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Environmental change in Australia and Brazil during last glacial maximum (LGM): major events and trends for biogeography research

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ABSTRACT

Distribution patterns of vegetation around the world are strongly influenced by the climatic factors, and afterwards, the study of vegetacional changes along time should always be in a tight relation with climate. This article will provide an overview of the modern characteristics of Australian and Brazilian humid tropics (rainforests and dry forests ecosystems), as well, along the Last Glacial Maximum (LGM), as focusing on Quaternary environmental upheavals and some trends for Biogeography research. After discussion of papers published during 1991-2008, it was presented research trends related to paleoecology sites and cores analyzed, focusing on three major features: human driven alterations, evolutionary biogeography/conservation and phytoindication and its relation to climate change. It can

be concluded that the features of these ecosystems and their range of response to environmental change are applicable to the both characteristics of similar biomes located in the tropical regions of Brazil (South America) and wet tropic Region (Australia).

PALAVRAS CHAVE:
Floresta Tropical
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Tendências em Biogeografia
UMG

RESUMO: MUDANÇAS AMBIENTAIS NA AUSTRÁLIA E NO BRASIL DURANTE O ÚLTIMO MÁXIMO GLACIAL (UMG): UMA REVISÃO COM FOCO NOS PRINCIPAIS EVENTOS E TENDÊNCIAS PARA A PESQUISA EM BIOGEOGRAFIA. Os padrões de distribuição da vegetação ao redor do mundo são fortemente influenciados por fatores climáticos e, consequentemente, o estudo de mudanças vegetacionais ao longo do tempo deve sempre estar em estreita relação com o clima. Este artigo irá fornecer uma visão geral das características das áreas tropicais úmidas modernas da Austrália e do Brasil, bem como, ao longo do Último Máximo Glacial (UMG), com foco em algumas tendências para a pesquisa em Biogeografia. Após a discussão de artigos publicados durante 1991-2008, foram apresentadas tendências de pesquisa relacionadas a locais e registros paleoecológicos analisados, com foco em três aspectos principais: alterações de origem antrópica, biogeografia evolutiva / conservação e fitoindicação e sua relação com as mudanças climáticas. Pode-se concluir que as características desses ecossistemas e o âmbito de suas respostas às mudanças ambientais são aplicáveis para ambas as características de biomas similares localizados nas regiões tropicais do Brasil (América do Sul) e trópico úmido (Austrália).

PALAVRAS CHAVE:
Bosque tropical
Cambio ambiental
Tendencias en Biogeografía
UMG

RESÚMEN – CÂMBIOS AMBIENTALES EN AUSTRÁLIA Y BRASIL DURANTE EL ULTIMO MÁXIMO GACIAL: UNA REVISION CON ÉNFASIS EN LOS PRINCIPALES EVENTOS Y LAS TENDENCIAS DE INVESTIGACIÓN EN LA BIOGEOGRAFIA. Los patrones de distribución de la vegetación en todo el mundo están fuertemente influenciados por factores climáticos y por lo tanto el estudio de cambios de vegetación en el tiempo siempre debe estar en estrecha relación con el clima. En este artículo se proporcionará una visión general de las características de las modernas zonas húmedas tropicales de Australia y Brasil, (bosques tropicales y sequías), así como en todo el Último Máximo Glacial (UMG), centrándose en los cambios ambientales del Cuaternario y en algunas tendencias de investigación en Biogeografía. Después de la discusión de los artículos publicados durante 1991-2008 se presentaron las líneas de investigación relacionadas con los locales y registros paleoecológicos analizados, enfocándose tres aspectos

principales: los cambios de origen antropogénico, biogeografía evolutiva / conservación y fitoindicação y su relación con el cambio climático. Se puede concluir que las características de estos ecosistemas y el alcance de sus respuestas a los cambios ambientales se aplican a biomas con características similares que se encuentran en las regiones tropicales de Brasil (América del Sur) y en los trópicos húmedos (Australia).

Introduction

Even Brazil and Australia being countries with continental dimensions, little is known about the evolution of distributional patterns of vegetation during the Quaternary, including the Last Glacial Maximum (LGM), a crucial period to understanding the processes that culminated in the current frame of the distribution of biomes.

Last glacial maximum environments were influenced by cold climates, likely caused by increased frequency of Antarctic fronts, which reached farther northward and had a higher influence in southeastern Brazil during the last glaciations than they do today (BEHLING; LICHTE, 1997).

