Applying palaeoecology to conservation and identifying 'natural' ecological conditions: Fynbos fire and vegetation history in the Langeberg Range, Western Cape, South Africa.

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Introduction:

The Cape Floral Kingdom (CFK) is located in the Western Cape Region, South Africa. Its designation as one of the world's six floral kingdoms is in large part due to its distinct and highly diverse flora, a high proportion of which is endemic. It covers ~90,000km², and approximately four fifths of this area is made up of the fynbos biome. The species diversity per geographical area of this region is unequalled anywhere in the world. It contains ~8,600 plant species, 5,800 of which are endemic. Comparisons of species diversity for a range of regions are shown in Figure 1. It is of concern therefore that the region is facing high species loss. 1400 plants feature on the Red Delta list as endangered, and 29 of these are already known to have become extinct (Cowling, 1995).

This paper reviews literature relating to fynbos ecology and palaeoecology. It recognises the need for conservation and restoration of natural vegetation, and argues, with supporting evidence, that palaeoecological information is needed for this. Examples of successful applications of palaeoecology to conservation and land management issues are presented, along with other relevant literature. Research using pollen and charcoal analysis is proposed with the aim of using palaeoecology to establish 'natural' (pre- colonial) conditions, and applying this information to the conservation/ restoration.

Figure 1: ***Species Richness of the Cape Floral Region compared with other regions*** **(Bond, 1997).**

Region	Area (10^3 km²)	No. of species	Species density (10^3 km^{-2})
Mediterranean climate regions			
Cape Floristic Region	90	8578	95.3
Cape Peninsula	0.47	2256	13.7
California Floristic Province	324	4452	13.7
SW Australia	320	3600	11.25
Temperate Regions			
British Isles	308	1443	4.7
Eastern N. America	3238	4425	13.7
Tropical Regions			
Malayan Peninsula	130	c.8000	61.5
Ivory Coast	320	c.4700	14.7

Literature review:

Fynbos consists of communities of grass- like plants, short shrubs and taller shrubs in varying combinations (DeBano, 1998). The main plant groups that make up fynbos are Proteas, Ericas, Resios and geophytes. The combination of these plant types in a species assemblage determines the type of fynbos vegetation. The five types are ericaceous, proteoid, restioid, dry and grassy fynbos. Ericaceous fynbos is found on the mid- upper slopes of the Langeberg range, and elsewhere in moist, cool environments. Grassy fynbos is present in the foothills of the Langeberg, extending in a widening band from west to east (Cowling, 1995). The members of these plant groups share similar growth forms, but are highly diverse along functional axis such as pollination and dispersal (Bond, 1997). The greatest proportion of endemics are found in mesic and wet habitats, particularly at high altitude, such as in the Langeberg (Macdonald and Cowling, 1993), where species are often endemic to a single peak or range (Cowling, 1995)

There are a number of factors that control the distribution of fynbos, which have also influenced its evolution and biodiversity. Nutrient poor soils in the area limit the colonization of the region by other vegetation types, allowing fynbos to proliferate since ~1.5 ma BP (Cowling, 1995). Climate also plays an important role in distribution, and is an important determinant in the biogeography of fynbos type within the CFK. A palpable example of this is between the winter and all- year rainfall zones; however there are intricate localized variations. However, the hypothesis of climate and soil as controls on the development and distribution of fynbos are undermined by the successful transplantation of plants from other biomes to fynbos, and the success of invasive species (Bond, 1997). The most dominant factor in both the distribution and biodiversity is fire.

Fire has been a fundamental factor in the evolution of fynbos and its diverse plant community. Before the 20th century botanists viewed its effects as destructive, however more modern ecology recognises its elemental role in the successionary process of destruction, regeneration, growth, maturity and destruction again (Cowling, 1995). Burning serves a number of ecological roles. Fynbos contains many serotinous species that require fire for their seed to germinate. Some species may also benefit from the destruction of competitor species by fire. Moreover, the majority of the essential nutrients needed for new plants to grow are held in existing vegetation, which can be released by fire to facilitate new growth (Cowling, 1995; Bond, 1997; Debano, 1999).

