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Journal of Environmental Management 74 (2005) 21–30

Journal of Environmental Management

www.elsevier.com/locate/jenvman

An analysis of the breakdown of paper products (toilet paper, tissues and tampons) in natural environments, Tasmania, Australia

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Received 8 August 2003; revised 21 June 2004; accepted 25 August 2004

Abstract

An examination of the relative breakdown rates of unused toilet paper, facial tissues and tampons was undertaken in nine different environments typical of Tasmanian natural areas. Bags of the paper products (toilet paper, facial tissues, tampons) were buried for periods of 6, 12 and 24 months at depths of 5 and 15 cm. A nutrient solution simulating human body wastes was added to half of the samples, to test the hypothesis that the addition of nutrients would enhance the breakdown of paper products buried in the soil. Mean annual rainfall was the most important measured variable determining mean breakdown in the nutrient addition treatment between sites, with high rainfall sites (mean annual rainfall of greater than 650 mm) recording less decayed products than the drier sites (mean annual rainfall of 500–650 mm). Temperature and soil organic content were important influences on the breakdown of the unfertilised products. Toilet paper and tissues decayed more readily than tampons. Nutrient addition enhanced decay for all products across all sites. Depth of burial was not important in determining the degree to which products decayed. In alpine environments, burial under rocks at the surface did not increase the speed of decay of any product. The Western Alpine site, typical of alpine sites in the Tasmanian Wilderness World Heritage Area, showed very little decay over the two-year period, even for nutrient enhanced products. Management prescriptions should be amended to dissuade people from depositing human toilet waste in the extreme (montane to alpine) environments in western Tasmania. Tampons should continue to be carried out as currently prescribed.

Keywords: Human toilet waste disposal; Toilet paper; Tampons; Tissues; Back-country; Urine; Breakdown rates

1. Introduction

Research into the impact of human faecal waste (faeces, urine and toilet paper) disposal on non-serviced wilderness areas appeared in the 1970s (Leonard and Plumley, 1979; Reeves, 1979) and in the 1980s (Temple et al., 1982). While recent studies have noted issues caused by inappropriate human faecal waste disposal in back-country areas (Cole et al., 1997; Leung and Marion, 2000a,b; Rochefort and Swinney, 2000; Cole, 2001), they have concentrated on other recreation impacts such as physical disturbances caused by camping and trampling, both in the US (Marion and Cole, 1996; Leung and Marion, 2000a,b) and Australia (Sun and Walsh, 1998). This gap in the knowledge of recreation impacts is recognised (Cilimburg et al., 2000) and is especially important in a context of increased visitor use of the back-country (Sun and Walsh, 1998; Lachapelle, 2000; Poll, 2002).

A Minimal Impact Bushwalking (MIB) Strategy was adopted by the Tasmanian Parks and Wildlife Service in an attempt to encourage bushwalkers to dispose of their waste in an environmentally safe manner (O'Loughlin, 1988). These guidelines advise campers to choose a toilet site that is at least 100 m away from any water source, where they should bury human waste (faeces and toilet paper) in a cat-hole approximately 15 cm deep. They are also advised to carry out used tampons. These guidelines were based on the Leave No Trace campaign in the USA. However, there are very few scientific data supporting the Australian guidelines. Recent surveys of campsites revealed the degree of non-compliance with MIB guidelines, with many cases of unburied toilet paper and/or faeces being recorded (von Platen, 2002; authors unpublished data).

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0301-4797/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvman.2004.08.004

The persistence of toilet paper around campsites is primarily an aesthetic issue, the importance of which escalates if Tasmania's reputation as the 'clean, green State' is to be upheld, especially in the Tasmanian Wilderness World Heritage Area. There has been no published study that directly addresses the relative breakdown rates of toilet paper, tissues and tampons buried in the ground in natural environments. Limited information from North American research states that toilet paper is slow to breakdown (Hart, 1984), and may be dug up by animals (Land, 1995). The practice of burning toilet paper is neither desirable in environments dominated by soils high in organic matter (Reeves, 1979), nor is it a management option for the fire-free 'fuel-stove only' regions of western Tasmania. It has been suggested that recreationalists should carry out used toilet paper (Meyer, 1994; Drake, 1995). While this suggestion has been publicised on some Tasmanian walk maps (TASMAP, 2001), it is not a general recommendation of the current Tasmanian MIB guidelines.

The research reported in this paper was undertaken to determine: whether the environments frequented by bushwalkers in Tasmania differed in their ability to break down toilet paper, tissues and tampons; the periods required for breakdown; the impact of nutrient additions on the breakdown of paper products; and, the influence of depth of burial, climatic and edaphic attributes on breakdown rates. The management implications of the results are discussed.

