Appendix 2: Literature review – soil functions

Biomass production

Definition

As a result of the increase in world population, there is mounting pressure on the amount of world biomass production that is required to meet this need. This includes not only food production, but also that of fibre and timber. However, it is vital that such an increase in productivity is managed carefully to ensure that the resource itself, along with the wider environment, is sustained to continue meeting the requirements of an increasing population.

The products of food, agriculture and forestry industries are therefore essential for human survival and are totally dependent on soil (Tzilivakis *et al*., 2005; Doran., 2002). The functionality of soil as a medium for biomass production provides the following functions:

1. To supply water and nutrients to vegetation
2. To provide stability of roots
3. To provide the basis for livestock production
4. To interact with the climate and determine the type of crops cultivated

To ensure the longevity of biomass production, care needs to be taken to protect the soil as any degradation of the soil will reduce its overall potential to perform the functions listed above. Pressures on the soil to carry out these functions come from a variety of sources. For example, the intensification and mechanisation of farming in general can lead to the compaction and ultimately the erosion of the soil, as well as reducing biodiversity and reducing the amount of organic matter within the soil. Other threats to the soil structure come as a result of poor timing of cultivation, overworking of soils or overstocking (Environment Agency, 2004). The effects of climate change on biomass production are also beginning to be taken into consideration, for example, Bradley *et al*. (2005) suggest that in general, the integrated impact of climate change is expected to increase crop yields in the UK, as a result of increased temperature and CO_2 concentrations which inevitably lead to greater inputs of carbon to the soil.

Drivers/properties

- Base status
- C/N ratio
- Chemistry (N, P, K and trace elements)
- Depth to impermeable horizon
- Drainage status (wetness class)
- Organic content
- P status (extractable)
- pH
- Soil biodiversity
- Soil depth
- Texture

Examples

Food production (agriculture)
Due to slow formation and regeneration processes, the amount of soil available for food production per person worldwide is limited (CEC, 2002). Soil is therefore one of the most

important natural resources in global food production. However, the sustainability of this resource is at risk from soil erosion in, which is widely considered to pose a significant threat to the world's food production capacity and global food security (den Biggelaar *et al*., 2003).

Many studies have been carried out using GIS and empirical models to assess the interaction between soil and its function as a basis for food production, including den Biggelaar (2003), Feoli *et al*. (2002), Badini *et al*. (1997) and Bachelet *et al*. (1995). Haileslassie (2005) used GIS to process and analyse spatially referenced information such as soil properties, precipitation and land use types to assess soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia. On a global scale, Blum and Eswaran (2004) mapped the global distribution of nine "land quality" classes, which define the suitability of soils for production. The most productive class comprises those areas with ideal soils occurring in ideal climates for crop production, for example with optimum soil temperature and moisture conditions. In comparison, the lowest class of land quality consists of soils belonging either to fragile ecosystems or are uneconomical to use for grain crop production and should be retained in their natural state.

Timber production

Globally, the demand for forest products is increasing despite the loss or degradation of forest land. Therefore there is a need to concentrate timber production on the most suitable sites for maintaining soil productivity to ensure the sustainability of these products. The Soil Action Plan (Defra, 2004) suggests that if good practice is adhered to, forestry can have both beneficial and protective effects on soil however, during cultivation and timber harvesting, the soil can be at risk from issues such as soil compaction and increased erosion risk. Research has also shown that the impact of forestry on soil productivity is variable and suggests that this impact may be positive, neutral or negative, depending upon the physical, chemical and biological properties of the soil (Fox, 2000). Alegre and Cassel (1996) demonstrate the effect of slash-and-burn practices and some alternative systems on the dynamics of soil physical properties at Yurimaguas, Peru. These properties included bulk density, soil water characteristics, infiltration rate, aggregate stability and penetrometer cone resistance and the results of the study showed that alley-cropping system significantly reduced soil erosion on sloping soils whereas the slash-and-burn method produced the least soil disturbance and structural degradation.

