet's edge through the middle of the country, the 2190-mile Appalachian Trail, and the 2600-mile Pacific Crest Trail from Mexico to Canada. There are 19 National Historic Trails within the National Trails System which are long-distance trails and historic in nature where the aim is to explore the rich history and cultural diversity, for example, the Iditarod National Historic Trail (Alaska) and 11 National Scenic Trails to explore the American natural landscapes, for example, the Pacific Northwest National Scenic Trail and the Florida National Scenic Trail (americantrails.org). In the UK there are 13 National Trails in England since the first was established as the Pennine Way in 1965, with over 3500 km of path network, 2 in Wales, and 4 in Scotland, with 745 km of trail.

2.2 Devotional Trails

There are some mountains and trails which are special because they inspire and attract spiritual and devotional pilgrims and as such create extra problems. Croagh Patrick in Co. Mayo (Republic of Ireland) is absolutely unique in its cultural status as it has international significance as a religious and spiritual summit, and its popularity is a direct consequence of this status. The mountain is named after St Patrick who is reputed to have spent 40 days and nights on the summit in 441 AD and is the location from where he reputedly banished snakes from Ireland. However, long before the arrival of Christianity, the summit of Croagh Patrick was occupied by Iron Age hill forts, ramparts, and dwellings. The whole of the summit area and its surroundings have significant archaeological remains, while a number of archaeological features, ranging from ancient walls to dwellings and religious stations, are found all over the mountain and adjacent to the main path. The religious status of the mountain also has an influence on the nature of footpath restoration works that may be acceptable on this mountain which is extremely heavily eroded, the worst in Ireland. The annual pilgrimage on Reek Sunday sees an estimated 30,000 individuals ascending the mountain in one day. Many of these individuals see this as a purely religious pilgrimage and regard the challenge of ascending a worn and difficult path as part of the pilgrimage, often wearing totally unsuitable clothing, some crawling or going part of the way on hands and knees. They would not want to see the challenge reduced by over-engineered paths. This pilgrimage is one of Ireland's most significant cultural events and is reputed to date back at least 1500 years and is one of the most extraordinary surviving pilgrimages in Western Europe. Any path works would need to ensure that the sanctity and religious significance of the route are fully appreciated, and the views of the pilgrims and their representatives would be a factor in determining the path works that were acceptable here (Jones 2013). A similar trail across northern Spain is the El Camino de Santiago from France to Santiago de Compostela, stretching 800 km and attracting approximately 200,000 pilgrims per year.

2.3 Formal and Informal Trails

Trails are either created as formal trails by various land management organisations and as we will see can be built from varying types of mate-

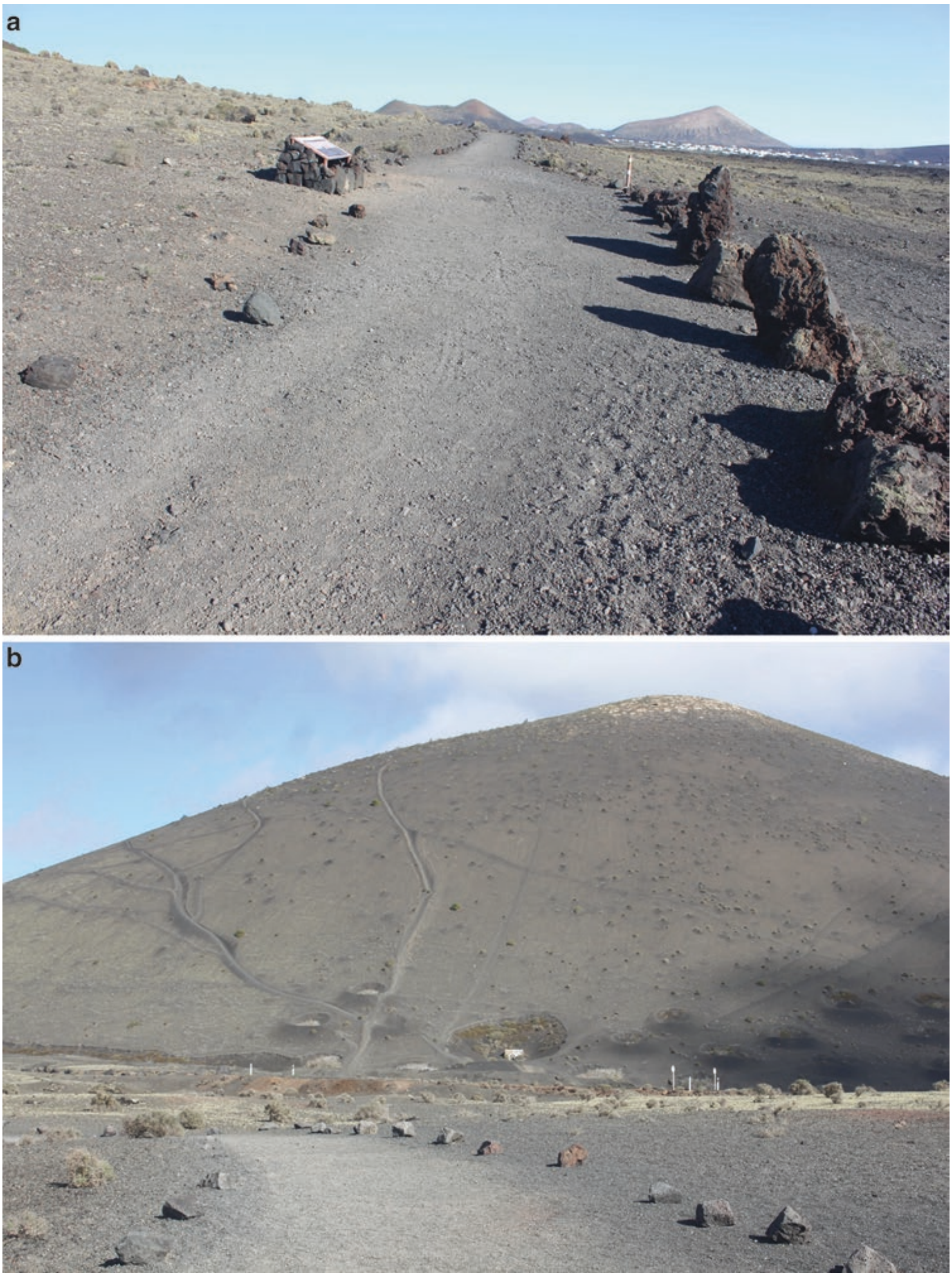

Fig. 2.1 (A) Lanzarote Geopark, Montaña Corona, demarcation of path by large boulders and information sign. The path surface is the local volcanic ash and is an example of a formal footpath. Photo by David Huddart. (B) Single formal trail up to the volcano flanks but then multiple informal, highly eroded trails in the volcanic ash, Lanzarote Geopark. Photo by David Huddart

rials depending on the local conditions (Fig. 2.1A), or they appear as informal, visitor-created networks which are totally unplanned (Fig. 2.1B).

An example of the juxtaposition of these two types of trail and the problems the informal trails can cause can be taken from Cadillac Mountain in Maine (Monz et al. 2010). Here there is high off-trail use as visitors disperse away from the formal trail system despite the adequate formal trail network that consists of two summit access routes that connect with a circular summit trail and formal observation sites. A total of 335 informal trails form a network that was mapped within the summit study area, and these trails lead to substantial vegetation cover loss, soil exposure, and erosion. These informal trail impacts are important as the subalpine/alpine vegetation communities on these mountain summits are typically fragile, spatially restricted, and rare (Ketchledge et al. 1985). Due to the fact that these informal trails were not planned or constructed, they are usually poorly located with regard to the terrain and resource protection needs. The proliferation over time means that there has been habitat fragmentation and impacts on the sensitive ecological communities. From the visitor's point of view, this has created a visually scarred landscape, especially above the tree line.

2.4 Global Perspective on the Numbers Involved

It is clear there are many ways in which walking participation in the UK is reported, either for tourism, recreation, or as an undifferentiated activity. Most data is based on surveys of relatively small and varied samples, and methodologies differ depending on the organisation and context. From the Sport England Active People Survey (2014), it was estimated that 23.313 million people (over 14 years of age) took part in recreational walking which was 53.8% of the population, whilst in Scotland this was between 79 and 88% of the population each year between 2004 and 2014, although 34% of that figure walked under two miles and only 8% walked over eight miles. In fact to illustrate the difficulties of interpreting these figures for 2013–2014, hillwalking and mountaineering were classed together and embraced just 2% of the population. The estimated annual recreational walking visits nevertheless reached over 300 million. Looking at the UK in the context of other European countries is similarly problematic. A study by Bell et al. (2007) compared the participation in walking as a recreation activity in six countries, and a consultation by TNS (2008) provides a figure for the UK from a similar time frame. The UK at 63% (at least once a year) is equal to Denmark but demonstrates less walking in population terms than Finland (68% of the population), Holland (74%), Norway (84%), and a similar ballpark figure for the USA (67%). Bell's comparison drew from secondary data taken from national surveys, and it is not clear whether all figures included the whole population (it states, e.g., that the Danish data only covered the adult population, whilst the Finnish data related to the "whole population"). Whilst these figures vary widely, both in their results and method of compilation, they do provide a rough benchmark on the importance of recreational walking. What can be seen from figures over time for the USA in Table 2.1 is the growth in popularity of this recreational activity, and it is easily the number one active outdoor pursuit worldwide.

The number of days for day hiking was estimated by Bowker et al. (2012) to be 1835 million, and for backpacking and primitive camping, the figure was estimated to be 1239 million. The figures continue to rise, and an estimate of the percentage of the US population taking part in

Table 2.1 Growth in popularity of recreational walking in the USA between 1982–1983 and 2005–2009 (numbers in millions) (adapted from Cordell 2012)

Activity	1982–1983	1994–1995	1999–2001	% change over that period	2005–2009	% of US population	% change 2001–2009
Day hiking	24.3	53.6	69.1	+44.8	79.7	33.9	+15.4
Walk for pleasure	91.0	138.5	175.6	+83.7	200.0	85.0	+13.9
Primitive camping	17.3	27.7	30.8	+13.5	34.2	14.5	+3.2
Backpacking	8.7	17.0	21.5	+12.8	23.2	9.9	+7.9

Table 2.2 Estimated growth in hiking and primitive area visits in the USA to 2060 (figures in millions) (adapted from Bowker et al. 2012)

Activity	Mean number	Mean number of total days	Range	% increase from 2008
Hiking	134.4	3330	117–150	45–82
Backpacking	141.0	1909	120–152	26–57

hiking/backpacking rose from 34% in 2012 to 47% in 2017. Bowker et al. (2012) had a range of estimates based on various parameters for the growth of these activities up to 2060 (Table 2.2).

Aggregating national figures of walking would be useful to gain a global perspective, but an exhaustive search for reports by organisations, including the World Tourism Organization and World Health Organization, suggests that no overall figures exist.

In terms of trail walking, Natural England (2015) synthesised research and monitoring from a number of National Trails: people counters, anecdotal estimates from the observations of their wardens, and baseline data from their "Monitor of Engagement with the Natural Environment Survey (MENE)." This provided them with a range of 63 million to 140 million people passing through areas intersected by a national trail. The large variation is due to an upper limit of people being surveyed within a range of 500 m from a trail. These estimates encompass any visitor, from those walking very small distances to the few that complete the long-distance trail. It is possible to estimate demand based on visits to locations and national scale surveys on activity participation, although the fragmented nature of available data suggests a low degree of precision.

