LITTER DECOMPOSITION ON DIRECTLY REVEGETATED TAILINGS AT THE KIDSTON GOLD MINE, NORTH QUEENSLAND, AUSTRALIA[1]

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Abstract. An investigation of litter decomposition was undertaken at the Kidston Gold Mine in north Queensland, Australia with the aim of assessing the status of nutrient cycling capacity on a directly-revegetated tailings dam. Weight losses from leaf litter contained in litterbags placed in a 5-year old revegetated section of the dam were not significantly different from losses observed at two unmined reference sites over the 18 month study period, representing a rapid improvement in nutrient cycling capacity in the reconstructed ecosystem. However, fitted decay curves for each site predicted a slower decay constant and a longer litter half-life on the dam, which indicated that full pre-mining capability had not yet been achieved. Weight loss in the reconstructed system was most constrained by the low build-up of microbial biomass within the surface soil, which is expected to take at least 10 years to achieve pre-mining levels. In contrast, weight losses in the unmined sites appeared more related to the abundance of invertebrate fauna rather than microbial content. The results presented here of a developing system suggest that the importance of different factors affecting decomposition will reflect those that are most limiting over the course of ecosystem recovery.

Additional Key Words: nutrient cycling, ecosystem recovery, microbial biomass, invertebrates.

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Introduction

Kidston Gold Mine in north Queensland, Australia, produced gold using a carbon-in-pulp extraction process from two open pits over the period 1985 to 2001. The fine waste material was disposed to a 300ha tailings dam up until decommissioning in 1998. Unlike many similar gold mining operations, the relatively benign nature of the tailings has permitted direct revegetation of the surface (without capping).

As part of mine decommissioning and lease relinquishment, Kidston Gold Mines seeks to demonstrate that the rehabilitated tailings dam will be self-sustaining. The initiation and maintenance of adequate nutrient cycling is recognised as one of the key indicators of self-sustainability (Bradshaw, 1987), in which litter decomposition plays a central role. Nutrient inputs from outside an ecosystem are generally small compared to the amounts being cycled internally (Aber and Melillo, 1991), and the re-instatement of adequate litter decomposition is essential. Decomposition is also important in the formation of soil organic matter which is known to improve soil structure and is intimately linked with soil fertility (Swift et al., 1979; Lavelle et al., 1993). The role of soil organic matter is especially important under the strong weathering conditions of the tropical climate experienced at Kidston.

Mining represents a gross disturbance to the environment and the rates and nature of decomposition may therefore be substantially different from undisturbed ecosystems, and will change over time. Re-instatement of decomposition processes generally follow the development of a vegetative cover and associated soil amelioration (e.g. Durall et al., 1985; Insam and Domsch, 1988; Ward et al., 1991), but the effects of disturbance on various groups involved may be evident for many years (Hutson, 1989; Greenslade and Majer, 1993; Sawada, 1996). Recovery in levels of soil organic matter may exceed 50 years (Insam and Domsch, 1988; Schwenke et al., 2000).

The study reported here investigated rates of litter decomposition within the developing ecosystem on the tailings dam and compared these with nearby unmined reference sites. Weight loss results were related to chemical, physical and biological characteristics of each community in an effort to understand the state of ecosystem development on the dam and the factors most controlling litter decomposition. The study formed part of a larger research program that also examined groups of invertebrate fauna that are intimately linked with decomposition, or are used as indicators of ecosystem function. The overall aim was to gain an integrated understanding of the processes operating on the dam and their status relative to the surrounding unmined ecosystems.

Methods

Study sites

Kidston mine is located 260km south-west of Cairns in northern Queensland, at an elevation of 540m. The climate is sub-tropical with most of the average annual rainfall of around 1100mm falling within a distinct wet season between November and March (Figure 1). The main study site was located in an 11ha trial area in the south-west corner of the tailings dam that was preserved in 1994 from further tailings disposal, and represents the oldest rehabilitation on the dam. The trial area (Figure 2) was established in January-March 1994 with the planting of a range of tubestock native tree and shrub species (predominantly eucalypts and acacias) directly into tailings last deposited in 1988. In December 1994, a number of improved pasture grasses, including *Cynodon dactylon* (L.) Pers. and *Chloris gayana* Kunth, were broadcast sown between the rows of tree plantings. Areas of bare sand were present, notably toward the centre of the site associated with an outfall zone containing a higher proportion of coarse sand particles.