In southern and southeastern regions of Brazil, through the interpretation of eight pollen records, asserts that large highland areas including mountain areas, were covered with grasslands during the last glacial, what reflects a dry and colder climate, and it's possible that these grasslands, today common at Santa Catarina State, expanded northward, occupying areas of southeastern region. During the late glacial *Araucaria* forests were rare in southern regions, probably only existing in places whose moisture availability permitted the development of such kind of vegetation and according to Behling; Lichte (1997), there is no evidence that *Araucaria* gender expanded northward during the LGM.

Poaceae records along lake records on Central-West Brazilian region have pointed out human settlements presence across Brazil territory since many years before to usually has been accepted for anthropology field studies. These cases of a paleoclimate and paleogeographic approach research are being carried in these areas through charcoal, ashes and pollen samples evidences as such (ADAM, 1994; BEHLING; LICHTE, 1997; MOSS KERSHAW, 2000).

LGM environmental change alterations in Australia and Brazil: Major events and shift patterns

Acacia forms the canopy of the majority of vegetation types, it has very low pollen representation due to poor dispersal ability. In this arid landscape, the vegetation appears to have been relatively insensitive to global scale climatic cyclicity. Apparently, the extent of eucalypt vegetation was lowest between c. 35 000 and 20 000 years ago, suggesting lowest rainfall towards the end of the last glacial period.

The area is within the transition between monsoon-influenced areas to the north where, regionally, *Acacia* species and some *Eucalyptus spp.* form open shrub and/or woodland covers respectively above a hummock grass understored,

and westerly wind belt-influenced areas to the south dominated by *Acacia* shrubland, as founded (Cyperaceae) found on Atherton Tableland. Consequently rain can be received in both summer and winter. Chenopodiaceae can be important components of the vegetation, and extensive areas of chenopodiaceous (saltbush) shrublands occur in coastal areas to the south of the site.

Furthermore, the Ocean Deep Point (ODP) number 820 (ODP 820)core contains a significant terrestrial sediment component that is suitable for pollen and charcoal analysis, which provides the opportunity to examine Quaternary vegetation change in the region, as well as allowing a direct comparison between marine and terrestrial environmental change. The initial pollen analysis of the ODP 820 marine core (see figure 1) revealed that, for much of the last 1.4 million years the vegetation of the region was quite stable, being dominated by araucarian dry rainforest.

AUSTRALIAN LOCATION SITES - 2005

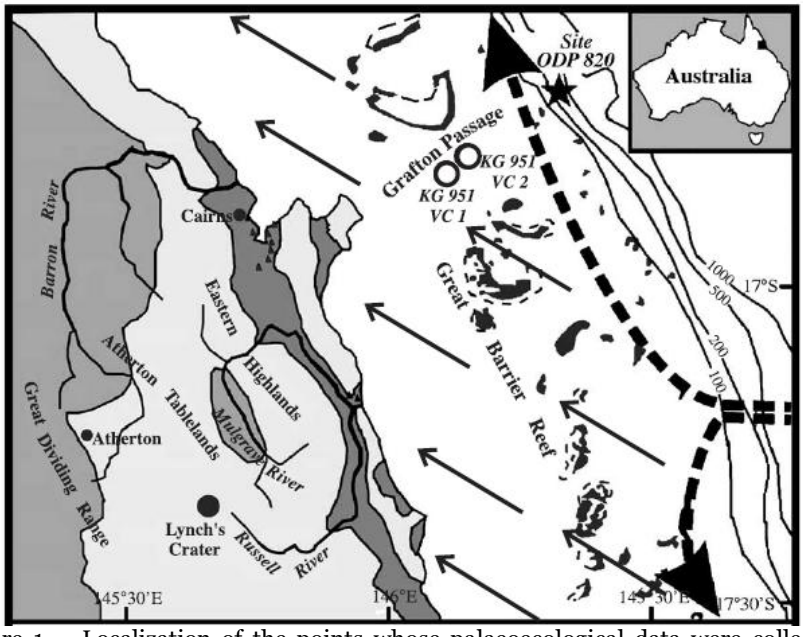

Figure 1 – Localization of the points whose palaeoecological data were collected in the analysed papers. (Image: MOSS, KERSHAW, GRINDROD, 2005)

Significant sclerophyll taxa include Casuarinaceae and Poaceae, while the aquatic taxon Cyperaceae maintained significant values through the length of the core. However, there are a number of important alterations in the ODP 820 pollen record (KERSHAW, 1994). The early to middle sections (~1.4 to ~1 Ma) of the core show the presence of *Dacrydium cupressinum* Lamb., *Dacrycarpus sp.* and *Nothofagus Brassospora*, which is similar to the Butcher's Creek record from the Atherton Tablelandwich is located within Lynch's crater (figure 1). These taxa disappear from the core around a million years BP, and this loss is consistent with

the disappearance of these taxa from all other parts of Australia by this time (KERSHAW; MOSS; WILD, 2005).