2.5 Trampling

This is the direct disturbance that results in the bruising, crushing, and breaking of plant tissue, and, as we can see from the growth figures since the 1970s and the projected figures for the next 40 years, the trampling pressure from recreational walking is likely to grow considerably. The management of the erosion caused has been one of the most serious problems facing recreation resource managers and continues to be so. The paradox is one of trying to protect ecosystems whilst providing for their recreation use as much as possible. In the UK up until the 1970s, there was not much concern about the ecological effects of recreation, and planners placed a low priority on this issue. This was partly because the total acreage of land that had become degraded was fairly minimal, except for a few well-publicised examples of vegetation loss around the Cairngorm ski lift in Scotland and the loss of stability of sand dune ecosystems. Few areas appeared to be under immediate threat. The outdoor recreation boom was only just getting under way, but there was a very rapid growth in the late 1960s and early 1970s. There was also little scientific information about the rates and directions of changes in natural ecosystems caused by recreation. Any reasoned discussion about the possible changes was hindered by a lack of quantitative data, so there was little for recreation resource managers to work with. At the same time, there were often divergent interests between conservationists and ecologists and the general public and the land managers. Conservationists were often trying to ensure the survival of a rare plant association, or even a single species, whilst the general public was unaware of the potential recreation impacts, was not concerned about them, or was not educated about them. The land managers were caught between the two groups. However, by the 1970s, there was a change because of the outdoor recreation boom which was part of a return-to-nature movement, because ecological change caused by this boom became much more obvious and research started to give land managers some information as to how to tackle the problems in an applied manner. Recreation ecology and recreation land management had become important in planning the countryside. It became clear that certain types of habitat were more vulnerable to recreation trampling: coastal systems such as sand dune and salt marshes, especially those in the early stages of the seral succession and on an unstable substrata; mountain habitats where the growth capacity and self-recovery were reduced by the climate and the mountain soils were thin, nutrient deficient, and often wet; systems with shallow soils, such as chalk grasslands, those with nutrient-deficient soils such as lowland heaths, and those with very wet soils like blanket bogs and fens; and those ecosystems which have taken a long time to develop, for example, caves, or have developed in different environmental conditions than those currently. In different habitats too, the numbers of recreation walkers will be different before major environmental damage results, although generally the more walkers, the more damage occurs. For example, it was estimated that 7500 walkers/season moving from a concrete path onto mature salt marsh caused complete vegetation loss, whereas the same figure over yellow sand dunes caused complete elimination of marram, sea couch grass, and prickly saltwort and considerable erosion. It has to be realised though that other factors are involved apart from the numbers involved, such as the slope of the terrain, the soil characteristics, the type of footwear used, visitor behaviour, and the climate of the area where trampling takes place.

Yet erosion is part of the natural world, and there is no doubt that geomorphic processes on hillslopes, within the soil profile and in all the other surface sub-environments, cause far more erosion in total than recreational walking. Nevertheless trails are often an important sediment source, even if they only represent a small fragment of the landscape, and sometimes, as Cole (2004) suggests, it is difficult to separate the impacts of recreational walking on trails from impacts caused by trail construction and maintenance and the impacts that would occur in the absence of walking, from erosion by rain channelled down a trail tread. Nevertheless, for example, Ramos-Scharrón et al. (2014) found that on the island of St. Croix in the US Virgin Islands, sediment production measured with sediment traps on 12 trail segments varied in annual erosion rates from 0.6 to 81 $Mg ha^{-} yr^{-}$. The lower figure was from abandoned trails with a dense vegetation cover, whilst the higher rates were associated with de-vegetated trails immediately following construction or restoration. Annual trail erosion rates were one to three orders of magnitude higher than measured surface erosion rates on undisturbed hillslopes that had not been trampled. So the problem here is how to minimise erosion caused by both recreational walking and any remedial attempts to counteract the damage caused. This is because all recreational walking is going to create changes in the natural ecosystems where it takes place. The aim must be to be able to control these changes when they get out of hand or preferably before they reach that stage and where prevention is better than cure. The avoidance of future erosion must be a strategy to use if at all possible. This may be attempted by discouraging the use of an eroded path for a time to allow natural revegetation, by the fencing off of a section of path and the provision of an alternative. However, as has been found in the Peak District (Northern England), this approach is difficult to apply if the path is a public right of way. It is not possible to divert or close a public right of way, without due legal procedure under the Highways Act (1980). It is not possible to do this unless that path is not needed for public use, and if a path is so well used that it is becoming eroded, then it is obvious that this path is needed for public use.

2.6 Footpath Erosion

The extent of footpath erosion in popular mountain areas in Scotland was mapped by Grieve et al. (1995) from air photos, and interestingly the mean length of eroded footpaths overall was found to be less than half that of large natural gullies. We cannot aim to manage these natural gullies, and it has been claimed by some that we have gone too far in terms of "erosion control" as the impassioned pleas by Hayes (1997) suggest that a footpath is the line of least resistance in a way that complements the land, whereas his so-called footways are a planned, engineered, and pre-eminently artificial imposition on the landscape, which are ugly to look at and often difficult to walk on. He argued that there was an unfortunate lack of recognition for the intrinsic beauty of a naturally eroded path, and many would agree with some of his views.

Trails though are generally regarded as an essential facility in parks and recreation areas, providing access to areas with no roads, offering recreation opportunities, and protecting resources by concentrating visitor-use impacts on resistant tread surfaces. However, much ecological change as we have seen assessed on trails is associated with their construction or rehabilitation and is considered unavoidable (Birchard and Proudman 2000). The principal challenge for trail providers is therefore to prevent post-construction degradation from both recreation use and natural processes such as rainfall and water runoff and to minimise the damage potentially caused by any remedial work on the trail network.

Trampling too is part of a set of processes in natural systems which are caused by animals such as rabbits, sheep, feral horses, and deer which cause paths to be created. Yet when recreation management in many popular areas has been lacking, or applied too late, there can be a series of changes that involve vegetation deterioration and erosion of the vegetation cover, soil changes, and soil erosion. However, there can be a whole spectrum of ecosystem changes that are classed under the umbrella term of trampling pressure which can range from the loss of a single attractive flowering species, the creation of permanent puddles in areas of locally concentrated pressure, such as gateways to multiple, braided, deeply eroded trails, and major gullying on thick, peat soils (Figs. 2.2 and 2.3).

In the last 20 years though, there has been a considerable amount of research into trampling pressure both on vegetation and soils, and there have been several reviews related to the impacts of recreational walking. Before we outline what the effects of trampling pressure are on vegetation and soils, the detailed reviews and summaries of the research literature can be found in Kuss and Graefe (1985), Cole (2004), Cole et al. (1987), Liddle (1975, 1997), Leung and Marion (1996, 2000), Marion and Leung (2004), Pescott and Stewart (2014), Hammitt et al. (2015), Marion (2016), and Marion et al. (2016) and the extensive literature used therein.

2.7 Trampling Impacts on Vegetation

Vegetation becomes bruised by light trampling pressure where there are broken rigid stems and a decrease in vegetation height. This is likely to represent a drop in primary production of the ecosystem, although after very low trampling intensity, there is a stimulation of plant growth,

Fig. 2.2 Excessive wide footpath in clay-rich soil caused by human and probably horse, trampling pressure, Pennine Way (UK). Photo by David Huddart

Fig. 2.3 (A) Braiding of footpaths, Snowdon, North Wales. Photo by David Huddart. (B) Eroded and braided, informal footpath, Clwydian Hills, Denbighshire Moors, North Wales. Photo by David Huddart

Table 2.3 Changes in plant physiognomy of two grasses with trampling (after Trew 1973)

Character average	*Lolium perenne* trampled	*Lolium perenne* untrampled	*Festuca rubra* trampled	*Festuca rubra* untrampled	Rye grass and red fescue
Height above ground (cm)	7.35	23.76	5.1	9.72	
Number of seedpods	12.61	21.00	13.00	18.00	
Length of seed head (cm)	3.1	8.6	1.75	3.2	
Length of leaves (cm)	2.1	5.3			

which probably marginally increases production. Very light use may only cause a slight decrease in total vegetation cover, although there may be increases in branching and a decline in the incidence of flowering. Damage sufficient to cause small patches of bare ground will, in many types of habitat, result in invasion by trample-resistant species, such as *Lolium perenne* and *Plantago major* (Speight 1973). Heavier use can reduce or even eliminate plant cover, with only the most trample-tolerant species surviving in gaps between stones or in similar places where direct wear is low. Generally though there is a loss in vigour in the plants, and if a single species is examined, the crested dog's tail grass (*Cynosurus cristatus*) from Dovedale (Peak District), it shows a 50% reduction in stem length in transects taken along the line of a grass-covered path. Similar changes can be seen in Tables 2.3 and 2.4 from Beer head (Devon) where there are also changes in the number of seedpods, the length of the seed head, and the length of the leaves. There are also changes in the onset of flowering time of herbaceous plants as can be seen from Table 2.5 from Porteynon Bay in Gower (South Wales). The trampling damage must at early stages increase the percentage of organic matter on the trampled areas, for example, the movement of 8000 people across chalk grassland in Southern England produced an accumulation of broken and dead ground vegetation sufficient to double the weight of leaf litter.

Trampling on upland vegetation, such as *Calluna vulgaris* (heather) and *Vaccinium myrtillus* (bilberry), has been found to make them vulnerable to desiccation and winter frost browning (Watson 1984; Cole et al. 1987). Of even more relevance to blanket bog and its restoration is the

Table 2.4 Changes in plant physiognomy from Beer head (Devon) (after Price 1987)

Average height of grass	On path (cm)	Adjacent to path (cm)
Agropyron repens couch grass	10	60
Phleum pratense (timothy)	15	60
Agropyron repens on pathway		
Average number of seedpods	16	20
Average length of seedpods	4 mm	9 mm
Average length of leaves	4	17

Table 2.5 Changes in onset of flowering of two herbaceous plants with trampling (after Trew 1973)

Intensity of trampling (people/year)	Onset of flowering: *Galium verum* (lady's bedstraw)	Onset of flowering: *Veronica arvensis* (wall speedwell)
2000	22 June	14 June
1000	7 June	2 June
500	29 May	26 May

impact of recreation on lower plants, particularly sphagnum mosses and lichens. Borcard and Matthey (1995) found that as low a figure as ten minutes of experimental trampling repeated only three times a year for three years almost destroyed the cover of *Sphagnum recurvum* and *S. fuscum*.

There are effects on flowering with many species failing to flower, and the abundance of flowering heads of grasses recorded a drop in frequency along a grass-covered path in Dovedale (Table 2.3).

Some plant species are resistant to trampling, and this plant resistance allows these opportunistic and aggressive plants to become more dominant. The species that are intolerant to trampling rapidly die out, and these are generally the species most characteristic of the habitat, for example, wild thyme on chalk grasslands in Southern England. The result is that with intermediate trampling pressure, there is some vegetation cover loss and some compositional changes. The resilient species start to dominate, and this can be seen in Table 2.6 where grasses are important. Research to monitor

Table 2.6 Resilient species to trampling (after Huxley 1970; Price 1987)

Common bent grass	*Agrostis tenuis*	Resistant species after Huxley
Crested dog's tail grass	*Cynosurus cristatus*	
Meadow fescue	*Festuca pratense*	
Rye grass	*Lolium perenne*	
Annual meadow grass	*Poa annua*	
Meadow grass	*Poa pratensis*	
White clover	*Trifolium repens*	
Couch grass	*Agropyron repens*	Resistant to trampling in middle of path, after Price
Timothy	*Phleum pratense*	
Crested dog's tail grass	*Cynosurus cristatus*	
Sheep's fescue	*Festuca ovina*	
Glaucous sedge	*Carex flacca*	
Yarrow	*Achillea millefolium*	Flourishing at path margin
Hoary plantain	*Plantago media*	
Dwarf thistle	*Cirsium acaulon*	
Restharrow	*Ononis repens*	

the changes taking place under increasingly severe recreational walking may identify stages at which species disappear and ultimately at what intensity the vegetation cover is removed completely. The loss of indicator species can show the general levels of wear and tear before the situation becomes too evident to the average recreationist, and it is then that appropriate management decisions can be taken. Certain growth forms become predominant, and the resistant species often possess several of them. These are the plants that are procumbent or trailing rather than erect; they have protective thorns or prickles; the stems are flexible rather than rigid or woody; the leaves are in a basal rosette rather than any other arrangement; the leaves are flexible and able to fold under pressure rather than fracture; growth is possible from intercalary (inserted between others) as well as apical meristems; seasonal regrowth depends on hidden cryptophytic buds, concealed beneath the soil surface rather than on aerial parts; reproduction is possible by means of suckers, stolons (shoots from the base of a plant, rooting, and budding at the nodes), or corms, in addition to seeding or runners and finally rapid growth rate. At the same time, it is possible to identify certain plant characteristics that make a species prone to trampling damage. Perennial species that are woody and have an erect growth form seem particularly vulnerable, including the dwarf shrubs such as heather (Calluna species) and tree seedlings.

