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Article

2001

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How to cite

RAY, Nicolas, ADAMS, Jonathan. A GIS-based vegetation map of the world at the Last Glacial Maximum (25,000-15,000 BP). In: Internet archaeology, 2001, vol. 11. doi: 10.11141/ia.11.2

This publication URL: <https://archive-ouverte.unige.ch/unige:17817>

Publication DOI: [10.11141/ia.11.2](https://doi.org/10.11141/ia.11.2)

A GIS-based Vegetation Map of the World at the Last Glacial Maximum (25,000-15,000 BP).

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Abstract

A preliminary, broad-scale vegetation map reconstruction for use by archaeologists and anthropologists is presented here for the world at the Last Glacial Maximum (18,000 BP, but broadly representing the interval from 25,000 to 15,000 BP). The global LGM map was produced from a range of literature and map sources, and drawn on a GIS with topographic information. Extended coastlines due to LGM sea-level drop were obtained using bathymetric information. The map is available in image and Geographic Information System (GIS) formats, on a global or regional basis.

Accompanying each regional map is a bibliography detailing the principal literature sources of evidence on Late Quaternary palaeovegetation and climates. The maps presented here are merely a preliminary attempt at appraisal of current knowledge and opinion, and future updated versions will be produced as more information on LGM environments becomes available. Nevertheless, together with the accompanying citation summary they should provide a valuable and readily accessible source of information on current opinion in the Quaternary community. It is also hoped that the maps will themselves act as a catalyst for archaeologists to use their own data to contribute to the broader climatic/palaeovegetational picture.

Résumé

Cet article présente une carte globale de la reconstitution de la végétation pour la période du dernier maximum glaciaire (18,000 ans BP mais représentant un intervalle de 25,000 à 15,000 ans BP). La carte a été reconstruite à partir de diverses sources de la littérature (articles et cartes), et introduite dans un Système d'Information Géographique (SIG), accompagnée d'une couche d'information sur la topographie. Les lignes côtières à la période considérée, plus étendues qu'aujourd'hui dû à une baisse du niveau des océans d'environ 120m, ont été

obtenues en utilisant des données bathymétriques. La carte est disponible en formats SIG et image, à une échelle régionale ou globale.

Chaque carte régionale est accompagnée d'une bibliographie détaillant les principales sources de la littérature sur la paléovégétation et le paléoclimat du Quaternaire tardif. Les cartes présentées ici peuvent être considérées comme une évaluation des connaissances et opinions du moment, et des versions mises à jour seront produites lorsque de nouvelles informations sur les environnements au dernier maximum glaciaire seront disponibles. Néanmoins, avec les références qui les accompagnent, ces cartes devraient fournir une source d'information pertinente et immédiatement accessible sur les opinions actuelles de la communauté du Quaternaire. Elles agiront aussi, on l'espère, comme agents catalyseurs afin que les archéologues contribuent, de par leurs données, à une meilleure compréhension des informations paléoclimatiques et paléovégétales.

Keywords: VEGETATION, GLACIAL MAXIMUM, HUMAN ECOLOGY, TOPOGRAPHY, GIS.

1 Introduction

In archaeology and anthropology there is now a great deal of interest in the global climate fluctuations which have occurred repeatedly over the last 2-4 million years, during the Quaternary period. In part, this interest reflects the hope that better understanding of the Earth's recent past will allow improved prediction of future human effects on the environment. There is also a great deal of purely academic curiosity amongst archaeologists, anthropologists, ecologists, climatologists, and biogeochemists about the ways that the global environment has changed during the recent past, and the way in which each aspect of the global system has interacted with others. In archaeology, it is becoming increasingly clear that it is necessary to include the study of the shifting climatic and ecological background if an understanding of the behaviour and movements of peoples is to be reached. A great deal of interesting work has begun to appear as a result of taking an "environmental" approach to human evolution and history (e.g. work by Ortloff and Kolata 1993; Wright 1993, Steele J et al. 1998, Anderson and Gillam 2000). Yet archaeologists and anthropologists, together with other Quaternary scientists, have difficulty obtaining the basic background information that exists in such a scattered form throughout the literature.

To make this task easier, and to aid understanding of how the Earth has changed since the peak of the last ice age (and the main sources of evidence for deducing these changes) around 18,000 radiocarbon years ago (or around 20,000-21,000 calendar years ago, allowing for the relative changes in ^{14}C abundance), we present here a set of maps depicting the world's changing vegetation cover on a region-by-region basis. The maps were compiled by the authors, based on modification and improvement of the earlier Quaternary Environments Network (QEN) <<http://www.soton.ac.uk/~tjms/adams1.html>> vegetation maps (Adams and Faure 1997).

There remains considerable room for disagreement about the history of certain parts of the late Quaternary world. The maps presented here certainly cannot be regarded as the definitive work on the subject: instead they represent a necessary step in the

process of assembling data and opinion from the many scientists who work on vegetation reconstruction. Anyone using these maps is urged to consult the description of methods presented in the following pages, to get some idea of the uncertainties that remain. Certain aspects of the maps remain to some extent controversial and they represent the views of the authors, not necessarily those of individual (although we have encountered broad support, and have made effort to consider the advice of every participant). Some marked disagreements in approach and overall conclusions were evident amongst the scientists who contributed to the Network, but despite a few wayward voices, a striking overall consensus was present.

As well as providing a ready source of information for archaeologists, we also hope that our maps may prove useful to those within the Quaternary palaeoecology community. As a coherent map of global vegetation for a particular interval in the past, it should act as a baseline for further work in vegetation reconstruction - even if only as a target for criticism.

2 The Last Glacial Maximum (LGM)

Although time is, of course, a continuum, it has been necessary here to concentrate the reconstructed scenarios around a particular slice of time, the Last Glacial Maximum (LGM), that seems particularly significant in relation to the processes taking place in the global system. We feel that the particular choice of this time slice here is likely to coincide with the interests of many others in archaeology, anthropology and palaeoecology. Other time slices such as the Younger Dryas (approx. 10,800-10,200 ¹⁴C years ago) are of similar interest, and we plan on producing updated maps in electronic format for different time slices in the near future (earlier maps are available as images at the QEN website <http://www.soton.ac.uk/~tjms/adams1.html>).

The LGM time-slice is placed at around 18,000 years ago in radiocarbon years. It is now thought that 18,000 years ago in radiocarbon terms corresponds to about 20,000-21,000 years ago in calendar years (Crowley and North 1991). We can consider, however, that the LGM *sensu stricto* is representative of the broader interval from 25,000 to 15,000 BP, during which climate was very similar in most areas. In this paper, our LGM maps refer to this slightly broader time interval, the LGM *sensu lato*.

The LGM is seen as the stage during the last glacial cycle at which the greatest mass of ice was present on Earth, showing up in ice cores and carbonates as a peak of ¹⁸O (Crowley and North 1991). It is also thought of as being the time at which other components of the ocean-atmosphere system were at their most "glacial" (e.g. lowest global temperatures, lowest atmospheric CO₂ concentration, and apparently greatest aridity in many continental regions). In fact, there are numerous signs that not all attributes and processes reached their peak of "glaciality" (in the sense of maximum cold, maximum ice extent, and maximum difference in water balance relative to the present) at exactly the same time during the last glacial phase; for example Colinvaux (1987) suggests that the lowest temperatures and maximum glacier extensions in tropical uplands may have occurred several thousand years before those at higher latitudes. In contrast, in the mountains of Africa and in the equatorial region of the Far East, at least some glaciers reached their maximum size well after the 18,000 years ago date, at around 15,000 ¹⁴C years ago (Crowley and North 1991; Markgraf 1993; Street-Perrott and Perrott 1994).

It is important to bear in mind that in some areas for which there is continuous well-dated evidence, climates only a few thousand years before or after 18,000 radiocarbon years ago can be shown to have been quite different from the LGM itself, often being much moister. The LGM phase was relatively brief (lasting for perhaps 2000 calendar years, and depending on the precise definition that one is using) and only the most extreme part of a globally cold and dry phase.

3 Methodology

3.1 A top-downwards approach

Throughout the process of putting together the LGM map, the emphasis has been on a pragmatic top-downwards approach. Regional experts are consulted on the basis of their own published reviews and maps; these experts discuss the problems and uncertainties in the evidence with the authors, and recommend key paper for them to read. The authors then return to each contributor in order to check that what has been written in the database is factual and reasonable. More extensive description and discussion of the methodology used here can be found in Adams and Faure (1997).

In summary, the LGM map is based on the following sources of data:

- Plant fossil data

Plant fossil data (macro- and micro-), the most direct and trustworthy source of information on past vegetation, are still very patchy for around the time of the Last Glacial Maximum, some 18,000 radiocarbon years ago. Because plant fossils can sometimes give a misleading picture of the local vegetation, due to biases in preservation (Adams and Faure 1997), it is necessary to supplement this information with other sources.

- Proxy data sources: zoological and sedimentological information.

Many other sources of data that can serve as proxy indicators of past vegetation cover and structure. Particular species of animals are found to be strongly associated with particular vegetation conditions in the present world, so their fossils can be used as a rough indicator of the ecology of an area in the past.

Sedimentological processes are often dependent on vegetation cover, either in the area where the sediment is being deposited or the area from which it is being eroded. A particular sediment grade or type of depositional structure can often give clues as to the type of vegetation that once existed there, although it is possible to be misled by processes in the past giving the same result by different means.

More tenuously and controversially there are biogeographical clues based on the present day distributions of animals and plants, which may be partly a legacy of the changed vegetation and climate conditions which existed during recent glacial phases, although not necessarily the most recent one. Generally, present-day biogeographical evidence must be regarded as taking lowest priority because it is the most ambiguous and the least direct. Here in the debate that has given rise to the maps, biogeography has been used only to back up or dispute patterns suggested on

the basis of palaeoenvironmental evidence, not as a primary source of ideas and opinions.

The approach used to produce the initial QEN maps and the maps presented here is thus highly interdisciplinary, in contrast to most previous attempts at broad-scale vegetation reconstruction for the Holocene and Last Glacial Maximum.

The problems of dating the evidence

An additional problem is that accurate dating is often lacking from deposits of palaeoenvironmental significance. This is especially so for well-oxidized or terrestrial sedimentary deposits such as sand dunes where there is little surviving organic matter that can be used for ^{14}C dating. Fortunately the range of direct and correlative dating techniques is expanding (for instance, optical dating of the quartz in sand dunes is now becoming widely used), and the accuracy of existing methods is also improving. Nevertheless, many sites which have been taken as revealing conditions under the Last Glacial Maximum remain poorly dated or even totally lacking in any real dating control. Obviously, such sources of evidence must be treated with more caution than those which have been thoroughly dated, and the decision whether to accept them or not is ultimately subjective and, of course, potentially clouded by one's own preconceptions of what past conditions were like. The editors have, for the most part, left these difficult decisions to local experts who have themselves studied the Quaternary geology of each area, and have drawn the map boundaries on the basis of their detailed advice.

The drawing of geographical boundaries in relation to climate

In all published palaeovegetation maps based on point sources of data, extrapolation or interpolation based on knowledge of present-day vegetation-to-climate relationships have been important. Each piece of data relating to climate or palaeovegetation provides a basis from which to deduce the climate/palaeovegetation for other adjacent areas. To some extent, the maps presented here are based by proxy on the vegetation-climate relationships that individual contributing authors have assumed, and on the pattern by which they feel climate would have varied across the region.

Such factors are difficult to control and to describe, for the authors who contributed to each individual palaeovegetation map often do not themselves state the assumptions which they are using. However, where such information is provided, it is included in the QEN database at the Web site.