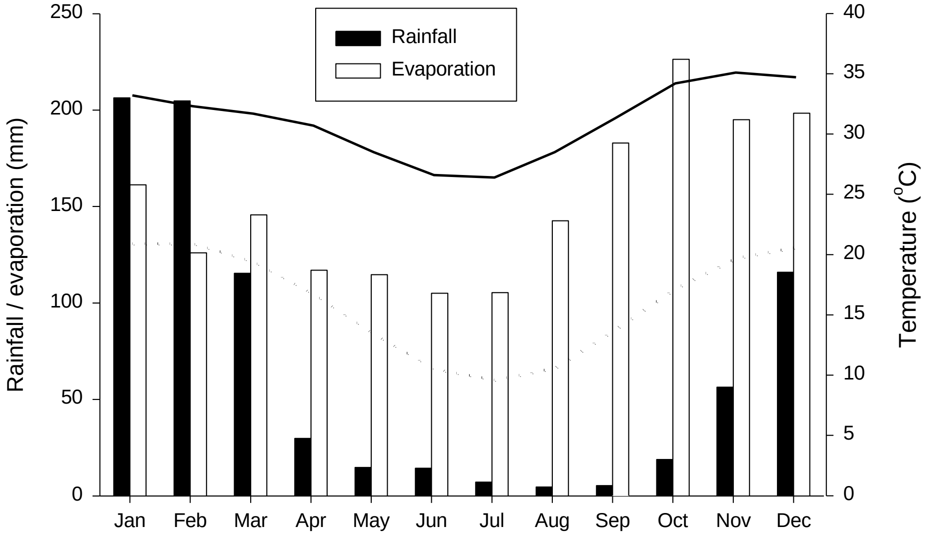

Figure 1. Long-term mean monthly rainfall, evaporation and mean daily minimum (dotted line) and maximum (solid line) temperatures for Mount Surprise, approximately 100km from the minesite. (Source: Bureau of Meteorology, 2002).

Two unmined communities were also chosen as reference sites. Site D was located in an open grassy woodland dominated by *Eucalyptus crebra* F.Muell. (Figure 3). The site, immediately to the south and within 100m of the 11ha trial site, was situated on a gentle slope with a northerly aspect, on a typically shallow red podzolic soil. The canopy layer was dominated by *E. crebra*, with a scattered shrub layer consisting of *Grevillea pteridifolia* Knight, *Petalostigma banksii* Britten & S.Moore and *Melaleuca citrolens* Barlow. Common grass species included *Cymbopogon bombycinus* (R.Br.) Domin and *Aristida* spp. Small termite mounds were scattered throughout this site (Figure 3). Site AS was located near the mine airstrip, on an alluvial loam or loamy sand material within a drainage channel or lower slope position. The site supported a low open grassy woodland dominated by *Eucalyptus microneura* Maiden & Blakely (Figure 4). The ground layer included mainly native grasses including *Panicum decompositum* R.Br., *Sporobolus australasicus* Domin, *Enneapogon lindleyanus* (Domin) C.E.Hubb., *Heteropogon contortus* (L.) Roem. & Schult. and *Aristida* spp.

Litterbag study

Leaf litter of *E. crebra* was collected from beneath individual trees located on the south western perimeter of the tailings dam in December 1998. Freshly fallen air-dry material (15g) was sealed in mesh bags (18cm x 25cm, mesh aperture 2mm). The bags were installed at each of eight station points located approximately 10m apart along transects of 80m length. A total of five such transects were established within the experimental 11ha area of the main tailings dam due to the variable nature of the site, and one in each of the two unmined communities. Five bags were installed at each of the eight station points along each transect in February 1999, totalling 280 bags. Bags were positioned in a row perpendicular to the transect, allowing approximately 15cm between each bag. Bags were secured on top of existing fallen litter after removing freshly fallen material. One bag was retrieved from each station point at intervals of 5, 15, 30, 52 and 80 weeks after installation, with the final bags collected in August 2000. There were some bag losses due to cattle grazing (Site AS), pig activity, and some remedial liming and resowing of parts of the 11ha trial site in mid-2000. Litterbag contents were manually separated from foreign materials, and if required washed to remove attached sediment. Cleaned litter was then oven dried (80^{o}C, 48 hours) and weighed to determine weight loss. The readily soluble component of the unexposed litter was measured by extracting replicate 2g samples in 50% aqueous methanol for 18 hours (O'Connell, 1987).