In fact systematically reviewing and a meta-analysis of all the experimental trampling pressure evidence led Pescott and Stewart (2014) to conclude that the effects of life-forms were more important than the intensity of the trampling experienced in causing erosion. This is illustrated from an example from Cole (1995a) in an experimental trampling study on an alpine grass and sedge turf, where 500 passes by a walker reduced plant cover by 40%, whereas the same trampling level in a subalpine forest with a herb and fern understory reduced cover by 97%. Studies have also shown that these differences in morphology and trampling resistance can be strongly correlated with sunlight intensity (Liddle 1997; Cole and Monz 2002). Nonwoody, shade-tolerant species require large leaf surfaces supported by strong rigid stems which are easily crushed, whereas in contrast sun-loving plants, especially grasses, can obtain the necessary sunlight with small or narrow leaves and flexible stems. Plant resilience which is the capacity of vegetation to recover from trampling pressure is well known from grasses and is attributed to leaf durability, fast growth rates, and stem flexibility (Sun and Liddle 1993).

As the trampling pressure increases beyond moderate levels, plant cover and biomass are reduced. Damage and leaf removal means that plants are unable to produce sugars and store carbohydrates in roots which slows or halts flowering and seed production and reduces plant growth in subsequent years (Liddle 1997). This is exacerbated by root damage via soil compaction and root death eventually. For example, tree root damage in the California redwoods can show a decrease in root branching and in the number of feeder rootlets and root exposure and damage, which can lead to tree death. The soil compaction caused by excessive trampling eventually inhibits seed germination as the roots cannot penetrate the soil. Seedling mortality is caused through desiccation and drought which are accentuated by the destruction of vegetation cover and the microclimatic changes which increase the surface soil temperatures. Injured plants trying to grow in full sun are particularly prone to desiccation and death. The high evaporation rates and high temperatures inhibit the plants becoming established, and crusts which form on the surface of bare, fine-grained soils inhibit seedling emergence. These crusts act too as a seal to water penetration which creates moisture stress in the upper soil surface layer and for the seedlings.

The trampling injury to plants causes many problems as outlined by Kuss and Graefe (1985), for example, a disordered use of energy which is reflected in abnormal cellular activity, injurious physiological processes, and impaired vital functions of the injured plants. The vital processes such as root formation; photosynthesis and assimilation; translocation of water, nutrients, and photosynthate; respiration; energy metabolism; and transpiration are impaired as a result of trampling injury. The symptoms of this impairment are similar to those caused by plant disease and nutritional disorders, and signs of stressed plants are reduced vigour and stunting, loss of photosynthetic surfaces, aborted or reduced flower counts, lessened fruit and seed production, defoliation, wilting and curling of leaves, dieback, and reduced biomass. Overall with time before complete vegetation loss, there is a decrease in species diversity and an increase in invasive species which are non-native to the area.

In fact though, what has been noted in many studies is that the trampling pressure and recreational walking use can increase with little further impact to the vegetation if the users stay on the well-established trails (Cole 1995a; Leung and Marion 2000; Monz et al. 2010). The impact-use relationship is usually curvilinear, but for more resistant and resilient grasses and sedges, they can withstand prolonged low to medium impacts, but eventually the cover is eroded in high-impact use.

In addition to physical changes in vegetation cover and in soil erosion resulting from trampling, there can be other effects, such as reductions in the cover of orchids as a result of picking by tourists (Bratton 1985) and of dead wood for campsite fires (Bratton et al. 1979).

The responses of vegetation to trampling have been reported to be affected by trampling intensity (number of human trampling passes; e.g. Cole et al. 1987; Cole 1995a), frequency (trampling passes per time period (Cole and Monz 2002), distribution (whether trampling passes are dispersed or clumped for a particular trampling frequency (Gallet et al. 2004)), season (Gallet and Roz'e 2002), weather (Gallet and Roz'e 2001), habitat (Liddle 1975), species (Gallet et al. 2004), Raunkiaer life-form (i.e. perennating bud position) and growth form (Cole 1995b; Pescott and Stewart 2014), and soil type (Talbot et al. 2003). Pescott and Stewart (2014) considered variation in trampling intensity, vegetation resistance, recovery time, Raunkiaer life-form of the community dominant, and broad habitat type as potential reasons for heterogeneity in experimental results across primary studies.

The results from Pescott and Stewart's (2014) analysis suggest that the initial resistance of a plant community, and the length of the recovery period, may be better predictors of vegetation resilience than the intensity of trampling undergone; that is, intrinsic properties of vegetation appear to be some of the most important determinants of resilience, with the magnitude of the actual disturbance explaining much less of the community response.

The results support a situation where particular plant functional traits are likely to be more important than projected intensity of use when considering the siting of recreation activities involving human trampling. This somewhat surprising result has important management ramifications because it suggests that even relatively low-intensity trampling could be as damaging as high-intensity trampling in certain plant communities. Thus, trampling may sometimes be unsustainable for vulnerable vegetation, potentially creating conflict between even relatively limited access and plant species, or community-focused conservation objectives.

These results confirmed the importance of Raunkiaer life-form as documented by Cole (1995a) across the 188 trials investigated, suggesting that hemicryptophytes and geophytes will be more resilient to trampling impacts relative to other life-forms. In contrast, chamaephyte-dominated vegetation did not show a main effect of recovery; indeed, chamaephyte-dominated communities have been shown to die back after trampling disturbance, despite initially high resistance (Cole 1995a; Cole and Monz 2002). Sites of conservation importance dominated by phanerophytes, chamaephytes, helophytes, or therophytes should not experience regular trampling disturbance if damaging impacts are to be avoided. Trying to reduce trampling intensities may not be effective where adverse impacts are already occurring, although it has been found that there is a negative relationship between initial resistance and resilience for chamaephyte-dominated vegetation (i.e. high initial impacts may be followed by some recovery). Conversely, the current evidence base suggests that vegetation dominated by hemicryptophytes and geophytes, life-forms with more protection for their perennating buds (Kent 2012), recover to a greater extent than vegetation dominated by other life-forms. They could therefore potentially be trampled more intensively, provided monitoring is undertaken to provide early warning of deterioration or unsustainable use.

2.8 Trampling Impacts on Soils

Soil erosion can result in aquatic system disturbance, excessively muddy trails, widening of trails, tread incision (Fig. 2.4), and braided or multiple trails and can lead to the creation of undesired trails (Hammitt et al. 2015; Marion et al. 1993). Unlike disturbed vegetation and compacted soil, soil erosion is the only trail degradation indicator, relatively speaking, that does not recover naturally over time. A study of 106 US National Park Service units found that almost

Fig. 2.4 Deep incision caused by trampling pressure, Peak District. Photo by David Huddart

50% of all park managers indicated that soil erosion on trails was a problem in many or most areas of the backcountry. Trail widening was cited by 31% of park managers, and 29% rated the formation of braided or multiple trails and the creation of undesired trails as serious problems (Marion et al. 1993).

Low levels of trampling pressure initially create increased organic material to be released to the soil because of dead plant leaves, broken grass stems and break-up of needles, and the pulverisation of the organic matter. However, fairly quickly this trampling also allows the disappearance of the soil litter layer by wind or water erosion, or it can decompose into the underlying organic soil layer. So soil break-up of the A_L and A_F layers takes place relatively quickly in the initial stages of path formation, but the break-up of soil layers deeper than the A horizons appears to be unusual, except on organic, peat soils. Instead soil compaction gradually takes place with use, and there is an increase in the soil's moisture content/unit volume of pore space. The mechanical forces of foot pressure cause the soil grains to rearrange and pack together more tightly, which increases the soil density and decreases water and air permeability, and roots can find it difficult to penetrate into the soil, and seeds find it more difficult to germinate. On flat surfaces compaction of the soil can lead to puddling and increased muddiness of the soil surface, especially where there are organic or clay components in the soil. This can lead to impeded drainage and gleyed soils which destroy the plant roots which might have helped re-establish the vegetation cover. It can also cause trail widening and the creation of secondary trails when users try to circumnavigate the puddled areas.

The continued loss of the soil litter layer can only lead to decreased nutrient cycling and a reduced population of organisms responsible for the recycling processes, changes in soil organism populations, and plant death. In addition there is a decrease in pore space abundance with compaction, and this leads to a decrease in the numbers of larger soil organisms. The impedance of drainage can lead to increased runoff on sloping surfaces and accelerates the soil erosion whilst at the same time decreasing the infiltration rates into the soil. For example, in Switzerland in woodland, it was found that on footpaths there was an 80% decrease in infiltration. The end products of high trampling are soil erosion, gullying, and often sediment fan deposition outside the trail boundaries, especially on steeper, relatively unvegetated slopes. Wind erosion can cause soil loss where the substrates are dry and loose and lack a vegetation cover, like in sand dunes, but water erosion is much more common, especially in mountain areas with steep slopes and in areas with high rainfall. Amount of use can be an important factor in soil erosion, but probably more important is the type of use, and horses and all-terrain vehicles are the worst culprits as we will see in later chapters of this book.

Soil erosion loss is important ecologically because the processes of new soil creation can be extremely slow and the sediment can have an effect on turbidity, sedimentation, and the populations in freshwater ecosystems. This of course is an argument for footpath management to control this soil erosion and against the argument of people such as Hayes (1997), quoted earlier in this chapter who have defended natural erosion.

2.9 Trampling Impacts on Water Quality

The impacts of concern here are all secondary impacts that can be caused by hiking on trails, with or without dogs, or by using packstock animals (see Chap. 9). There seems to be a correlation between increased humans and packstock animals and an increase in harmful bacteria in water and a degradation in water quality in wilderness areas (Derlet and Carlson 2006; Kellogg et al. 2012; Clow et al. 2013). For example, Derlet and Carlson (2006) in the Sierra Nevada found that 12 out of 15 backcountry sites sampled with packstock traffic gave high levels of coliform bacteria, and Kellogg et al. (2012) found high faecal hand contamination amongst tested wilderness hikers. Meanwhile Reed and Rasnake (2016) found elevated *Escherichia coli* and other coliform bacteria in springs and streams near Appalachian Trail shelters in the Great Smoky Mountains National Park, particularly during the summer months. Other biological impacts could be the introduction or spread of protozoa like *Giardia lamblia*. Chemical impacts are mainly related to nutrient influx to streams and lakes which can lead to lowered dissolved oxygen rates but which can include impacts from soap, sunscreen, food particles, and human and animal wastes (Ursem et al. 2009). Nutrient loading in lakes can contribute to algal bloom increases and decreased water quality (Hammitt et al. 2015). Most of these water quality issues are local in nature, and usually it is impossible to directly link the water quality to a specific trail impact.

An indirect effect too could be on river bank erosion as Madej et al. (1994) linked a 27% increase in channel changes, including bank erosion in the Merced River in Yosemite National Park to the effects of heavy human traffic. The changes in the river since 1920 documented on detailed maps correlate with a dramatic increase in tourists since that date, and there were over 3.5 million visitors to that national park in 1991, and it was estimated that 90% of them visited the upper Yosemite valley and the upper river study reach. Over 1000 campsites were within 500 m of that reach too. Trampling can damage or destroy the riparian vegetation close to the river and reduce the bank stability. The causes of the increased bank erosion were evaluated, but there were no changes in precipitation, flood peaks, or sediment load. However, the degree of channel widening was inversely correlated with bank stability ratings, and these were associated with high visitor use areas. Hence Madej et al. (1994) suggested that human trampling and flow constriction by bridges, locally aggravated by bank revetment placements, were likely to be the most probable causes of the erosion problems. In reality how much was caused by human trampling is still debateable.