The boundary between tropical and temperate vegetation types is reconstructed on the basis of palaeotemperature estimates from various sources. The distribution of the tropical-temperate boundary is assumed here to follow the minimum monthly temperature limits detailed in the vegetation scheme at the end of this paper. In fact, the precise position of the demarcation of "tropical" from "temperate" vegetation is fairly arbitrary if one looks at the problem objectively (see detailed discussion in Adams 1993), but there is no doubt that there is a general gradient in vegetation ecology and composition as one travels away from the equator. It is always necessary to draw the tropical versus temperate line somewhere, and in the maps here the boundary for most tropical vegetation types is set at a coldest mean monthly

value of 10 deg. C. This follows the general correspondence between global present day poleward vegetation boundaries and the present day temperature isotherms (e.g. see the *Times Atlas* (Times 1992) which presents good general maps of both). For tropical rainforest vegetation, a somewhat higher temperature limit of 15.5 deg. C (as the mean temperature of the coolest month of the year) seems to correspond well to the map boundaries drawn by various authors (I. C. Prentice, pers. comm.).

For the boreal-to-temperate transition, a more generalized definition based on the prevalence of cold climate conifers or birch woodland (*Betula*) is used as the basis for demarcating the boundary, and a similar floristic type of definition is used for tundra as distinguished from temperate steppe.

In drawing the palaeovegetation maps, the general assumption is made that the overall pattern of isotherms remained approximately the same, but that temperature was lowered (for the LGM) or raised (for the early Holocene) by a particular amount in each area. This seems generally reasonable with the exception of certain areas close to ice sheets or where large shelf areas had appeared: all general circulation model (GCM) reconstructions give generally similar qualitative spatial patterns to those existing at present, albeit shifted quantitatively, and that at around the outer boundaries of the tropics the temperature lowering at the LGM was at least 5.5 deg. C (10 deg. F) (e.g. Crowley and North 1991; Broecker 1995). Thus for the majority of vegetation types, the tropical-temperature boundary is moved equatorwards from the present 10 deg. C (50 deg. F) isotherm for the coldest month, to what is presently the 15.5 deg. C (60 deg. F) isotherm. Another important factor to include in extrapolating from scattered data points to produce a palaeovegetation map is the likely pattern of variation in precipitation. From finding evidence of a particular vegetation type having existed at a particular site in the past, it is possible to arrive at a rough quantitative estimate of precipitation for that place. From this it is reasonable to extrapolate the possible pattern of rainfall across a wider area, and to turn this back into an estimate of vegetation cover. If more than one data point is available, it is possible to interpolate between these. Extrapolation/interpolation of past rainfall patterns from proxy data points can be carried out using a numerical model (which may be coupled to a GCM), and although this brings with it an element of consistency, this is no guarantee that the model itself is correct judging by the problems that are evident in many GCM models (see discussion by Crowley and North 1991, Kagan 1995 and Broecker 1995), and a certain degree of scepticism would be healthy.

Here, the approximate relative precipitation patterns are generally assumed to have varied much as today (the present rainfall distribution being taken from such sources as the *Times Atlas* (Times 1992) and other regional climatological maps), but to have been shifted in amount. The amount by which rainfall shifted is dictated by the indications from regional sources of terrestrial palaeoevidence, except where there is evidence to the contrary. Assuming this, the boundaries of palaeovegetation types are extrapolated across from areas where relevant data have been found, assuming a broadly similar distribution of rainfall maxima and minima to those which occur today. In fact, there is good evidence that even during the LGM, most areas that are relatively moist today tended to be relatively moist during the LGM (even if shifted substantially overall to drier and cooler conditions, they were generally still moister relative to their surroundings). Hence, extrapolation along these principles seems perfectly reasonable in most areas (though not all; see the text of the QEN website <<http://www.soton.ac.uk/~tjms/adams1.html>> for exceptions).

Web-based expert consultation as a source of information for the maps.

Once the preliminary version of the map was ready, it was made available online for review. Requests for comments on the map were sent out to approximately 20 Quaternary vegetation experts for different parts of the world. The global map was split into six regions, allowing reviewers to easily access their region of specialization. An announcement of the availability of this review page was also made through the QUATERNARY list server (Canadian Research in Quaternary Science, <<http://www.mun.ca/lists/quaternary/>>), to ensure a wide targeted audience. This process was very efficient, with numerous valuable feedbacks from palaeovegetation specialists. The comments helped us correct vegetation categories or extensions of certain areas, and revealed various additional literature sources.

3.2 Vegetation map

3.2.1 Digitalization

A first set of hand-drawn maps were digitized and merged in the GIS facility of UNEP/GRID-Geneva (United Nations Environment Program / Global Resource Information Database-Geneva) using the Geographic Information System (GIS) ArcInfo 7.2 (ESRI Inc., Redland, USA). After correction of typological errors with ArcInfo, we exported the file into the GIS package ArcView 3.2 (ESRI Inc., Redland, USA), where the rest of the map production was carried out. Vegetation borders were then directly corrected with ArcView, using the standard digitizing tools. When contours were based on altitudinal zonation or past LGM coastlines, they were altered directly on screen, with the appropriate information in the background.

3.2.2 Key to Vegetation Types

In compiling these maps, we have tried to adhere as closely as possible to the well-known and widely cited scheme developed by Olson *et al.*(1983). Given the nature of the task we have, however, merged some categories and added others, including some vegetation types for the past that have no close analogue in the present world.

A key to the vegetation types under which the data are categorized can be found in Table 1. The coding numbers correspond to the numbers on the regional maps. A brief description of the physiognomy of each vegetation type is given, together with the nearest corresponding vegetation type(s) on the global ecosystems map and carbon storage database of Olson *et al.*(1983). Finer subdivisions of vegetation type were not mapped onto our global map, as we feel that there is presently insufficient information to allow such subdivision to be used.

3.2.3 Expressing the uncertainties in the vegetation map reconstruction

It is difficult to relay any simple measure of the amount of confidence to be placed in the patterns of vegetation distribution drawn onto the maps presented here. It has been necessary here to weigh up each case according to which of the cited authors and contacts presents the most convincing set of evidence and arguments. The justification for presenting any particular vegetation reconstruction in the maps is a complex and subtle process (which can be best understood by studying the discussions in some of the individual source papers, or the on-line QEN database <<http://www.soton.ac.uk/~tjms/adams1.html>>).

3.3 Altitudinal zonation

We used the topographical data sets GTOPO30 at 30 arc-sec resolution (about 1 km at the equator) from the US Geographical Survey <<http://edcdaac.usgs.gov/gtopo30/gtopo30.html>> as the basis for our altitudinal contours. All the individual tiles, less the ones from Antarctica, were merged together using the tools available in the ArcView extension "Spatial Tools" (Hooge 1999). The global data set was then resampled to a lower resolution of 10 km, by using the standard ArcView resampling tools. This allowed an easier handling of the data. A simple reclassification of this data set allows us to highlight the desired altitude range, which is then vectorized by creating polygons by hand in ArcView. To ensure that this lower resolution did not significantly affect the borders of the vegetation zones, we made several tests consisting of the same manipulation with the original resolution. These tests showed that a resolution of 10 km gives similar results, which was acceptable, especially when recalling the very subjective nature of these maps, and the uncertainties of border locations.

Altitudinal vegetation zones were substantially lower at the LGM than at present, due mainly to the cooling relative to the present, which is evident in all parts of world. These differences will be described in detail for each region, but in general it seems that altitudinal zones were approximately 500-1000m lower than at present. The cooling, and the lowering of altitudinal zones, was most dramatic in the mid- and high- latitudes, where most areas beyond 50 degrees north would probably have had no vegetation above 500m. In the tropical latitudes, the shift in vegetation zones was less drastic, but still involved a change of the order of hundreds of meters. In effect, the lower montane zone of tropical mountains spread out into the tropical lowlands, as indicated by the abundance of montane trees in lowland vegetation at that time (e.g. Hooghiemstra 1989; Behling 1998).

Tropical altitudinal zonation:

The following altitudinal zones were used everywhere in the tropics between 22 degrees North and South of the Equator, on the basis of various reviews of LGM vegetation in the tropics (e.g. Behling 1998):

In areas where tropical forest of some sort is reconstructed from palaeoevidence as being present in the lowlands, the upper limit of tropical lowland forest is designed as 500 above present sea level. Montane forest is present in the interval 500-2000m. Tundra is in the interval from 2000m to 3500m. Alpine desert, perennial snow or ice is present above 3500m.

All these vegetation zones are lowered some 500m (Hope 1987; Hooghiemstra 1989; Behling 1998) from the present-day vegetation zonation.

Higher-latitude zonation:

a) For the zones 22 degrees-30 degrees North or South of the Equator: upper forest limit (if forest is present in lowlands) is at 1200m. Regardless of lowland vegetation tundra is present in the interval from 1200m to 2000m. Montane/polar desert is present beyond 2000m, unless specific evidence suggests the presence of an ice cap (Hooghiemstra 1989; Hope 1987).

b) We placed the LGM upper forest line in the latitudinal band 30 degrees North to 45 degrees North at 800m. We put "tundra" vegetation above 800m (e.g. Yu et al. 2000).

c) All areas above 500m altitude, and north and south of 50 degrees, were labelled as alpine/polar desert, unless regional evidence suggests an ice sheet. This is based on the general assumption that in the high latitudes, greater cooling superimposed upon the background cooling due to ice age conditions would eliminate montane vegetation. However, the use of the 500m upper vegetation limit is preliminary, covering a very broad latitudinal band in which temperature certainly varied considerably, and may need to be revised on the basis of reconstructed summer temperatures on a more regionally specific basis. Since no forested areas are recorded from the LGM beyond 50 degrees North and South, no upper forest limit is ascribed.

In specific regions (e.g. in the western USA) where a more complex altitudinal mosaic was clearly present, refinements to the scheme were added. These are described in the regional sections.

3.4 LGM extended coastlines

Due to the extent of the ice sheets during LGM, coastlines were dramatically changed in certain areas due to the drop of sea-level. Based on coral cores, a common accepted mean value for this drop is about 120 meters (e.g. Fairbanks 1989), even though this change was locally higher or lower, due to the glacio-hydro-isostatic contributions to sea-level (Lambeck and Chappell 2001).

To our knowledge, there is no available global map of LGM coastlines. Most authors mapping LGM environments have used bathymetric data sets to reconstruct the shorelines of the area of interest based on the accepted sea-level drop value of 120 meters. We used the global sea-floor topography data set (version 8.2, <http://topex.ucsd.edu/marine_topo/mar_topo.html>), compiled by Smith and Sandwell (1997). The data set is at 2 arc-min resolution (about 4 km at the equator). Since the data set was originally in the Mercator projection, we used standard ArcView tools to reproject the data set to geographic projection. For a more convenient use, we also changed the original extent of the data set (0 to 360 decimal degrees) to -180 to +180 decimal degrees. A simple legend reclassification of the values highlights the 120 meters depth contours (Figure 1), allowing to modify accordingly the vegetation boundaries.

This contour map was compared with a recent map of South-Eastern Asia that was compiled from a wide array of sources, taking into account tectonic information when available (Voris 2000). Unfortunately, this map was not available in electronic format, so we were not able to compare the differences within the GIS system. However, a simple visual comparison showed only few areas where the differences between the two maps were noticeable at this scale. These differences were relatively small, in the order of 20-50 km. This encouraged us in the view that the global bathymetric data set is appropriate to generate a global map of past coastlines when one accepts the approximation inherent to this approach.

We thus corrected our initial vegetation map to fit these LGM coastlines using the standard digitizing tools in ArcView.

3.5 GIS database

The map was digitalized in geographic projection, which simply takes latitude and longitude as coordinates on a flat surface. This ensures easier conversion into any other specific projection. The drawback is that distance and surface are increasingly exaggerated as we move toward high latitudes, which gives a biased view of vegetation schemes in these areas. The adequate projection depends on the scale and the extent of the area of study (global, hemisphere, continental, regional, etc.), and on the spatial analysis that are to be done (distance or area computation, least-cost paths analysis, etc.). Numerous authors have recommended specific projections depending on the tasks to be achieved. Readers can consult the extensive literature on the subject to find recommended least-distorted projections for specific areas (e.g. Bugayevskiy and Snyder 1995; Steinwand et al. 1995).