Figure 2. The 11ha trial area on the tailings dam, August 2000.


Figure 3. Unmined study site, Site D.


Figure 4. Unmined study site, Site AS.

Site characterisation

Measurements of selected environmental parameters, together with sampling of surface soil, were carried out concurrent with installation of litterbags. Surface soil was collected adjacent to the line of litterbags, using a brass coring ring 6cm deep x 7.3cm diameter. Samples were sealed in plastic bags, and returned to the University of Queensland under cooled conditions for microbial biomass determinations by the incubation-fumigation method of Amato and Ladd (1988). Sub-samples were analysed for particle size distributions, and electrical conductivity and pH in 1:5 aqueous solutions. Within the rectangle formed by the line of litterbags, percentage bare ground, detached litter cover and live ground cover were estimated visually. Standing cover (live and dead) up to 25cm above this rectangle, and again in the column 25cm to 1m above (looking vertically down), were recorded.

Results

Weight loss from litter at all sites was in the range 52-63% after 80 weeks. Weight loss at the two unmined sites was consistently greater than on the tailings dam at each collection (Figure 5), but differences with weight loss on the tailings dam were not significant ($P<0.05$) except at the first collection after 5 weeks exposure. At this collection, losses at each of the unmined sites were significantly greater ($P<0.01$) than losses at three of the five tailings dam transects.

There were no significant differences in weight loss between transects on the tailings dam at any of the collections, and data were subsequently combined. Single (Olson, 1963) and double exponential decay models (Bunnell and Tait, 1974) relating weight loss to time of decomposition were fitted to the data from each of the unmined sites and combined data for transects on the dam (Table 1), using the curve fitting package within SigmaPlot (SPSS, 1986-99). The single exponential decay function has the form

$$W_t = W_0 e^{-kt}$$

where W_0 is the initial weight of litter, W_t is the weight of litter at time t and k is the decay constant. The double exponential decay model has the form

$$W_t = W_1 e^{-k_1 t} + (\mathrm{W}_0 - W_1) e^{-k_2 t}$$

where W_1 is the measured amount of readily soluble component present initially and k_1 and k_2 are the decay constants for the labile and resistant litter components, respectively.