2. Methodology

2.1. Field methods

Nine sites were chosen that were representative of common plant communities found in a number of Tasmanian national parks (Fig. 1). These sites varied in altitudinal range, substrate, and climate conditions. Three sites were located in lowland vegetation on sand or dolerite in the south-eastern (warmer, drier) part of the State (coastal eucalypt forest, grassy eucalypt forest, heathy eucalypt forest), three sites were located on dolerite soils in alpine/subalpine vegetation (subalpine rainforest, montane eucalypt forest, eastern alpine heath), and three sites were located in the relatively low-nutrient quartzite country in western Tasmania (lowland rainforest, montane moorland, western alpine). More detailed site descriptions are presented in Bridle and Kirkpatrick (2003).

At each site two parallel transects, each approximately 20 m in length, were laid out along the contour. Within each transect 20 quadrats (50×50 cm) were located in areas that would be attractive as a toilet spot for bushwalkers, that is, the area was free from prickly shrubs, and the soil depth was a minimum of 15 cm. Quadrats were marked by steel roof spikes in each corner and the distance along the transect, and distance and direction of offset from the transect line was recorded. Quadrats were located at least 50 cm from each other in all directions to avoid overlap.

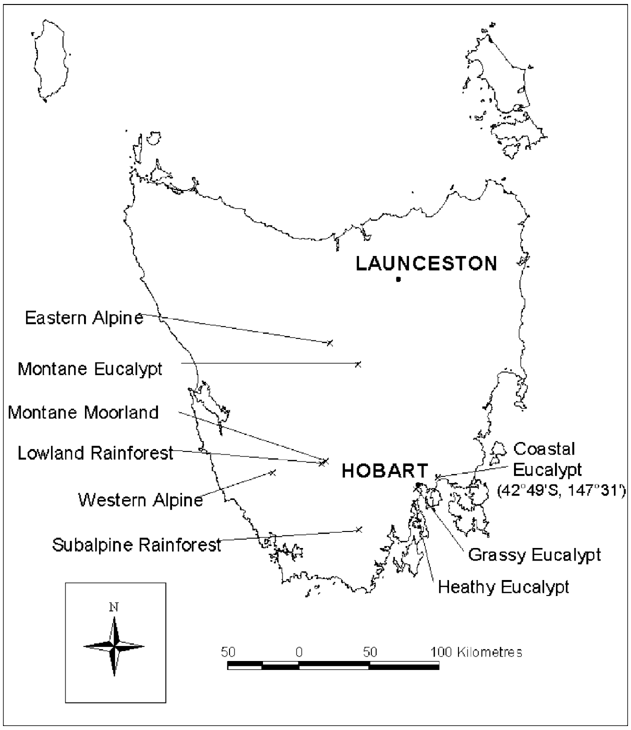

Fig. 1. Location of study sites.

Given that human waste is a major source of nutrient additions in natural environments, we decided to test the hypothesis that nutrient additions would enhance the decay of toilet paper and tampons in natural environments. We created an artificial solution to approximate the nutrients that would be added by defaecation and urination into the natural environment. Urine and faeces are made up of nitrogen, phosphorus, carbon, calcium and potassium, with roughly similar proportions of each (Gotaas, 1956). A formula was used to ensure that the solution was of consistent strength/dilution between quadrats and sites.

Two treatments were chosen to represent the process of digging holes (15 cm deep and approximately 10 cm in diameter) to bury human waste, one with a nutrient addition and one without.

Plastic mesh bags filled with known weights of bleached and unbleached toilet paper, facial tissues and tampons were sealed and then buried. It was difficult to maintain an even weight across all products in all bags. Each product weighed approximately 2 g, with tampons being the heaviest (2.7 g) and unbleached toilet paper being the lightest (1.7 g). Tissues had a mean weight of 2.5 g and bleached toilet paper weighed 2.1 g on average. All products had a carbon content of greater than 96%.

Bags were randomly allocated to treatments, with the same treatment being applied to bags in the same hole. Treatment 1 'dug' consisted of two bags that were buried at 15 and 5 cm in the same hole. Bags were wetted with 60 ml of distilled water before being covered by soil excavated

Table 1
Number of bags retrieved and excavated at each site

Site	Date first buried	6 m aw	6 m ss	12 m	24 m	All	Lost	Excavated	
								5 cm	15 cm
Coastal eucalypt forest	May 00	20	20	20	20	80	0	0	0
Eastern alpine	Feb 00	30 (inc. rock)	20	30 (inc. rock)	20	100	0	8	0
Subalpine rainforest	Feb 00	20	19	20	19	78	2	5	0
Heathy eucalypt forest	May 00	20	20	20	20	80	0	12	3
Lowland rainforest	Apr 00	20	20	17	18	75	5	2	1
Montane eucalypt forest	Feb 00	19	20	20	19	78	2	2	0
Western alpine	Mar 00	30 (inc. rock)	20	30 (inc. rock)	19	99	1	1	0
Montane moorland	Feb 00	20	20	20	20	80	0	0	0
Grassy eucalypt forest	May 00	20	20	20	20	80	0	0	0
Total		199	179	197	175	750	10	30	4

a/w, autumn–winter; s/s, spring–summer; m, month.

from the hole. Treatment 2 ‘urine’ also consisted of two bags buried at 15 and at 5 cm. However, 250 ml of the nutrient-rich solution was poured over each bag before they were covered by soil. The sites were revisited and the solution was applied to the appropriate bags every 6 months. A total of 40 bags (20 per treatment) were buried from February to May 2000 (Table 1). Bags were removed after 6, 12 and 24 months.