The extent most often used for global map display is -180;+180 decimal degrees. For LGM maps, this has the disadvantage of separating the Bering Strait features into the far western and eastern sides of the map. This is not very harmful for a simple display, but it becomes problematic when one needs a spatial contiguity of that region for dynamic studies (e.g. species replacement, population migrations, etc.). For that reason, the map is also available in an extent that allows for that spatial contiguity, which is -25;+335 decimal degrees.

Vector maps were then exported into ArcInfo GRID raster format (e00) and image (tiff). Besides the global maps, regional maps were also produced in these three export formats. We believe that these various forms of outputs will greatly facilitate the import and the use of the vegetation maps.

The maps are available for download in these various formats from the Download Page <http://lgb.unige.ch/home/ray/intarch/download_page_full.htm>.

4 Description of vegetation patterns

4.1 Index to the Regions

This text is divided up on a regional basis, roughly corresponding to traditional notions of "the continents", although the detailed choice of boundaries for each region is fairly arbitrary. The legend for the maps is found in Figure 3.

The order of the regional treatment is as follows:

North and central America: includes the U.S.A. along with Mexico and the Caribbean, Canada, Greenland, "Beringia" and central America;

South America: includes the South American area and the Falkland Islands;

Africa: includes Madagascar, Arabia and the Levant;

Europe: includes the area eastwards to the Urals, and also Asia Minor;

Eurasia: includes northern Eurasia, mostly Russia east of the Urals, southern and eastern Asia, the Middle East, and from the central Asian desert southwards and eastwards to Malaysia/Indonesia;

Australasia: includes Australia, New Guinea and New Zealand.

4.2 North and Central America

In North America, the dominant feature was the presence of a vast ice sheet covering Canada. Forest dominated the eastern USA, but it was more open in character and contained trees adapted to the cooler climates.

Regionally specific altitudinal zones: in the Rockies in the west, altitudinal zones were lowered: For the LGM western USA montane mosaic region, between around 26 and 42 Deg.N the following vegetation zones seem to have predominated: alpine tundra, above 2500m, subalpine parkland of open stands of spruce, pines and fir between 1500-2500m, and scrub/woodland below about 1500m (Tallis 1991).

In the Cordillera region of the western USA, the areas below 500m altitude were "semi-desert". Everything below 500m was semi-desert, and scrub in the 500-1500m range. Same for the whole "desert" area to the south, covering Texas and northern Mexico; if below 500m the vegetation was ascribed to the semi-desert category, above 500m, it was reconstructed as scrub. In the Sierra Nevada of California, the areas above 2000m were labelled as ice (Tallis 1991).

Figure 4.

Selected literature sources for the region of North and Central America

Barnosky et al. (1987); Barry (1987); Benson and Thompson (1987); Blum et al. (1994); Cole and Monger (1994); Delcourt and Delcourt (1987, 1991); Denton and Hughes (1981); Dyke and Prest (1986, 1987); Elias (1995, 2001); Forman et al. (1992); Graham and Mead (1987); Harris (1993); Herwitz (1992); Holliday (1987); Hopkins et al. (1982); Nordt et al. (1994); Overpeck et al. (1992); Plummer (1993); Richard (1995); Ritchie (1982); Ritchie and Cwynar (1982); Rochefort et al. (1994); Rosseau and Kukla (1994); Schwalb and Burns (1995); Schweger et al. (1982); Tallis (1990); Tchakerian (1994); Thompson and Mead (1982); Thompson and Anderson (2000); Watts (1980); Watts and Stuiver (1980); Webb et al. (1983); Webb et al. (1993); Wells (1992); Wilkins (1991); Williams et al. (2000); Woodcock and Wells (1990).

4.3 South America

South America was slightly cooler and generally drier than at present. It appears that the Amazonian rainforest was substantially reduced in area (though large uncertainties remain). The Atlantic forest of Brazil was also much diminished. Some desert and semi-desert areas formed in what are presently grassland and scrub zones.

Regionally specific altitudinal zones: "permanent ice" above 4100m throughout the Andes at the LGM, based on Hooghiemstra (1989).

Figure 5.

Selected literature sources for the region of South America:

Absy et al. (1991); Absy and van der Hammen (1976); Behling (1995); Bonatti and Gartner (1973); (Broecker 1995); Bush 1994); Bush and Colinvaux (1990); Campbell (1989a,b); Clapperton (1993); Colinvaux (1972, 1987); Colinvaux et al. (1988); Colinvaux et al. (1989); Denton and Hughes (1981); de Oliveira et al. 1995); Grossjean and Messerli (1995); Haffer (1969); van der Hammen (1992); van der Hammen and Absy (1994); Heine (1994, 1995); Heusser (1983a,b, 1987); Hooghiemstra (1989); Hooghiemstra et al. (1992a); Irion (1984); Iriondo (1988); Iriondo and Garcia (1993); Latrubesse and Rancy (1995); Ledru (1992a,b); Leyden (1985); Leyden et al. (1993); Markgraf (1989, 1991, 1993); Markgraf et al. (1992); Nelson et al. (1990); Schwalb and Burns (1995); Stude et al. (1995); Suguio et al. (1993); Thomas (1994); Thompson et al. (1995); Villagran (1988, 1990); Wijmstra and van der Hammen (1966).

4.4 Africa

Africa was slightly cooler but much drier than at present. The Sahara Desert and the Namib Desert were both expanded, and in equatorial Africa there was relatively little forest cover.

Regionally specific altitudinal zones: In the eastern part of South Africa: areas above 1000m were labelled "temperate steppe grassland" based on Coetzee and van Zinderen Bakker (1988). In the central part of the Sahara desert, areas above 1500m were reconstructed as "semi-desert", based on the fact that some winter rains apparently occurred in altitude and maintained scattered vegetation (Faure et al. 1995, p. 79; Leroux 1998; Maley 2000).

Figure 6.

Selected literature sources for the region of Africa:

Aucour, Hillaire-Marcel and Bonnefille (1994); Bar-Yosef (1990); Battistini (1970); Belluomini et al. (1980); Bengo and Maley (1991); Bonnefille and Riollot (1988); Close and Wendorf (1990); Coetzee and van Zinderen Bakker (1988); Colyn, Gautier-Hion and Verhaven (1991); Deacon (1990); Dupont (1993); Dupont et al. (2000); El-Nakhal (1993); Fairbridge (1964); Faure (1984); Gasse (1977); Gasse et al. (1994); Gasse et al. (1990); Giresse et al. (1990); Giresse and Le Ribault (1990); Goodfriend and Margaritz (1988); Hamilton (1982, 1988); Hamilton and Taylor (1991); Hooghiemstra (1988); Hooghiemstra et al. (1992b); Isaar et al. (1989); Jansen (1990); Kortlandt (1984); Lézine (1989); Lézine and Vergaud-Grazzini (1994); Lézine and Cassanova (1989); Livingstone (1980, 1993); Maley (1987, 1989, 1992, 2000); Matima (1991); Mordeckai and Goodfriend (1987); Neumann (1989); Petit-Maire, Sanlaville and Zhong-Wei (1994); Preuss (1990); Ritchie (1994); Roberts (1990); Sarnthein (1978); Schwartz (1991); Scott (1989); Servant and Servant-Vildary (1980); Ssemmda and Vincens (1993); Street-Perrott (1994); Tallis (1991); Tamura (1990); Taylor (1990); Thomas and Shaw (1991); Van neer (1984); Vincens (1991); Walker (1990).

4.5 Europe

Ice sheets covered northern Europe and Scandinavia. Most of the rest of northern Europe resembled semi-desert, with a mixture of tundra and grassland elements (steppe-tundra). In southern Europe, vegetation resembled a semi-desert steppe, with scattered pockets of trees in moist areas.

Figure 7.

Selected literature sources for the region of Europe:

Becze-Deak et al. (1995); Bennett et al. (1991); Borsy (1987); Davis (1995); Dawson (1992); Denton and Hughes (1981); Frenzel (1992); Grichuk (1992); Harvey (1984); Hooghiemstra et al. (1992b); Huntley (1988, 1990, 1992); Huntley and Prentice (1993); Kozłowski (1990); Laval and Medus (1989); Laval et al. (1991); Pérez-Obiol and Julià (1994); Sjerup (1987); Soffer (1990); Soffer and Gamble (1990); Starkel (1991); Turner and Hannon (1988); Velichko and Kurenkova (1990); Velichko and Isavea (1992); Wells (1992); Weniger (1990); West (1978); Willis (1994); Willis et al. (2000); van Zeist and Bottema (1988).

4.6 Eurasia

Much of Siberia and central Asia was desert-like, but with some large areas of steppe-tundra (rather resembling semi-desert in most areas). China had relatively little tree cover. The vegetation resembled dry steppe in northern China, with scattered areas of trees in the uplands across southern China (in a predominantly grassland lowland landscape). Japan had an open woodland cover. In south-east Asia, there was much more open grassland and dry forest than at present.

Figure 8.

Selected literature sources for the region of Southern Asia:

Agrawal (1988); An et al. (1990); An et al. (1991); Barmawindjaja et al. (1993); Bellwood (1990); Broecker et al. (1988); Caratini and Tissot (1988); Chen and Olson (1990); Cullen (1981); Edwards (1994); Erdelen and Preu (1990); Fang (1991); Frakes and Jianzhong (1994); Gasse and van Campo (1994); Han (1991); Hantoro et al. (pers. comm.); Heusser (1990); Hovan et al. (1989); Hyams (1976); Jarvis (1993); Krinsley (1966); Kuhle (1991); Li and Zhou (1993); Li et al. (1995); Liew et al. (1995); Lin and Liew (1986); Lindsey and Thunell (1990); Liu (1986); Loeffler et al. (1984); Morley (1981, 1982); Morley and Flenley (1983); Ooi et al. (1990); Ooi and Tsuji (1989); Petit-Maire et al. (1994); Pye and Zhou (1989); Reynolds and Kanser (1990); Rostek et al. (1995); Singh et al. (1974); Stuijts et al. (1988); Sukumer et al. (1993); Sun and Chen (1991); Tamuru (1992); Thomas (1994); Thomas and Thorp (1992); Tong and Shao (1991); Tsukada (1988); van Campo (1986); van Zeist and Bottema (1988); Velichko (1991); Wang and Sun (1994); Whitmore (1984); Williams and Clarke (1984); Winkler and Wang (1993); Yang and Wang (1990); Yasuda and Tabata (1988).

Selected literature sources for the region of Northern Asia:

Alexeeva (1995); Baryshnikov and Markova (1994); Dawson (1992); Denton and Hughes (1981); Dodonov (1988); Drozdov et al. (1995); Frenzel (1992); Frenzel et al. (1992); Goncharov (1989); Grichuk (1992); Grosswald (1980, 1995); Kolpakov (1995); Lozhkin and Anderson (1993); Madeyska (1990); Peck et al. (1994);

Spasskaya (1992); Sun et al. (2000); van Campo et al. (1993); Velichko et al. (1984); Velichko and Spasskaya (1991); Velichko and Kurenkova (1990a,b); Velichko (1993); Volkov and Zykina (1984).

4.7 Australasia

A large extreme desert zone dominated the central part of the Australia continent, and all areas seem to have been drier and cooler than at present. Forest cover was much diminished. In New Zealand, a large ice cap dominated the South Island, with open grassland in the North.

Figure 9.

Selected literature sources for the region of Australasia:

Allen (1990); Dodson et al. (1988); Hess (1994); Hope (1987); van der Kaars (1990); Kershaw et al. (1991); Kershaw (1988); Markgraf et al. (1992); McGlone (1988); McGlone et al. (1993); McTaintish (1989); Nanson et al. (1992); Thom et al. (1994).

