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Australian peatlands: a brief consideration of their origin, distribution, natural values and threats

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Abstract

Peatlands cover a very restricted area of the earth's surface. Their total reliance on water to maintain natural processes make them highly significant terrestrial ecosystems. They are typically biologically hostile environments due to waterlogging, low pH and anaerobic conditions. The most extensive peatlands occur in the maritime and Tundra areas of the Northern Hemisphere, although tropical peats contain large volumes of peat. Peatlands in Australia are restricted and are rare due to the prevailing environmental conditions in this country. Nevertheless there are highly significant and unique peatlands with few similarities to those in other parts of the world. The natural diversity (geodiversity and biodiversity) of Australian peatlands needs to be investigated and recognised in order to understand, manage and protect these vulnerable environments. They are under increasing pressure from human development and climate change. A better understanding of their distribution, conservation status and hydrological characteristics would contribute to their protection and conservation.

Keywords: Australian peatlands, distribution, origin, threats, classification, geodiversity.

Introduction

Peatlands cover about 5 % of the earth's surface (Gorham 1991). Humans have used peatlands and peat for thousands of years. They have lived in houses cut from peat, used it as a fuel, used it in powerplants, made beer and whisky with it, and used it for medicinal purposes or as sacrificial depositories.

Peat cutters in northern European bogs have discovered numerous human fossils in peatlands. Pete Marsh or Lindow Man, the bog body discovered in the United Kingdom in the 1980's was bludgeoned with an axe, garrotted, stabbed with a long thin blade that was plunged into his throat and finally thrown into a bog (Stead *et al* 1986). It was his presence in such fine condition, including intact nails, hair and skin which was testimony to the anaerobic conditions typical of peat areas, slow rates of decomposition, the lack of animal decomposers and the generous nature of his Celtic brethren who offered him as a sacrifice. Celtic people often threw offerings to the gods into rivers and mires and it is even thought that Pete may have been a druid who could consider it a great honour to have died in such a fashion (Stead *et al* 1986). The oldest bog body, Koelbjerg woman died 8000 years ago at the age of about 25 (Stead *et al* 1986). She did not have an axe hole in her head or a garrotte intact, but appears to have died from drowning.

Peatlands can be threatening to many living things. They are wet, soggy, hostile environments which *Homo sapiens* and many plants and animals find inhospitable unless they are specially adapted to cope with the conditions (Maltby *et al* 1992).

Peatlands could be described as being analogous to living organisms because they grow, mature and can die quite naturally. This could be a response to a loss of water supply or change in preferred climatic conditions (Moore & Bellamy 1974). It is also quite likely that peat deposits do not just grow and develop at an even rate. There can be changes which result in a decrease or increase in plant growth and organic accumulation, or a change in the type of plants which develop at particular sites.

Peatlands are unusual terrestrial ecosystems being composed of up to 90 % water. The environmental conditions in peatlands are often harsh with very low pH, low dissolved oxygen levels and very low nutrient levels (Lindsay 1995). In some instances nutrients may be imported into the peatlands by groundwater. They are different to other terrestrial ecosystems primarily because organic matter accumulates at a greater rate than it can decompose.

Peatlands pose research and management challenges to land managers, fire managers, planners and natural scientists (geomorphologists, ecologists, pedologists, hydrologists, botanists, and zoologists). This is because the processes which operate in these ecosystems are quite different to most other terrestrial ecosystems.

Water is important to all ecosystems, or at least to life in all ecosystems. In peatlands it is critical to the natural processes which control the way they function (Hughes & Heathwaite 1995). They must be wet for long periods and would rapidly decline if deprived of water.

Peatlands are intricately linked to water (Bragg 2002) whether it is groundwater in areas that receive very little rain or rain where there is little to no groundwater. Peatland hydrology is often poorly understood, even in areas with far more extensive peatlands than Australia (Moore & Bellamy 1974). In this country this is an important consideration, given climate change and particularly the demand for water, which can impact directly on these, typically marginal ecosystems.