The first twenty bags (10 per treatment) were removed from August to November 2000. The holes were refilled with new bags, which were then dug up after 12 months. The nutrient solution was added to the soil surface covering the urine bags that were not disturbed for 24 months. The removal of bags after 12 months allowed a second set of 6 month (spring/summer) bags to be buried. An additional 10 bags were buried under rocks on the soil surface at the two alpine sites. These bags were collected after 6 and 12 months. These bags were also wetted with distilled water. No nutrient solution was added. A total of 750 bags were buried (Table 1).

On removal, the bags were dried (at 55 °C for a minimum of 5 days) and then weighed. A sample of 10, of each of the unburied products was weighed, dried, then weighed again to determine the moisture content of unused samples. After drying and weighing used bags, some bags were found to be heavier after burial than before, due to the presence of plant roots and the soil attached to them. Therefore, it was necessary to adopt a scalar estimate of decay: 1 = no decay, 2 = up to 1/4 decayed, 3 = 1/2 decayed, 4 = 3/4 decayed, 5 = all decayed.

A bulked soil sample (five samples) of the top 5 cm of soil was taken from each site. The following attributes of surface soil samples were determined in the laboratory, following the methods described in Rayment and Higginson (1992): pH; conductivity; extractable P; total P; total N; available N; extractable K; total Ca; Cu; Zn; Mn; Fe; organic carbon.

Total soil depth was determined at 10 points along a transect by inserting a 3 mm diameter steel probe to maximum depth. Soil samples were taken from each of the 10 points (15 cm deep) for soil particle size analysis (Rayment and Higginson, 1992) and to determine root density. After air-drying, each of the 5 cm square blocks of soil was divided into 3 sections (0–5, 5–10, 10–15 cm). Each section was ground and sieved through a 2 mm sieve, separating roots from soil. Both roots and soil were weighed and root density was calculated as a percentage of total soil weight for each 5 cm segment. The following properties were measured for each horizon from each site: conductivity, pH and carbon content determined by loss on ignition (Rayment and Higginson, 1992).

Temperature and rainfall data were collected from the nearest meteorological station to each site with adjustments being made for changes in temperature over altitude (0.65 °C per 100 m increase in altitude) and rainfall in the southwest, after Nunez et al. (1996).

2.2. Statistical analysis

The decay scores for the four products were averaged to give a mean decay score for each bag. Generalised linear modelling was used to determine the single and interactive effects of site, time, treatment and depth of burial using the 6 m a/w (autumn–winter), 12 and 24 m buried bag data, and the single and interactive effects of site, time and treatment for the two sets of 6 m buried bag data. The distribution of the residuals was examined to ensure normality. One way analysis of variance was used to determine the significance of variation in mean decay rates between site, time, depth and treatment classes.

The Wilcoxon Signed Rank test was used to compare the relative decay of pairs of products, using the full data set. The Kruskal-Wallis H test was used to determine the significance of differences between the means of decay classes for individual products by site. Pairwise multiple comparisons employed Dunn’s test.

Continuous environmental variables were used as independent variables in multiple regressions for decay for product-time-treatment combinations for the sites as a whole. Only regressions that approximated normality in the residuals were used. The procedure was to examine scatter graphs of all relationships with a dependent variable, searching for the strongest meaningful relationship. If that relationship was not linear, transformations, and quadratic and polynomial fits were attempted, searching for the most explanatory significant model. Using residuals, this process was iterated until no more variables with significant slopes could be fitted into the equation. Where more than one variable was included in the model, the multiple regression procedure in Minitab (Minitab Inc, 2000) was used for the final model.

3. Results

3.1. Mean decay for all products combined

There was a significant site × time × treatment interaction in the generalised linear model for mean decay rates which included 6 m (a/w), 12 and 24 months (Table 2). At 6 months over autumn and winter mean decay of products was well-advanced at the coastal eucalypt forest and the grassy eucalypt forest, but negligible in the lowland rainforest, the heathy eucalypt forest, the montane moorland and the western alpine sites (Fig. 2). By 24 m decay was almost complete (at least 75% decayed) at all sites except the montane moorland and the western alpine site (Fig. 2). At all sites, except lowland rainforest, there was a significant positive impact of nutrient addition on decay (Fig. 2). The impact of nutrient addition on decay was most marked at six months over autumn–winter (Fig. 2).

Of the 750 bags that were buried, 34 were dug up either by native or exotic animals (montane eucalypt, subalpine rainforest, lowland rainforest, heathy eucalypt forest), or were frost-heaved out of the ground (eastern alpine). These bags were located and reburied or collected as necessary. A total of 10 bags were irretrievably lost. Thirty of the 34 bags that were excavated were initially buried to a depth of 5 cm (Table 1).