Variables in the fire regime include the intensity of burning, season in which fire occurs, time between fires (fire- free interval (FFI)) and the area burned. The combination of these variables means that each fire that occurs is different. The high diversity of species functional types in fynbos ecosystems means that different species have varying optimum and least preferred fire types. It is this relationship between plant functional type and varying fire regime that led to the evolution of the unique and biologically diverse flora (Naveh, 1974; Cowling, 1995; Bond, 1997; Debano, 1999). Endemics are vulnerable to changing fire regimes, and therefore human impact or climate change could lead to extinctions (MacDonald and Cowling, 1993; Bond, 1997).

Most fynbos land management and conservation plans incorporate some form of fire management. In fact, most management plans are fire- based (Cowling, 1995). Fynbos thrives on low frequency fires (<20 year FFI) which produce low intensity fires. Cowling (1995) proposes that the optimum fire frequency for fynbos is 12- 15 years. The ecological basis for this recommendation, and others offered, tends to be based on short- term (<50 years) observations. Considering fynbos has burned periodically over the last 100,000 years (DeBano, 1999) and that significant human disturbance occurred on the Western Cape before fynbos fire ecology was recorded or understood, it is conceivable that current burning regimes might not represent 'natural' conditions. The proposition can also be made therefore that modern plant species assemblages may not represent natural conditions. Moreover, modern ecological studies often focus on organisms whose life- span is greater than the period being studied, and so can not represent ecosystems that are highly dynamic and have continually unique disturbance regimes (Whitlock, et al. 2003).

There is increasing recognition of the importance of palaeoecological and historical information among conservationists and land managers (Birks, 1996; Willis and Birks, 2005; Gillson and Duffin, 2007; Willis, et al., 2007). This is due, firstly, to the burgeoning need to understand species responses to changing environments, information on which is available through palaeoecological sources (Huntley, 1996). Secondly (and more important to the proposed purpose of this study), there has been a shift in the dominant paradigm in ecology from one that recognised the 'balance of nature', to an understanding of the 'flux of nature' and recognition of ecosystem dynamics (Fielder, et al. 1997). However, the conservation/ management and palaeoecological communities have been slow in unifying. Willis, et al. (2007) attribute this to perceptions of lack of spatial and temporal resolution, and improper, or lack of, application of palaeo- studies to needs of conservationists. Moreover, palaeoecologists usually chose study sites on the basis of the highest quality available record, and conducting studies directly related to conservation often means sacrificing that preference.

Palaeoeclogical applications to lucastrine environmental problems have been a good example of how 'baseline' conditions can be established (see Battarbee, 1989). The notable majority of successful examples of using palaeoecological data to formulate management plans for terrestrial environments come from south west North America (Zazula, et al. 2005). For example, Sweetnam et al, (1999) used palaeoecological data from 'packrat' middens to determine baseline conditions for vegetation communities in South West U.S. They also facilitated the distinction between natural and human causes of environmental change. The results of the packrat midden study, along with fire scar chronologies were used to develop a fire management and reintroduction programme.