2.10 Ways of Assessing Trampling Patterns Caused by Recreational Walking

2.10.1 Analytical, Descriptive Field Survey

There are several ways of assessing the trampling patterns caused, and these have been developed and summarised by Liddle (1975), Bayfield et al. 1988, Cole and Bayfield (1993), Cole (1991, 2004), Leung et al. (2011), Marion and Cole (1996), Marion et al. (2011), and Hammitt et al. (2015) in their Chapter 11. There is analytical, descriptive field survey where the vegetation and soil parameters are measured for the trail and the adjacent areas to assess the current conditions. So here the impact conditions for trampled and untrampled areas can be measured over large areas rapidly and with minimal expertise. The assumptions here are that the whole area was homogeneous before, that the adjacent taller vegetation is undisturbed by trampling, and that there has been no overall environmental change since the trail was introduced. The adjacent areas are the undisturbed control sites which provide an estimate of the change which has resulted from use, but the control sites are never perfect replicates of the pre-existing conditions. The parameters that are measured can be the width and depth of the path; the vegetation cover to estimate the plant frequency, usually using a quadrat; and the plant height and soil parameters such as soil compaction (using an impact penetrometer), organic content, grain size, pH, and water content. It would be possible to measure plant biomass, but as this is destructive of the vegetation, it is not often applied. It is useful if there are estimates of the number of tramples in an area, but these are not usually available, but sometimes there are walker counts, automatic counters using an interrupted beam or tramplometers (Bayfield 1971), using lengths of wire soldered to pins.

2.10.2 Experimental Trampling

An alternative approach would be to use experimental trampling, although approaches using heavy weights or rollers have been totally unrealistic. It is common though to subject an untrampled area to a known amount of trampling and record the changes. It is then possible to use a method to show the vulnerability of different habitats which can be compared (Liddle 1975). This technique uses the number of passes the vegetation could withstand before the vegetation is reduced to a 50% cover: the trample dosage (TD50). So what are recorded on a previously untrampled area are the vegetation cover at intervals and the number of passes. The percentage of live vegetation remaining at the various measurements (y) is then regressed on the log of the number of passes (x) to produce an equation which may be used to estimate the number of passes which reduced the vegetation to 50% cover. This has proved to be a useful concept of the vulnerability to abrasion, but it does not take into account longer-term changes resulting from either the regenerative ability of the vegetation or responses to change mechanisms other than direct trampling, for example, climate factors. As Cole (2004) suggests, the maximum insight can be obtained by using several approaches simultaneously, as was used by Marion and Cole (1996).

All the trampling results can be treated graphically, with regression lines and correlation coefficients. The percentage cover reduction (Cole 1978) across the trail can be measured by CR = $(C_2 - C_1)\ 100/\ C_2$ where C_1 is the percentage cover in quadrat 1 close to the path and C_2 is the percentage cover in quadrat 2 away from the path. The change in species composition can be quantified by a coefficient of floristic dissimilarity where the larger values indicate greater vegetation alongside trails (Cole 1978), a change in species diversity can be found using a diversity index (Liddle 1975), or the Shannon diversity index and the relative abundance of species in the point quadrats can be worked out by the number of touches of species A x100/total touches of all species and the frequency in percent by the number of points of As occurrence/total number of points measured.

A study of experimental trampling can be taken from the Cairngorms (Scotland) which looked at the vegetation damage since the opening up of the Cairngorm plateau by the introduction of ski chairlifts and roads (Pryor 1986). The *Juncus trifidus* heath was one of the main vegetation types assessed because it is widespread but confined only to the Cairngorm Mountains. Thus the trampling of this vegetation type was important for its continued existence and survival. An experimental approach was adopted, and ten sites at each of six different abundant vegetation types were used. For each site a plot was divided into two parallel sections, one to be trampled on and the other as a control. Each plot and vegetation type was subjected to the same degree of trampling, 300 tramples in the same direction on the same day. Four quadrats were used to measure percentage vegetation cover in each plot. The results were that the most resistant was the alpine Nardus grass and the open *Juncus trifidus* heath. Medium resistant was the Rhacomitrium heath and the Empetrum-Vaccinium heath, whilst the least resistant was the heather (Calluna) and the lichen-rich, dwarf Calluna heath. So the most resistant species were the tussock species which produced a large number of tillers over the winter which emerge in the spring causing a rejuvenation of the plant in trampled areas. Other results were that there was generally a size reduction of the tussock species; moderate trampling actually increased the number of smaller and younger individuals, and the effects of trampling were only evident when disturbance was high.

2.11 Hiking Pole Impacts

With the great increase in use of hiking poles over the last 20 years, there is some evidence that there are impacts on the vegetation and soils (Marion et al. 2000).

2.11.1 Vegetation Impacts

Trailside vegetation can be damaged from the swinging action of trekking poles, particularly from contact with the baskets, which can get caught in low-growing plants. One North Carolina hiker noted in an email to the Appalachian Trail Conference that "the ground was becoming "torn up" by spiked walking poles. On the uphill side of the trail, moss and wild flowers were torn from their bedding. On the downside of the trail, parts of the trail were also torn away." The potential consequences of such damage include a reduction or loss of vegetation cover, change in vegetation composition, and trail widening. It was also noted that trail maintainers generally trim only higher, overhanging vegetation that is unaffected by trekking pole use.

2.11.2 Soil Impacts

A number of soil impacts could result from repeated contact and penetration by trekking pole tips. In wet or loose soils, pole tips can penetrate up to two inches and leave holes half an inch in diameter. These holes are often V-shaped, wider at the top due to the swing of the upper pole once the tip is embedded in soil. Under some conditions it was seen that soil was lifted by pole tips and dropped onto the ground surface. In a letter to the editor of Appalachian Trailway News, a Virginia hiker observed that trekking pole use has become nearly universal and that "These things are tearing up the trail on each side of the footpath. Some places look like they have been freshly plowed." Potential soil impacts from such disturbance include the loss of organic litter and exposure of soil and increased erosional rates and muddiness. Research is needed to document if, or to what extent, pole use could increase erosional rates. Muddiness could develop following rainfall, when surface water runoff fills the holes created by pole tips. The increased water and soil contact in areas with high densities of holes could turn trail sides to mud, as often occurs on horse trails when water fills hoof prints. Trails that are outsloped for water drainage would not prevent such muddiness, and water bars and drainage dips would prevent muddiness only on the downhill sides of trails.

2.11.3 Rock Impacts

The carbide tips on trekking poles leave visually obvious white scratch marks on rock surfaces and also damage lichens. A hiker in Maine related in an ATN letter that "the scratching is so pronounced on granite surfaces that it is sometimes easier to follow where the poles have been than to locate a white blaze. …the scratching is something I vividly remember from my hike, so remarking about it is justified." In an opinion letter to *Backpacker* magazine's website, a hiker in the Adirondack reported that "I was upset to see all the rocks had little white marks on them. Not just a rock here or there, but *all* the rocks on the trail were chipped by hundreds of people …. It got to the point where I could not concentrate on anything else but these thousands of little white gashes in the rocks I was stepping on. It really left a bad taste in my mouth and a grim look to the future." How serious the impacts of trail pole use are is debateable, but with the dramatic increase in use, they are clearly having some impact.

In some parts of the world, there have been suggestions that hiking poles should be banned as in Hong Kong country parks where rapid erosion has partly been attributed to the effects of the extensive use of hiking poles (South China Morning Post 2018, www.scmp.com/lifestyle/health-wellness/article/2140427/could-hikin).

2.12 Summary Related to Impacts of Recreational Walking

As a summary here, Cole (2004) offers five key generalisations regarding the impacts of recreational walking which are:

1. Impact is inevitable with repetitive use. Numerous studies have shown that even very low levels of repetitive use cause impact.

Therefore, avoiding impact is not an option unless all recreation use is curtailed as even extremely low levels of repetitive use cause impacts. Managers must decide on acceptable levels of impact and then implement actions capable of keeping use to these levels.

2. Impact occurs rapidly, while recovery occurs more slowly. This underscores the importance of proactive management, since it is much easier to avoid impact than to restore impacted sites. It also suggests that relatively pristine places should receive substantial management attention, in contrast to the common situation of focusing most resources in the impacted places. Finally, it indicates that restoration of sites (periodically closing damaged sites, to allow recovery, before reopening them to use) is likely to be ineffective.
3. In many situations, impact increases more as a result of new places being disturbed than from the deterioration of places that have been disturbed for a long time. This also emphasises the need to be attentive to relatively pristine places and to focus attention on the spatial distribution of use. It suggests that periodic inventories of all impacted sites are often more important than monitoring change on a sample of established sites.
4. Magnitude of impact is a function of frequency of use, the type and behaviour of use, season of use, environmental conditions, and the spatial distribution of use. Therefore, the primary management tools involve manipulation of these factors.
5. The relationship between amount of use and amount of impact is usually curvilinear (asymptotic), although this now is debated (as we will discuss later). This has numerous management implications and is also fundamental to many minimum-impact educational messages. It suggests that it is best to concentrate use and impact in popular places and to disperse use and impact in relatively pristine places.

2.13 Effects on Wildlife

Trails, and the presence of visitors, can also impact wildlife, fragment wildlife habitat, and cause avoidance behaviour in some animals and attraction behaviour in others seeking to obtain human food (Hellmund 1998; Knight and Cole 1991). While most impacts are limited to a linear disturbance corridor, some impacts, such as alterations in surface water flow, introduction of invasive plants, and disturbance of wildlife, can extend considerably further into natural landscapes (Kasworm and Monley 1990; Tyser and Worley 1992). Even localised disturbance can harm rare or endangered species or damage sensitive resources, particularly in environments with slow recovery rates. Animal life is disturbed by trampling, and most species decline in numbers or move somewhere else as most animals are unsettled by noise, rapid movement, and the nearness of people. However, some species are more sensitive than others, usually the commoner species the least so. In the breeding season, nearly all are very sensitive, and the decline of the Little Tern in Europe correlates with the recreation use of its once-inaccessible breeding beaches. It has been shown that in Scotland 5% of greylag geese do not return to the nest once flushed and duck nests are also vulnerable. In breeding areas that were visited three times a week, all the nests were predated; weekly visits meant a 60% loss, whilst in the nests with no visits, there was only a 10% loss. Birdwatchers are possibly responsible, but recreation walkers must be too.

Recreation disturbances often cause birds to spend considerable amounts from their energy reserves which is likely to be detrimental to their breeding success and migration, and it is thought that recreation can have significant negative effects at the individual, population, and community levels.

Human recreation disturbances are known to cause reduction of reproductive success and nesting failures (Bolduc and Guillemette 2003; Finney et al. 2005; McGowan and Simons 2006; Steven et al. 2011; Whitfield and Rae 2014). As explained by Holm and Laursen (2009), disturbances caused by hikers alone can negatively affect territorial densities of certain birds, causing effective habitat loss for breeding. However, such impacts seem to be species-specific, and for some birds, human use of recreation trails has no apparent effect on nest survival (Smith-Castro and Rodewald 2010).

Many studies have correlated higher pedestrian or vehicle traffic in wildlife refuges to reduced species richness and abundance of birds (Fernández-Juricic 2000; Burger et al. 2004; Marcum 2005; Steven et al. 2011). However, not all bird species are equally affected by human recreation disturbances. Certain bird species can tolerate greater degrees of disturbances (Marcum 2005; Gill 2007; Cardoni et al. 2008). The response of birds to human recreation disturbances may depend on the nature or type of disturbance, as well as on the distance from the disturbance (Fernández-Juricic 2000; Pease et al. 2005; Ruddock and Whitfield 2007). For instance, contrary to the general belief that motorised, nature-based tourism activities cause greater disturbances to birds (Stolen 2003; Schlacher et al. 2013), non-motorised recreation such as hiking and biking that often involve close encounters with birds have been found to cause more severe negative effects on a wide range of bird species (Buckley 2004; Pease et al. 2005). In the case of species that are sensitive to human recreation disturbances, continuous exposure to such disturbances may ultimately lead to permanent avoidance of habitats and changes in regular behavioural patterns.