Remnant *Araucaria* trees located on Magnetic Island and other offshore islands of northeastern Queensland. In general, the community type found in southeastern Queensland, is thought to be similar to the araucarian dry rainforest that occurred in northeastern Queensland, is composed of two strata. The lower stratum is 6–18 m tall, continuous and composed of a number of different species, while the upper stratum is composed of tall (>30 m) emergent *Araucaria* trees like *Araucaria bidwillii* Hook. (Bunyan Pine) (ADAM, 1994).

During the late glacial *Araucaria* forests were rare in southern regions, probably only existing in places whose moisture availability permitted the development of such kind of vegetation and according to Behling; Lichte (1997), there is no evidence that Araucaria expanded northward during the LGM.

The occurrence of *Araucaria* and *Podocarpus* within the late glacial reflects somewhat wetter environmental conditions. The record of Catas Altas (20°05'S, 43°22'W) also indicates widespread grassland, but with *Araucaria angustifolia* (Bert.) O. Kuntze forming gallery forests along watercourses (BEHLING, 2002).

This range of *Araucaria* can be explained by the fact that the species needs a subtropical climate without significant dry period to develop, and the climate being colder and dryer during the last glacial maximum the development of this kind of vegetation was possible only in places with higher moisture availability.

In Atlantic lowlands, there is no evidence of *Araucaria angustifolia* during the last glacial and the Atlantic forest was probably reduced to a narrow belt between the coast and the Serra do Mar and probably did not exist between Serra do mar and Serra da Mantiqueira (Southeast region – Minas Gerais and Rio de Janeiro States), as it does nowadays and cloud forests similar as those found at this regions did not exist during the glacial times. Expansion of *Araucaria* forests probably only began about 3000 yr B.P., indicating a wetter environment than before.

Since 1000 yr B.P., the expansion of *Araucaria* covered the highland grassland campos of Santa Catarina state and in Paraná state since about 1500 yr B.P. The southeastern cerrado vegetation was marked larger in early Holocene than in late Holocene, and probably expanded eastward, towards Atlantic Ocean, what can be the explanation for modern enclaves of cerrado in semideciduous forests, reflecting a larger distribution of this kind of vegetation earlier in Holocene, suggesting a longer dry period of five or six months during this period (BEHLING, 2002).

These shifts on species range can be related to a cold and dry climate during the LGM (BEHLING; LICHTE, 1997), with a cooling of 5°C or according to other authors of 5-7°C (BEHLING; NEGRELLE, 2001) or 5° to 6°C (CAULINVAUX et al., 1996).

Other changes which give rise to major debates and controversies are those that occurred in the Amazon landscape during the LGM.

The Amazon rainforest is the largest forest ecosystem, representing near 50% of the total tropical rainforest area on Earth. The Amazon forest plays a significant role in global climate, the carbon cycle and biodiversity. To understand the Amazon rainforest ecosystem, and how it may respond to future changes,

paleoenvironmental and paleoecological studies are important. During the Ice Age, the Amazon forest was extremely reduced, but the existence, during this period, of the so-called Forest Refugia (islands of forest) is still being debated, since number of records is scarce (BEHLING et al., 2001).

During the late glacial period, the records of Lagoa do Curuça (0°46'S, 47°51'W) indicates that dense and tall tropical rain forest occupied that region, and no evidence of non-forest formations were found. The pollen record still indicates that the species composition of Amazon forest during the LGM was different from the composition of early Holocene vegetation or Amazon recent one (BEHLING, 2002). The record from Lago Calado (3'16'S, 60'35'W), from late glacial period, indicates an area influenced by long-term water level changes, caused by the Quaternary sea-level fluctuations, and also by seasonal water level variations of the Amazonian drainage system, including a period of development of the palm-swamp genus *Mauritia* (BEHLING et al., 2001), what reflects a high moisture availability period. (See figure 2).

Figure 2 – Localization of the points whose palaeoecological data were collected in the analysed papers. (Image: Idealization by the authors, 2010).