The use of spatial techniques to analyse the effects of soil properties on timber production has increased over recent years. For example, Guo *et al*. (2001) used a combination of GIS and simulation models to investigate the effect of ecological factors (including soil) on forest ecosystem function in Hubei Province of China. Similarly, Bateman and Lovett (2000) demonstrate the use of GIS to apply carbon sequestration models to data on tree growth and soil type distribution.

Fibre production

Fibre products include fibrous wood and non-wood raw material for primary industries producing sawn timber, wood-based panels, and pulp and paper products (FAO, 1997). Fibre is not only used in the textiles industry but as a renewable resource in the manufacture of plastics, replacements for fibreglass and insulating materials. Some plant fibres have also been shown to selectively absorb oil from water or remove heavy metal ions from industrial effluent and are therefore being developed for the treatment of pollution (Anon, 1999; Angelova *et al*., 2004; Linger *et al*., 2002). Some research even suggests that fibre crops, such as hemp and flax, may be used as an alternative land use for radioactively contaminated arable land (Vandenhove and Hess, 2005) and stabilising slopes against soil erosion using coir (Lekha, 2004).

Studies looking at the spatial distribution of fibre production include Cieszewski *et al* (2004) who used GIS, Landsat imagery and inventory information to assess the sustainability of long-term fibre supply in Georgia, USA; and Boll *et al* (2005) who demonstrated that soil moisture, along with site, slope inclination and topographic position, influenced the spatial distribution of palm along the Pastaza and Urituyacu rivers in Peru.

Environmental interaction

Definition

Soil, water and air interact chemically, physically and biologically, therefore it is essential that they are considered as one ecosystem (Environment Agency, 2004). The role that soil plays in performing functions related to the interaction of the environment can be split into four sub-functions – storage, buffering, filtering and transforming. The roles that soil plays within these subfunctions include:

1. To link the atmosphere, geology water resources and land use
2. To filter substances from water – natural filter for groundwater/drinking water
3. To receive and transform particles (eg. pollutants) deposited from the atmosphere
4. To emit and absorb atmospheric gases – releases CO2, methane and other gases in atmosphere
5. To act as a reservoir for carbon (greenhouse gases)
6. To regulate the flow of water in the water cycle
7. To store and degrade organic matter
8. To breakdown toxic compounds present in the soil

The importance of these functions has been highlighted by international organisations who warn that the loss of these functions can have detrimental effects. For example the Commission of the European Communities suggest that the ability of certain contaminants to exceed irreversibility thresholds for storage and buffering capacity unnoticed requires monitoring and early warning systems to prevent environmental damage and risks to public health (CEC, 2002).

Drivers/properties

- base saturation
- bulk density
- C/N
- CEC
- clay mineralogy
- depth to rock
- DOC
- metals
- microbial biomass
- OC
- pathogens
- permeability (including depth to impermeable horizon)
- pH
- sesquioxides
- slope
- soil depth
- susceptibility to by-pass flow (combination of structure, packing density and drainable porosity
- texture

Examples

Buffering
The importance of the buffering function of soils is related to its use as an indicator of soil health. This is due to the fact that it prevents large fluctuations in soil pH and therefore affects the stability of the soil, influencing the amount of chemicals (such as lime or sulphur) needed to

change the soil pH (Krull *et al*., 2004). Soil buffering can therefore be defined as the resistance of soils to changes in the pH of the soil solution and can be explained in terms of the equilibrium that exists among the active, salt-replaceable, and residual activities (Brady and Weil, 1996). This means that soils with a higher cation exchange capacity have a greater buffer capacity and a more stable soil pH, therefore preventing the soil exceeding its critical load. Research has also been carried out into the effect of applying alkali to acidic soils and the effect this has on the pH buffering capacity of the soil (Conyers *et al*., 2000). The consequences of a reduced buffer capacity include a reduction in the biological activity of soil microorganisms, the leaching out of some nutrients, damage to higher plants and decreased quality of drinking water (Brady and Weil, 1996; CEC 2002). However, it has been suggested that the buffering capacity of soil can be applied to any soil property, not just soil acidity (Howard *et al*., 1989). For example, Loveland and Thompson (2001) suggest that the ability of a soil to adsorb additions of agro-chemicals or substances deriving from water or atmospheric deposition could also be referred to using the term 'buffering'.