They can be considered as geological/ geomorphological deposits, wetlands, water bodies, wasteland or just land. There is often a confusion of terminology relating to the different disciplines, which investigate these ecosystems. Their uses can be wide ranging from agriculture, forestry, fuel production, pollution control, recreation, tourism, nature conservation and scientific research.

The objectives of this paper are to provide an overview of peatland terminology where they occur in Australia, how they have developed and the wide range of threats posed to their natural values.

Terminology, classification and definitions

There are clearly acknowledged difficulties in peatland classification given the broad range of disciplines interested in these ecosystems. Charman (2002) has argued that the classification of peatlands is one of the most fraught and misunderstood taxonomic systems of all. Moore (1984) has indicated that this is probably because there are so many criteria which can be used, and almost all of them are continuous rather than discrete variables. Many countries with peatlands have developed classification systems of their own and few are identical or similar in detail. There are however common elements such as the predominance of water logging, high organic contents and chemical conditions, which can be hostile to flora and fauna.

According to Gore (1983) the general term to cover ecosystems referred to as swamp, bog, fen, moor, muskeg and peatland is mire. There appears to be some interchange between peatland and mire in Gore (1983) and for the purposes of this discussion the term peatland will be used to describe these ecosystems. The distinguishing feature they typically have is that they are usually underlain by, or consist of peat.

Gore (1983) further recommends subdivision of mire into fen and bog. Bog generally refers to mineral poor peatlands with low pH, while fens are less acid or possibly alkaline and mineral rich peatlands. There is no reference to pH limits although Wheeler & Proctor (2000) suggest bogs have a pH of < 5.0 and fens have a pH > 6.0. No explanation is made of peatlands with a pH between 5.0 and 6.0.

The bog/fen division is to a considerable extent based on the origin of the water and its chemistry. Bogs are rain fed and ombrotrophic, the nutrients being supplied predominantly from rainwater, while fens are more likely to be fed by groundwater derived from bedrock or soils, but also by lakes or rivers (Gore 1983). Nitrogen and phosphorous are generally the limiting nutrients with both elements lower in bogs than in fens although no limits have been defined (Wheeler & Proctor 2000).

Peatlands can be classified according to their shape or morphology (*e.g.,* raised bogs and blanket bogs), chemistry (origin and chemistry of water supply), botanical composition (broad distinctions include moss, herbaceous and woody), hydrology (source and flow of water), peat characteristics (for example the degree of humification) and, related to this, stratigraphy (Charman 2002). Classification may depend on what the classification is to be used for but the hydrological approach may be the most appropriate given the significance of water in peatlands. Combinations such as hydrotopographic classifications have also been developed (Gore 1983).

Little attempt has been made to classify peatlands in Australia, which is not surprising, given their limited extent and the lack of systematic scientific work. Most classifications have been developed for the Northern Hemisphere and have little relevance to Australia. This is probably a consequence of the different environmental and climatic conditions between the two hemispheres.

From a soil perspective peats are typically referred to as organic soils or organosols. Organosol (Isbell 2002) is now the preferred term for Australian peats. This class of soils caters for most soils dominated by organic materials. Data on these soils are limited in Australia and that there have been few previous attempts to subdivide them (Isbell 2002).

Organosols are "Soils that are not regularly inundated by saline tidal waters and either:

1. have more than 0.4 m of organic materials within the upper 0.8 m. The required thickness may either extend down from the surface or be taken cumulatively within the upper 0.8 m; or

2. have organic materials extending from the surface to a minimum depth of 0.1 m; these either directly overlie rock or other hard layers, partially weathered or decomposed rock or saprolite, or overlie fragmental material such as gravel, cobbles or stones in which the interstices are filled or partially filled with organic material. In some soils there may be layers of humose and/or melacic horizon material underlying the organic materials and overlying the substrate." (Isbell 2002).