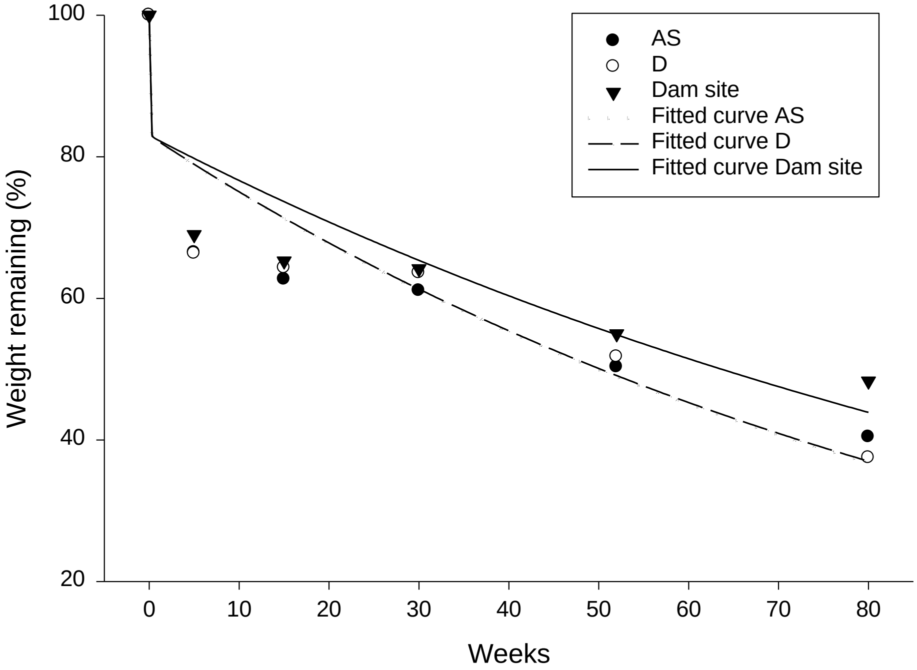

Figure 5. Decomposition of leaf litter on the tailings dam and at two unmined reference sites (AS and D) at the Kidston Gold Mine. Fitted curves are derived from the double exponential decay model (see text).

The double exponential decay model was able to explain more of the variance than the single exponential model at each of the three sites (Table 1). This indicates that weight loss is best described in terms of initial loss from a more labile fraction followed by slower loss from a more resistant fraction. For all three sites at Kidston, loss of the labile fraction was extremely rapid and values for the decay constants in this phase should be viewed with some caution. Half-lives of less than one week are indicated, reflecting the relatively high rainfall conditions at the mine in the first few weeks after placing the bags. Laboratory results indicated a readily soluble fraction of 17% in the leaf litter, which is insufficient to account for much larger losses of 25-30% observed in the first five weeks (Figure 5). Associating the modelled curves with chemical components gives a more explicit definition of the processes involved (Swift et al., 1979), but in this case much of the variance left unexplained in the model probably relates to the discrepancies between laboratory- and field-derived estimates of the labile fraction. During the hot wet period in February and early March, it is likely that not only the soluble carbohydrates are removed through leaching, but also some of the more complex carbohydrates are degraded through microbial catabolism. Rates of decomposition were much slower after the initial period for all three sites (Table 1), but calculated half lives of 68-69 weeks in the unmined sites were less than that on the dam (87 weeks).

Table 1. Double and single exponential decay models fitted to weight loss from litterbags at each of the two unmined sites (AS and D) and at the tailings dam site (combined transect data). k_1 = decay constant for the labile component of the litter, k_2 = decay constant for the resistant component of the litter, t_1(½) = half life of the labile component and t_2(½) = half life of the resistant component. k = decay constant and t(½) = half life for the litter in the single exponential decay model. Half life is determined from the equation t(½) = 0.693/k (Olson 1963). Standard errors in parentheses.

Site	Double exponential model					Single exponential model		
	k_1 (yr^{-1})	k_2 (yr^{-1})	t_1(½) (weeks)	t_2(½) (weeks)	Variance explained (%)	k (yr^{-1})	t(½) (weeks)	Variance explained (%)
AS	849	0.53 (0.09)	<1	68	85.2	0.79 (0.27)	46	31.9
D	653	0.53 (0.09)	<1	69	87.2	0.78 (0.25)	46	40.2
Dam	856	0.42 (0.07)	<1	87	83.8	0.66 (0.23)	55	14.4

Weight loss and site characteristics

Environmental conditions at the dam site differed in a number of respects to the two unmined reference sites (Figure 6). The dam site tended to have less bare ground and more detached litter than the undisturbed sites, and while low standing cover (mostly grasses) was similar, the dam exhibited more shrubby cover compared to the unmined open-woodlands.

Differences were also evident in the characteristics of the surface soils (Figure 6). The dam site contained elevated electrical conductivities related to an abundance of sulfate salts (Roseby, 2000), while the unmined sites were non-saline. Mean pH on the dam appeared neutral (Figure 6) but actual values clustered around two midpoints of pH8 and pH3.6, representing neutral and/or limed areas and acid oxidized areas, respectively. The tailings also contained a greater proportion of sand-sized particles (85% compared with 79% and 75% for Sites D and AS,