Research has shown that the buffering capacity of soil is also closely related to organic matter content. For example, Krull *et al*. (2004) demonstrate that there is a close relationship between soil cation exchange capacity (CEC), pH and buffering capacity and that the availability of different functional groups (eg. carboxylic, phenolic and others) allows soil organic matter to act as a buffer over a wide range of soil pH values. Burauel & Bassmann (2005) assess the role of the plough layer as a filter and buffer for pesticide molecules and suggest that understanding the fate of natural organic matter in the soil as a result of the addition of pesticides is essential to implementing better management of the filter and buffering function of soils.

Although there are few examples of the quantitative assessment of buffering capacity (Howard *et. al*., 1989), research is beginning to emerge looking at the spatial distribution of soil buffering capacity. For example, Weaver *et al*. (2004) used GIS to combine remotely sensed organic content and clay datasets to assess the feasibility of predicting soil pH buffering capacity in Georgia, USA. This research suggests that rates of change in pH, with known inputs of nitrogen fertilizer and nitrogen mineralized from soil organic matter for example, can be investigated using maps of soil pH buffering capacity. Ahern *et al*. (1994) also used GIS to produce a pH map of surface soils in Queensland to investigate the extent, severity and distribution of acidic soils. In this case, the authors suggest that the identification of the soil type, in combination with climate data, can assist with predicting pH as the organic, coarse and medium textured soils are more likely to be acidic and therefore have a low buffering capacity.

Filtering

The role of soil as an environmental filter includes both soil-water and soil-atmosphere interactions. The process of filtration mechanically filters solid substances out of the percolating water, and binds dissolved substances, mainly by the binding powers of humus and clay (UEIS, 2002). For example, soil performs as a natural filter for groundwater and therefore ultimately of drinking water. There have been a number of studies using soils data to map the vulnerability of groundwater to contamination, including Meinardi *et a*l. (1995), Alemaw *et al*. (2004), Lake *et al*. (2003) and Thapinta & Hudak (2003). Most recently, Dixon (2005) used an integration of GIS and neuro-fuzzy techniques to predict groundwater vulnerability in a spatial context using soil hydrological groups to describe the soil profile's ability to transmit water.

In terms of soil-atmosphere interactions, soil serves as a facilitator for the exchange of gases between the atmosphere and the ground. For example, Skiba & Smith (2000) identify the key drivers of nitrous oxide emissions from the soil as not only substrate supply, but also soil water content and soil temperature. Bowden *et al*. (1998) also highlight the effect of soil temperature and soil moisture on the exchange rate of CO_2 and methane within forest soils. These results showed that CO_2 emissions increased exponentially with increasing temperature in forest floor material, with emissions reduced at the lowest and highest soil moisture contents. Other results from the study suggest that methane uptake is very strongly correlated with moisture content in mineral soils and that there is a strong relationship between temperature and CO_2 flux rates in temperate soils. Little research exists on the spatial extent of soil-atmosphere interactions; however Bilaletdin *et al*. (2001) used a GIS-based model to predict relative regional changes in soil and soil water chemistry for given atmospheric deposition and nutrient uptake scenarios in eastern Finland. This research suggests that despite limitation in spatial information and model structure, in general terms, the model was able to produce reasonable spatial results for these parameters.

Storing and Transforming

Soil acts as a store of minerals, organic matter, water and energy and diverse chemical compounds. For example, soil also has a high capacity for storing persistent organic pollutants (POPs). Dalla Valle *et al*., (2005) suggest that soils have a large capacity for POPs and as a result, not only store such pollutants but can be a source of POPs to the atmosphere, or a sink or atmospherically derived POPs. However these functions are dependent upon factors such as the compound itself, soil properties, environmental conditions and time, among others.