5 Suggestions and Comments from Readers

The LGM maps presented here represent the latest stage in an ongoing process (as at 4 December 2001). To take account of newly published evidence, and the advice of those working in the field of LGM environments, the maps are certain to be updated, and we aim to present further updated material on the Web. Any further additions, suggestions or criticisms of the maps, or of the interpretations presented here, should be directed to J. M. Adams or N. Ray. We hope that we have cited the opinions of individual contributors as they had intended, but take full responsibility for any misunderstandings which might arise from these citations.

6 Acknowledgements

The authors would like to thank the reviewers of the map for their helpful comments, and the many people who earlier contributed information and advice to the earlier QEN maps, which were precursors to the present set of maps. We are indebted to Hugues Faure for his many helpful suggestions.

N.R. would like to thank Dominique Del Pietro at UNEP/DEIAEW/GRID-Geneva for access to the digitizer and help for map corrections, at University of Geneva David Roessli for help on the download page and the review of an earlier draft, and Alicia Sanchez-Mazas for her comments.

N.R. was supported by a Swiss National Science Foundation grant No. 31-054059.98.

7 Bibliography

- Absy, M. L., Cleef, A. M., Fournier, M., Martin, L., Servant, M., Sifeddine, A., Ferriera, M. F., Soubies, F., Suguio, K., Turcq, B. and Van der Hammen, T. 1991. Mise en évidence de quatre phases d'ouverture de la forêt dense dans le sud-est de l'Amazonie au cours des 60,000 dernières années. Première comparaison d'autres régions tropicales. *Comptes Rendus de l'Académie des Sciences de Paris Série II* **312**, 673-678.
- Absy, M. L. and van der Hammen, T. 1976. Some palaeoecological data from Rondonia, southern part of the Amazon Basin. *Acta Amazonica* **6**, 293-299.
- Adams, J. M. 1993. Towards a Better Vegetation System for Global Mapping and Monitoring. Background paper for UNEP- HEM Charlottesville workshop, January 1993. United Nations Environment Programme—Harmonisation of Environmental Monitoring.
- Adams, J. M. and Faure, H. 1997. Preliminary vegetation maps of the world since the Last Glacial Maximum: an aid to archaeological understanding. *Journal of Archaeological Science* **24**: 623-647.
- Agrawal, D. P. 1988. Palaeoclimatic data from Kashmir: a synthesis and some correlations. In (D. P. Agrawal, Ed.) *Palaeo-climatic and Palaeoenvironmental Change in Asia During the Last 4 Million Years*. New Delhi: Indian National Science Academy, pp. 1-10.
- Alexeeva, N. V. 1995. Pleistocene small mammal fauna of the Transbaikal area. Abstracts, *14th INQUA Congress*, Berlin, p. 9.
- Allen, H. 1990. Environmental history in southwestern New South Wales during the Late Pleistocene. In (O. Soffer and C. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, pp. 296- 300.
- An, Z., Wu, X., Lu, Y., Zhang, D., Sun, D., Dong, G. and Wang, S. 1990. (in Chinese) *Advances in the Natural Sciences* **64**, 131-165.
- An, Z., Pinxian, W., Shumig, W., Guangrog, D., Xianjun, S., De'er, Z., Yanchou, L., Shaohua, Z. and Shonglin, Z. 1991. Changes in the monsoon and associated environmental changes in China since the last interglacial. In (T. Liu, Ed.) *Loess, Environment and Global Change*. Series of INQUA Congress. Beijing: Science Press, pp. 1-25.
- Anderson, D.G. and Gillam, J.C. 2000. Paleoindian colonization of the Americas: implications from an examination of physiography, demography, and artifact distribution. *American Antiquity* **65**(1): 43-66.
- Aucour, A.-M., Hillaire-Marcel, C. and Bonnefille, R. 1994. Late Quaternary biomass changes from 13 C measurements in a high-land peatbog from Equatorial Africa (Burundi). *Quaternary Research* **41**, 225-233.
- Barnosky, C. W., Anderson, P. M. and Bartlein, P. J. 1987. North-western US during the last deglaciation. In (W. F. Ruddiman and H. E. Wright, Eds) *North America and Adjacent Oceans during the Last Deglaciation*, Geology of North America Volume K-3. Boulder, Colorado: Geological Society of America, pp. 289-321.
- Barmawindjaja, B. M., Rohling, E. J., van der Kaars, W. A., Vergnaud Grazzini, C. and Zachariasse, W. J. 1993. Glacial conditions in the northern Moluccan Sea region Indonesia. *Palaeogeography, Palaeoclimatology, Palaeoecology* **101**, 147-167.
- Barry, R. G. 1987. Late-Pleistocene climatology. In (H. E. Wright, Ed.) *Late-Quaternary Environments of the United States*. Volume 1. London: Longman, pp. 390-407.
- Bar-Yosef, O. 1990. The last glacial maximum in the Mediterranean Levant. In (O. Soffer and G. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, pp. 58-75.
- Baryshnikov, G. F. and Markova, A. K. 1994. Main mammal assemblages of the Upper Pleniglacial of the last glaciation. In (B. Frenzel, B. Pecsí and A. A. Velichko, Eds) *Atlas of Palaeoclimates and Palaeoenvironments of the Northern Hemisphere*. Budapest: INQUA/Hungarian Academy of Sciences.

- Battistini, R. 1970. Le Quaternaire littoral de Madagascar et des îles voisines. *Palaeoclimatology of Africa* **12**, 153-154.
- Becze-Deak, J., Verrecchia, E. and Langohr, R. 1995. Particular types of secondary CaCO₃ accumulations as indicators of environments in the Upper Pleistocene loess palaeosols of Europe. Abstracts, *14th INQUA Congress*, Berlin, p. 25.
- Behling, H. 1995. Late Quaternary environmental history from 5 new sites in the Brazilian tropics. Abstracts, *14th INQUA Congress*, Berlin, p. 25.
- Behling H. 1998. Late Quaternary vegetational and climatic changes in Brazil. Review of *Paleobotany and Palynology*. v.99 p.143-156.
- Belluomini, G., Esu, D., Manfra, L. and Matteucci, R. 1980. Gasteropodi dulcicoli et terrestri nell'isola di dahlak kebir— testimonianze di una fase umida Olocenia nelle isola Dahlak, Mar Rosso. *Bolletino Malacologico* **16**, 369-390.
- Bellwood, I. 1990. From late Pleistocene to early Holocene in Sundaland. In (O. Soffer and G. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, pp. 255-263.
- Bengo, M. D. and Maley, J. 1991. Analyses des flux polliniques sur la marge sud du Golfe du Guinée depuis 135,000 ans. *Comptes Rendus de l'Academie des Sciences de Paris Série II* **313**, 843-849.
- Bennett, K. D., Tzedakis, P. C. and Willis, K. J. 1991. Quaternary refugia of Northern European trees. *Journal of Biogeography* **18**, 103-115.
- Benson, L. and Thompson, R. S. 1987. The physical record of lakes in the Great Basin. In (W. F. Ruddiman and H. E. Wright, Eds) *North America and Adjacent Oceans during the Last Deglaciation, The Geology of North America*, Volume K-3. Boulder, Colorado: Geological Society of America, pp. 241-260.
- Blum, M. D., Toomey, R. S. and Valastro, S. 1994. Fluvial response to late Quaternary climatic and environmental change, Edwards Plateau, Texas. *Palaeogeography, Palaeoclimatology, Palaeoecology* **108**, 1-21.
- Bonatti, E. and Gartner, S. 1973. Caribbean climate during Pleistocene Ice Ages. *Nature* **244**, 563-565.
- Bonnefille, R. and Riollet, G. 1988. The Kashiru pollen sequence (Burundi). Palaeoclimatic implications for the last 40,000 yr BP in tropical Africa. *Quaternary Research* **19**, 30-35.
- Borsy, Z. 1987. Palaeogeography of blown sand in Hungary. In (M. Pecsí and A. A. Velichko, Eds) *Palaeogeography and Loess*. Budapest: Akademiai Kiado, pp.75-87.
- Broecker, W. S. 1995. Cooling the tropics. *Nature* **376**, 212-213.
- Broecker, W. S., Andree, M., Klas, M., Bonani, G., Wolfli, W. and Oeschger, H. 1988. New evidence from the South China Sea for an abrupt termination of the last glacial period. *Nature* **333**, 156-158.
- Bugayevskiy, L. M. and Snyder, J. P. 1995. *Map Projections: A Reference Manual*. Taylor and Francis, London. 328 p.
- Bush, M. B. 1994. Amazonian speciation: a necessarily complex model. *Journal of Biogeography* **21**, 5-17.
- Bush, M. B. and Colinvaux, P. A. 1990. A pollen record of a complete glacial cycle in lowland Panama. *Journal of Vegetation Science* **1**, 105-118.
- Campbell, K. E. 1989a. Amazon flooding. *Nature* **342**, 350.
- Campbell, K. E. 1989b. Late Pleistocene history of the Altiplano and southwestern Amazonia and its bearing on faunal inter-change. Abstract; *5th International Theriological Congress*, Rome, pp. 267-268.

- Caratini, C. and Tissot, C. 1988. Evidence from offshore cores near India. *Review of Palaeobotany and Palynology* **55**, 217-228.
- Chen, C. and Olson, J. W. 1990. China at 18,000 BP. In (O. Soffer and G. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, p. 120.
- Clapperton, C. M. 1993. *Quaternary Geology and Geomorphology of South America*. London: Elsevier.
- Close, A. and Wendorf, F. 1990. North Africa at 18,000 BP. In (O. Soffer and C. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, pp. 41-55.
- Coetzee, J. and van Zinderen Bakker, E. M. 1988. A review of late Quaternary pollen studies in east, central and southern Africa. *Review of Palaeobotany and Palynology* **55**, 155-174.
- Cole, D. R. and Monger, H. C. 1994. Influence of atmospheric CO₂ on the decline of C₄ plants during the last deglaciation. *Nature* **368**, 533-535.
- Colinvaux, P. A. 1972. Climate and the Galapagos islands. *Nature* **240**, 17-20.
- Colinvaux, P. A. 1987. Environmental history of the Amazon Basin. *Quaternary of South America and Antarctic Peninsula* **5**, 165-189.
- Colinvaux, P. A., Olson, K. and Liu, K.-B. 1988. Late-glacial and Holocene pollen diagrams from two endorhic lakes of the Inter-Andean Plateau of Ecuador. *Review of Palaeobotany and Palynology* **55**, 83-100.
- Colinvaux, P. A., Bush, M. B., Liu, K.-B., De Oliveira, P., Steinitz-Kannan, M., Reidinger, M. and Miller, M. 1989. Amazon without refugia: vegetation and climate change of the Amazon Basin through a glacial cycle. In papers of *International Symposium on Global Changes in South America during the Quaternary*. Sao Paulo, Brazil, pp. 99-105.
- Colyn, M., Gautier-Hion, A. and Verhaven, W. 1991. A re-appraisal of palaeoenvironmental history in central Africa: evidence for a major fluvial refuge in the Zaire Basin. *Journal of Biogeography* **18**, 403-407.
- Crowley, T. J. and North, G. R. 1991. *Palaeoclimatology*. Oxford: Oxford University Press.
- Cullen, J. L. 1981. Microfossil evidence for changing salinity patterns in the Bay of Bengal over the last 20,000 years. *Palaeogeography, Palaeoclimatology, Palaeoecology* **35**, 315-356.
- Davis, B. A. S. 1995. Palaeolimnology and Holocene environmental change from Endorheic Lakes in the Ebro Basin, North-East Spain. *Quaternary Newsletter* **75**, 57-58.
- Dawson, A. G. 1992. *Ice Age Earth; Late Quaternary Geology and Climate*. London: Routledge.
- Deacon, J. 1990. Changes in the archaeological record in South Africa at 18,000 BP. In (O. Soffer and C. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, pp. 170-188.
- Delcourt, P. A. and Delcourt, H. R. 1987. *Long-term Forest Dynamics of the Temperate Zone: a Case Study of Late-Quaternary Forests in Eastern North America*. New York, NY: Springer.
- Delcourt, H. R. and Delcourt, P. A. 1991. *Quaternary Ecology; a Palaeoecological Perspective*. London: Chapman and Hall.
- Denton, G. H. and Hughes, T. J. (Eds) 1981. *The Last Great Ice Sheets*. London: Wiley-Interscience.
- de Oliveira, P. E., Bush, M. B., Miller, M. and Colinvaux, P. A. 1995. A 40,000 year record from the Amazonian lowland forest of Brazil. Abstracts, *14th INQUA Congress*, Berlin, p. 41.