2.13.1 Flight and Behaviour Change

A very substantial amount of research has focused upon measuring how and when walkers disturb wildlife through approaching them, and/or causing noise, which triggers, in essence, an anti-predator response of escape ("flight"). Within this literature there is once again, however, a very heavy focus upon birdlife (for reviews see Sidaway 1990; Taylor et al. 2005), which itself focuses substantially upon ground-nesting birds (for a "systematic review," see Showler et al. 2010) and disturbance by dogs accompanying walkers. Indeed, in their review of the disturbance impacts of dogs, Taylor et al. (2005) conclude that there is very little relevant research that has focused on the effects of dogs on animal groups other than birds. The central concern is that disturbance can cause birds, and other animals, to flee from cover or nests which can impact on their energy balances, feeding behaviour, and the vulnerability of young, eggs, or fledglings (Dahlgren and Korschgen 1992; Fox and Madsen 1997; Rasmussen and Simpson 2010). Each of these potentially affects not only individuals but also populations through affecting breeding success and can thus be a particular concern for endangered or vulnerable species of conservation interest. Considerable attention has been given to flight responses of water birds (see, e.g., Carney and Sydeman 1999; Nisbet 2000) but much less to forest bird species. Searches relating to the recreation disturbance of 35 "woodland bird" species found in the UK (as defined by Amar et al. 2006) identified very few studies (Ibanez-Alamo and Soler 2010; Luka and Hrsak 2005; Fernández-Juricic et al. 2001a, b; Fernández-Juricic and Tellería 2000; Fernández-Juricic 2000; Müller et al. 2006). Most of these studies were conducted in Europe, and five relate to empirical work in urban woodlands in Madrid (Spain), and conclusions from these studies are useful. Human disturbance was found to negatively influence the number of bird species, their persistence, and guild density (Fernández-Juricic 2000), along with blackbird feeding strategies, habitat selection, and abundance (Fernández-Juricic and Tellería 2000). However, various factors affect an animal's tolerance of disturbance and subsequent likelihood of flight, particularly the surrounding habitat structure and composition (Fernández-Juricic 2000). In essence, alert distances and individual "buffer zones" vary with the presence of "escape cover" such as shrub and tree cover. This effect is reported in the wider literature (e.g. Langston et al. 2007). Interestingly, Fernández-Juricic et al. (2001b) noted that blackbird buffer distances were greater in "highly visited" parks, which the authors related to habituation. Studies relating to other birds associated with woodlands in the UK include black grouse (*Tetrao tetrix*) and capercaillie (*Tetrao urogallus*). Baines and Richardson (2007), for example, report that "The disturbance regimes imposed had no discernible impact upon black grouse population dynamics," although one study by Patthey et al. (2008) revealed a considerable impact of skiing on black grouse populations in the European Alps. An earlier study of red grouse (Picozzi 1971) similarly showed no negative breeding impact, stating that grouse bred no worse on study areas on moors where people had unrestricted access, and grouse bags showed no evidence of a decline associated with public access agreements. Newton et al. (1981) investigated the potential impacts of recreation walkers on merlin (*Falco columbarius*) in the Peak District National Park (UK). Their conclusion was that it was "unlikely" to have caused the sharp decline in merlins during the 1950s but that it could possibly slow re-colonisation. Other studies of merlin (e.g. by Meek 1988) similarly suggest little negative impact by recreation, instead focusing on general habitat degradation by agriculture and pollution as the most likely causes of decline. In contrast, studies of capercaillie suggest a negative impact by recreation activity (Summers et al. 2004, 2007; Theil et al. 2011) where attention was drawn to the birds' avoidance of woodland areas near tracks and suggested a causal connection between this and recreation use. Although counts of recreation visitors in these studies are very low, the authors find a statistically significant difference between capercaillie use of wooded areas adjacent to tracks classified as "high" and "low" human use. Extrapolation from total track length led these authors to assert reduced woodland "carrying capacity" as the species avoids using between 21 and 41% of the two forests studied. Studies of forest bird disturbance by walkers and dogs beyond the UK reveal some useful findings. In their study of 90 peri-urban (urban fringe) woodlands north of Sydney, Banks and Bryant (2007) identified a substantial, although seemingly short-term, effect of dogs on native birds, especially ground-nesters. They found that dog walking caused a 41% reduction in the numbers of bird individuals detected and a 35% reduction in species richness compared with areas where dogs were prohibited, but they suggested that the long-term impacts may be small. Nevertheless they argue against access by dog walkers to sensitive conservation areas. In the UK, a high proportion of walkers using woods and forests are accompanied by dogs: Taylor et al. (2005) assert a figure of up to 50% in lowland areas, with fewer in upland areas This can serve to increase (in some cases dramatically) the scale of disturbance (or "sphere of influence," Taylor et al. 2005). The impact of dogs has received widespread attention, although again primarily in relation to ground-nesting birds, although Miller et al. (2001) illustrated increased disturbance of mule deer by dogs and in non-forest environments.

In contrast, Gutzwiller et al. (1998) found little evidence that intrusion altered vertical distributions of four passerines that nest, forage, sing, and seek refuge in subalpine forest. The minimal effects they observed indicate that the species studied were able to tolerate low levels of intrusion. Similarly, in their study of nesting northern cardinals in riparian forests in Ohio (USA), Smith-Castro and Rodewald (2010) found no association between nest survival and the tendency of birds to flush. On balance, the available evidence does not indicate significant negative impacts on forest birds following "flight" responses to walking, including no clear long-term or population-level impacts.

However, responses to human intrusion are well documented for a range of species. These include elevated heart rate (Weimerskirch et al. 2002), increased alarming or defensive behaviours (Andersen et al. 1996; Reby et al. 1999), and ultimately the avoidance of high-risk areas, either completely or by using them for limited periods only (Gill et al. 1996). Disturbance by people can also increase the risk of predation (Anderson 1988). Consequently, in areas where levels of human activity are high, repeated disturbance by visitors can lead to a reduction in the survival or reproductive success of individuals (Goodrich and Berger 1994; Burger et al. 1995). Ground-nesting birds, such as waders (*Charadriidae* spp.), are thought to be particularly at risk from human disturbance. When approached, birds often flush from nests, leaving eggs and chicks exposed to possible chilling or predation and imposing an energetic cost on the adults (Nudds and Bryant 2000; Bolduc and Guillemette 2003). For example, human disturbance is thought to significantly reduce the chick-rearing ability of African black oystercatchers *Haematopus moquini*, which breed on the coasts of South Africa at the height of the summer tourist season; breeding success outside protected areas was approximately one third of that on reserves (Leseberg et al. 2000). Similarly, human disturbance was found to interrupt incubation and reduce chick foraging time in New Zealand dotterels *Charadrius obscurus* (Lord et al. 1997, 2001). However, other studies have found no evidence of an adverse effect of human disturbance on bird populations (Gill et al. 2001; Verboven et al. 2001). Nevertheless responses to transient human disturbance seem well known, and they are predicted to lead to population-level impacts on some bird species (Hill et al. 1997). Local wildlife does not seem to become habituated to continued disturbance because the effects of dogs seem to occur even where dog walking is frequent.

Data collected over 13 years was used to investigate the impact of recreation disturbance on the distribution and reproductive performance of golden plovers breeding in close proximity to the Pennine Way (UK), an intensively used long-distance footpath (Finney et al. 2005). Importantly, the Pennine Way was resurfaced in 1994 to prevent further erosion of the surrounding vegetation. Finney et al. (2005) were therefore able to examine if the response of golden plovers to recreation disturbance was influenced by changes in the intensity and extent of human activity resulting from the resurfacing work. Before the Pennine Way was resurfaced, golden plovers avoided areas within 200 m of the footpath during the chick-rearing period. At this time over 30% of people strayed from the footpath, and the movement of people across the moorland was therefore widespread and unpredictable. Following resurfacing, over 96% of walkers remained on the Pennine Way, which significantly reduced the impact of recreation disturbance on golden plover distribution; golden plovers only avoided areas within 50 m of the footpath at this time. Despite the clear behavioural responses of golden plovers to the presence of visitors, there was no detectable impact of disturbance on reproductive performance.

These findings are consistent with those from an earlier study (Yalden and Yalden 1989), which used the alarm-calling behaviour of adult birds to estimate the sensitivity of golden plovers to visitor disturbance. They found that the average distance at which adult birds began alarm-calling in response to an approaching human was approximately 200 m during the chick-rearing period. This suggests that for breeding waders, similar behavioural studies could be used to indicate the distances from sources of disturbance over which habitat occupancy is likely to be reduced. For example, response distances include 75 m for common sandpipers *Actitis hypoleucos* (Yalden 1992), 100 m for New Zealand dotterels (Lord et al. 2001), and in excess of 1 km for both curlew, *Numenius arquata*, and redshank, *Tringa totanus* (Yalden and Yalden 1989). These figures suggest that the impact of increased recreation activity on breeding waders will vary depending on the sensitivity of the particular species concerned. For golden plovers, the avoidance of areas within 200 m of a footpath is unlikely to be a serious threat in places where a single footpath crosses a large area of suitable habitat. However, human disturbance may become a problem in areas where there is a network of footpaths.

Alwis et al. (2016) found that heavy use of nature trails for recreation has affected the bird species that occur on the Kudawa nature trail in the Sinharaja World Heritage Forest. Under high levels of disturbance, bird communities avoided edge habitats and flushed far into the forest (up to 150 m). Certain bird species seem to tolerate greater degrees of recreation disturbances. The sensitivity of individual bird species to visitor recreation disturbances varies with the stratum/layer of the rain forest usually occupied by these bird species. Effects of recreation disturbances were more profoundly felt by birds occupying understory and sub-canopy layers of the forest near the nature trail. Accordingly, the following species ashy-headed, laughing thrush, dark-fronted babbler, spot-winged thrush, Tickell's blue flycatcher, brown-breasted flycatcher, greater flameback, Malabar trogon, orange-billed babbler, Sri Lanka scimitar-babbler, and yellow-browed bulbul avoid habitat edges along the jungle trail under increased visitor activity. Bird species occupying the canopy and higher layers of the forest are more tolerant to recreation disturbances. A forest bird, the Sri Lanka blue magpie did not show noticeable signs of avoidance behaviour under human presence. Instead, they seem to be attracted towards small- to medium-sized visitor groups. This was evident by the high number of Sri Lanka blue magpies being recorded under low and moderate levels of recreation disturbances and their numbers showing a positive correlation with disturbance level, although the relationship was not statistically significant. This suggests a possible habituation of the Sri Lanka blue magpie population ranging around the Kudawa nature trail to low and moderate levels of recreation disturbances or human presence. In fact, during their field studies, it was often observed that a group of Sri Lanka blue magpies was perching near the trail in anticipation of food, when visitor groups were present. Similar behavioural observations were made on ground-occupying Sri Lanka junglefowl and visitors feeding both species were a common observation. Such visitor behaviour along with exposure to recurring recreation disturbances can alter the normal behaviour of birds and induce habituation to human presence.

Few studies have attempted to assess the impacts of flight responses to walking on forest species other than birds. Some studies show, for example, that human presence on foot can in some circumstances disturb wild deer. Langbein and Putnam (1998) and Recarte et al. (1998) studied disturbance of British park deer, although came to different conclusions. The former reported significant immediate behavioural responses of deer to human presence, but these had no long-term impacts (such as on body weights or overwinter mortality), whilst Recarte et al. (1998) reported less disturbance and concluded that level of disturbance response was related to surrounding habitat and habituation. Other UK deer research includes Ward et al. (2004), who found that wild roe deer (*Capreolus capreolus*) did not flee from or otherwise change their behaviour, when disturbed by night-time ecological survey. They were found, however, to avoid paths and roads even at night when human activity was very low. In a US study, Miller et al. (2001) reported that for all species, area of influence, flush distance, distance moved, and alert distance (for mule deer) were greater when activities occurred off-trail versus on-trail and that for mule deer, the presence of a dog resulted in a greater area of influence, alert and flush distance, and distance moved than when a pedestrian was alone. Studies by de Boer et al. (2004) and Marini et al. (2008) highlight a number of factors affecting the flight responses of wild deer. The structure of surrounding habitat is repeatedly identified as a major factor. In the only study of disturbance of squirrels by recreation identified in this review, Gutzwiller and Riffell (2008) concluded that abundance of red squirrels at foot sites in the USA did not differ significantly from that at other control sites during their experiments. Although immediate/short-term behaviour change may be apparent, the limited available evidence shows little or no long-term negative impacts upon forest mammals following "flight" caused by walking in woodlands.