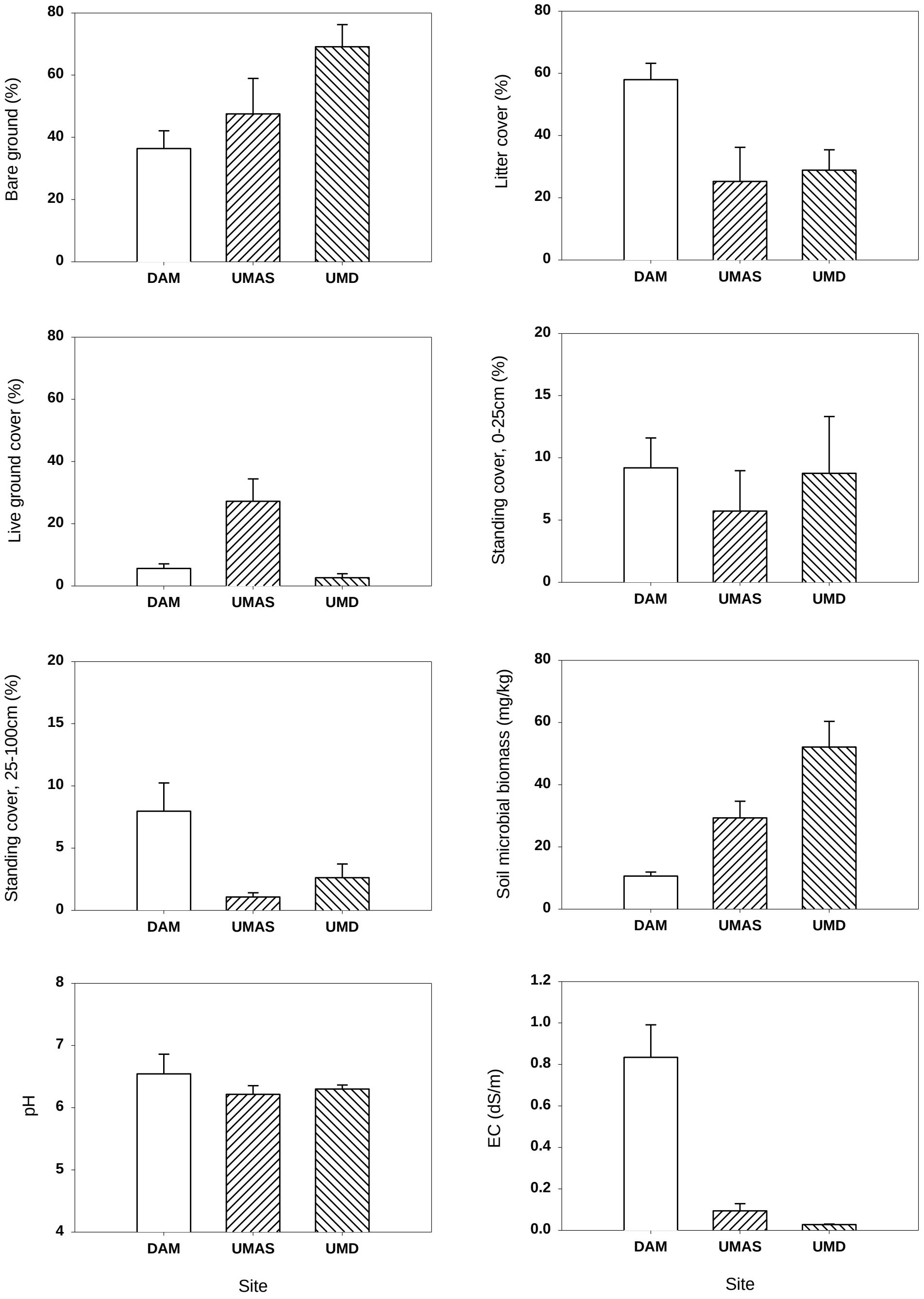

Figure 6. Comparison of vegetation and surface (0-6cm) soil characteristics at the dam site (open column) and at two unmined reference sites (hatched columns).

respectively) and less silt and clay fractions (total 14% compared with 21% and 25%). This reflects the location of the dam site on its perimeter where tailings outfalls were positioned, and where the coarser fraction of the waste was concentrated.