- Dodonov, A. E. 1988. Upper Pliocene-Quaternary reference sections in Soviet central Asia: stratigraphy, correlation, geological events. In (D. P. Harding, Ed.) *INQUA International Symposium on Stratigraphy and Correlation*. CCOP Technical Secretariat, pp. 39-44.
- Dodson, J. R., Fullager, R. and Head, H. 1988. *The Naive Lands*. Melbourne: Longman-Cheshire.
- Drozdo, N., Tcheba, V., Mestdagh, H. and Damblon, F. 1995. Loess and palaeosol record of middle Ineisei Basin: a reference sequence for upper Pleistocene of central Siberia. Abstracts, *14th INQUA Congress*, Berlin, p. 69.
- Dupont, L. D. 1993. Vegetation zones in NW Africa during the Bruhnes chron reconstructed from marine palynological data. *Quaternary Science Reviews* **12**, 189-202.
- Dupont, L. M., Jahns, S., Marret, F. and Ning, S. 2000. Vegetation change in equatorial West Africa: time-slices for the last 150 ka. *Palaeogeography, Palaeoclimatology, Palaeoecology* **155**: 95-122.
- Dyke, A. S. and Prest, V. K. 1986. *Late Wisconsinian and Holocene Retreat of the Laurentide Ice Sheet*. Geological Survey of Canada Map 1702A, scale 1:5,000,000.
- Dyke, A. S. and Prest, V. K. 1987. Late Wisconsinian and Holocene history of the Laurentide ice sheet. *Geographie physique et Quaternaire* **41**, 237-263.
- Edwards, D. S. 1994. *Belalong: a Tropical Rainforest*. Singapore: Suntree publishers.
- Elias, S. A. 1995. Postglacial vegetation lag in Southern Alaska USA, evidence from fossil insects. Abstracts, *14th INQUA Congress*, Berlin, p. 73.
- Elias S.A. 2001. Beringian paleoecology: results from the 1997 workshop. *Quaternary Science Reviews* v.20 p.7-13.
- El-Nakhal, H. A. 1993. The Pleistocene cold episode in the Republic of Yemen. *Palaeogeography, Palaeoclimatology, Palaeoecology* **100**, 303-307.
- Erdelen, W. and Preu, C. 1990. Quaternary coastal and vegetation dynamics in the Palk Strait region, South Asia—the evidence and hypotheses. In (J. B. Thornes, Ed.) *Vegetation and Erosion*. London: John Wiley and Sons Ltd, pp. 491-520.
- Fairbanks, R. G. 1989. A 17,000-year glacio-eustatic sea level record. Influence of glacial melting rates on the Younger Dryas event and deep ocean circulation. *Nature* **342**: 637-642.
- Fairbridge, R. W. 1964. African ice-age aridity. In (A. E. M. Nairn, Ed.) *Problems in Palaeoclimatology*. London: Wiley-Interscience, pp. 356-520.
- Fang, J.-Q. 1991. Lake evolution during the past 30,000 years in China, and its implications for environmental change. *Quaternary Research* **36**, 37-91.
- Faure, H. 1984. Tropical peats: hydrogeologic and climatic control. In (N. A. Morner and W. Karlen, Eds) *Climatic Changes on a Yearly to Millennial Basis*. New York: D. Reidel Publishing Company, pp. 201-203.
- Faure H., Leroux M., Faure-Denard L., Lezine A. M., Lioubimsteva E., Mbaitoudji M., Soulie-Marsche I., Vernet R. and P. M. Vincent. 1995. High altitude lakes of Sahara during the Last Glacial Maximum and Holocene. XIV INQUA Congress, Terra Nostra, Berlin 3-10 Aug.1995. Vol. 2/95.
- Forman, S. L., Goetz, F. H. and Yuhas, R. H. 1992. Large-scale stabilized dunes on the High Plains of Colorado. *Geology* **20**, 145-148.
- Frakes, L. A. and Jianzhong, S. 1994. A carbon isotope record of the upper Chinese loess sequence: estimate of plant types during stadials and interstadials. *Palaeogeography, Palaeoclimatology, Palaeoecology* **108**, 183-189.

Frenzel, B., Pecsí, B. and Velichko, A. A. 1992. *Atlas of Palaeoclimates and Palaeoenvironments of the Northern Hemisphere*. Budapest: INQUA/Hungarian Academy of Sciences.

Frenzel, B. 1992. Vegetation for the maximum cooling of the last glaciation. In (B. Frenzel, B. Pecsí and A. A. Velichko, Eds) *Atlas of Palaeoclimates and Palaeoenvironments of the Northern Hemisphere*. Budapest: INQUA/Hungarian Academy of Sciences.

Gasse, F. 1977. Evolution of Lake Abhe, from 70,000 BP. *Nature* **265**, 42-45.

Gasse, F. and van Campo, E. 1994. Abrupt post-glacial climate events in west Asia and North Africa monsoon domains. *Earth and Planetary Sciences Letters* **126**, 435-456.

Gasse, F., Cortijo, E., Disnar, J.-D. *et al.* 1994. A 36 kyr environmental record in the southern tropics: Lake Tritivakely (Madagascar). *Comptes Rendus de l'Académie des Sciences de Paris* **318**, 1513-1519.

Gasse, F., Ledee, V., Massault, M. and Fontes, J.-C. 1990. Water level fluctuations in Lake Tanganyika in phase with oceanic changes during the last glaciation and deglaciation. *Nature* **342**, 57-59.

Giresse, P., Malounguila-Nganga, N. and Moguedel, G. 1990. La succession des palaeoenvironnements Quaternaires des plate-formes continentales du sud du Gabon, du Congo, du Cabina et du Zaïre. In (R. Lanfranchi and D. Schwartz, Eds) *Paysages Quaternaires de l'Afrique Centrale Atlantique*. Paris: Editions de l'Orstom, pp. 71-77.

Giresse, P. and Le Ribault, M. 1990. Reconstitution palaeo-géographique des derniers épisodes du Quaternaire littoral du Congo par l'étude exoscopique des Quartz. In (R. Lanfranchi and D. Schwartz, Eds) *Paysages Quaternaires de l'Afrique Central Atlantique*. Paris: Editions de l'Orstom, pp. 98-99.

Goncharov, S. P. 1989. PhD thesis. *Last Glaciation in Western Siberia and Glacial Dammed Lakes in the Middle Ensei River Basin*. (In Russian.) Academy of Sciences, Moscow: Institute of Geography.

Goodfriend, G. A. and Margaritz, M. 1988. Palaeosols and late Pleistocene rainfall fluctuations in the Negev Desert. *Nature* **362**, 144-147.

Graham, R. W. and Mead, J. I. 1987. Environmental fluctuations and the evolution of mammal faunas during the last glaciation in North America. In (W. F. Ruddiman and H. F. Wright, Eds) *North America and Adjacent Oceans During the Last Deglaciation, The Geology of North America Volume K-3*. Boulder, Colorado: Geological Society of America, pp. 371-402.

Grichuk, V. P. 1992. Main types of vegetation (ecosystems) for the maximum cooling of the last glaciation. In (B. Frenzel, B. Pecsí and A. A. Velichko, Eds) *Atlas of Palaeoclimates and Palaeoenvironments of the Northern Hemisphere*. Budapest: INQUA/Hungarian Academy of Sciences.

Grossjean, M. and Messerli, M. 1995. Late Pleistocene and Holocene changes in the Atacama Altiplano, Northern Chile. Abstracts, *14th INQUA Congress*, Berlin, p. 98.

Grosswald, M. G. 1980. Late Quaternary ice sheet of Northern Eurasia. *Quaternary Research* **13**, 1-32.

Grosswald, M. G. 1995. The case for the East Siberian ice sheet. Abstracts, *14th INQUA Congress*, Berlin, p. 34.

Haffer, J. 1969. Speciation in Amazon forest birds. *Science* **165**, 131-137.

Hamilton, A. C. 1982. *Environmental History of East Africa: a Study of the Quaternary*. London: Academic Press, p. 328.

- Hamilton, A. C. 1988. Guenon evolution and forest history. In (A. Gautier-Hion, Ed.) *A Primate Radiation: Evolutionary Biology of the African Guenon*. Cambridge: Cambridge University Press, pp. 13-34.
- Hamilton, A. C. and Taylor, D. 1991. History of climate and forests in tropical Africa during the last 8 million years. *Climate Change* **19**, 65-78.
- Han, T. 1991. Quaternary geology of Qinghai-Tibet (Xizang) plateau. In (Z. Zhang, Ed.) *The Quaternary of China*. Beijing: China Ocean Press, pp. 405-440.
- Harris, A. H. 1993. Wisconsin pre-pleniglacial biotic change in southeastern New Mexico. *Quaternary Research* **40**, 127-133.
- Harvey, A. M. 1984. Aggradation and dissection sequences on Spanish alluvial fans: influence on morphological development. *Catena* **11**, 289-304.
- Heine, K. 1994. The Mera site (Ecuador) revisited: ice-age Amazon in the light of new evidence. *Quaternary International* **21**, 113-119.
- Heine, K. 1995. Late Quaternary glacial sequences in Bolivia, Ecuador and Mexico—data and palaeoclimatic implications. Abstracts, *14th INQUA Congress*, Berlin, p. 53.
- Herwitz, S. R. 1992. Quaternary vegetation change and dune formation on Bermuda: a discussion. *Global Ecology and Biogeography Letters* **2**, 65-70.
- Hess, P. P. 1994. Record of continental dust from Australia in Tasman Sea sediments. *Quaternary Science Reviews* **13**, 257-272.
- Heusser, C. J. 1983a. Late glacial and Holocene vegetation and climate of Subantarctic South America. *Review of Palaeobotany and Palynology* **65**, 9-15.
- Heusser, C. J. 1983b. Quaternary pollen record from Laguna de Tagua Tagua, Chile. *Science* **219**, 1429-1432.
- Heusser, C. J. 1987. Quaternary vegetation of southern South America. *Quaternary of South America and the Antarctic Peninsula* **5**, 197-221.
- Heusser, L. E. 1990. Northeast Asian pollen records for the last 150,000 years. *Review of Palaeobotany and Palynology* **65**, 1-8.
- Holliday, V. T. 1987. A re-examination of late-Pleistocene boreal forest reconstructions for the southern High Plains. *Quaternary Research* **28**, 238-244.
- Hooge, P. N. 1999. Spatial tools extension to ArcView. ver. 3.2. Alaska Biological Science Center, U.S. Geological Survey, Anchorage, AK, USA. Available: <http://www.absc.usgs.gov/glba/gistools/index.htm> Accessed: 30 January 2001.
- Hooghiemstra, H. 1988. Palynological records from northwest African marine sediments: a general outline of the interpretation of the pollen signal. *Philosophical Transactions of the Royal Society of London* **318**, 431-449.
- Hooghiemstra, H. 1989. Quaternary and Upper Pliocene glaciations and forest development in the tropical Andes; evidence from a long high resolution pollen record from the sedimentary plain of Bogota, Colombia. *Palaeogeography, Palaeoclimatology, Palaeoecology* **72**, 11-26.
- Hooghiemstra, H., Clef, A. M., Noldus, G. W. and Kapelle, M. 1992a. Upper Quaternary vegetation dynamics and palaeoclimatology of the La Chonta bog area, Costa Rica. *Journal of Quaternary Science* **7**, 205-225.
- Hooghiemstra, H., Stalling, H., Agwu, C. O. C. and Dupont, L. M. 1992b. Vegetational and climatic changes at the northern fringe of the Sahara 250,000-5,000 years BP. *Review of Palaeobotany and Palynology* **74**, 1-53.