The role of soil as a store of carbon is well-known and consists of two components: soil organic carbon (SOC) and soil inorganic carbon (SIC). In terms of the impact that soil carbon sequestration has on the wider environment, Lal (2004) describes this as a “truly win-win strategy” as it restores degraded soils, increases biomass production, purifies surface and ground waters and reduces the rate of enrichment of atmospheric CO_2 by offsetting emissions due to fossil fuel. As a result, Bradley *et al* (2005) suggest that reduced soil carbon could lead to poorer soil structure, stability, topsoil water holding capacity, nutrient availability and erosion. A number of studies have suggested the use of spatial tools to model soil carbon using a combination of GIS, remote sensing and modelling (Lal, 2002; Paustian *et al*., 1997; Ardö and Olsson, 2003). For example, Wang *et al*. (2002) used GIS to extrapolate site-specific estimates of vegetation and soil organic carbon to the entire area of northeast China and suggest that it is important to take into account spatial heterogeneity in vegetation carbon and soil organic carbon when estimating regional carbon budget estimates.

Soil can also function as a transformer of substances and this can be demonstrated by the transformation of heavy metals within the soil. The effect of heavy metals on soil chemical and biological properties has been discussed in some detail, however there are few studies which investigate the effect that these properties have on the degradation of heavy metals over time (Ma and Uren, 1998; Bataillard *et al*., 2003). However, Lu *et al* (2005) demonstrate the important role that soil pH and organic matter have over time on the fractionation of heavy metals in three Chinese soil types and the effect this has on metal mobility and bioavailability.

A number of studies have been carried out into the spatial distribution of heavy metals within soils in general (Li *et al*., 2004; Li *et al*., 2004; McGrath *et al*., 2004; Korre *et al*., 2002), Fachineilli *et al*., 2001) and over time (Pichtel *et al*., 1997), however there appears to be very little research into the effect of specific individual soil properties on this distribution.

Biological habitat and gene reserve

Definition

Soil provides an important habitat for organisms, spending whole or part life cycles in the soil. For example, the CEC (2002) estimate that in a pasture, for each 1 to 1.5 tons of biomass living on the soil (from grass to livestock), approximately 25 tons of biomass (such as bacteria, earthworms, etc) are present in first 30cm of soil. These organisms are vital for maintaining soil functions.

Biological activity within the soil includes the following functions:

1. To ensure the maintenance and functioning of specific ecosystems or habitats
2. To drive processes such as soil formation, nutrient cycling and nitrogen fixation,
3. To provide a source of symbiotic soil fungi on which many plants depend
4. To generate, stabilise and maintain soil structure
5. To contribute to the structure and fertility of soils
6. To strengthen erosion resistance
7. To provide resilience to and counteract the effects of environmental stresses through the breakdown of chemical contaminants and pathogens

These functions provided by the presence of biological organisms in turn enable the soil in general to maintain valued semi-natural habitats and to define landscape character. This also assists the soil in regulating habitat quality, such as those suffering or at risk from changes in land use, agricultural nutrient runoff or soil erosion (Environment Agency, 2004). Römbke *et al*. (2005) highlight the importance of protecting the biodiversity of soil at a National and International level, as well as addressing the legal issues surrounding the protection of soil as a biological function.

<u>Drivers/properties</u>

- Aeration/eH
- Average annual soil moisture deficit
- Base status
- C/N ratio
- Chemistry
- Organic carbon content
- P status (extractable)
- Particle size distribution
- pH
- Presence and persistence of toxic residues
- Soil biodiversity (biological and microbiological)
- Soil depth
- Soil texture
- Structural development
- Vegetation/land use
- Wetness class