Depth of burial was only significant in interaction with site (Table 3), this relating to variability between sites in the ratio of decay at the two depths. At the eastern alpine site, the heathy eucalypt forest and the subalpine rainforest, decay was faster at 15 cm, whereas, at the other sites it was faster at 5 cm (Table 3). However, excavated bags were frequently found at these sites (Table 1). At the eastern alpine site at 12 months, buried nutrient-enriched bags broke down faster (3.85) than bags on the surface, placed under rocks (2.86), which in turn broke down faster than buried bags without nutrient enrichment (1.35) (ANOVA $F=30.36$, $P=0.000$). At the western alpine site there was no breakdown at all at 6 months at any depth, but by 12 months there was some decay (1.25) at 5 cm, negligible decay under rocks (1.02) and no decay at 15 cm (ANOVA, $F=4.07$, $P=0.036$).

There was a significant site × time × treatment interaction in the generalised linear model for the two 6-month samples (d.f. = 6, $F=2.36$, $P=0.031$, Fig. 2). All sites included in the analysis showed significant variation between treatment/time combinations, except the lowland rainforest and western alpine (Fig. 2). In all cases where there was significant variation, the nutrient addition treatment in the autumn–winter period produced the most decay, although in the case of the grassy eucalypt forest this decay was statistically identical with both the spring–summer treatments (Fig. 2).

The data for all sites combined show a significant difference in the relative decay of different products over time. Tissues decayed more readily than tampons (Wilcoxon Signed Rank test, $P \leq 0.001$), but decayed more slowly than bleached ($P \leq 0.001$) or unbleached ($P \leq 0.001$) toilet paper. Bleached and unbleached toilet paper decayed more readily than tampons ($P \leq 0.001$, $P \leq 0.001$), and unbleached toilet paper decayed more readily than bleached toilet paper ($P \leq 0.001$) (Fig. 3).

The application of nutrients was found to significantly increase tampon (the most resistant product) decay at all sites except for lowland rainforest and western alpine.

Table 2
Generalised linear model for mean decay (for all products combined)

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Site	8	397.919	385.564	48.195	117.32	0.000
Time	2	264.878	271.581	135.790	330.55	0.000
Depth	1	0.604	1.042	1.042	2.54	0.112
Treat	1	131.751	131.724	131.724	320.65	0.000
Time × Depth	2	2.272	2.124	1.062	2.59	0.077
Time × Treat	2	1.006	0.953	0.476	1.16	0.315
Depth × Treat	1	0.047	0.043	0.043	0.1	0.747
Site × Time	16	59.723	59.155	3.697	9	0.000
Site × Depth	8	8.796	10.061	1.258	3.06	0.002
Site × Treat	8	51.305	51.874	6.484	15.78	0.000
Time × Depth × Treat	2	0.287	0.183	0.091	0.22	0.801
Site × Time × Depth	16	7.772	8.659	0.541	1.32	0.182
Site × Depth × Treat	8	2.179	2.608	0.326	0.79	0.608
Site × Time × Treat	16	52.632	53.315	3.332	8.11	0.000
Site × Time × Depth × Treat	16	7.591	7.591	0.474	1.15	0.302
Error	423	173.769	173.769	0.411		
Total	530	1162.532				