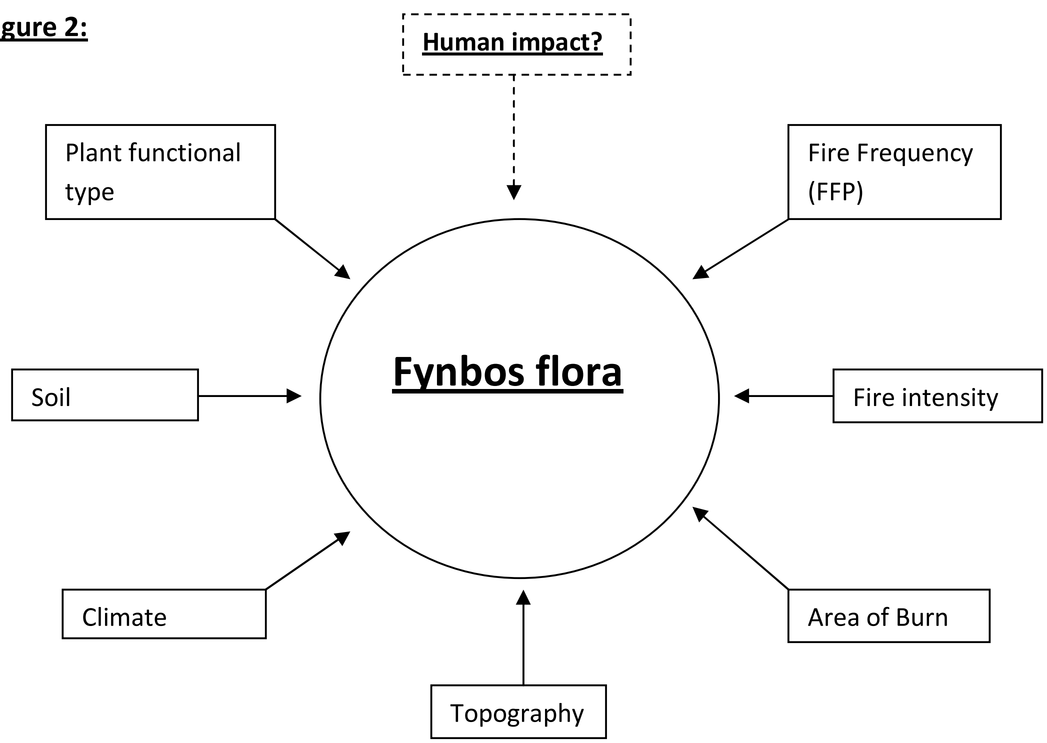
The middens of hyrax (*Procavia capensis)*, a medium sized mammal, are found throughout arid and semi- arid regions of the Americas, Australia, Africa and the Middle East. In the Americas and the Middle East hyrax middens tend to be constructed as nests with twigs and other macro-botanical matter, and provide a 'snap shot' in time. Southern African middens tend to be faecal deposits, and are continually accumulated over long periods of time. Hyraxes have a preference to defecate in the same place, usually a cave or rocky escarpment, over generations. They urinate on their faecal accumulations, and this then crystallizes forming a cohesive structure known as 'hyracium'. These middens are rich in fossil pollen and have often contained strong stratigraphic and temporal resolution (Gil-Romera, 2007; Scott and Woodborne, 2007; Thomas, et al, 2008). The fossil pollen has been found to be representative of wider landscape vegetation; however some bias does exist due to hyrax diet preferences (Scott and Woodborne, 2007). A study by Scott and Volgel (1992) in Orange Free State, SA, tested the reliability of hyrax middens. It used multiple sources of information over the last 30 years, and found that the midden fossil pollen correlated with observed vegetation changes, and showed particularly high resolution data. Scott and Woodborne (2007) pooled data from a number of middens found in the Cedarberg range, SA to establish a proxy record of vegetation change since 23, 000 BP.

A more traditional method of palaeoecological investigation involves the 'coring' of sediments from lakes or wetlands, and the analysis of its microfossil (and macrofossil) content. These often provide high resolution records with considerable temporal extension. This however is often not the case on the Western Cape, where the record tends to be poor, with shallow and weakly stratified sediments (Scott and Lee- Thorp, 2004). However, a number of successful studies of this nature have been carried out. Meadows and Baxter (2001) took a core from Klaarfontein Springs in the winter rainfall region of the W. Cape. The study involved a number of cores being taken representing the late Holocene. Pollen analysis of the core representing the period c. AD1500- 1830 showed clear evidence of colonial period environmental alteration. The data from strata lower in the core show fynbos elements well represented, including Proteaceae; Restionaceae; Rosaceae. Further up in the strata there is a marked decrease in fynbos and Poaceae which is representative of the colonial period. Towards the surface the pollen spectra are considerably less diverse. Similar results were obtained by Meadows, et al. (1996) using the same technique.