See Appendix 1 for definitions of organic materials and see Isbell (2002) for other definitions relevant to organic rich soil horizons which are not generally referred to as peat.

Organosol profiles can be further divided into the suborders fibric (generally at the top of the profile), hemic (generally in the middle of the profile) and sapric (generally at the base of the profile) which are terms applying to the level of decomposition with less decomposed material at the top of the profile and more decomposed towards the bottom. All suborders do not necessarily occur in a particular soil profile. See Appendix 1 for definition of suborders.

This terminology is similar to the terminology used in Canada, England and Wales (Isbell 2002). Organosols are then further divided into great groups and subgroups, which are presented in Isbell (2002).

Different disciplines treat peat classification in a variety of ways. For example, in other areas of the earth sciences, sedimentary geologists would simply call peats a sedimentary deposit which may then grade, through diagenesis or low grade metamorphism, to organic sediments and finally coal seams.

A brief consideration of world peatlands

Peatlands have characteristically received little attention from the international conservation community, but due to a drastic reduction in their extent in the Northern Hemisphere, this is starting to change. The impact of the 1997/98 peat fires in Indonesia also drew attention to how critical peatlands are for carbon storage and sequestration.

At the international level, peatlands have principally been recognised for their wetland conservation values due to their importance as habitats for waterbirds and particular flora species. This was the driving force for the Ramsar Convention. Peatlands are the most widespread of all wetland types in the world comprising 50 to 70 % of global wetlands (Pastor *et al* 2003).

The total area of peatland in the world is not known with any accuracy (Charman 2002) but is estimated to be about 5 % (Gorham 1991). This includes approximately 15 % of boreal and subarctic regions (Bridgham *et al* 2001). As a consequence of climatic and topographic controls the large majority occur in the northern temperate zone and around the equator. Canada, Russia, Sweden and Finland dominate the temperate world peatland areas, while Indonesia, Malaysia and Brazil have the greatest extent of peatland in the equatorial zone. Pfadenhauer *et al* (1993), Immirzi *et al* (1992) and Lappalainen (1996) provide good accounts of the extent and composition of the world's peatlands. Difficulties in worldwide estimates are a consequence of the differences in definitions and terminologies applied in different countries. Immirzi *et al* (1992) estimate the total world extent at around 400 million ha. This is most likely an underestimation given the lack of data from Africa, tropical peats and even Australia, which has relatively small areas of peatland. For example, the blanket bogs of western Tasmania are very rarely referred to in the international literature despite the fact that they cover about 1 000 000 ha (see below) and are by far the most extensive peatlands in the country and possibly the southern hemisphere.

Peatlands in the Northern Hemisphere have been widely impacted by land use change and exploitation including commercial exploitation for fuel, forestry, overgrazing, burning, moorland drainage and acid precipitation (Lindsay 1995). It is estimated that only 10 % of the original area of blanket bogs in Britain remain in a more or less natural state (Lindsay 1995) and there is a major concern that extensive blanket bogs in eastern Europe are threatened by the eastward expansion of mining companies with all the bogs in the Netherlands and Poland lost. Similarly Ireland has 19 % of its original bog area left intact (Lindsay 1995).

Australian peatlands and their palaeoenvironmental constraints

Australian peatlands are found from the wet tropics in the north to the temperate zone, the alpine regions in the south east (Whinam & Hope in prep) to the coastal plains in the south west. Their occurrence is restricted except in Tasmania where the blanket bogs in the west of the State, considered to be the most extensive in the southern hemisphere (Pemberton 1993, Pemberton & Cullen 1995), cover about 1 000 000 ha. In general, however, peatlands are rare in Australia.

Many of the peatlands are peculiar to the continent, or at least the Australasian region, given the processes which have lead to their development, whilst there are some which have Northern Hemisphere counterparts such as *Sphagnum* bogs, sedge fens and *Phragmites-Typha* riparian fens (Whinam *et al* 1989, Clarke & Martin 1999, Crowley & Gagan 1995). Australian peatlands fall into coastal and montane regions with the mound springs in central areas some of the most peculiar from a peatland perspective (Boyd 1990a, 1990b). Peatlands associated with deflation hollow wetlands are probably fairly widespread although they are not very well documented.