2.14 Impacts Are Not Always Negative

A study of salamanders actually identified a beneficial relationship between trail presence and species success, noting that trails result in more microhabitats for salamanders around them (Davis 2007). However, other analyses of human disturbance of reptiles describe some significant negative impacts, for example, the removal and accelerated decay of woody debris vital for skinks (Hecnar and M'Closkey 1998).

Invertebrates must be affected by walking trampling pressure, and an example can be given from sand dunes at Dundrum (Northern Ireland) where Buchanan (1976) found the following: (a) A lowering of total animal numbers and the number of species (diversity was lower) occurred. Mites and Collembola (springtails) which form the bulk of the terrestrial soil fauna are reduced by around 90% in the fixed yellow dunes by a trampling pressure of just over 13 people/m/hour. 1500 people/year seemed to be insufficient to cause a reduction in invertebrate numbers in Calluna heath or fixed dunes but caused a 45% decrease in mite populations in bracken heath, whilst the springtails were reduced by 65%. (b) The roundworms and threadworms increased significantly with trampling, but they decreased in the Calluna and bracken heath. However, some doubts were expressed about the validity of these results because of the extraction method used. (c) An increase in scavenging species occurred because of the deaths of many animals, and there was an increase in species associated with ephemeral habitats, for example, the tiger beetle probably requires the presence of bare, sandy paths to be kept open by trampling in order to survive in heathland localities.

2.15 Management Implications for Recreational Walking-Induced Change in the Landscape

The evidence presented so far, systematically accumulated across field observations and measurements and high-quality experimental studies, suggests that vulnerable vegetation of conservation value should not be trampled, irrespective of the projected intensity of use: even moderate disturbance can have significant effects on plant communities. Simple indicators such as life-form of the dominant community may be useful for rapid assessments of a community's vulnerability to recreation pressure. The evidence is clear that positive management to conserve the physical, biological, and aesthetic qualities of the countryside is needed, and this implies control of the walker's behaviour, the management of vegetation, and improvements in trail surfaces in many cases. The management approaches are many, but they involve either raising the capacity or reducing use, and usually a combination of elements of both. The alternative is to do nothing and accept deterioration, but this is not a viable alternative for recreation land managers who are looking after national parks and wilderness areas. What is important is a consideration of the recreation carrying capacity which is the level of recreation an area can sustain without an unacceptable degree of deterioration of the character and quality of the land resource in terms of vegetation, soils, and the recreation experience. However there are various types of carrying capacity and not just one. The ecological carrying capacity is the maximum level of recreational walking that can be accommodated before there is a decline in the ecological value, assessed from an ecological viewpoint. There has been criticism of this definition because it fails to take sufficient account of any acceptable change away from the desired state. It relies on three conditions which have to be accepted: there is a most desirable state, there is a degree of change away from this which is only just acceptable, and both of these are matters of judgement. In a country park close to urban areas, a rye grass cover may be acceptable, but in a protected nature reserve, the loss of a single species may be looked at as too much to pay for a certain use level. There are also problems because a number of factors can bring about a change in ecological carrying capacity such as wet weather, steep slopes, and the kind of use. Thus this concept is never likely to be a useful applied principle where the number of people which bring about whatever threshold of change is used to define it can be predicted for a wide range of situations: the concept seems specific to particular sites and local circumstances. However, productive vegetation generally has a higher ecological carrying capacity than vegetation on poorer soils, and most amenity ecosystems are unproductive and are so because most of the fertile soils are under cultivation. The physical capacity is the maximum level of use that a site can accommodate spatially and is never likely to apply on recreation trails, but the perceptual carrying capacity, which is the use level above which there is a loss of enjoyment because of overcrowding, may well occur. Again it varies between different people, but it is likely to be well below the physical capacity.

What we can say from all this is that carrying capacity depends on the management policy and is the maximum intensity of recreational walking use an area will continue to support under a particular management regime without inducing permanent change in the biotic environment maintained by that management. As Wagar (1964) put it, “the final definitions of recreational carrying capacity must be of an administrative nature.” The recreation manager has effectively four attitudes to adopt: (a) ensure that recreational walking exerts a minimal modifying influence on the ecosystem, (b) attempt to retain the essential character of the ecosystem but otherwise accept some changes from the walking, (c) replace those elements of the ecosystem which are more susceptible to trampling pressure by components which are more resilient, and (d) ignore ecological changes resulting from the trampling pressure. However, in most cases with suitable management, the planned use of an area for recreational walking is perfectly compatible with the maintenance of this ecological value. The degradation from overuse must be prevented, and walkers must be excluded from using certain paths or discouraged from doing so.

Zonation of recreational walking into high- and low-intensity usage, with “honeypots” located away from vulnerable vegetation, may be a more effective conservation strategy than encouraging moderately intensive but more widespread walking usage. This is especially given that occasional use can result in the development of informal path networks which may subsequently encourage further disturbance (Roovers et al. 2004). The siting and development of new trails, nature trails, car parks, toilets, and information centres can be used to dictate the recreational walking use pattern and help implement a zoning policy.

The potential strategies to manage recreation walkers and their experiences are many and have been discussed in many publications, but excellent reviews can be found in Cole et al. (1987), Leung and Marion (2000), Manning and Anderson (2012), Hammitt et al. (2015), and Marion (2016). The many elements usually embrace trying either to raise capacity or reduce the use of an area. Reducing the use of the entire area may be attempted by limiting the number of walkers; limiting the length of stay; charging increased fees either to enter the recreation area or to park in reduced car parks, which will reduce access; encouraging the use of other areas by developing better facilities there; and advertising extensively these new areas or existing alternatives. Reducing the use of the areas where problems occur can be attempted by informing the recreational walkers of the problems of these areas (Figs. 2.1A and 2.5) and/or the advantages of alternative areas, limiting the numbers to these

Fig. 2.5 Sign asking for no access up the volcano flank because of the highly erodible coarse volcanic ash, Lanzarote Geopark, Montana Corona. Photo by David Huddart

areas or limiting the stay length, charging differential fees, prohibiting use, making access more difficult, and eliminating facilities.

A modification of the use location within problem areas can be attempted by locating facilities on durable sites, making trails more durable, supplying information on these walking trails, and banning off-trail walking. A key effort must be made to reduce off-trail hiking, and methods to try and achieve this have been developed and evaluated by Clark and Leung (2007) and Hockett et al. (2010, 2017). It might be possible to modify the timing of use by encouraging use outside peak use periods, by charging higher fees for use during high-use or high-impact periods or lowering fees for use during low-use or low-impact periods, and by discouraging or banning use when there is high-impact potential. It might be possible to change visitor behaviour by information and education and to modify their expectations. The resistance of the trails can be strengthened in various ways, and the problem areas can be monitored, maintained, and/or rehabilitated.

Soils vary greatly in their resistance to wear. Surfaces with a high proportion of coarse particles (rocks or stones) are generally least affected by recreation use, and clay and peat soils are most affected in that they show the greatest erosion of soil material and changes in soil structure. Most soils have lower resistance to wear under wet ground conditions because water acts as a lubricant and allows soil particles to rub against each other and soil compaction to occur. Peat and clay soils are particularly vulnerable to wear under wet conditions and often require special protection, such as improved drainage, more durable surfacing, or reduced levels of use.

The wear-resistant properties of vegetation vary from species to species. However, the types of wear exhibited by different communities reflect not only the durability of the vegetation but also the extent to which the vegetation structure limits or modifies recreation movement. For example, stands of rushes are not easily walked through, so use and wear tend to be confined to meandering routes between clumps. In contrast short grassland has high resistance to wear but low resistance to movement, resulting in extensive scuffing with only a few areas of localised severe wear. Bog and fen have poor wear resistance but high impedance to movement, with the result that there tend to be fewer but heavily worn paths.

What we can see here is that certain environments are prone to recreational walking pressure: peat soils, upland blanket bog, and water-logged soils. We will look at a case study from the Three Peaks project (English Pennines) in Sect. 2.20, which has been particularly badly affected by trampling pressure and many remedial approaches have been developed to try and counteract severe erosion problems in that area.

2.16 Path Wear and Deterioration

The factors that influence path deterioration are many and include soil and vegetation characteristics and the type and intensity of use. There are, however, some relatively straightforward relationships between site characteristics and path wear that are of fairly general applicability and which have important implications for path design and management. Much pioneering work for remedial work on footpaths was carried out on paths in the Cairngorms, in other parts of Scotland, and in the Yorkshire Dales (see later section) by Bayfield and Miller (1988) and Bayfield et al. (1990, 1991a, b) but subsequently confirmed by studies in other types of terrain (review by Liddle 1989). In the Cairngorms investigations, the effects of site factors were determined by examining path sample data where site characteristics other than the major variable were similar, for example, samples that varied in surface wetness but were otherwise similar in terrain type, level of use, and soil and vegetation types. The data showed that irrespective of the level of use, path width increased with the surface wetness and roughness and also with the angle of slope along the path. More surprising was that the roughness of adjacent ground decreased path width; and paths were narrowest where they passed through the roughest terrain (provided the path surface remained of the same quality). Although fairly obvious, these relationships can be of considerable importance for path design and management. Clearly for minimum path deterioration, the path surface needs to be dry and smooth (minimum values for wetness and roughness) and it should not have steep slopes where possible. The effect of adjacent ground roughness implies that paths should be sited through broken terrain rather than smooth ground, if a choice exists. Furthermore, deterioration might be limited on existing routes by increasing the roughness of ground adjacent to paths by placing rocks or logs or planting tussocky or otherwise coarse vegetation as obstacles to help reduce path spread. A further important observation concerned the relative impacts of uphill and downhill walking. Downhill walkers were found to take more steps and to have a greater impact with each step than uphill walkers. They also tended to deviate more from the centre of the path than walkers going uphill, possibly because when walking uphill, the field of view (and choice) is relatively restricted. The differences increased with slope steepness. These observations imply that it may be possible to reduce the impacts of use if the direction of travel can be manipulated so that users go mainly uphill on steep slopes and downhill on gentle slopes. On circular walks, for example, there is usually an optional direction for use.

2.17 Techniques for Managing the Footpath Surface

2.17.1 Creating More Resistant Footpath Surfaces

Land managers can apply more sustainable construction and maintenance techniques to increase the ability of their trails to resist impact by adding types of stonework, such as stone flags laid across peat, aggregates, borders, and boardwalks, or adding drainage features, like water bars, drains, treads that dip away from the slope, and ditches. Much pioneering work took place in the UK and was published in handbooks and research reports by Agate (1983), Bayfield and Aitken (1992), Davies and Loxham (1996), Barlow and Thomas (1998), Backshall et al. (2001), the National Trust for Scotland (2003), and a whole series of reports published by the Institute of Terrestrial Ecology, Banchory, Scotland, published by Bayfield and his co-workers, such as Bayfield and McGowan (1986) and Bayfield and Miller (1988). In the USA there were publications addressing similar issues, for example, by Hingston (1982), USDA Forest Service (1985), Birchard and Proudman (2000), Marion and Olive (2006), and Hesselbarth et al. (2007).

2.17.1.1 Geotextiles

These are water-permeable textile materials (fabrics,) used as an underlay to conserve gravel on trails and stabilise erodible surfaces. The textile allows water to pass through it but keeps soil layers from mixing and breaking down. There are three main types of geotextiles used for erosion control: (1) nettings laid on the surface mainly to trap sediment and slow surface runoff (Fig. 2.6), (2) partly buried three-dimensional nettings intended to provide some shallow subsurface stability and sediment trapping, and (3) subsurface cellular webs, which provide deeper surface stability.

Surface Nettings

Geojute is an example of this category which is a jute-based, open-weave netting with a mesh size of 1–2 cm. The netting is rolled out and pegged in place with long wire staples. It has the advantages of stretching and closely fitting irregular ground contours (particularly after being wetted) and is also biodegradable. The jute retains some of the moisture from rain and surface flow and rots to provide surface organic material, both features which may be of minor benefit to establishing vegetation. As the netting is merely pegged to the surface, no special soil preparation is required.