- Hope, G. 1987. Climatic implications of timberline changes in Australasia from 30,000 yr BP to present. In (T. H. Donnelly and R. J. Wasson, Eds) *CLIMAN 33, Proc. of Symp. CSIRO*, Canberra, pp. 91-99.
- Hopkins, D. M., Matthews, J. V., Schweger, C. E. and Young, S. B. (Eds) 1982. *The Palaeoecology of Beringia*. London: Academic Press.
- Hovan, S. A., Rea, D. K., Pisias, N. G. and Shackleton, N. J. 1989. Direct link between China loess and marine ^{18}O records. *Nature* **290**, 296-298.
- Huntley, B. 1988. Europe. In (B. Huntley and T. Webb III, Eds) *Vegetation History*. London: Kluwer Academic Publishers, pp. 341-384.
- Huntley, B. 1990. European post-glacial forests: compositional changes in response to climatic change. *Journal of Vegetation Science* **1**, 507-518.
- Huntley, B. 1992. Pollen-climate response surfaces and the study of climate change. In (J. M. Gray, Ed.) *Applications of Quaternary Research. Quaternary Proceedings* **2**, 91-99.
- Huntley, B. and Prentice, I. C. 1993. Europe. In (H. E. Wright Jr., J. E. Kutzbach, T. Webb III, W. F. Ruddiman, F. A. Street-Perrott and P. J. Bartlein, Eds) *Global Climates Since the Last Glacial Maximum*. Minneapolis: University of Minnesota Press, pp. 136-168.
- Hyams, E. 1952. *Soil and Civilisation*. London: John Murray.
- Hyams, E. 1976. *Soil and Civilization* (second edition). London: John Murray.
- Irion, G. 1984. Quaternary geological history of the Amazon lowlands. In (H. Sioli, Ed.) *In the Amazon*. Dordrecht: Junk, pp. 201-214.
- Iriondo, M. H. 1988. Climatic history of the Argentine plains. *Quaternary of South America and the Antarctic Peninsula* **6**, 297.
- Iriondo, M. H. and Garcia, N. O. 1993. Climatic variations in the Argentine plains during the last 18,000 years. *Palaeogeography, Palaeoclimatology, Palaeoecology* **101**, 209-220.
- Isaar, A., Tsoar, H. and Levin, D. 1989. Climatic changes in Israel during historic times and their impact on hydrological, pedological and socio-economic systems. In (M. Leinen and M. Sarnthein, Eds) *Palaeoclimatology and Palaeometeorology: Modern and Past Patterns of Global Atmospheric Transport*. The Hague, Netherlands: Kluwer Academic Publishers, pp. 525-541.
- Jansen, J. H. F. 1990. Glacial-interglacial oceanography of the southeastern Atlantic Ocean and the palaeoclimate of west-central Africa. In (R. Lanfranchi and D. Schwartz, Eds) *Paysages Quaternaires de L'Afrique Centrale Atlantique*. Paris: Editions de l'Orstom, pp. 110-123.
- Jarvis, D. I. 1993. Pollen evidence of changing Holocene monsoon climate in Sichuan Province, China. *Quaternary Research* **39**, 325-337.
- Kagan, B. A. 1995. *Ocean-Atmosphere Interaction and Climate Modelling*. Cambridge Atmospheric and Space Science Series. Cambridge: Cambridge University Press.
- Kershaw, A. P. 1988. Australasia. In (B. Huntley and T. Webb III, Eds) *Vegetation History*. London: Kluwer Academic Publishers, pp. 237-306.
- Kershaw, A. P., D'Costa, D. M., McEwan Mason, J. R. C. and Wagstaff, B. E. 1991. Palynological evidence for Quaternary vegetation and environments of mainland southeastern Australia. *Quaternary Science Reviews* **10**, 391-404.
- Kolpakov, V. V. 1995. Ventifacts on the territory of the former USSR. Abstracts, *14th INQUA Congress*, Berlin, p. 140.

- Kortlandt, A. 1984. Vegetation research and 'bulldozer' herbivores in tropical Africa. In (A. C. Chadwick and C. L. Sutton, Eds) *Tropical Rain Forest*. Leeds: Spec. Publ. Leeds Phil. Lit. Soc., pp. 205-206.
- Kozlowski, J. L. 1990. Moravia during the upper Pleniglacial. In (O. Soffer and G. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, pp. 207-215.
- Krinsley, D. B. 1966. The palaeoclimatic significance of the Iranian Playas. *Palaeoclimatology of Africa* **6**, 114-120.
- Kuhle, M. 1991. The Pleistocene glaciation of Tibet. *Glaciers-Ocean-Atmosphere Interactions*. Proceedings of the International Symposium held at St Petersburg, September 1990. IAHS Publ. no. 208, pp. 425-438.
- Lambeck, K. and Chappell, J. 2001. Sea level change through the last glacial cycle. *Science* **292** (5517), 679-86.
- Latrubesse, E. M. and Rancy, A. 1995. Late Quaternary alluvial sediments and vertebrate palaeontology indicative of aridity in southwestern Amazonia. Abstracts, *14th INQUA Congress*, Berlin, p. 226.
- Laval, H. and Medus, L. 1989. Analyse pollinique de sédiments du Quaternaire récent de l'Etang de Berre (Bouches-du-Rhône, France). *Comptes Rendus de la Académie des Sciences de Paris Série II* **309**, 2135-2141.
- Laval, H., Medus, J. and Roux, M. 1991. Palynological and sedimentological records of Holocene human impact from the Etang de Berre, southeastern France. *The Holocene* **1**, 269-272.
- Ledru, M.-P. 1992a. Late Quaternary environmental and climatic changes in central Brazil. *Quaternary Research* **39**, 90-98.
- Ledru, M.-P. 1992b. Modifications de la végétation du Brésil Central entre la dernière époque glaciaire et l'interglaciaire actuel. *Comptes Rendus de la Académie des Sciences de Paris Série II* **314**, 117-123.
- Leroux, M. 1998. Dynamic analysis of weather and climate. Wiley, Wiley-Praxis. Series in Atmospheric Physics, 365p.
- Leyden, B. W. 1985. Late Quaternary aridity and Holocene moisture fluctuations in the Lake Valencia basin, Venezuela. *Ecology* **66**, 1275-1295.
- Leyden, B. W., Brenner, M., Hodell, D. A. and Curtis, M. 1993. Late Pleistocene climate in the Central American lowlands. In *Climate Change in Continental Isotopic Records*. American Geophysical Union: Geophysical Monograph 78, pp. 165-178.
- Lézine, A.-M. 1989. Late Quaternary vegetation and climate of the Sahel. *Quaternary Research* **32**, 317-334.
- Lézine, A.-M. and Vergaud-Grazzini, G. 1994. Evidence of forest extension in west Africa since 22,000 BP: a pollen record from the eastern tropical Atlantic. *Quaternary Science Reviews* **12**, 203-210.
- Lézine, A.-M. and Cassanova, J. 1989. Pollen and hydrological evidence for interpretation of past climates in tropical west Africa. *Quaternary Science Reviews* **8**, 45-55.
- Li, J. *et al.* (18 authors) 1995. *Uplift of the Qinghai-Xizang (Tibet) Plateau and Global Change*. China: Lanzhou University Press.
- Li, P.-Y. and Zhou, L.-P. 1993. Occurrence and palaeoenvironmental implications of late Pleistocene loess along eastern coasts of Bohai Sea, China. In (K. Pye, Ed.) *Dynamics and Environmental Context of Aeolian Sedimentary Systems*. London: Geological Society, pp. 293-310.

- Liew, P.-M., Kuo, C.-M. and Tseng, M.-H. 1995. Vegetation of northern Taiwan during the last glacial maximum as indicated by new pollen records. Abstracts, *14th INQUA Congress*, Berlin, p. 161.
- Lin, H.-L. and Liew, P.-M. 1986. Pollen analysis of the Pleistocene Kuelichung-chi Section. *Petroleum Geology of Taiwan* **22**, 127- 138.
- Lindsey, A. and Thunell, G. 1990. The record of deglaciation in the Sulu Sea. *Palaeoceanography* **5**, 1025-1039.
- Liu, K.-B. 1986. *Pleistocene Changes in Vegetation and Climate in China*. American Quaternary Association: Conference Abstract, p. 94.
- Livingstone, D. A. 1980. Age of deglaciation in the Ruzizi range, Uganda. *Nature* **194**, 859-860.
- Livingstone, D. A. 1993. Evolution of African climate. In (P. Goldblatt, Ed.) *Biological Relationships Between Africa and South America*. New Haven: Yale University Press, pp. 455-499.
- Loeffler, E., Thompson, W. P. and Liengsakul, M. 1984. Quaternary geomorphological development of the lower Mun River basin, North-East Thailand. *Catena* **11**, 271-279.
- Lozhkin, A. V. and Anderson, P. M. 1993. Late Quaternary lacustrine pollen records from southwestern Beringia. *Quaternary Research* **39**, 314-324.
- Madeyska, T. 1990. The distribution of human settlement in the extra-tropical Old World 24,000-15,000 BP. In (O. Soffer and G. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, pp. 24-37.
- Maley, J. 1987. Fragmentation de la forêt dense humide africaine et extension des biotopes montagnards et chronologiques. Implications palaeoclimatiques et biogéographiques. *Palaeoecology of Africa* **18**, 307-334.
- Maley, J. 1989. Late Quaternary changes in the African rainforest. In (M. Leinen and M. Sarnthein, Eds) *Palaeoclimatology and Palaeometeorology; Modern and Past Patterns of Global Transport*. Amsterdam: Kluwer Academic Publishers, pp. 585-616.
- Maley, J. 1992. Mise en évidence d'une péjoration climatique entre ca. 2500 et 2000 ans BP en Afrique tropicale humide. *Bulletin de la Société Géologique de France* **163**, 363-365.
- Maley, J. 2000. Last glacial maximum lacustrine and other Saharan mountains, and large-scale climatic teleconnections linked to the activity of the Subtropical Jet Stream. *Global and Planetary change* **26**: 121-136.
- Markgraf, V. 1989. Reply to C. J. Huessler's "Southern westerlies during the last glacial maximum". *Quaternary Research* **31**, 426- 432.
- Markgraf, V. 1991. Late Pleistocene environmental and climatic evolution in southern South America. *Bamberger Geographische Schriften* **11**, 271-281.
- Markgraf, V. 1993. Climatic history of Central and Southern South America since 18,000 yr BP. In (H. E. Wright Jr., J. E. Kutzbach, T. Webb III, W. F. Ruddiman, F. A. Street-Perrott and P. J. Bartlein, Eds) *Global Climates Since the Last Glacial Maximum*. Minneapolis: University of Minnesota Press, pp. 357-385.
- Markgraf, V., Dodson, J. R., Kershaw, A. P., McGlone, M. S. and Nichols, N. 1992. Evolution of late Pleistocene and Holocene climates in the circum-south Pacific land areas. *Climate Dynamics* **6**, 193-211.
- Matima, J. W. 1991. Pollen records from the Lake Victoria region. *Quaternary Research* **35**, 234-245.