The best comparison to the type of study this paper will propose comes from Kruger National Park, SA. Gillson and Duffin (2007), used fossil pollen data (from cores) to induce a series of 'endpoints', or maximum and minimum levels of ecosystem variables that if surpassed highlight need for concern. These are known as 'Thresholds of Potential Concern' (TPC). The TPC help land managers identify changes that appear to be outside the limits of natural variation. For example, a TPC for woody taxa was established at 80%, meaning that the modern recorded levels of that vegetation type should not fall below 80% of 'highest ever cover' (Gillson and Duffin, 2007). Similar applications have been made, most notably in N. America, using a technique that aims to calculate the range of natural variability (RNV) of ecosystem components (Sweetnam, et al. 1999). Both the TPC and RNV techniques avoid the establishment of fixed 'baseline' conditions, and incorporate the concept of ecosystem 'flux' into preservation or restoration of ecosystems. They can also be applied to both fire and vegetation history.

In summary, fynbos flora is highly unique and biologically diverse, and has been degraded and altered by human activity. Its conservation requires addressing the question '*what is natural?'* The issues of human impact and ecosystem flux mean that it is necessary to incorporate a palaeoecological perspective into management plans for both burning regimes and vegetation. Pragmatic applications of this sort have been uncommon; however recent development and use of the RNV and TPC techniques provide excellent examples of what can be achieved. A summary of the controls of, and impacts on, fynbos is provided in Figure 2.

Figure 2:



Aims and Objectives:

This research aims to induce information to address the question 'can palaeoecology provide proxy data representing 'natural' ecological conditions which can be applied to fynbos conservation/ restoration?'

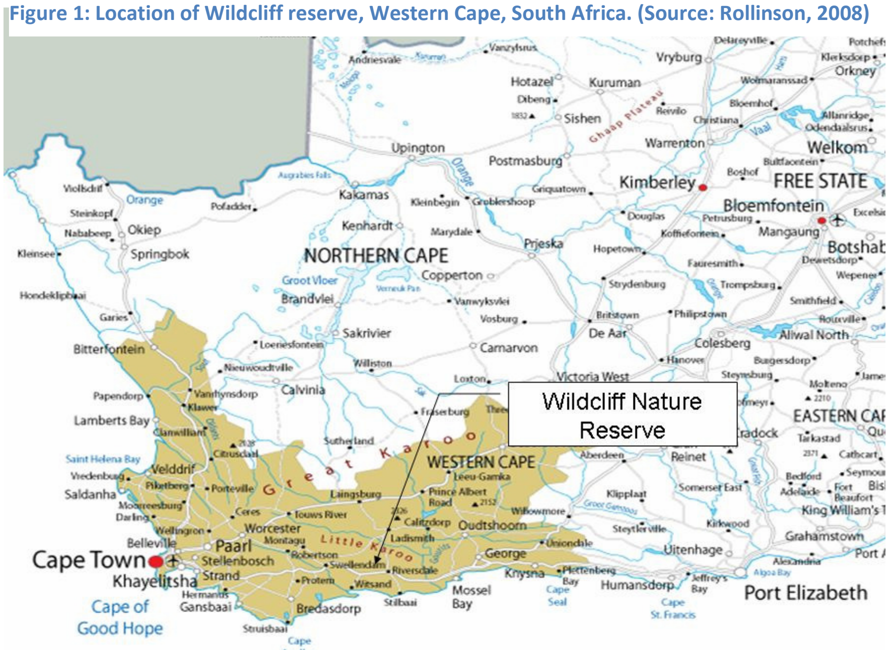
In order to achieve this aim the following objectives will be pursued:

- Establish fire regime history for the past 500 years;
- Establish history of vegetation through selected indicator species represented in a sediment core for the past 500 years;
- Reconstruct vegetation through selected indicator species from fossil pollen; found in hyrax midden samples;
- Collect neo- pollen samples to calculate spatial representation of fossil pollen;
- Apply either RNV or TPC technique to the charcoal and pollen data.