2.17.1.2 Three-Dimensional Nettings

Enkarnat types of geotextile are made from two or more layers of fine and coarse grade net, tacked together to provide both reinforcing and soil-holding abilities. In use they are laid on the ground, and soil is worked into the upper layer. The geotextile is thus placed at or just below the

Fig. 2.6 Geotextile. Originally covered with aggregate, but this has been eroded as the geotextile was not laid deep enough so that there was an adequate aggregate fill. It should have trapped sediment and slowed surface runoff (Three Peaks project). Photo by David Huddart

surface. These materials are stronger than jute netting but not biodegradable. Unless laid very carefully, they do not fit as closely to the surface as jute, and sometimes surface runoff can wash out soil from under the netting, leaving the netting suspended, visually intrusive, and ineffective. Geocells and geogrids are three-dimensional webs providing a network of cells resembling a honeycomb (e.g. Armater). The webs are placed on the slope to be protected, pegged down at intervals with stakes, and the cells filled with soil. This is a substantial reinforcement technique that can provide subsurface stabilisation to about 10 cm or more and some surface protection by reducing the runoff velocity and runoff and sediment trapping. Due to its high cost and heavy earthmoving requirement, it is not often justified for erosion control at recreation sites but has been effective in increasing the resistance and load-bearing capacity of wet tread substrates. Other effective products include drainage mats (Polnet) and turf reinforcement mats, like Pyramat (Monlux and Vachowski 2000; Meyer 2002; Marion and Leung 2004; Groenier et al. 2008).

2.17.1.3 Chemical Binders

There are a number of soil stabilisers using different chemicals that have been developed to increase the adhesion of soils, improving moisture resistance and bearing and shear strength of the soil (Bergmann 1995; Meyer 2002).

2.17.1.4 Mulch Mats

Mats, such as Greenfix, are sheets of lightweight netting enclosing a mulch layer of straw, coir, or other organic materials. The mats are sometimes pre-sown with appropriate grass seed or may be laid on top of sown slopes. They are pegged down with wire staples and provide protection from raindrops, reduce runoff velocities, and trap sediment. The mulch can have the disadvantage in some situations of stifling the growth of vegetation, although in the longer term, decomposition adds valuable organic matter to the soil. Mulch mats are bulky and relatively costly and, like geowebs, not often justified at small-scale recreation sites.

2.17.1.5 Mesh Elements

This technique involves reinforcing soils by mixing them with small pieces of plastic mesh. The mesh acts as a root substitute to strengthen the soil and to some extent traps sediment and reduces runoff velocities. The main drawback of this technique is the problem of satisfactorily mixing the mesh elements into the soil to be protected. In commercial practice soils and mesh are often pre-mixed off site, but this substantially increases the cost.

2.17.2 Surface Glues

Surface glues, or soil stabilisers, are usually applied to soils as a component of hydroseed mixtures or sprayed on after manual seeding or planting. They form a porous skin on the surface to prevent soil particles washing away and are mainly intended for short-term protection. As in the case of geotextiles, there are a large number of products on the market. All appear to be more or less efficient as glues, although there is very little comparative information on the effectiveness of different formulations. In selecting a product, important considerations will be cost and the method of application. Powder glues are much easier to apply to small areas than emulsions, which tend to clog small sprayer equipment. All types can be used in hydroseeding. Although each manufacturer claims low toxicity, some products are more toxic to plants than others. Bayfield and McGowan (1990) compared the toxicity of a small range of glues on both grasses and bryophytes and found use had a stimulating effect on the growth of some test species. It was not clear if this effect was due to release of nutrients or some hormonal effect of the glues.

2.17.3 Surface Moulding

This technique consists of cutting horizontal ledges or grooves in slopes instead of dressing them to a flat profile. This approach is fairly common in the USA and is also used in the tropics but appears to have been rarely tried in the UK. In the USA, serrated "steps" are recommended, between 15 cm and 1.3 m high. In Malaysia, grooves 5 cm deep and 25 cm between centres are cut in the dressed surface. Both methods help trap waterborne sediment, reduce runoff velocities, and increase slope permeability. Trials by the Malaysian Thai Development Company indicate about 25–75% better germination of grasses and legumes on grooved slopes, probably because of better permeability and moisture retention than on ungrooved slopes.

2.17.4 Aggregate Paths

Aggregate paths are mainly suitable for use on mineral soils, where there is firm subgrade material. Simple excavation of a path base is followed by infilling with an appropriate fill material. No reinforcing is required although a filter geotextile may help to prevent the surface becoming clogged with fines. Angular quarry graded material is the most suitable fill since it will pack down firm and solid. Often, though, material from local sources, such as borrow pits or streams, will be used. These materials may be satisfactory, but problems can arise if there is too high a proportion of rounded gravel or too much or too little clay present: these combinations make poor path surfaces. A solution can be to mix in a proportion of angular material or clay to improve the properties of the mixture. Mixing can, however, be difficult and time-consuming, particularly at remote sites. A variation is to form a wearing surface with stones or rock ("cobbling"). This can be very durable but has to be carefully laid and consolidated, as protruding angular material can be both unpleasant to walk on and even dangerous. Effective drainage is important to prevent scour and loss of finer surfacing material. It should be possible to build in a camber or shedding slope, but in practice this appears to be difficult to achieve and sustain.

2.17.5 "Floated" Aggregate Paths

Aggregate paths can be rafted or floated on soft ground or peat by laying them on geotextiles, to prevent them from sinking. The earliest such use of geotextiles in path construction was with Terram. Although this material is a good filter textile, it lacks tensile strength, and some of the early trials were not successful, as the resultant paths tended to slump and sag. In recent years there has been recognition that over wet amorphous peat, slabs need to be laid onto a base of chestnut paling, about 1.5 m wide, bound with polypropylene cord. In a few locations, slabs have been laid onto a base of aggregate, but this appears to be overspecification and should not be required at most sites. Except at very wet locations, the evidence is that direct laying onto bare peat is satisfactory as there have been few instances of sinking or loose slabs.

2.17.6 Boardwalk

Boardwalk is a well-established technique for creating an acceptable walking surface across difficult ground, usually wet and peat-covered, although also very rocky ground (Fig. 2.7). Possibly the oldest documented path in Britain, the Bronze Age "Sweet Track" through a bog in Somerset is a type of boardwalk, made from split logs. Boards for the surface can be laid either across or along the route. In either case they normally rest on bearers to tie the structure together and to help spread the load. Many boardwalks are built on site, particularly where the ground is uneven or the route circuitous, but prefabricated sections or rafts are sometimes delivered to site by vehicle or helicopter. Boardwalk is relatively more temporary than most path surfaces in that it can be lifted and removed fairly easily without leaving much damage. Sections need to be checked regularly for wear and tear since, more than most path techniques, it manifestly implies a public safety obligation on the manager. For similar reasons it should be covered with chicken wire or tar and gravel to counteract any slippery surface. Boardwalk is an excellent solution for paths through wet sites of high ecological interest as it avoids any interference with lines of drainage. It can also be successful in woodland and coastal settings. Although it does not offer a pleasant walking experience over long distances, it has nevertheless been used in quantity in some remote areas such as the Pennine Way in the Cheviots, where there is a shortage of local materials for alternatives.

2.18 Vegetation Reinstatement

Given time, almost any bare soil surface will be revegetated by natural colonisation. Studies of bulldozed hill roads in the Cairngorms show that even at almost 1000 m, sites are probably recolonised within five years, and some in two or three. Even these rates are, however, unacceptably slow for most recreation sites, where the aim is to reinstate bare or damaged surfaces as rapidly as possible, to minimise both erosion and visual intrusion. In the past it has been acceptable to merely provide some kind of vegetation cover, in fact any kind of vegetation cover. Recently though planners and managers have begun to demand higher standards of revegetation, involving use of native species and landscaping schemes that try to blend damaged areas to the surrounding ground.

Reinstatement aims to use appropriate native species, to use local or native strains which are similar to the impacted ground, to create ecologically diverse stands of vegetation, to prepare surfaces for planting that blend with surrounding

Fig. 2.7 Boardwalk across extremely rough aa lava, Timanfaya National Park, Lanzarote. Photo by David Huddart

landforms, and to integrate engineering, vegetation reinstatement, and landscaping management of damaged sites.

2.18.1 Transplanting

The techniques described here are all ways of reusing existing plant resources. They include movement of intact vegetation in the form of turves or larger "clods," dividing clumps of vegetation, bare root transplants, and taking cuttings. All transplanting techniques have the advantages of providing a greater or lesser degree of instant cover and of being able to use local material (where available) appropriate to the site. All the techniques also have the disadvantage of having a relatively high labour requirement and are usually more costly than corresponding seeding methods.

2.18.2 Seeding

Seeding is probably the most widely used method of reinstating damaged ground at recreation sites, but the issues include the selection of appropriate seed mixtures, methods of sowing, and the use of species as nurse cover, or as permanent contributors to vegetation.

There are three main methods: drilling by direct placement of seeds in the soil, broadcasting (dry spreading seeds), and hydroseeding (spreading seeds in a water slurry, usually with other ingredients, such as fertilisers and tackifiers). Broadcasting sowing is the most commonly used method and can involve hand-sowing or the use of various types of backpack or tractor-mounted, seed spreaders. Care needs to be taken to ensure even spreading of seed. With very small seeds, it is useful to mix the seed with sand or fine sawdust to make it easier to see gaps or dense patches. The ground to be sown is best raked and roughly levelled to form a seedbed prior to sowing. After seeding, rolling or some other method of light compaction will help partially bury seeds and keep the surface moist. Hydroseeding is a relatively large-scale operation like drilling but is better suited to sloping and rough ground. Little surface preparation is needed, although establishment will be improved if the surface is raked and levelled. Hydroseed slurries are sprayed on to areas to be seeded from a vehicle-mounted nozzle or using extension hoses. The slurry typically includes seeds, soluble and slow-release fertilisers, and peat or woodpulp mulch and tackifier (soil stabiliser or glue). Most of the ingredients are insoluble and have to be kept in suspension by agitation prior to spraying. Although this is essentially a large-scale technique requiring special equipment, it has been quite widely used at ski resorts such as Cairngorm and has been tested on parts of the Three Peaks footpath system.

Overall though the site management actions should remain as unnoticeable as possible, and they should be visually and ecologically less obtrusive to natural conditions than the walkers' impacts that prompted the remedial action (Marion and Sober 1987).

2.19 The Trampling Impact on Blanket Peat and Other Organic-Rich Soils

Much of the published information indicates that there have been progressive declines in the condition of footpaths, particularly in the uplands, and that in some places there has been a proliferation of routes. For example, early observations on the popular, intensively used Pennine Way long-distance footpath in Northern England in 1971 and 1983 (Bayfield 1985) showed that bare and trampled widths had about doubled over this period. Later monitoring in 1988 showed that the width of bare ground had increased by 300–900%, resulting in an average width of 7–8 m of bare peat but extending to 70 m in places and an estimated peat loss of 10 mm/yr. (Porter 1990).

The removal of surface vegetation and exposure of bare peat soils by trampling also heighten the risk of soil erosion through the natural weathering by wind and water. In an upland environment such as a blanket bog, the linear nature of the paths on a gradient may localise water runoff, rapid transport of sediment, and soil deposition in watercourses, and change species composition, with extensive gully erosion, up to several metres deep (Morgan 1995; Grieve 2001).