The appearance of *Podocarpus* and the interpretation of colder conditions on Amazon rainforest quaternary sediments reach different ages on other records. At Lagoa do Caçó (2°58'S, 43°25'W), the Phase 3 of the record (13,000 to 11,500 ^{14}C yr BP; 15,000 to 14,500 cal yr BP), register an increase of *Podocarpus*, what denotes a cool and moist climate conditions in late glacial period. (LEDRU et al., 2001). At about the same age *Podocarpus* is also found at Lagoa do Curuça record (0°46'S, 47°51'W), but with an extended distribution throughout the

record reaching the zone CUR A3 dated of 10,270 to 9,600 uncal yr BP. The pollen signal of *Podocarpus* is followed by high values of Amazonian pollen taxa, indicating wet climatic conditions (BEHLING; NEGRELLE 2001).

Abundant herb pollen, and the presence of species like *Curatella Americana* L., indicate the development of a *campo Cerrado* vegetation in Lagoa Nova region during the early Holocene where nowadays close and dense semideciduous forest predominates. The increase of pollen concentration and accumulation may indicate an increase in vegetation cover, forests were not very extensive and probably occurred only in river courses. *Cecropia* increases continuously throughout the early Holocene zone of this record, what means an expansion of gallery forests as well as disturbances caused by fire. Between about 8560 and 7560 BP, the gallery forests probably expanded into the *cerrado*, and between about 7560 and 6060 BP *cerrado* expanded into forest, being replaced again by gallery forest at the end of this period. The *cerrado* expansion could have been a consequence of lower annual precipitation and a longer dry season and by the hire frequency of fires (BEHLING, 2003). Since mid Holocene, at São Francisco de Assis region, subtropical gallery forests developed along rivers. The plant diversity of this forest was at that time relatively low, represented only by a few tree species (BEHLIN; PILLAR; BAUERMAN, 2005).

Material and Methods

Papers were selected based on descriptors environmental change, Last Glaciation Maximum (LGM), Quaternary among others which have been published in international journals on English between 1991-2010 years. It was selected a final amount of 30 papers twenty of which were related to Brazilian sites and ten cases relating to Australian ones, covering nearby twenty different authors.

A second criterion consisted unselect the areas of occurrence of palaeo records: Australia and Brazil.

Furthermore, it has been cross-classified of the descriptors with the occurrence of areas that have been refined to the records located in biogeography realms (bioregions): Amazon Forest and Atlantic Forest (Brazil - Figure 1) located at North and Southeastern Brazilian Regions. Australian case studies (tropical and dry rainforest realms and some remnants) records are focused on Atherton Tablelands and Cairns Region, besides the section of the ***Ocean Deep Point (ODP*** site) ***820 marine core*** water depth. 280 m, located at 16838VS, 146818VE at South Pacific Ocean (Northeast Queensland coast).

The sites location and its representativeness were defined due to number of occurrences and citations references in selected papers besides cross-reference citations double checking. After reading, each record was classified by sort of palaeo samples (ashes, charcoal and pollen) in an ascending frequency way for absolute occurrences numbers in the array of papers within the set of papers. Finally, it was proceeded a records correlation long-term analysis (synchronic/diachronic) to highlight correlations between the events recorded into palaeo palynology sequences under LGM for the two areas (35,000 to 12,000 YBP).

Long-term analysis and C_{14} and others isotopes records dating analyzed along the papers articles permitted To establish current trends in Biogeography research on the specified themes of human driven alterations, evolutionary biogeography/conservation/landscapes systems and phytoindication/climate change allowed points out significant gaps in knowledge from research questions which have founded within chosen papers.

Major trends on biogeographic research

Human driven alterations

In the absence of any known major global climate change around this time, they consider that burn- 92 A.P. by Aboriginal people was responsible for this initial vegetation change. They suggest further that more open vegetation was then sustained, even during the wetter Holocene period, by the reduction in moisture feedback between the vegetation and atmosphere

Human activity in the studied areas are generally deduced from the records by the increase of carbonized particles, when it is not associated with natural fires characteristic of vegetation dynamics or when supported by strong archaeological evidences; from the presence of exotic pollen taxa associated to crops or, more recently, of exotic pollen taxa used in reforestation projects and, more uncommonly, from signals of deforestation like the appearance of species characteristic from disturbed environments.

In Amazon rainforest is expressive the presence of “terra nigra” (black soil) traces in samples as example of human settlement presence in region during millennia before preset time. Fires associated to anthropogenic action are deduced from increasing of charcoal particles since early Holocene, reaching higher values also in 1650 ^{14}C yr BP (BEHLING; PILLAR; BAUERMAN, 2005). The higher occurrence of Poaceae pollen at the beginning of the zone samples may suggest some opening of the forest that perhaps reflects human activity (BEHLING; NEGRELLE, 2001). According to Behling (2002), charcoal records indicate that palaeofires were frequent in the Amazon rainforest and borders of Atlantic rainforest evidences setting through the same direction.