Study area:

The study will be carried out at Wildcliff Nature Reserve, Western Cape, South Africa (Figure 3). The reserve consists of 955 hectares of upland fynbos, as well as containing afro-montane forest in deep kloofs (Giddy, 2008). It is elevated between 290m and 1130m, and is centred around 33°57'S, 21°2E, approximately 17km North- East of Heidelberg (Rollinson, 2008). A small farm was previously located on part of the land. It is located slightly to the East of the winter- all year- rainfall boundary, receiving moisture all year round. However, most rainfall is received in winter. Climate oscillations have occurred in the area in the late Holocene, and a stadial period occurred c. 1570 (Scott and Lee- Thorp, 2004).

Figure 1: Location of Wildcliff reserve, Western Cape, South Africa. (Source: Rollinson, 2008)



There are three wetland areas at Wildcliff, the largest of which is approximately 2-3ha and 1-2m deep. Local knowledge suggests that at least one of these wetlands has existed for a long period of time (though how long is unknown). There are also rocky kloofs and escarpments. No active fire management plan is now in place, although there is currently an informal fire control group. Wildcliff has plans to collaborate with the neighboring provincial reserve for active fire management, and it is possible that the results of this study will help inform future plans.

Methods:

A sediment core will be taken from the wetland areas, and the core with the best stratification and depth will be selected for analysis. It is thought that a core of 1m in depth is likely to represent at least c. 500 years. A Hillier borer will be used to extract from the deepest point of the wetlands. The core will then be sub-sampled at 2cm intervals and stored in cellophane. The samples will then be prepared in accordance with the methods described in Moore and Webb, (1978), and the Point Count Method and total abundance measure will be used for analysis of indicator species pollen. The charcoal analysis will be carried out in accordance with the method recommended as a result of an evaluation of numerous methods by Turner, et al. (in press 2008), whereby a first stage separates macro and meso- charcoal suitable for size measurement, and a second applies the total abundance measure to micro- charcoal. The Point Count Method will be used for all sizes of charcoal particles. A research assistant will be required for coring.

Hyrax midden hyraceum has the physical properties of a brittle plastic, and samples will be extracted using a hammer and chisel. On the W. Cape middens have yielded data representing ~150 years per 1cm (Thomas, et al. 2008). A number of 5cm samples will be collected, sealed in cellophane and sub- sampled at a later date in the laboratory. Drilling has allowed sub- sampling at 2-3cm intervals, and use of a dentist drill can reduce this to <1cm. The laboratory method that will be used for middens is similar to that of the wetland core method (Thomas, et al., 2008). The Point Count Method and total abundance measure will be used and indicator species identified. A dating method will be applied to the samples (both midden and core), but as yet it is unclear what this will be. The dating can however be viewed as non- essential as patterns can still be identified through time in the data.

Modern pollen data may also be collected, but the exact method that will be used is as yet unclear. The collection of modern pollen is likely to be accompanied by use of biogeographical survey data, and software such as ‘Mosaic’ or ‘PolFlow’ (See Gilson and

Duffin, 2007). This will allow for detailed spatial resolution to be applied to palaeo- pollen data. An example of this type of method is provided by Bradshaw, (1981).

Figure 4 evaluates the methods described.