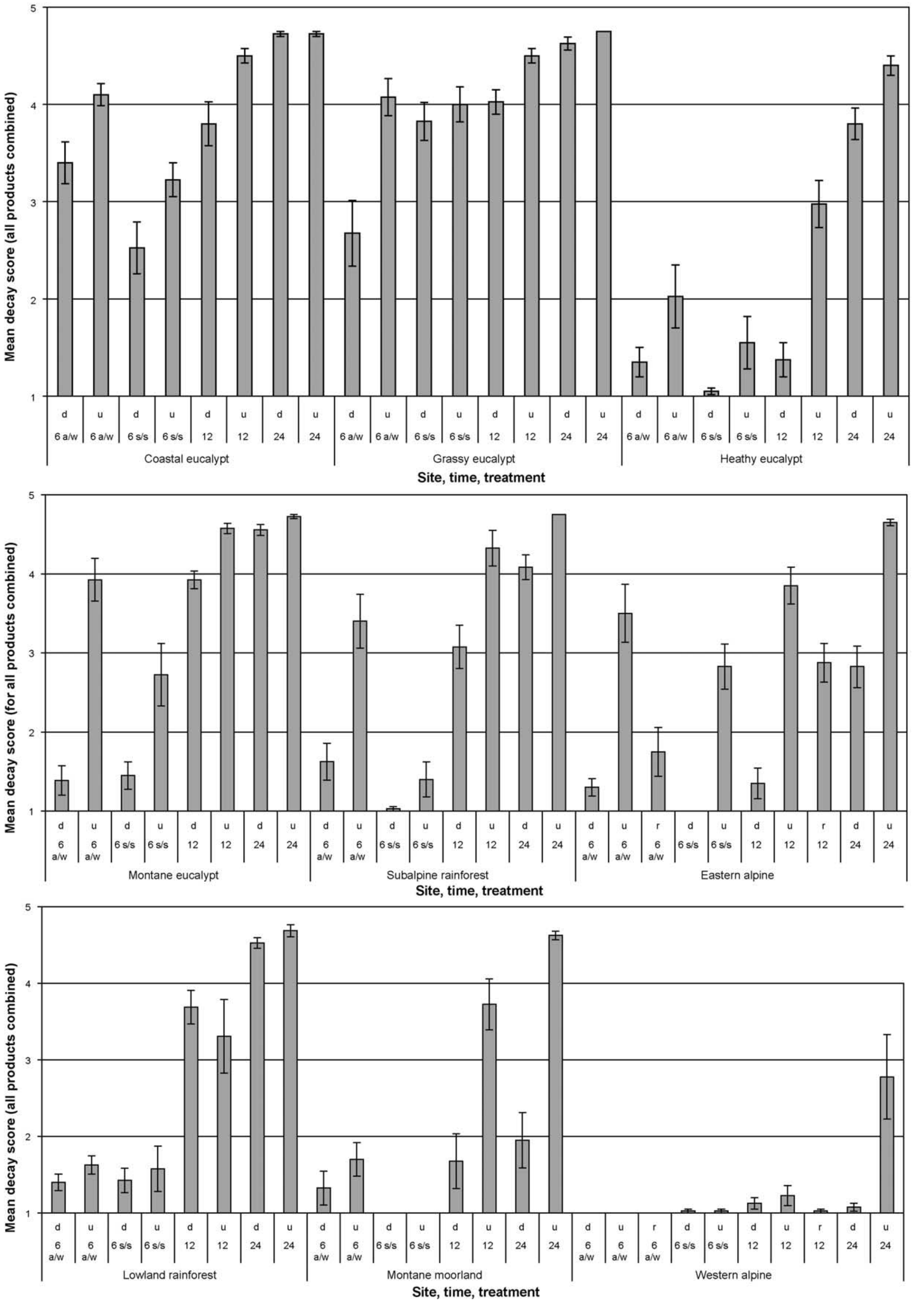

Fig. 2. Mean decay score and standard error bars for all products combined for each of the nine sites over 24 months: 6 a/w, 6 months autumn/winter; 6 s/s, 6 months spring/summer; 12, 12 months; 24, 24 months; d, dug; u, nutrient addition; r, rock.

Table 3
Mean decay scores (for all products combined) by site and depth, showing *F* and *P* from ANOVA for the differences between depths

Site	Depth (cm)		Ratio (15/5)	*F*	*P*
	5	15			
Subalpine rainforest	3.32	3.74	1.13	2	0.197
Eastern alpine	2.83	2.99	1.06	0	0.672
Heathy eucalypt forest	2.58	2.73	1.05	0	0.684
Montane eucalypt forest	3.91	3.85	0.98	0	0.850
Grassy eucalypt forest	4.17	4.05	0.97	0	0.608
Coastal eucalypt forest	4.29	4.13	0.96	1	0.326
Lowland rainforest	3.26	3.02	0.92	0	0.546
Montane moorland	2.64	2.36	0.89	1	0.469
Western alpine	1.55	1.14	0.74	3	0.078

3.2. Models of decay

Mean annual rainfall was the most important factor determining mean bag decay (of all products combined) for all sites, treatments and times, with decay declining as precipitation increased (Table 4). Rainfall, iron, nitrogen, phosphorus (P), zinc, pH and root weight were important components of the models predicting decay in products that had been subjected to nutrient addition, while temperature, potassium, magnesium, manganese and organic content were important components of the models predicting decay in the unfertilised treatment (Table 4). Values for soil properties are presented in the Appendix A.

While individual products decayed at different rates, the variables that were important in the decay process were relatively consistent between the four products. Tissues and toilet paper were most similar in environmental requirements.

The degree of the positive impact of nutrient addition on mean decay, as indicated by the *F* value for the difference between the two treatments is strongly related to total P ($F=19.7878-0.100709\times\text{Total P}+0.0002392\times\text{Tot P}^2$, $P=0.002$, $R^2=87.3\%$), with high total P values giving the strongest differentiation between treatments, suggesting that N/P ratios may be important in breakdown of the products. The residuals from the above equation are explained best by % sand ($r=-0.842$, d.f.$=8$, $P=0.004$).

4. Discussion and conclusions

Unbleached toilet paper does break down faster than bleached toilet paper and tissues. However, tampons stand out as being most resistant to decay, with the other products not strongly differentiated in their rates.

The sites that recorded the greatest decay rates were those that were warm, relatively dry and not acidic (Table 5). Breakdown of most products was well advanced within 6 months of burial at these sites. Microbial activity, measured by cellulase assay, was also greater at these sites (Bridle et al. unpublished data). Line (1998) found that the cellulose flocking used in disposable nappies decayed after 5 months in warm environments with neutral, fertile soils.