2.20 The Three Peaks Project: Background to the Project (Yorkshire Dales, UK)

In 1986 a survey of the area's 65 km of footpaths found that 21 km were severely damaged and a further 21 km needed immediate remedial work to avoid them deteriorating to a similar state (Smith 1987). The average path width was found to be 11.4 m, whilst in north of Pen-y-ghent at Black Dub Moss, the path was 150 m wide. The paths had been getting measurably worse, and something had to be done in terms of management as the path erosion rivalled some of the more famous areas of the Pennine Way, with deep mud gulleys in places and paths on the flanks of the fells as ugly scars visible from a long distance. What was attempted in 1987 was that the Yorkshire Dales National Park set up the Three Peaks project where the aim was to repair the paths using techniques which would be ecologically and visually acceptable. This was an undertaking which would take some time since little work of this type had been carried out elsewhere, especially on deep peat soils. Initially the project was set up to run until 1992 and was funded by the Countryside Commission, the Sports Council, and the Nature Conservancy Council. These fragile uplands could not withstand the levels of use without remedial work because the alternative was destruction and permanent loss of a unique upland habitat. The measured use levels were obtained by mechanical counter-stiles after an initial visitor survey in 1985 had established that Ingleborough had 150,000/yr., Pen-y-ghent 60,000/yr., and Whernside 40,000/yr. The techniques used were based around a whole series of both engineering and ecological trials to try and establish what was likely to succeed best and the potential value of path construction techniques on paths that were already severely damaged and where no other form of intervention seemed possible (Bayfield 1987).

2.20.1 Chemical Consolidation of Soil

Between 1986 and 1988, engineering trials on organic peat soils with a clay fraction of under 5% were attempted using a chemical consolidator of weak, clay soils called "Solidry." The chemical was supposed to stick the soil particles together, giving the soil an improved structure and so increasing its strength. Although the manufacturer suggested an application rate of 1% by weight, the chemical was tested at rates of 1%, 1.5%, and 2% on 20-m path lengths at Churn Milk Hole, on the southern flank of Pen-y-ghent. Each section had been rolled and resulted in a surface strong enough to carry a truck weighing four tonnes. The surface remained intact for three months until the hard winter of 1987 when freeze-thaw transformed the whole stretch into a quagmire. An application of 4% was tried, but this proved no more successful, and so the entire path was covered in bituminised geotextile matting and also on some stretches with limestone chippings. So this chemical consolidation was not a success, especially as a later trial at High Birkwith at lower elevation also failed.

2.20.2 Aggregate Path Construction

Traditional methods of path construction on organic soils involve the excavation of the weak, load-bearing soils. However, this technique has considerable drawbacks: the impact on the site hydrology is marked especially if peat pipes are encountered, and it may have localised impact on the adjacent plant communities. The disposal of unwanted soil is often problematic, and narrow paths can create a serious barrier to the use of machinery for future path building and maintenance. Therefore alternative methods for aggregate path construction were examined. The most extensively used repair technique has been the use of matting covered by stone chippings. Two different types of mat have been used: (a) a plastic mesh alongside the Ribblehead Viaduct and (b) geotextile matting which is much denser than the plastic matting, and it was used on Little Ingleborough and Pen-y-ghent. The major difficulty is that these paths were far too wide (2 m), but the reason was that when the stone chippings were laid, they have to be rolled flat, and therefore the path has to be wide enough for the roller and most of the stone had to be transported by dumper truck. A further variation on the theme was used at Churn Milk Hole where a bituminised geotextile mat was laid, and where the ground was most boggy, chestnut palings were placed underneath. Apart from a tendency to distort to the shape of the palings which produced a slightly corrugated path, this proved successful. There are many different geotextile products, and they serve one of the three primary functions—filtration, separation, and reinforcement—but most geotextiles are only designed to meet one of them. In fact there was an evaluation of a range of geotextiles: initially there was an assessment of spun and needle-punched products such as Terram and Typar. However, the entire range was eliminated as they proved so elastic that they tended to either buckle and then rupture under the load of the machine carrying stone or swell and blister due to excessive groundwater pressure. Then six varieties of woven geotextiles were tested between 1987 and 1991 and high tensile strength geotextiles and geogrids in 1988–1989. The geogrids laid directly onto the ground and then covered with at least 200 mm of stone chippings were most effective, although there was some stone migration from the two sloping edges of the path. Over 2.85 km of path was constructed on Whernside from Bruntscar and on Simon Fell Breast and proved very effective in canalising use.

2.20.3 Temporary Boardwalks

These were used well before the Three Peaks project began such as in the mid-1980s across High Lot Nature Reserve on the flanks of Ingleborough built of old railway sleepers and with pile-driven posts deep into the peat, giving more of a bridge over the muddy peat. However, this type of temporary boardwalk is costly to lay, and therefore a decking system called Flexboard was evaluated on Whernside at Force Gill (1989) and on High Lot (1990). Here flexible boards constructed of treated timber plank, bound by iron bands and joined together by iron hinges and pins and held in place with anchoring pins were airlifted in by helicopter. They were surfaced in two different ways with chicken wire on High Lot and with tarmac and chippings at Force Gill. The latter is much harder-wearing and effective except in severe frosts when ice fills in voids in the tarmac and therefore becomes slippery and the chicken wire tends to rip as the walkers slip on wet boards. However, they are highly effective in canalising use, and 200 m/day could be laid and so was very efficient. Due to the seed bank in the soil, the areas which were up to 50 m wide of black mud became recolonised right up to the edges of the flexboard. They were effective and could be laid on slope up to 15°, but one problem was that the toe of the walker's boot was not able to gain sufficient purchase, especially when ascending.

2.20.4 Stone Pitching

This was used on severely sloping sites up to 40^0 where aggregate paths were unsuitable, especially in the upper reaches of paths where they meet the Millstone Grit summits of the mountains. Stones are placed vertically in the ground so that two thirds of each stone is buried, and the technique has been widely used successfully in the Lake District and Snowdonia (Fig. 2.8). However, in the Three Peaks unfortunately a year later, the stones had moved as subsurface channels had been breached during path construction, so the path had to be re-laid and had to incorporate a base layer of concrete which proved effective.

Fig. 2.8 Stone pitching in Snowdonia, North Wales. Photo by David Huddart

2.20.5 Mechanised Path Construction Using Subsoil

The reorganisation of soil profiles took place on Simon Fell Breast, Little Ingleborough, and Whernside using a 12-ton Hymac digger on loan from the Cairngorm Chairlift Company. The peat was taken off and rearranged on either side of the path to expose the underlying mineral soil. A ditch was dug on either side of the peat to aid drainage, and the path was surfaced using crushed limestone from either side of the path. This technique was relatively cheap and rapid.

2.21 Ecological Trials

These trials focussed on four specific areas: reinforcement of existing vegetation, restoration of severely damaged peat soils, revegetating mineral soils, and revegetating aggregate paths built as part of the engineering programme.

2.21.1 Reinforcement of Existing Vegetation

These trials had actually started in 1986 with fertiliser applications to try and increase the trampling resistance of the existing vegetation, but the results between 1986 and 1989 were inconclusive, and it was decided that fertiliser alone did not increase trampling resistance in a situation of continuing or increased trampling intensity. So synthetics as turf reinforcement were installed to act as reinforcement for the root zone, to allow the plants to grow through the synthetic layer where the roots would become intertwined with the fibres of the synthetic layer and so improve turf strength. Macadamat, a plastic matrix with the voids filled with bitumen, was used at Churn Milk Hole in 1989, and a whole series of products resembling synthetic carpets from the sports turf industry were evaluated at Grain Ings on Whernside. The vegetation was strimmed to provide a level surface, fertilised to promote vegetation growth through the synthetic material and then seeded. Some plots were fenced. However, these trials were not a success as the product costs were high, installation was difficult, and the cover did not achieve 10% on trampled and only 30% on untrampled areas. The Notts Sports Turf VHAF GR700 and the Tensar Mat with Tensar SS35 proved the most effective and were the only ones to allow the growth of the original turf through the synthetic material.

2.21.2 Restoration of Severely Damaged Peat Soils

The first phase involved trying to recreate the native vegetation by using seed mixtures comprising indigenous species, improving species diversity through the introduction of plant litter, germinating the seed bank, and relocating of turves for regenerating the native vegetation. The conclusions were though that large-scale implementation of this policy was not realistic because of the cost and that seed availability was not sufficient. The second phase of this trial was to use a seed mixture whose only function was to rapidly establish and stabilise the bare soil surface. Once this had stabilised, this would generate more favourable environmental conditions for invasion of native plants. Perennial rye grass was applied by hydroseeding, and over 14,000 m^2 of Whernside summit was reseeded by spraying seed, fertiliser, soil, and adhesive out of a spray gun mounted on the back of a vehicle. Within a month of seeding, the grass had begun to seed, and up to an 80% cover was established quickly. The same technique was used to spray the banks and ditches produced by the soil rearrangement and in an attempt to green up the white limestone chip path at Hunt Pot on Pen-y-ghent.

2.21.3 Revegetating Mineral Soils

The same techniques were used as in the previous trials, but tests from Whernside had shown that soil erosion from the high gradients and high rainfall made germination difficult, but pre-seeded erosion control blankets were used where the seed was held on a thin backing layer which was placed directly on the ground. This reduced the erosive potential, but the cost was the problem.

2.21.4 Revegetating Aggregate Path Surfaces

This was to minimise the environmental impact as the roots bind the aggregate and make the path more durable and the surface water and rainfall are intercepted. Hydroseeding was used, although at Ribblehead a material marketed under the name Fibresand was used. This was sand with random plastic fibres, and it did improve the vegetation cover, but as usual the main problem was cost.

2.21.5 Conclusions Related to the Three Peaks Project

The five years of this project proved that tackling footpath erosion and habitat restoration for a major path network is technically possible if the correct intervention strategies are used and it was possible to evaluate the effectiveness of a large range of management options. Specific solutions were found in the following areas:

Aggregate paths can be built over the most severely eroded peat soils which can be cost-effective in construction and maintenance. Subsoil paths are cheaper where the subsoil has a clay fraction, but further work was needed to establish whether this technique was able to guarantee success. Constructed paths can be effectively revegetated through seeding techniques, but the vegetation restoration techniques using native species were not as successful because such seeds are not commercially available from the right provenance and those that were available were not in the quantities needed. Fertiliser application by itself could not increase the trampling resilience of existing turf, but reinforcement through the installation of a synthetic layer appears possible. Hydraulic seeding offers major advantages in vegetation restoration techniques in comparison to more labour-intensive techniques, and erosion control blankets may prove effective at the most difficult sites where hydraulic seeding alone would not. Visitor attitudes towards the need for restoration work and the work itself have proved very positive. The preference of walkers was ranking from most preferred to least preferred: turf reinforcement, soil reorganisation, Flexboard, boardwalk, aggregate path, stepped boardwalk, and steps. However, satisfying walkers' needs can only go so far because, for example, turf reinforcement is only an option where damage is less severe and only on level terrain.

Concluding Remarks

We have established that recreational walking in its various forms has impacts on all types of recreation landscape ranging from wilderness through national parks to country parks in the urban fringes. The vegetation is impacted with any level of walking, but we have illustrated that in certain terrains, severe trampling pressure can result in major vegetation cover loss. At the same time as the vegetation loss occurs, there is parallel soil erosion. In high mountains with severe environmental conditions including high rainfall, low temperatures, and strong winds and on moorlands with blanket bog development and peat soils, there can develop deep gulley erosion. We also know that these recreation impacts will grow because the projected growth figures for recreational walking are high and it has grown consistently to become the most popular active outdoor pursuit in most parts of the world. This means that recreation land managers will continue to need a growth in resources and manpower to manage these ecological impacts, with a need for more research funding and the application of the experience that has built up in the last 30 years or so to counteract the problems and to manage the recreation resource for this activity in a sustainable manner. It seems even more difficult today to preserve the high-quality, natural environments for a high-quality, recreational walking experience, and although the area of land affected by such impacts remains relatively low on a world scale, some individual mountains and natural landscapes seem to have been lost as "honeypots," such as Snowdon in North Wales, the Yosemite valley in California, and some of the national parks, like Arches and Zion National Parks in the southwest of the USA where at certain times of the year the carrying capacity of the recreation land has been far exceeded. What is needed here is more effective education and regulation of the recreation walkers so that all areas are managed sustainably. There is no doubt that there is plenty of recreation resource available for walkers, even in such a small island as the UK, so on a world scale, there should be no problem in providing the demand for recreational walking whilst maintaining, conserving, and sustaining the natural landscape and its wildlife.

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