Aboriginal people had been a presence recorded on landscape concerning human alteration in some transitional areas of Atherton Tablelands through open pockets as resulting of fire management of forest regions for human survivor (KERSHAW, MOSS, 2007).

Evolutionary biogeography / conservation / landscape systems

It´s possible to point out an evolutionary trend of ways to dryer environments in Austrália shifting wet tropics into a dryer bioregion as in the long past along glacial period. Such ttrend is shown into parts of Amazon and Atlantic Forest understorey areas, as well as tropical rainforest in Australia.

This kind of shifting trends on landscapes systems to allow opening of an specified research field agenda for that is what the paper intends to point in Biogeography research trends, specially about extension, location and stability process in tropical rainforests (ASH, 1988).

Rather than thinking always in the long run, it’s important highlights a major gap and lack of scientific certainty evidenced by data about the influence of

Environmental Change on the expansion / retraction of the realms, only controlled by climate oscillations in the long term. However, the same framework is not entirely applied on the standards of expansion / retraction of key species along time cycles. (KERSHAW; VAN DER KAARS; MOSS, 2003).

Besides all that facts, a promising research biogeography trend can be devised along papers regarding environmental change process implications on physiognomic formations and ecological succession in Australia and Brazil as well.

Phytoindication / Climate change

A dramatic change in vegetation and fire activity is also seen around 150,000 to 120,000 years BP in which the araucarian dry rainforest decline and sclerophyll taxa, mainly Poaceae and Myrtaceae, increase, as well as an associated peak in charcoal values, suggesting increased burning (KERSHAW 1994). Kershaw Has demonstrated in several works (2003, 2003a) how vegetation has responded to orbital forcing in northeastern Australia, with clear interglacial/glacial periods associated with variation in rainfall being observed during the late Quaternary. That is rainforest expand with the wet interglacial periods, which then contract during the longer duration drier glacial phases and are replaced by sclerophyll arboreal communities and/or araucarian dry rainforest.

Conclusion

In general, it can be observed that the Amazon basin retained its forests during the Last Glacial Cycle, not existing direct evidences suggesting a fragmentation in the Pleistocene (COLINVAUX; DE OLIVEIRA, 2000). Through the records here presented, it was noticeable that the main shifts on Amazon rainforest communities were within the range of floristic composition, but not physiognomic, i.e. there was no major canopy opening and no replacement of the forest by savanna vegetation where currently exists rainforest. According to Colinvaux; De Oliveira (2000), it seems clear that open savanna such as “cerrado”, could not be present in a region without a prominent appearance of grass in the pollen sum.

Apparently the change in water balance, through a direct reduction of precipitation, lengthening of dry season, or lowering of water table, was not sufficient to disrupt the forest. The moisture regime remained within the tolerance of most rainforest taxa (COLINVAUX et al., 1996) and forest cover has been continuous through the glacial times, with no minor adjustment of ecotonal boundaries in the southwest (COLINVAUX; DE OLIVEIRA, 2000) as suggested by Behling; Hooghiemstra (2000) for the range of savanna registered in Laguna Loma Linda record for the early Holocene (8,720 to 6,060 ^{14}C yr BP), that could have reached 100 km farther south.

It can be seen that these ecosystems as such Australia Wet Humid Tropic such as Brazilian Amazon and Atlantic Rainforest cores are heavily influenced by modern environmental factors, particularly precipitation, temperature, underlying geology and soil type, and as such share a number of similarities

across tropical biomes from the Northeastern Australia and South America rainforests.

The tropical mesophyll rainforests of the Australian humid tropics appear highly resilient to climatic variation (KERSHAW 1994). This is particularly evident for the late Quaternary period, with mesophyll rainforests rapidly expanding across the region in response to higher precipitation levels that characterise interglacial periods and a similar response has been identified in palaeoecological records from other comparable tropical regions throughout the globe (MORLEY, 2000).

This resilience is further demonstrated through the response of the Australian tropical evidence from the ODP 820 core and the various records from the Atherton Tableland suggest that mesophyll rainforest had fully re-established across the region by ~8000 years ago and that increased burning associated with people only delayed its return; (KERSHAW, 1994; MOSS; KERSHAW, 2003,b). These findings provide some optimism for the future of this biome in the face of future climate change and human impacts on these ecosystems.

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