The vast majority of Australian peatlands are late Pleistocene to Holocene in age with most having formed in the last 15 000 years following the last Pleistocene glaciation (Bowler *et al* 1976). In south eastern Australia this corresponded to the onset of more humid and maritime/temperate conditions following climatic change.

Montane and Tasmanian lowland areas

Highland areas in south eastern Australia provided ideal locations for the development of peatlands following deglaciation. Topographic depressions formed by ice action resulting in the development of cirques, knock and lochan landscapes, nivation hollows and glacial valleys created the on ground conditions suitable for peat accumulation. The cool relatively wet conditions with low evaporation are also conducive to organic accumulation. These are most widespread in the Tasmanian highlands and the Australian Alps (Hope 2003).

Tasmanian blanket bogs occur down to sea level on the west coast of the State, often beyond the range of the most recent ice and glacial action (Pemberton 1993, Pemberton & Cullen 1995). These have formed in response to wet, humid conditions with low evaporation and cover undulating flats to steeper slopes forming a semi-continuos blanket. They are typically only 30 cm deep. In topographic depressions occasional 4 m deep profiles occur (Pemberton 1993). Lowland peatlands also occur on Macquarie Island (Rich 1996) with the greatest depths approaching 6 m.

Sphagnum peatlands are extremely restricted in Australia occurring in isolated parts of Tasmania (Whinam *et al* 1989), Victoria, New South Wales and the ACT (Clarke & Martin 1999). These are often associated with glaciated terrain in Tasmania where they can be over 4 m deep (Pemberton 1986).

The montane swamps of eastern Australia occur in similar areas and are more widespread but do not occur in previously glaciated country. These are composed of fens dominated by sedges and other restionaceous species which can be highly productive with up to 6 m of peat having formed in 3000 years (Hope 2003). These are arguably some of the most productive peatlands in the country.

Coastal regions

The Post Marine Transgression occurred from 12 000 to 6 000 years ago as sea levels rose following the last glaciation (Thom & Chappell 1975). Sea levels stabilised around 6000 years ago and have remained relatively stable since this time, a period referred to as the Holocene stillstand (Thom & Roy 1983). The rapidly rising (some suggest a rise of 1.5 m every 100 years) sea levels before the stillstand reworked sandy coastal landforms inland (Thom & Roy 1985). Following the stillstand many coastal dune systems experienced a period of rapid accretion or growth (Thom & Roy 1983). The development of a new series of dune fields also created conditions for the development of dune barred lakes/ swamps, which resulted in the formation of peatlands. Former valley systems were flooded creating a variety of conditions around the Australian coast for peat accumulation. Permanent or frequent inundation in estuaries and lagoons provided ideal environments for organic accumulation.

The dune barred and estuarine peatlands in temperate Australia include a variety of forms. Interdune swales contain sedge swamps and lakes. The waterbodies can have peat floors where organic matter has collected helping to form an impermeable substrate.

Excellent examples of perched lakes occur in the Fraser Island dunefields and the Cooloola sandmass in southern Queensland (Longmore & Heijnis 1999). The Fraser Island peats exceed 100 000 years in age while the Cape Flattery dunefields have peats dated at 30 000 years. These typically have shallow peat deposits and are derived from Cyperaceous and Restionaceous vegetation.

The large "permanent" wetlands on the Swan Coastal Plain, Western Australia fall into the coastal peatland category. They are associated with groundwater aquifers where the deep sandy soils are regularly if not permanently saturated (Hill *et al* 1996). The organic build up is from Cyperaceae and Myrtaceae vegetation whilst the wetland shapes are controlled to some extent by Pleistocene dunes systems (Semeniuk 1988).