The independent variables that were incorporated in the models of decay (Table 4) are largely consistent with those that are associated with peat formation, which occurs in cold and/or waterlogged and/or acid places (Moore and Bellamy, 1974). Indeed the two sites that exhibited little decay after 24 months (montane moorland and western alpine) had organic soil profiles, while the others had mineral soils with a surface organic horizon of varying depths. The importance of cations (both measured directly, and indicated by pH), relatively dry soils and high temperatures in promoting disintegration has been noted for cotton strip assays in a wide variety of environments

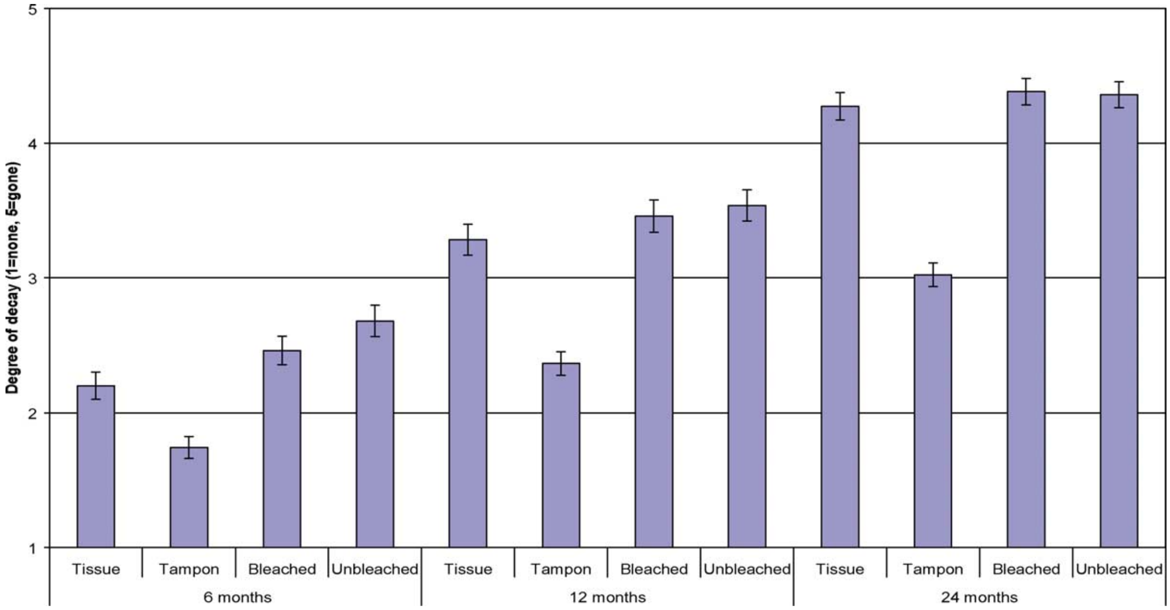

Fig. 3. Mean decay and standard error bars for all products over the 6 months (autumn/winter), 12 and 24 months.

Table 4
Elements, directionality, explanation and significance of regression models for mean decay of all products combined, buried materials and the average for buried materials

Response	Prec	Temp	Fe	Tot N	Exc N	Tot P	K	Ca	Mg	Mn	Zn	pH	MSD	Alt (m)	Cond	LOI	Roots	R^2 (%)	Prob.
Mean (all products)	***−																	80.8	0.001
6 m dug		***+				*−				*+								87.2	0.000
12 m dug									***+							**+	*+	97.3	0.000
24 m dug		**+							***+							***+		99.0	0.000
6 m urine			***+											**−	***−			99.3	0.000
12 m urine	***−		***+	***+													***+	99.9	0.000
24 m urine	***−		*+			*+											***+	99.2	0.000
Tissues																			
6 m dug							**−											66.1	0.008
12 m dug										***+			**+		*+			95.4	0.001
24 m dug		***+							**+							***+	*+	99.4	0.000
6 m urine												**+^{2}						69.0	0.006
12 m urine	***−				*+						*−						**+	97.6	0.002
24 m urine	***−		*+			**+											***+	99.5	0.000
Tampons																			
6 m dug							*−											49.5	0.035
12 m dug								***+								**+		94.6	0.000
24 m dug																*−		59.6	0.015
6 m urine												***+						87.6	0.000
12 m urine								*+										52.6	0.027
24 m urine	***−												*+				***+	94.1	0.002
Bleached																			
6 m dug							*−											63.5	0.010
12 m dug										*+								60.3	0.014
24 m dug															*−	*+		82.8	0.005
6 m urine	**−		***+									***+						98.6	0.000
12 m urine	***−		***+								**−							98.2	0.000
24 m urine	***−					*+											***+^{1}	98.1	0.000
Unbleached																			
6 m dig							*−											57.2	0.018
12 m dig								*+								**+$^{1/2}$		86.0	0.003
24 m dig															**−^{3}	*+$^{1/2}$		85.4	0.003
6 m urine												**+^{2}						70.3	0.005
12 m urine	***−				**+						**−						***+$^{1/3}$	99.1	0.000
24 m urine	***−					*+											***+^{1}	96.0	0.001

Prec, mean annual precipitation; Temp, mean daily maximum summer temperature; Tot N, total N; Exc N, exchangeable N; Ca, total Ca; Mg, natural logarithm of Mg; MSD, mean soil depth. Significance of slope: *$P<0.05$, **$P<0.01$, ***$P<0.001$. +, positively related to decay; −, negatively related to decay; m, month.