Figure 4:

Method	**Rationale**	**Limitations**
Palaeocore from wetlands	- Continuously accumulated samples representing a period extending from present to pre- colonial time can be obtained. - The sample will contain both fossil pollen and charcoal- representative of the key ecological variables that are the subject of this study. - This is a standard method in palaeoecolgy, and as such there is a wealth of information regarding its application.	- Sample site is remote and large sample volumes are needed. - Quality and extension of wetland records in the region is often poor. - Analysis is time consuming.
Hyrax midden pollen analysis	- Hyrax middens are well distributed in the region and provide an alternative (or additional method) to sediment coring. This is particularly useful if other palaeoecological records, such as wetland sediments, are unavailable or of poor quality (Thomas et al., 2008).	- Middens may be hard to locate in landscape. - Analysis is time consuming.
Collection of modern pollen	- Allows for greater spatial resolution to be applied to the fossil pollen data	- The application of this method is dependent on season and availability of researches at that time.

Anticipated problems and shortcomings:

As has been mentioned, the reliability and availability of palaeoecological data records on the W. Cape is uncertain. This problem has been overcome by using a number of different methods that can potentially be used as alternatives if one method fails. The location and collection of samples could be particularly difficult and time consuming. Therefore a 'buffer period' of two weeks will be added to the anticipated timetable for research.

The timescale that this research proposes to study is much shorter than those suggested by many who have reviewed both palaeoecology and its applications to conservation. This is due, first, to the potentially limited quality of available records relating directly to Wildcliff reserve. Second, it is because of limits to time and resources. However, these are problems likely to be faced by most aiming to use long- term ecology for conservation and land management. This means that something positive can be taken from a conceived shortcoming: this research will incorporate 'real life' problems faced by conservationists and land managers, therefore serving as an exercise in 'applied palaeoecology'.

Preliminary research timetable:

Monday 21st July- arrive at Wildcliff Nature Reserve;

Friday 1st August- complete field research;

Saturday 2nd to Saturday 16th of August- 'buffer' research period;

Friday 24th October- Progress report;

Friday 31st October- Complete data analysis;

Friday 5th December- First draft submitted;

Friday 6th February (2009) - Final draft.

References:

Bond, W. J. (1997). 'Functional types for predicting changes in biodiversity: a case study in Cape Fybos' in Smith, et al. (1997) 'Plant Functional Types'. Cambridge University Press, UK.

Battarbee, R. W. (1989) 'Geographical research on acid rain: The acidification of Scottish Locks.' The Geographical Journal. Vol. 155, No. 3 pp353- 377.

Birks, H. J. B. (1996). 'Contributions of Quaternary palaeoecology to nature conservation'. Journal of Vegetation Science. 7. 89-98.

Bradshaw, R.H.W. (1981). 'Modern pollen representation factors for woods in South- East England.' The Journal of Ecology. Vol. 69, No. 1.pp 45-70.

Cowling, R. M. and Richardson, D. (1995). 'Fynbos: South Africa's unique floral kingdom'. Tien Wah Press, Singapore.

DeBano, L., Neary, G., Ffolliott, P. (1998). 'Fire's effects on ecosystems.' John Wiley and Sons Ltd, Canada.

Fielder, P. L., White, P. S. and Leidy, R. A. (1997). 'The paradigm shift in ecology and its implications for conservation' in Picket, S., Ostfeld, R. and Shachack, M. (eds) 'The ecological basis for conservation: heterogeneity, ecosystems and biodiversity.' Pp. 83- 92. Chapman and Hall, NY.

Giddy, I, (2008). 'Wildcliff Nature Reserve'. www.wildcliff.org. Accessed 3/04/08.

Gillson, L and Duffin, K. I. (2007). 'Thresholds of potential concern as benchmarks in the management of African savannahs' Philosophical Transactions of the Royal Society:B. 362. pp 309-319.

Gil- Romeria, G., Scott, L., Marias, E., Brook, G. (2007)'Late Holocene environmental change in the North Western Namib desert margin: new fossil pollen evidence from hyrax middens.' Palaeogeography, Palaeoclimatology, Palaeoecology. 249, 1-2. pp 1-17.