<u>Examples</u>

Soil structure is inherently affected by the presence of soil organisms, through their influence on rooting, aeration and drainage of the soil. This includes small organisms, such as bacteria and fungi, through to larger organisms, such as earthworms and arthropods. For example, Blanchart *et al*. (2004) show that earthworms, through their burrowing and feeding activities, can influence particle size distribution, organic matter content, organic matter location, soil aggregation, aggregate stability and tensile strength, soil roughness, and water infiltration. As a result they can provide spaces for macro-invertebrates to colonise, modify organic matter dynamics and nutrient availability and facilitate the transport of some organisms (Decaëns, 1999**;** Jiménez *et al*, 2004). However, the presence of earthworms can also have a negative effect by increasing the susceptibility of soil to erodibility and erosion, however, this is dependent upon a number of factors, including the soil type, the organic matter content in the soil and ultimately, the species of earthworm present within the soil (Blanchart *et al*, 2004).

The presence of organisms within the soil not only affects the structure of the soil but is also important for maintaining the biological functioning of the soil through their effects on soil chemistry, including nitrogen, carbon, phosphorus and potassium, amongst others. For example, Jiménez *et al*. (2004) showed that the casts of a particular species of earthworm in Columbia acted as “microsites” of short-term mineral nitrogen production and medium-term soil organic matter accumulation. Similarly, the research showed that a build-up of carbon occurs gradually during cast ageing, possibly due to the influence of other organisms such as autotrophic microorganisms, small invertebrates and plant roots. In general, the amount of carbon present within the soil is a result of the level of sequestration or release in soils which in turn is affected by the balance between inputs of plant litter to the soil and the breakdown of litter by soil biota (Vetter *et al*, 2004; Blanco-Canqui and Lanl, 2004). Other studies have shown that a high soil content of phosphorus and potassium is positive for the basic long-term fertility of the soil (Mattsson *et al*, 2000). In addition, the presence of heavy metals within the soil has an effect on the functioning of microorganisms. For example, Giller *et al*. (1999) attempt to explain how microorganisms may become affected by gradually increasing soil metal concentrations in relation to defining "safe" or "critical" soil metal loadings for soil protection. Methods have been introduced to use soil organisms as biological indices to assess soil quality and its impact on soil functions. More information regarding these methods can be found in Knoepp *et al*. (2000), Griffiths *et al*. (2001), Lobry de Bruyn (1999) and Parisi *et al*. (2005).

Various studies have attempted to map the spatial extent and scale of soil biodiversity, and the effect that such organisms have on soil functions (Ettema and Yeates, 2003; Ekschmitt, 2003; Caruso *et al.*, 2005). For example, Ettema and Wardle (2002) suggest that soil organism distributions often have a predictable spatial structure which can influence the maintenance of soil biodiversity and soil-plant community feedbacks. This therefore has a knock-on effect on the degree of plant growth and community structure. More recently, Bastardie *et al*. (2005) have used powerful image processing to accurately map the spatial burrowing pattern of earthworms to link this distribution with the spatial variability of soil functions under natural conditions.

Above ground, the Berlin Digital Environmental Atlas (UEIS, 2002) shows the influence of soil condition on the habitat for natural vegetation. For example, soils characterised by high groundwater levels, such as bog and gley associations in glacial-stream channels, river plains and valley-sand areas have a high importance as habitats for natural vegetation but are limited to a few small sections and are restricted to near-natural soils in the outlying areas of Berlin. Other studies suggest that studying geographic patterns may lead to an improved understanding of the variability in plant genetic structure and the conservation and use of plant genetic resources (Jarvis *et al*., 2005; Guarino *et al*., 2002; Hijmans *et al*., 2001; Jones, 2002).

Despite this body of research, Nannipieri *et al*. (2003) suggest that the links between biodiversity and soil functioning are still poorly understood and that understanding the relations between genetic diversity and community structure and between community structure and function are the most critical problem posed by the link between microbial diversity and soil function.

It is not yet possible to derive soil habitat and soil biodiversity characteristics by physiographic mapping – although predictive vegetation mapping is possible at this stage. There is evidence for linkages between vegetation type and soil microbial community characteristics, and the importance of the soil biological community in determining plant community diversity and dynamics, this work is at an early stage. What is required is an extensive and sustained investigation into the effect of soil, vegetation and biophysical combinations on the genotypic, phenotypic and functional configurations of the soil biological community before a “soil biological function” could be derived by mapping.