In tropical Australia, peat accumulation in coastal sites occurs in similar locations such as interdune swales, but also in mangrove swamps (Crowley & Gagan 1995). True mangrove peat is rare requiring sheltered locations where restricted water circulation prevents flushing.

The broad floodplains on the tropical river systems have organic accumulation in the lagoons inland from the main channel formed under *Melaleuca* forest. They are typically thin deposits with high mineral content (Lees & Saenger 1989).

Rivers along the lower coastal plains of southern Australia also have peat deposits although in the east most of these have been cleared. Some of the best examples are the sedgeland and *Melaleuca* thickets in the south west of Western Australia (Hodkin & Clark 1988). Paper bark communities in northern Tasmania, including the Furneaux Group (Harris *et al* 2001) and King Island (Barnes *et al* 2002), have well developed peat profiles. The coastal wallum (sand heath) of north east New South Wales and south east Queensland also fall into the coastal peatland category, which provide relatively long sedimentary records for coastal sea level fluctuations and environmental change (Woodroffe 2003).

In tropical Australia, conditions are generally not conducive to organic accumulation due to seasonal drought and high rates of decomposition. Where conditions are favourable, significant build up can occur, such as in the relatively cool, wet conditions on the Atherton Tableland where some of the best know accumulations of tropical peat occur. These are also the oldest known peats in the country and are probably older than 200 000 years. These form in the low broad volcanic craters referred to as Maars (Whinam & Hope in prep).

Desert peatlands

Perhaps some of the most peculiar peatlands are associated with the spring mounds of the Great Artesian Basin (Boyd 1990a). The fresh water flowing from these permanent point sources in a largely waterless environment generally evaporates or soaks into the soil within tens or hundreds of metres of the springs. There is sometimes sufficient water to form permanent swamps with peat, such as the dramatic examples at Dalhousie Springs (Boyd 1990b) in the Witjira National Park close to the Simpson Desert. This area receives about 100 mm of rainfall per annum. The contrast with the surrounding rock covered plains and saltbush is dramatic.

Deflation hollows

Peatlands developed in deflation hollow wetlands have not been described in great detail in Australia but occur in the midlands of Tasmania, on Cape Barren Island in the Bass Strait (Lazarus & Jerie 2004) and in parts of Western Australia (Horwitz *et al* 1997). They most likely occur in other deflation hollow complexes around the country such as in the Monaro (Bowler 1983).

Geodiversity and natural diversity

This section specifically addresses the issue of conserving geodiversity in peatlands. Issues considered are the significant relationship, which occur between geodiversity and biodiversity in peatland processes and conservation.

To conserve peatland values all natural values should be considered. There has been a tendency in nature conservation to concentrate on biodiversity when conservation values are being assessed (Eberhard 1997). Geodiversity (see Appendix 2 for definition) is an integral part of peatlands, whether it is in the foundations of the landforms providing the on ground conditions for organic accumulation such as impeded drainage, or in the peatland proper where organic accumulation is occurring. There is a very close relationship between the physical processes influencing peatland development and the contribution that is made by plant material. There is therefore a strong link between abiotic and biotic processes in the formation and maintenance of peatlands.

Direct influences from landforms in peatland development include providing restricted drainage which creates the waterlogged conditions needed for peatlands. This can be provided by glaciated landscapes, dune barred lakes, deflation hollow/lunette complexes or accreting floodplains. These provide the environment for organic accumulation, which in turn provides the foundations for further plant growth and biological activity. Geoconservation values are usually intricately linked with the functioning of the ecosystems and their biological values. Management and conservation of these ecosystems must consider all these aspects of functioning peatlands.

The conservation arguments for the protection of geodiversity can be very strong. Disturbance or removal of most earth features is normally permanent unless there is a willingness to look at sustainability over thousands or millions of years, and even this does not allow for the re-creation of features that may have formed under particular geological or climatological conditions. In general, peat formation is so slow that any damage to the deposit or long term change to the processes responsible for organic accumulation, are likely to compromise the integrity of the peatland.