Huntley, B. (1996). 'Quaternary palaeoecology and ecology.' Quaternary Science Reviews. 15. Pp 591-606.

MacDonald, D.J. and Cowling, R.M. (1993). 'Towards a profile of an endemic mountain fynbos flora: Implications for conservation.' Biological Conservation. 72, 1. pp 1-12.

Meadows, M. E. and Baxter, A. J. (2001). 'Holocene vegetation history and palaeoenvironments at Klaarfontein Springs, Western Cape, South Africa.' The Holocene. 11. 6. pp 699-706.

Meadows, M. E., Baxter, A.J. and Parkington, J. (1996). 'Late Holocene environments at Verlorenvlei, Western Cape Province, South Africa.' Quaternary International. 33. 81-95.

Moore, P.D. and Webb, J.M. (1978). 'An illustrated guide to pollen analysis'. Hodder and Stoughton, London.

Naveh, Z. (1974). 'The evolutionary significance of fire in the Mediterranean region.' Plant Ecology. Vol. 29. 3. pp 199-208.

Rollinson, N. (2008). 'Surveying amphibians, identifying chameleon habitat and developing long-term monitoring programmes at Wildcliff Nature Reserve, South Africa.' Research Proposed of May, June and July, 2008. Available at www.wildcliff.org accessed 3/04/08

Scott, L. and Woodborne, S. (2007). 'Pollen analysis and dating of late Quaternary faecal deposits (hyraceum) in the Cedarberg, Western Cape, South Africa.' Review of Palaeobotany and Palynology. 144, 3-4. 123-134.

Scott, L. and Lee- Thorp, J. (2004). ‘Holocene climatic trends and rhythms in Southern Africa.’ In Battarbee, R. W., Gasse, F. and Stickley, C. E. (eds) ‘Past climate variability through Europe and Africa.’ Springer, The Netherlands.

Sweetnam, T.W., Allen, C.D. and Betancourt, J.L. (1999). ‘Applied historical ecology: using the past to manage the future.’ Ecological Applications. Vol. 9, No. 4 pp 1189-1206.

Thomas, D., Chase, B., Meadows, M. and Scott, L. (2008) ‘Fossilized herbivore middens: New perspectives on South West African climate change.’ Oxford University School of Geography ongoing project (2006-2009). Details available at www.geog.ox.ac.uk/research/arid-environments accessed 18/03/08.

Turner, R., Kelly, A., and Roberts, N. (in press 2008). ‘A critical assessment of the methods used to extract and experimental comparison of microscopic charcoal from lake sediments’ in: G. Fiorentino and D. Magri (eds) ‘Charcoal from the past: Cultural and palaeoenvironmental implications’. Proceedings of the Third International Meeting on Anthracology. Cavallino (Lecce), June 2004. Bar International Series, Archaeopress, Oxford, UK.

Whitlock, C., Shafer, S.L., and Morlan, J. (2003).’The role of climate in shaping past and future fire regimes in the North- West US, and implications for ecosystem management.’ Forest Ecology and Management. 178. 5-21.

Willis, K. J. and Birks, H.J.B (2005) ‘What is natural? The need for a long- term perspective in biodiversity and conservation’. Science. 314 pp 1261- 1265.

Willis, K. Araujo, M., Bennet, K., Figueroa- Rangel, B., Froyd, C., and Myers, N. (2007).’How can knowledge of the past help to conserve the future? Biodiversity conservation and the relevance of long- term ecological studies’. Philosophical Transactions of the Royal Society: B. 362, 175- 186.

Zazula, G., Froese, D., Westgate, J., La Forge, C. and Mathews, R.W. (2005). ‘Palaeoecology of Beringian ‘packrat’ middens from central Yukon Territory, Canada.’ Quaternary Research. 63. 2. 189-198.