Physical medium

Definition

Pressure on the natural environment from human activity such as building houses and transport links inevitably puts a significant amount of pressure on the ability of soil to:

1. To form the foundation for the built environment
2. To influence land use and shape the landscape
3. To act as an essential component in many waste treatment systems for built land-uses
4. To ensure performance and safety of all domestic and commercial electricity systems through soil conductivity potential for earthing
5. To act as an aquifer recharge
6. To control flash runoff from built areas and hard surfaces
7. To provide recreational space in urban and urban-fringes (e.g. gardens, parks, public open space, allotments etc)
8. To provide a means of transport for sediment and nutrients

These functions are profoundly affected by the physical and chemical properties of the upper layers of the soil. Wood *et al*. (2005) identify that natural variations in soil texture and chemical properties have a significant effect on the functionality of soil in the built environment. For example, any change in the pore volume and distribution in the soil profile (e.g. as a result of compaction) determines the rate of water transfer to groundwater as well as the movement of air to and from the soil surface.

Loveland and Thompson (2001) highlight the fact that any damage to the soil surface, or risk of damage to soils in a vulnerable state, will reduce the ability of the soil to perform the functions listed above. An additional risk to the ability of soils to provide a solid foundation for the built environment comes from the threat of climate change. For example, Bradley *et al*. (2005) suggest that increased droughts will enhance the risk of shrink-swell in clay soils. This has the potential to increase disturbance to building foundations and may therefore result in the need for underpinning or repair. Other effects of climate change include potentially increased chemical attacks on foundations as a result of increased soil temperature.

Drivers/properties

- % volumetric shrinkage between -5 and -1500 kPa
- Bulk density
- Clay content
- Clay mineralogy
- Load bearing capacity
- Soil moisture content
- Tension

Examples

Webb (1994) examines the use of soil itself as a building material and suggests that although soil in its natural form has lacked the strength and durability against the elements through its traditional use as a building material, the correct use of low energy mechanical input and solar heat can produce good quality stabilised soil building blocks which compete favourably with conventional fired clay bricks and concrete blocks.

Source of raw materials

Definition

Historically, and up to the present day, soil has been seen as a storage and source of raw materials to support human activity. These functions of soil and the effects of such activities on the physical and chemical properties of the soil are often overlooked but are important aspects of planning and restoration projects. Such functions include:

1. To provides raw materials such as clay, sands, minerals, peat, topsoil

2. To act as a storage-site for raw materials
3. To act as a natural reservoir for water

Drivers/properties

- Consistency
- Depth to rock
- Horizon depths
- Parent material
- Peat deposits
- pH
- Structure
- Texture
- Wetness class

In considering soil functionality in terms of providing raw materials, there are two issues to take into account (King, 2005). Firstly, there are the requirements of a site to actually provide the raw materials from the upper layers of the soil, such as topsoil, peat and Brick Earth clays). For example, Van Seters and Price (2001) show that the extraction of peat has a long-term effect on the hydrological function of the Cacouna peatland in Quebec. Secondly, the requirements of a site where minerals have been extracted from below the solum itself (e.g. coal, sands and gravels) need to be taken into consideration, particularly in reference to the restoration of the site to its original land use. Both of these situations ultimately lead to considerable soil disturbance, through the removal of soil to allow extraction, the storage of removed soil on top of another at an alternative site, and the disposal of material generated during extraction onto soil at another site (Loveland and Thompson, 2001).

Cultural heritage

Definition

Despite early research into the importance of using soil survey information for recording and mapping archaeological finds (Dekker, 1973), the interaction between soil and archaeological remains has received little attention, despite it's overwhelming importance for understanding past uses of the landscape and providing an insight into historical cultural activities. The Defra Soil Action Plan (2004) highlights this fact by stating that there is currently a "*poor awareness of the importance of soils and their heterogeneity in heritage and landscape, partly because of the concealed nature of the archaeological resource and partly because of a lack of relevant soil quality indicators*".