Intact peatlands that are accumulating organic matter are valuable palaeoenvironmental archives. They can be used for reconstructing past landscape change, climate change and to document the timing of environmental contamination across the world (Pastor *et al* 2003).

Conserving peatland values should not concentrate only on areas of maximum diversity and it could be that the extent of a particular peatland type or process is significant from a conservation perspective because of their uniformity. Peatland conservation should include the representative range of peatland types, which in turn requires a comprehensive peatland classification.

Peatland conservation and management needs to comprise more of the peatland than its physical boundaries given the complexities of the hydrological relationships in these environments. This should include the entire peatland catchment.

Threats and conservation considerations

Peatlands have characteristics such as high organic contents that make them vulnerable to fire, climatic constraints such as moisture availability that put them at risk from climate change, a reliance on high water tables that result in threats from ground water extraction and high water retention characteristics which results in a demand for the organic matter from the horticultural industry.

Fire

Fire is one of the major threats to Australian peatlands. In contrast to many other parts of the Australian environment fire can completely destroy peatland ecosystems. Recovery may be considerably retarded following a severe peat fire. Despite this, research into the relationship between fire, vegetation dynamics and organic accumulation in Australian peatlands has been limited.

This contrasts with the Northern Hemisphere, which has more extensive peatlands, but less of a fire adapted landscape with lower fire frequencies. Despite this, fire has impacted on extensive areas of peatland (Radley 1965), including areas of permanently frozen ground. Bower (1959) and Tallis (1973, 1985 and 1987) have studied, in considerable detail, the impact of fire on peatlands of the southern Pennines. Racine (1979) did a comprehensive investigation of 360 000 ha of maritime tundra in Alaska affected by fire. It was estimated that about half of the organic soil had been removed by fire and revegetation was very slow. This affected permafrosted soils and increased thaw depths in summer. In some places blistering occurred on the soil surface as a result of steam produced from melting permafrost. It appears likely that this type of peat burn would have considerable impact on the physical and chemical nature of the soil.

Maltby *et al* (1990) report that, in the north York moors, fire burnt deeply into blanket peat, and largely destroyed thinner peat reducing it, in the most extreme cases, to a layer of ash. Lindsay *et al* (1995) considers that burning is recognised as a major initiator of erosion in the Peak District of northern England where problems of peat erosion are extreme in places.

Peatlands are potentially unstable terrains because the organic soils have very little inherent structure and are mainly bound together by roots. In contrast, mineral soils have superior structures derived from the more cohesive mineral particles in the soil. Peat soils are very vulnerable to physical disturbance because of their soft nature and typically waterlogged condition.

Peatlands are affected in the following ways by fire in increasing order of impact:

- Removal of some vegetation and litter left intact leaving a protective layer.
- Removal of all vegetation with some surface litter left intact leaving a protective layer.
- Removal of vegetation and surface litter which exposes the soil surface potentially leading to greater drying and cracking of the peat. If the removal of vegetation and litter occurs frequently the raw material for organic soil development is lost which can retard soil formation. Ash may be blown or washed away.
- Removal of vegetation, litter and peat to varying depths. Ash may be blown or washed away. The more soil removed the longer it is likely to take for the soil to reform because of greater stresses on plant development. Soils can be burnt to bedrock or underlying mineral substrates.

Evidence for erosion of peat includes exposed substrates, truncated peat profiles, accumulation of organic matter at the change of slope and peat profiles covered by a layer of sand which has been washed downslope (Pemberton 1989). The other major physical impact is complete removal of all seed stock. Seed is unlikely to survive peat fires, which can burn at temperatures of between 300 and 600°C (Frandsen 1991).