- McGlone, M. S. 1988. New Zealand. In (B. Huntley and T. Webb III, Eds) *Vegetation History*. London: Kluwer Academic Publishers, pp. 557-602.
- McGlone, M. S., Salinger, M. J. and Moar, N. T. 1993. Palaeovegetation studies of New Zealand's climate since the last glacial maximum. In (H. E. Wright Jr., J. E. Kutzbach, T. Webb III, W. F. Ruddiman, F. A. Street-Perrott and P. J. Bartlein, Eds) *Global Climates Since the Last Glacial Maximum*. Minneapolis: University of Minnesota Press, pp. 294-317.
- McTaintish, G. H. 1989. Quaternary aeolian dust processes and sediments in the Australasian region. *Quaternary Science Reviews* **8**, 253-255.
- Milanova, E. (Ed.) *et al.* (20 authors) 1994. *Atlas of World Landscape Types*. Moscow: Moscow State University.
- Mordeckai, M. and Goodfriend, G. A. 1987. Movement of the desert boundary in the Levant from the latest Pleistocene to the early Holocene. In (M. Mordeckai and G. A. Goodfriend, Eds) *Abrupt Climatic Change—Evidence and Implications*. Holland: Reidal Publishing Co., pp. 173-183.
- Morley, R. J. 1981. Development and vegetation dynamics of a lowland ombrogenous peat swamp in Kalimantan Tengah, Indonesia. *Journal of Biogeography* **8**, 383-404.
- Morley, R. J. 1982. A palaeoecological interpretation of a 10,000 year pollen record from Danau Padanag, Central Sumatra, Indonesia. *Journal of Biogeography* **9**, 151-190.
- Morley, R. J. and Flenley, J. R. 1983. Late Cenozoic vegetational and environmental changes in the Malay Archipelago. In (T. C. Whitmore, Ed.) *Biogeography of the Malay Archipelago*. Cambridge: Cambridge University Press, pp. 110-135.
- Nanson, C. G., Price, D. M. and Short, S. A. 1992. Wetting and drying of Australia over the past 300,000 years. *Geology* **20**, 791-794.
- Nelson, B. W., Ferreira, A. C., de Silva, M. F. and Kawasaki, M. L. 1990. Endemism centres, refugia and botanical collection density in Brazilian Amazonia. *Nature* **345**, 714-716.
- Neumann, K. 1989. Middle Holocene vegetation of the Sahara. *African Archaeological Review* **7**, 97-116.
- Nordt, L. E., Boutton, T. E., Hallmark, C. T. and Waters, M. R. 1994. Late Quaternary vegetation and climate changes in central Texas based on the isotopic composition of organic carbon. *Quaternary Research* **41**, 109-120.
- Olson, J. S., Watts, J. A. and Allinson, L. J. 1983. *Carbon in Live Vegetation in Major World Ecosystems*. Environmental Sciences Division Publication No. 1997. Tennessee: Oak Ridge National Laboratory.
- Ooi, N., Minaki, M. and Noshiro, S. 1990. Vegetation changes around the last glacial maximum and effects of the Aira-Tn ash, at the Itai-Teragatani site, Central Japan. *Ecological Research* **5**, 81-91.
- Ooi, N. and Tsuji, S. 1989. Palynological study of the peat sediments around the last glacial maximum at Hikone, the east shore of Lake Biwa, Japan. *Journal of Phytogeography and Taxonomy* **XXXVII**, 37-42.
- Ortloff, C. R. and Kolata, A. C. 1993. Climate and collapse: agro-ecological perspectives on the decline of the Tiwanaku state. *Journal of Archaeological Science* **20**, 195-221.
- Overpeck, J., Webb, R. S. and Webb, T. 1992. Vegetation maps for eastern North America reconstructed from pollen evidence. *Geology* **20**, 1071-1074.
- Peck, J. A., King, J. W., Colman, S. M. and Krachinsky, V. A. 1994. A rock-magnetic record from Lake Baikal, Siberia: evidence for late-Quaternary climate change. *Earth and Planetary Science Letters* **122**, 221-238.

- Pérez-Obiol, R. and Julià, R. 1994. Climatic change on the Iberian Peninsula recorded in a 30,000 year pollen record from Lake Banyoles. *Quaternary Research* **41**, 91-98.
- Petit-Maire, N., Sanlaville, P. and Zhong-Wei, Y. 1994. Changements globaux et paléomoussons: la zone transition afro-asiatique au cours des derniers 140,000 ans. *Géochronique* **50**, 16-19.
- Plummer, L. N. 1993. Stable isotope enrichment in palaeowaters of the southeast Atlantic coastal plain. *Science* **262**, 2016-2019.
- Preuss, J. 1990. L'évolution des paysages du bassin intérieur du Zaïre pendant les quarante derniers millénaires. In (D. Lafranchi and D. Schwartz, Eds) *Paysages Quaternaires de L'Afrique Centrale Atlantique*. Paris: Editions de l'ORSTOM, pp. 260-312.
- Pye, K. and Zhou, L.-P. 1989. Loess magnetic susceptibility as a palaeoclimatic indicator. *Palaeogeography, Palaeoclimatology, Palaeoecology* **73**, 11-23.
- Rackham, O. 1980. *Ancient Woodland: Its History, Vegetation and Uses in England*. London: Arnold.
- Reynolds, T. E. G. and Kansler, S. C. 1990. Japan. In (O. Soffer and C. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, pp. 227-241.
- Richard, P. J. H. 1995. Le couvert végétal du Québec-Labrador il y a 6,000 ans BP: essai. *Géographie Physique et Quaternaire* **49**, 117-140.
- Ritchie, J. C. 1982. *Postglacial Vegetation of Canada*. Cambridge: Cambridge University Press.
- Ritchie, J. C. and Cwynar, L. C. 1982. The late Quaternary vegetation of the North Yukon. In (D. M. Hopkins, J. V. Matthews, C. E. Schweger and S. B. Young, Eds) *The Palaeoecology of Beringia*. London: Academic Press, pp. 113-126.
- Ritchie, J. C. 1994. Holocene pollen spectra from Oyo, northwestern Sahara: problems of interpretation in a hyperarid environment. *The Holocene* **4**, 9-15.
- Roberts, N. 1990. Ups and downs in African lakes. *Nature* **346**, 107.
- Rocheftort, R. M., Ronda, L. L., Woodward, A. and Peterson, D. L. 1994. Changes in sub-alpine tree distribution in western North America: a review of climatic and other causal factors. *The Holocene* **4**, 89-100.
- Rosseau, D. and Kukla, G. 1994. Late Pleistocene climate record for the Eustis Loess Section, Nebraska, based on land snail assemblages and magnetic susceptibility. *Quaternary Research* **42**, 176-187.
- Rostek, F., Ruhland, R., Bassinot, F. C., Muller, P. J., Labeyrie, L. D., Lancelot, Y. and Bard, E. 1995. Reconstructing sea surface temperature and salinity using oxygen-18 and alkenone records. *Nature*, **364**, 319-321.
- Sarnthein, M. 1978. Sand deserts during glacial maximum and climatic optimum. *Nature* **272**, 43-46.
- Schwab, A. and Burns, S. 1995. Interhemispheric comparison of upper midwest (USA) and northern Chilean climate dynamics from environmental isotopic investigations of lake archives. Abstracts, *14th INQUA Congress*, Berlin, p. 146.
- Schwartz, D. 1991. Intérêt de la mesure du delta-13C des sols en milieu naturel équatorial pour la connaissance des aspects pédologiques et écologiques des relations savane-forêt. *Cahiers Orstom, Série Pédologique* **16**, 327-341.
- Schweger, C. E., Matthews, J. V., Hopkins, D. M. and Young, S. B. 1982. Palaeoecology of Beringia: a synthesis. In (D. M. Hopkins, J. V. Matthews, C. E. Schweger and S. B. Young, Eds) *The Palaeoecology of Beringia*. London: Academic Press, pp. 425-475.

- Scott, L. 1989. Climatic conditions in southern Africa since the last glacial maximum, inferred from pollen analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology* **70**, 345-353.
- Servant, M. and Servant-Vildary, A. 1980. L'environnement quaternaire du bassin du Tchad. In (M. A. J. Williams and H. Faure, Eds) *The Sahara and the Nile; Quaternary Environments and Prehistoric Occupation in Northern Africa*. Rotterdam: A. A. Balkema, pp. 133-163.
- Singh, G., Joshi, R. D., Chopra, S. K. and Singh, A. B. 1974. Late Quaternary history of vegetation and climate of the Rajasthan Desert, India. *Philosophical Transactions of the Royal Society of London* **267**, 467-501.
- Sjerup, H. P. 1987. Quaternary stratigraphy of the Fladen area, central North Sea. *Journal of Quaternary Science* **2**, 35-58.
- Smith, W. H. F. and Sandwell, D. T. 1997. Global seafloor topography from satellite altimetry and ship depth soundings. *Science* **277**, 1956-1962.
- Soffer, O. 1990. The Russian Plain at the LGM. In (O. Soffer and C. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, pp. 228-241.
- Soffer, O. and Gamble, C. 1990. *The World at 18,000 BP*. London: Unwin Hyman.
- Spasskaya, I. I. 1992. Dominant geomorphic processes during the maximum cooling of the last glaciation. In (B. Frenzel, B. Pecsí and A. A. Velichko, Eds) *Atlas of Palaeoclimates and Palaeoenvironments of the Northern Hemisphere*. Budapest: INQUA/Hungarian Academy of Sciences.
- Ssemada, I. and Vincens, A. 1993. Végétation et climat dans le bassin du lac Albert (Ouganda-Zaïre) depuis 13,000 ans BP; apport de la palynologie. *Comptes Rendus de l'Académie des Sciences de Paris, Série II* **316**, 561-567.
- Starkel, L. 1991. Environmental changes at the Younger Dryas—Preboreal Transition and during the early Holocene: some distinctive aspects in central Europe. *The Holocene* **1**, 234-242.
- Steele J, Adams J, and Sluckin T. 1998. Modelling Paleoindian dispersals. *World Archaeology* **30**(2): 286-305.
- Steinwand, D. R., Hutchinson, J. A. and Snyder, J. P. 1995. Map projections for global and continental data and an analysis of pixel distortion caused by reprojection. *Photogrammetric Engineering and Remote Sensing* **61**(12): 1487-1497.
- Street-Perrott, F. A. 1994. Palaeo-perspectives: changes in terrestrial ecosystems. *Ambio* **23**, 37-43.
- Street-Perrott, F. A. and Perrott, R. A. 1994. Holocene vegetation, lake levels and climate of Africa. In (H. E. Wright, Ed.) *Global Climates Since the Last Glacial Maximum*. Minneapolis: University of Minnesota Press, pp. 322-356.
- Stude, M., Forster, M., Frischkorn, H., Serejo, A., Clark, J. F., Schlosser, P., Broecker, W. S. and Bonani, G. 1995. Cooling of tropical Brazil (5 °C) during the last glacial maximum. *Science* **269**, 379-383.
- Suguo, K., Absy, M. L., Flexor, J. M., Ledru, M. P., Martin, L., Sifeddine, A., Soubies, F., Turcq, B. and Ybert, J.-P. 1993. Evolution of continental and coastal environments during the last climatic cycle in Brazil (120 ky BP to the present). *Boletim IG-USP, Seria Cientifica* **24**, 27-41.
- Stuijts, I., Newsome, J. C. and Flenley, J. R. 1988. Evidence for late Quaternary vegetation change in the Sumatran and Javan high-lands. *Review of Palynology and Palaeobotany* **55**, 207-216.
- Sukumer, R., Ramesh, R., Pant, R. K. and Rajagopalan, G. 1993. A C-13 record of late Quaternary climate change from peats in southern India. *Nature* **364**, 703-705.