The dam contained significantly lower levels of microbial biomass than the unmined sites (Figure 6). However, there were no significant relationships between microbial biomass and any of the measured soil or vegetation parameters.Distinct differences between the dam site and the two unmined sites were observed when weight loss at the conclusion of the experiment was compared with the levels of soil microbial biomass (Figure 7). On the dam, the amount of weight remaining was negatively related to increasing levels of soil microbial biomass ($r^2 = 0.41$. $P < 0.01$). In the unmined sites, no significant ($P > 0.05$) relationship was evident.

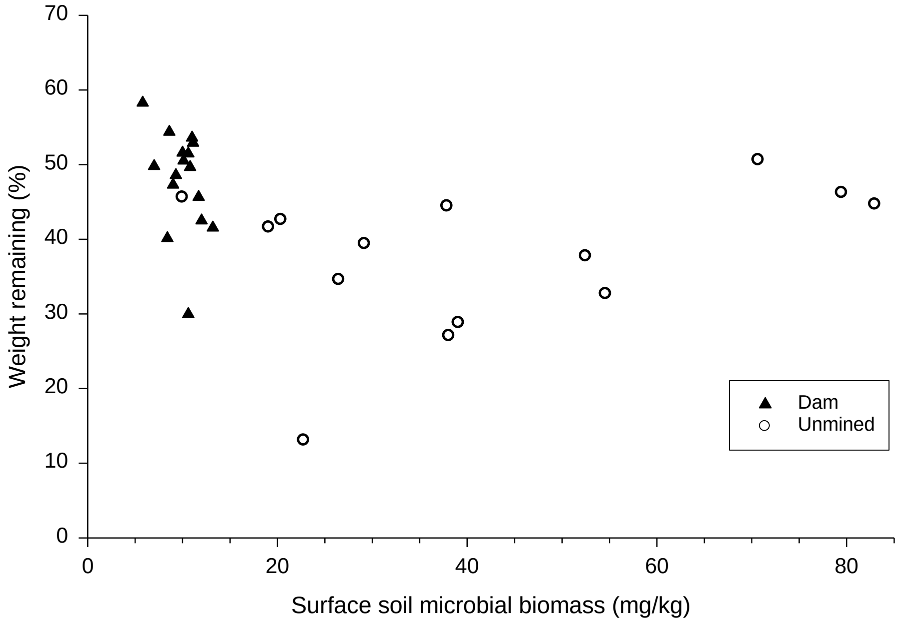

Figure 7. Weight loss after 80 weeks from bagged litter in relation to surface (0-6cm) soil microbial carbon on the dam and at two unmined sites.

Discussion

Weight loss rates observed in this study are comparable to or are higher than in similar studies using eucalypt leaf litter under temperate and sub-tropical climates of Australia (e.g. Birk, 1979; Baker and Attiwill, 1985; O'Connell, 1987). Rates are slower than that recorded for eucalypt leaf litter near Innisfail with a mean annual rainfall of 3600mm (Spain and LeFeuvre,

1987) but the long dry season at Kidston will have significantly limited decomposer activity for much of the time (Spain and Hutson, 1983). Losses in the early stages of decay observed here are extremely high when compared with other studies but reflect the somewhat artificial situation of freshly fallen litter collected prior to the wet season being exposed well into the period of highest rainfall. Most leaching typically occurs during this period, but it is apparent from the disparity between weight loss in the field after the first five weeks and the readily soluble component determined in the laboratory that loss via microbial release also plays an important part.