Table 5
Predictive index for mean paper product breakdown

Site	Mean decay	Precip	pH	Temp	Index
Western alpine	1.37	1	1	1	3
Montane moorland	2.52	1	1	1	3
Heathy eucalypt forest	2.65	1	1	2	4
Eastern alpine	2.93	1	2	1	4
Lowland rainforest	3.20	1	1	2	4
Subalpine rainforest	3.55	1	1	2	4
Montane eucalypt forest	3.85	1	2	1	4
Grassy eucalypt forest	4.12	2	2	2	6
Coastal eucalypt forest	4.20	2	2	2	6

Temp, mean maximum daily summer temperature ($1 \leq 13$ °C, $2 = > 13$ °C). Precip = mean annual rainfall ($1 = > 650$ mm, $2 \leq 650$ mm). pH = ($1 \leq 4.5$, $2 = > 4.5$).

(Harrison et al., 1988). Higher decay rates during the late summer–autumn period than during the spring–early summer period has also been reported elsewhere (French, 1988). However, our data show that three sites (coastal eucalypt, subalpine rainforest, montane moorland) recorded greater decay in the cooler months than in the warmer months for the fertilised bags. There was no significant difference for decay within the same treatments but between times for any of the other sites. The difference in decay between the seasons is likely to be related to precipitation patterns during the sampling times. The autumn–winter bags were buried in 2000, while the spring–summer bags were buried in 2001–2002. There was a severe drought during 2000, and heavy summer rainfall during the spring–summer of 2001–2002. Rainfall is an important indicator of decay for fertilised bags (Table 4). The greater decay in the drier period is consistent with our model (Table 5).

Depth of burial is an important factor in decay at sites where soils freeze (Lawson, 1988). Under such conditions, there is a difference in decay with depth down the soil profile during the early summer, though this difference is not evident later in the season. Our data show depth of burial to be largely unimportant across all sites in Tasmania, but in wetter areas where water tables are within 15 cm of the surface, paper products are likely to decay more readily at 5 cm depth than at 15 cm depth. While decay may be slightly enhanced at shallower burial depths, access of faeces to native animals and transport of faecal bacteria may occur more readily at 5 cm depth than at 15 cm depth. The burial of waste under rocks at the soil surface does not increase decay, and is inadvisable from a public health point of view (Bridle et al., 2003).

It has been shown that the addition of nutrients via sewage sludge enhanced decomposition of cotton-strips compared to an untreated control soil (Obbard and Jones, 1993). The addition of both N and P to cotton strip assays in an Everglades marsh led to greater decomposition than was recorded for the addition of only one of the elements, especially where the strips were buried in the peat layer rather than in the water column (Maltby, 1988). There was no relationship between C/N ratios and breakdown success. This finding has also been documented for the decay of coarse woody debris in forest environments (Mackensen et al., 2003).

Research into the decay of coarse woody debris in forest environments showed temperature to be an important determinant of decay (Mackensen et al., 2003), but initial density of the wood was also important. These results can be related back to tampon decay, as tampons are much denser than toilet paper or tissues.

Mackensen et al. (2003) found a relationship between annual rainfall and decay rates, where decay was less at sites that received more than 1300 mm of rainfall. Ineson et al. (1988) suggested that that potential evaporation could be a good predictor of cellulose decay. We have developed a simple index of decay that is also based on temperature, rainfall and pH. The index is derived from two classes of mean annual precipitation (> 650 mm $= 1$, < 650 mm $= 2$), mean annual temperature (< 13 °C $= 1$, > 13 °C $= 2$) and pH ($< 4.5 = 1$, $> 4.5 = 2$). This index reconstructs the order of mean decay using all 6 month autumn–winter, 12 month and 24 month data (Table 5). A score of three on this index indicates that 2 years is insufficient for decay of all paper products buried in the soil, even when fertilised with faeces or urine. A score of six indicates a rapid dissolution of products, whether fertilised or not. This index may be exportable to other parts of the world.

4.1. Implications for management

A key question in deciding the implications for management of our decay data is the social and environmental acceptability of different periods of persistence of human waste disposal products in the soil. Social acceptability relates to the probability of excavating the evidence of a past faecal burial event, when undertaking preparations for a new event. This probability can be high in some well-used places (von Platen, 2002; authors unpublished data). Environmental acceptability relates to variation from the natural condition of the soil, which would obviously be considerable where deposits remain intact over several years. In the western alpine and high altitude moorland environments decay is extremely slow. In our judgement it is both socially and environmentally undesirable to continue to advise people to bury their wastes in these environments. This would not be a major imposition on walkers, as locations in these environments are usually in close proximity to forest or scrub vegetation, which provide more privacy than buttongrass moorland and alpine vegetation.