If surface organic material is burnt, differential removal can lead to the formation of surface irregularities or small pits which may alter vegetation patterns and creates a hummocky land surface. This has occurred in parts of Tasmania, the Swan Coastal Plain and most likely other peatlands in Australia. Where fire does expose a mineral surface plant establishment is hindered by summer drought which can have serious implications for plants that are adapted to wet conditions.

Estimates in Tasmania suggest up to 3 million m^3 (100 000 ha) of organic soil has been lost from blanket bogs due to fire with some profiles having been burnt to bedrock (Pemberton & Cullen 1995). The complex relationship between the fire adapted buttongrass communities which develop on the peatland and the (potentially) vulnerable soils which occur below need careful land management/conservation consideration. There is a question of whether these communities actually need fire to develop.

Agriculture and Urban Expansion

Some of the greatest impacts on peatlands have occurred to coastal peatlands from drainage for agriculture and settlement. In Victoria and South Australia interdune swale peats and riverine peats have been impacted with the loss of up to 2000 000 ha of peatland. Drainage has resulted in oxidation of the peat and further loss through fire (Taffs 2001).

Montane mires have also suffered from fires where drainage and burning to promote pasture grasses has destroyed peats (Cullen 1995). Peatlands in tropical Australia (Whinam & Hope in prep) are threatened by drainage works and a reduction in groundwater resulting from over-exploitation of artesian water supplies.

Urban expansion in many locations has resulted in the drainage and "in-filling" of peatlands. The exploitation of groundwater resources also provides a direct threat to these ecosystems. Unchecked urban expansion will continue to apply pressure. This is most notable on the Swan Coastal Plain.

Peat Extraction

Removal of peat for horticultural uses has occurred in a wide range of peatland ecosystems across Australia. In comparison to the Northern Hemisphere, where it is also used as a fuel, Australian peat mining operations are reasonably small, but the extent of this countries peatlands does not compare with those of the Northern Hemisphere. In the Northern Hemisphere peat extraction for power plant operation has all but destroyed the blanket bogs in the United Kingdom and Ireland (Lindsay 1995).

Unreserved *Sphagnum* moss peatlands in Tasmania and Victoria have been under considerable pressure for harvesting where attempts have been made at sustainable harvest by removing shallow surface layers of moss (Whinam *et al* 1989). This is not necessarily the case in many other locations such as Western Australia and New South Wales where peat is removed right down to the mineral substrate. This effectively mines out the peatlands, which can take thousands of years to regrow if the right conditions occur. Perhaps one of the best known examples of peatland extraction is Wingecarribbe swamp in New South Wales, which collapsed following extensive mining carrying peat and sediment into the neighbouring Wingecaribee Reservoir (Arachchi & Lambkin 1999).

Climate Change

Peatlands are threatened by global climate change (Charman 2002), but also pose a threat it they are burnt or drained (Intergovernment Panel on Climate Change 2001) as this can lead to large carbon emissions. It is estimated that 500–1000 million tonnes of carbon dioxide was emitted from peatland fires in Indonesia in 1997–1998. Many peatlands are net carbon sinks and all store significant amounts of carbon. It is estimated that worldwide peatlands store up to 550 billion tones of carbon and they store more carbon per unit area than any other ecosystems (Lafleur *et al* 2003). Pastor *et al* (2003) estimate that peatlands contain about one third of the world's soil carbon pool. If, as a consequence of climate change, peatlands stop accumulating and start releasing carbon, as they decompose or are burnt, the threats posed are to the worlds climate and the peatland as well.

Climate change also directly threatens many peatlands due to the reliance of these ecosystems on high humidity, low evaporation and adequate rainfall for their well being. Although these conditions may be enhanced in some parts of the world, which is not necessarily a good thing, there are other parts where peatlands could be stressed by climate change. Australia is one such area.