In terms of differences between the sites, the results indicate significant progress in the reinstatement of nutrient cycling capacity at the study site on the tailings dam. For a rehabilitated site of only five years of age, weight losses for all three sites are remarkably similar. The result is possibly assisted by the proximity of the dam site to sources of propagules and colonising fauna on the dam perimeter, but the level of development is nevertheless encouraging. Despite these gains, the evidence suggests that decomposition processes within the reconstructed ecosystem have not yet fully developed, limited principally by levels of microbial biomass that are 3-5 times lower than in the surrounding unmined soils. This is evident in the relationship between weight loss and soil microbial biomass at the dam site, and equally by the clear lack of such a relationship at the unmined sites. Support can also be drawn from the significantly lower weight loss observed at the dam site compared to the two unmined sites at the five-week collection, when the availability of readily catabolized carbon compounds in litter was relatively high. Such a result is not unexpected, as chronosequence studies elsewhere show that the build-up of microbial biomass may take 15 years or more, particularly where there is no direct return of topsoil (Insam and Domsch, 1988; Sawada, 1996). Build-up usually corresponds with the development of a plant cover and is associated with increasing levels of organic C in the surface soil (Visser, 1985; Wardle, 1992). No relationships between microbial biomass and measures of litter accumulation or vegetation cover were evident in this study. The ratio of microbial carbon to total carbon in the soil is known to be a more sensitive indicator of recovery (Sparling, 1992; Sawada, 1996) but data on total carbon in this study were not collected. Raw tailings at Kidston, however, are known to be extremely low in total organic carbon (0.1-0.2%, Mulligan et al., 1994).

Weight losses in this study were compared to data on invertebrates from soil cores sampled adjacent to the litterbags at the final collection, as part of the larger study previously mentioned (Figure 8). A negative relationship with weight remaining was apparent for unmined sites, but there was no clear relationship at the dam site, even though total numbers of invertebrates per core were similar. Clearly, these are preliminary data but they suggest that invertebrate fauna and the roles they play in litter decomposition (Moore et al., 1988) may be relatively more important in the unmined communities. Various studies attempting to correlate the abundance or diversity of soil microarthropods with ecosystem function have been equivocal (e.g. Visser et al., 1987; Wardle and Lavelle, 1997; Sulkava et al., 2001). The results presented here of a developing system suggest that the importance of any particular agent of decomposition will reflect those that are most limiting over the course of ecosystem recovery.

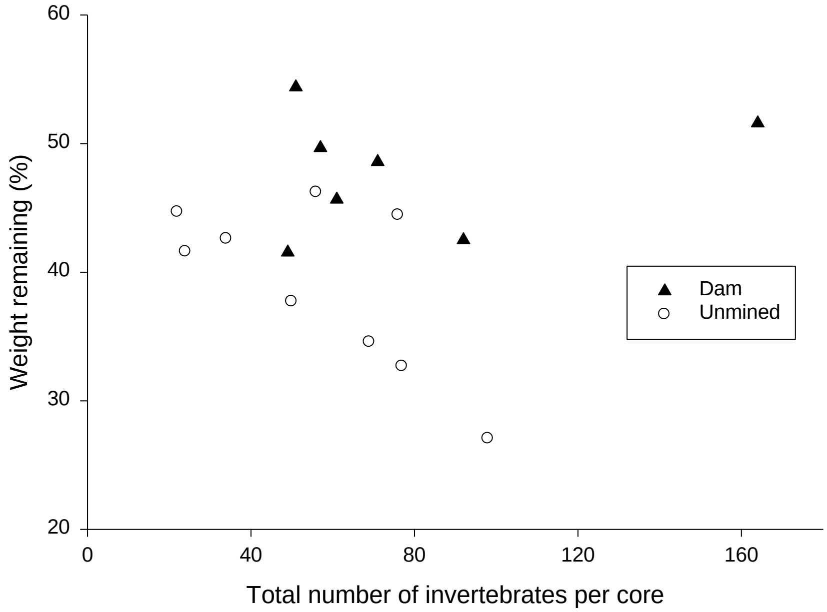

Figure 8. Weight loss after 80 weeks from bagged litter in relation to the total number of invertebrates per core collected from soil cores (6cm deep x 7.3cm diameter) adjacent to each litterbag on the dam and at two unmined sites.

In conclusion, decomposition processes on the directly revegetated tailings dam at Kidston have recovered rapidly over the five years since revegetation occurred. However, rates of decomposition have not yet attained those of the surrounding unmined communities. Decomposition is constrained at present by low levels of microbial biomass in the tailings, but recovery to pre-mining levels is reported to take at least 10 years. In the unmined reference communities, levels of microbial biomass are non-limiting and weight losses may be better related to the abundance of invertebrate fauna.

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