If anything is to be carried out, tampons are an appropriate target. Current MIB prescriptions request that tampons are carried out and not buried in the ground. As this is a simple and broad-ranging message with little public health risk to the walker, we suggest that the message is retained, despite the relatively successful decay of tampons, albeit after 2 years at some of the sites.

Walkers may place their wastes under rocks in alpine areas because they are reluctant to damage alpine vegetation by digging. We hope that the results of this research and those from our vegetation study (Bridle and Kirkpatrick, 2003) will convince them that it is less environmentally harmful to bury their waste than to leave it exposed.

Soil depth proved sufficient in parts of all our sites to enable burial of waste at 15 cm, as is suggested by the code. However, obstructions such as roots, rocks or very hard clay soil made it difficult to dig a hole 15 cm deep at some sites. Digging to that depth was impossible to severely challenging at most sites using plastic trowels of the kind sold in many outdoor stores. There is a need for prescriptions in the MIB guidelines on the strength and quality of trowels. Burial at 5 cm does present some relatively low chance of excavation by animals, compared to 15 cm, so the 15 cm recommendation in the code should stand.

Recent research which aimed to determine the impact of the addition of real faeces and urine on toilet paper decay, showed similar responses over a one year period to the results we have detailed above. Results from two extreme sites (coastal eucalypt and montane moorland) were consistent with the data presented in this paper (von Platen, 2002). While the presence of faeces may have allowed additional bacteria to survive in the environment, toilet paper decay was not significantly enhanced in a 6-month-period.

The above results suggest that the minimum impact bushwalking code should be amended to: (1) to recommend no disposal of faeces, toilet paper or tissues in treeless vegetation above 800 m in western Tasmania; (2) to emphasise that placement of waste under rocks causes more environmental harm than disposal by burial, even in alpine environments; (3) to emphasise that strong metal trowels are necessary to excavate holes for defecation in most wild places. The significantly longer decomposition times for tampons compared to toilet paper supports the current policy of carrying out tampons.

Guidelines should also advise walkers to choose their toilet site carefully. Choose a well-drained soil in woody vegetation rather than a poorly drained soil or peat in alpine or moorland vegetation.

The index we derived for predicting the speed of decay of human waste disposal products requires testing outside Tasmania, to determine its potential universality.

Acknowledgements

We would like to thank the CRC for Sustainable Tourism for funding this project. Thanks to the many field assistants and technical officers with special mention to Denis Charlesworth, Margaret Gill, Paul Smart, Mona Loofs, Micah Visoiu and Bonnie Wintle. Grant Dixon and other members of the Tasmanian Parks and Wildlife Service, the Forestry Commission, the University of Tasmania and Jennie Whinam of the Nature Conservation Branch, are thanked for their inputs and co-operation. Martin Line

Appendix A

Results of soil depth, texture and chemical analyses of some elements from bulked soil samples at each site

Site	OC (%)	Tot N (%)	pH (H_20)	PH ($CaCl_2$)	P (ppm)	K (ppm)	Zn (ppm)	Cu (ppm)	Fe (ppm)	Ca (ppm)	Mg (ppm)	Mn (ppm)	Tot P (ppm)	Tot Ca (ppm)	Exc N (ppm)	Cond	Mean soil depth (cm)
Western alpine	13.0	0.46	4	3.2	11	240	9.6	1.6	130	770	80	7	140	610	40	210	30.2
Eastern alpine	8.7	0.37	5.4	4.4	18	210	2.3	1.7	76	450	100	64	760	410	25	45	25.9
Montane moorland	42.0	1.06	3.5	2.8	10	390	4	0.7	460	640	90	7	160	760	120	300	36.7
Subalpine rainforest	19.0	0.40	4.2	3.8	10	250	4.9	2.6	830	1050	250	140	270	890	50	190	29.7
Montane eucalypt forest	7.7	0.31	5.1	4.4	24	290	11	2.5	510	1800	300	130	440	1520	70	135	17.9
Lowland rainforest	13.0	0.44	3.9	3	33	250	3.4	0.5	180	310	140	77	260	330	60	135	46.4
Heathy eucalypt forest	17.0	0.52	3.7	2.7	15	200	20	0.2	84	450	480	14	130	540	30	75	33.6
Grassy eucalypt forest	3.0	0.16	5.8	5	8	70	13	4	300	1210	480	190	120	1630	20	60	13.6
Coastal eucalypt forest	2.2	0.16	5.9	5.1	9	80	6.6	0.3	52	1350	180	62	55	1200	40	75	65.2

OC, organic carbon; Cond, conductivity.

(University of Tasmania) is thanked for his insight into factors affecting the decay of cellulose products.

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