The main functions that soil provides in terms of cultural heritage can be summarised as follows:

1. To conceal and protect archaeological remains
2. To provide an historical record of land use and settlement patterns
3. To inform current knowledge and investigation of archaeological sites
4. To influence the deterioration of archaeological remains (through contamination and modern day agricultural practices)
5. To provide an historical record of climate change

Drivers/properties

The main drivers of the cultural heritage function of soil are:

- Aeration/eH

- Amino acids
- Carbon
- Corrosivity
- Electrical resistivity
- Heavy metals
- Iron deposits
- Minerals
- pH
- Susceptibility to disturbance
- Wetness class

Examples

The physical and chemical properties of soil can assist in preserving irreplaceable archaeological remains and therefore can be essential to our understanding of past cultures and landscapes. However, the extent of preservation or degradation is dependent upon the interaction between the material of the artefact themselves and the properties of the soil. For example, Rettalack (1984) suggests that each kind of fossil can be considered chemically stable under certain general conditions of pH and Eh. In other words, potential fossils will tend to decay or dissolve under conditions outside those in which they are normally preserved.

Additional research has also shown that soil pH in particular can significantly affect the preservation or deterioration of archaeological artefacts, particularly in terms of the corrosion of metallic items (Favre-Quattropani *et al*, 2000; Abraham *et al*, 2001). Through the study of iron objects from five important archaeological sites in Germany, Gerwin and Baumhauer (2000) also show that artefacts experiencing the most severe effects of corrosion came from sandy and acidic soils, as well as from urban soils. In addition, Koon *et al* (2003) have investigated the effect of soil pH on distinguishing heated from unheated bone within archaeological sites. This showed that bone that had been buried within a neutral pH soil did not alter the fibrils of the bone as had been the case with samples from acidic soil. Haslam (2004) analysed the effect of soil properties on starch grains recovered from archaeological contexts, which have an important role in archaeological analyses. He suggests that variations in soil pH, along with soil temperature and moisture affect the level of starch degradation, as well as the interaction of these properties with soil organic matter and microorganisms.

The effect of waterlogging and microbial activity has also been shown to both preserve and degrade archaeological samples depending upon the condition and biological nature of the artefact. For example, using sections of archaeological wood samples from Sweden, Bjordal *et al* (1999) found that waterlogged wood suffers from microbial degradation, with the extent of the decay being dependent upon sample age, wood species and differing oxygen levels. However, English Heritage (2002) suggest that plant macrofossils can be preserved by anoxic conditions resulting from waterlogging in places where the water-table has remained high enough to inhibit destruction by decay-causing organisms, particularly in Britain and the rest of North West Europe.

There is little research regarding the use of archaeological evidence to explain the spatial distribution of present-day soils. However, Kristiansen (2001) used an intact Bronze and Iron Age site in Denmark (Alstrup Krat) to demonstrate the interaction between present-day soil distribution and the former land-use of the site. The results of this research suggest that Iron Age agriculture is believed to have physically rejuvenated the soil in certain areas, causing podzolisation and therefore influencing the present day soil distribution. The authors suggest that archaeological information can provide a powerful tool for explaining soil spatial distribution in addition to more traditional soil survey methods and chemical analyses. In comparison, Fry *et al* (2004) used geographic information systems (GIS) for the analysis and mapping of landscape characteristics, producing an indication of zones with a high probability of possessing cultural heritage interest.

However, research has also shown that valuable archaeological remains have been damaged as a result of modern land use practices (Loveland and Thompson, 2001; Environment Agency, 2004; Cluett *et al*, 2005), contamination (Gerwin and Baumhauer, 2000) and climate change (Bradley *et al*, 2005). Use of this knowledge should enable suitable procedures to be put in place to reduce future damage to archaeological sites.

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