Increases in temperature across Australia of between 1.0–6.0° C are expected by 2070 (Howden 2003). The CSIRO (2001) has predicted increased rainfall in summer and autumn for most of Australia, but a wetter winter and drier spring, summer, and autumn for south eastern Australia. Peatland ecosystems in south eastern Australia could be under increased pressure as a consequence. Recent investigations in Tasmania indicate that evaporation is greater than precipitation during drier months and that recent extended dry periods and lower water tables have been recorded for blanket bogs in the State (Bridle *et al* 2003). It is unclear whether these peatlands are actively accumulating and there is some indication that they are in decline. Increased drying may well result in an accelerated decline.

Conclusions

Peatlands are unusual ecosystems to find on the second driest continent in the world. Although rare, they have developed in restricted habitats in Australia around the coast, in montane locations, in deflation hollows and, the most peculiar, in the deserts associated with the Great Artesian Basin spring mounds. They have both biotic and abiotic conservation values, which need to be taken into account when considering management and protection requirements.

Some of Australia's peatlands remain in reasonably good condition and although no systematic review of these ecosystems has been conducted, it seems apparent that it is the coastal peatlands which are under considerable pressure from land use change, fire, water extraction and drainage. Other risks include grazing, burning and weed invasion in montane peatlands. The pressure on the inland desert peatlands arises from stock access and broader pressures on the Great Artesian Basin. Deflation hollow peatlands have been impacted by forestry operations and agriculture.

Management and conservation of peatlands needs to include more of the peatland than its physical boundaries given the potential complexities of their hydrological relationships.

There is an urgent need for investigations of the spatial extent of peatlands and an assessment of peatland condition and management requirements in Australia. The land use and development pressures also require identification and, most importantly, hydrological characteristics and influences on peatland hydrology should be investigated.

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APPENDIX 1

Organosol suborders are defined as follows:

"**Fibric** – Soils in which the *organic materials* are dominated (about 75 % by volume) by *fibric peat*.

Hemic – Soils in which the *organic materials* are dominated by *hemic peat*.

Sapric – Soils in which the *organic materials* are dominated (about 75 % by volume) by *sapric peat*." (Isbell 2002).

Fibric, hemic and sapric peat are further described by Isbell (2002) as follows:

"Fibric Peat – Undecomposed or weakly decomposed organic material; plant remains are distinct and identifiable; yields clear to weakly turbid water; no peat escapes between fingers (authors note; when squeezed in the palm of the hand).

Hemic Peat – Moderately to well decomposed organic material; plant remains recognisable but may be rather indistinct and difficult to identify; yields strongly turbid to muddy water; amount of peat escaping between fingers ranges from none up to one-third (authors note; when squeezed in the palm of the hand); residue is pasty.

Sapric Peat – Strongly to completely decomposed organic material; plant remains indistinct to unrecognisable; amounts ranging from half to all escape between fingers (authors note; when squeezed in the palm of the hand); any residue is almost entirely resistant remains such as root fibres and wood."

Organic materials:

"These are plant-derived organic accumulations that are either:

(i) Saturated with water for long periods or are artificially drained and, excluding live plant tissue, (a) have 18 % or more organic carbon (Wakley-Black x 1.3 or a total combustion method, Rayment and Higginson 1992, Methods 6A1 or 6B2 in Isbell 2002) if the mineral fraction is 60 % or more clay, (b) have 12 % or more organic carbon if the mineral fraction has no clay, or (c) have a proportional content of organic carbon between 12 and 18 % if the clay content of the mineral fraction is between zero and 60 % or

(ii) Saturated with water for no more than a few days and have 205 or more organic carbon." (Isbell 2002)

Loss on ignition

Loss on ignition may be used as an estimate of organic carbon.

APPENDIX 2

Geodiversity can be defined as "The natural range (diversity) of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes. Geodiversity includes evidence for the history of the Earth (evidence of past life, ecosystems and environments) and a range of processes (biological, hydrological and atmospheric) currently on rocks, landforms and soils" (Eberhard 1997).

Geoconservation can be defined as "The identification, and conservation of geological, geomorphological and soil features, assemblages, systems and processes for their intrinsic, ecological or heritage values "(Eberhard 1997).