- Sun, X. and Chen, Y. 1991. Palynological records of the last 11,000 years. *Quaternary Science Reviews* **10**, 537-544.
- Sun, X., Li, X., Luo, Y. and Chen, X. 2000. The vegetation and climate at the last glaciation on the emerged continental shelf of the South China Sea. *Palaeogeography, palaeoclimatology, palaeoecology* **160**: 301-316.
- Tallis, J. H. 1990. *Plant Community History: Long-Term Changes in Plant Distribution and Diversity*. Chapman & Hall, London.
- Tamura, T. 1990. Late Quaternary landscape evolution in the west Cameroon Highlands and the Adamaoua Plateau. In (R. Lanfranchi and D. Schwartz, Eds) *Paysages Quaternaires de L'Afrique Centrale Atlantique*. Paris: Editions de l'Orstom, pp. 298-313.
- Tamura, T. 1992. Landform development and related environmental changes in the Chi River basin, Northeast Thailand. *Science Reports of Tohoku University* **42**, 101-127.
- Taylor, D. M. 1990. Late Quaternary pollen records from two Ugandan mires, Rukiga Highlands SW Uganda. *Palaeogeography, Palaeoclimatology, Palaeoecology* **80**, 283-300.
- Tchakerian, V. P. 1994. Palaeoclimatic interpretations from desert dunes and sediments. In (A. D. Abrahams and A. J. Parsons, Eds) *Geomorphology of Desert Environments*. London: Chapman and Hall, pp. 200-211.
- Thom, B., Hesp, B. and Bryant, E. 1994. Last glacial 'coastal' dunes in Eastern Australia and implications for landscape stability during the Last Glacial Maximum. *Palaeogeography, Palaeoclimatology, Palaeoecology* **111**, 229-248.
- Thomas, D. S. G. and Shaw, P. A. 1991. *The Kalahari Environment*. Cambridge: Cambridge University Press.
- Thomas, M. F. 1994. *Geomorphology in the Tropics: a Study of Weathering and Denudation in the Low Latitudes*. Chichester: Wiley.
- Thomas, M. F. and Thorp, M. B. 1992. Landscape dynamics and surface deposits arising from Late Quaternary fluctuations in the forest-savanna boundary. In (P. A. Furley, Ed.) *Nature and Dynamics of Forest Savanna Boundaries*. London: Chapman and Hall.
- Thompson, L. G., Mosely-Thompson, E., Davis, M. E., Lin, P.-E., Henderson, K. A., Cole-Dai, B., Liu, K.-B. 1995. Late glacial stage and Holocene tropical ice core records from Huascaren, Peru. *Science* **269**, 46-50.
- Thompson, R. S. and Mead, J. I. 1982. Late Quaternary environments and biogeography in the Great Basin. *Quaternary Research* **17**, 39-55.
- Thompson R.S. and Anderson K.H. 2000. Biomes of western North America at 18,000, 6000 and 0 ¹⁴C yr BP reconstructed from pollen and packrat midden data. *Journal of Biogeography* **28**, 555-584.
- Times Concise World Atlas* 1992. London: Times Books.
- Tong, G. and Shao, S. 1991. Evolution of Quaternary climate in China. In (Z. Zhang, Ed.) *Quaternary of China*. Beijing: China Ocean Press, pp. 42-76.
- Tsukada, M. 1988. Japan. In (B. Huntley and T. Webb III, Eds) *Vegetation History*. London: Kluwer Academic Publishers, pp. 459-518.
- Turner, C. and Hannon, G. E. 1988. Vegetational evidence for late Quaternary climate changes in SW Europe. *Philosophical Transactions of the Royal Society* **126**, 451-485.
- van Campo, E. 1986. Monsoon fluctuations in two 20,000 yr BP oxygen-isotope/pollen records off southwest India. *Quaternary Research* **26**, 378-388.
- van Campo, E., Guiot, J. and Peng, C. 1993. A data-based re-appraisal of the terrestrial carbon budget at the last glacial maximum. *Global and Planetary Change* **8**, 189-201.

- van der Hammen, T. 1992. Untitled abstract. *Abstracts of 8th International Palynological Congress, 1992*, p. 151.
- van der Hammen, T. and Absy, M. L. 1994. Amazonia during the last Glacial. *Palaeogeography, Palaeoclimatology, Palaeoecology* **109**, 247-261.
- van der Kaars, W. A. 1990. *Late Quaternary Vegetation and Climate of Australia as Reflected by the Palynology of Eastern Indonesian Deep Sea Piston-Cores*. PhD thesis, University of Amsterdam.
- van Neer, W. 1984. Faunal remains from Matupi cave, an iron age and late stone age site in Northeastern Zaire. *Academiae Analecta* **46**, 58-76.
- van Zeist, W. and Bottema, S. 1988. Late Quaternary vegetational and climatic history of southwest Asia. In (W. van Zeist and S. Bottema, Eds) *Palaeoclimatic and Palaeoenvironmental Change in Asia During the Last 4 Million Years*. New Delhi: Indian National Science Academy, pp. 201-148.
- Velichko, A. A. 1991. Globalnye izmeneniya klimata i reactiya landshaftnoi obolochki. Moscow: *Seriya Geograficheskaya* **5**, 5-22. (In Russian; translated for QEN by A. A. Velichko.)
- Velichko, A. A. 1993. *Evolution of Landscapes and Climates of Northern Eurasia. Late Pleistocene-Holocene elements of prognosis*. Vol. 2. Moscow: 'Naukei'.
- Velichko, A. A. and Kurenkova, A. A. 1990a. Landscapes of the Northern Hemisphere during the late glacial maximum. In (O. Soffer and C. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, pp. 255-265.
- Velichko, A. A. and Kurenkova, A. A. 1990b. Northern Eurasia at 18,000 BP. In (O. Soffer and C. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, pp. 435-450.
- Velichko, A. A. and Isavea, L. L. 1992. Landscape types during the last glacial maximum. In (B. Frenzel, B. Pecsli and A. A. Velichko, Eds) *Atlas of Palaeoclimates and Palaeoenvironments of the Northern Hemisphere*. Budapest: INQUA/Hungarian Academy of Sciences.
- Velichko, A. A., Isayeva, L. L., Makeyev, V. M., Matishov, G. G. and Faustova, M. A. 1984. Late Pleistocene glaciation of the Arctic shelf, and the reconstruction of Eurasia ice sheets. In (A. A. Velichko, Ed.) *Late Quaternary Environments of the Soviet Union*. London: Longman, pp. 35-44.
- Velichko, A. A. and Spasskaya, I. I. (Eds) 1991. *Legend of Regions of the Land During Maximum Stage of Late Valdai Glaciation*. Geogeodezia SSSR (also includes accompanying maps by a large number of authors).
- Villagran, C. 1988. Expansion of Magellanic moorland during the Late Pleistocene: palynological evidence from northern Isla de Chiloe, Chile. *Quaternary Research* **30**, 304-314.
- Villagran, C. 1990. Glacial climates and their effects on the history of the vegetation of Chile: a synthesis based on palynological evidence from Isla de Chiloe. *Review of Palynology and Palaeo-botany* **65**, 17-24.
- Vincens, A. 1991. Late Quaternary vegetation history of the South-Tanganyika Basin. Climatic implications for South-Central Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology* **86**, 207-226.
- Volkov, I. A. and Zykina, V. S. 1984. Loess stratigraphy in south-western Siberia. In (A. A. Velichko, H. E. Wright and C. W. Barnosky, Eds) *Late Quaternary Environments of the Soviet Union*. London: Longman, pp. 119-124.

- Voris, H. K. 2000. Maps of Pleistocene sea levels in Southeast Asia: shorelines, river systems and time durations. *Journal of Biogeography* **27**, 1153-1167.
- Walker, N. J. 1990. Zimbabwe at 18,000 BP. In (O. Soffer and G. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, pp. 148-156.
- Wang, P. and Sun, X. 1994. Last glacial maximum in China: comparison between land and sea. *Catena* **23**, 341-353.
- Watts, W. A. 1980. Late Quaternary vegetation at White Pond on the inner coastal plain of South Carolina. *Quaternary Research* **13**, 187-199.
- Watts, W. A. and Stuiver, M. 1980. Late Wisconsin climate of northern Florida and the origin of species-rich deciduous forest. *Science* **210**, 325-327.
- Webb, T. III, Cushing, E. J. and Wright, H. E. Jr. 1983. Holocene changes in the vegetation of the Mid-West. In (H. E. Wright Jr., Ed.) *Late Quaternary Environments of the United States. Vol. 2; The Holocene*. Minneapolis: University of Minnesota Press, pp. 142-165.
- Webb, T. III, Bartlein, P. J., Harrison, S. P. and Anderson, K. J. 1993. Vegetation, lake levels and climate in eastern North America for the past 18,000 years. In (H. E. Wright Jr., J. E. Kutzbach, T. Webb III, W. F. Ruddiman, F. A. Street-Perrott and P. J. Bartlein, Eds) *Global Climates Since the Last Glacial Maximum*. Minneapolis: University of Minnesota Press, pp. 415-467.
- Wells, G. L. 1992. *The Aeolian Landscapes of North America for the Late Pleistocene*. D. Phil. Thesis, University of Oxford, U.K.
- Weniger, G. C. 1990. Germany at 18,000 BP. In (O. Soffer and C. Gamble, Eds) *The World at 18,000 BP*. London: Unwin Hyman, pp. 172-178.
- West, R. 1978. *Quaternary Geology and Biology*. Cambridge: Cambridge University Press.
- Whitmore, T. C. 1984. *Tropical Rainforests of the Far East*. Oxford: Oxford University Press.
- Wijmstra, T. A. and Van der Hammen, T. 1966. Palynological data on the history of tropical savannas in northern South America. *Leidenschrift Geologische Mededelin* **38**, 71-83.
- Wilkins, G. R. 1991. Palaeoecology of central Kentucky since the last glacial maximum. *Quaternary Research* **36**, 224-239.
- Williams, M. A. J. and Clarke, M. F. 1984. Late Quaternary environments in north-central India. *Nature* **308**, 633-635.
- Williams J.W., Webb III T., Richard P.H. and Newby P. 2000. Late Quaternary biomes of Canada and the eastern United States. *Journal of Biogeography* **27**: 585-607.
- Willis, K. J. 1994. The vegetational history of the Balkans. *Quaternary Science Reviews* **13**, 769-788.
- Willis, K. J., Rudner, E. and Sümegei, P. 2000. The Full-Glacial Forests of Central and Southeastern Europe. *Quaternary Research* **53**(2), 203-213.
- Winkler, M. G. and Wang, P. H. 1993. Late-Quaternary vegetation and climate of China. In (H. E. Wright Jr., J. E. Kutzbach, T. Webb III, W. F. Ruddiman, F. A. Street-Perrott and P. J. Bartlein, Eds) *Global Climates Since the Last Glacial Maximum*. Minneapolis: University of Minnesota Press, pp. 221-264.
- Woodcock, D. W. and Wells, P. V. 1990. Full glacial summer temperatures in eastern North America as inferred from Wisconsinian vegetational zonation. *Palaeogeography, Palaeoclimatology, Palaeoecology* **79**, 305-312.
- Wright, H. E. Jr. 1993. Environmental determinism in Near Eastern Prehistory. *Current Anthropology* **34**, 458-469.

Yang, H. and Wang, J. 1990. Quaternary transgressions and coast-line changes in the Huanghe River (Yellow River) Delta. *Marine Geology and Quaternary Geology* **10**, 14.

Yasuda, Y. and Tabata, H. 1988. Vegetational and climatic changes in Nepal Himalayas. Late Quaternary vegetational and climatic history of southwest Asia. In (W. van Zeist and S. Bottema, Eds) *Palaeoclimatic and Palaeoenvironmental Change in Asia During the Last 4 Million Years*. New Delhi: Indian National Science Academy, pp. 201-211.

Yu, G., X. Chen, J. Ni, R. Cheddadi, J. Guiot, H. Han, S.P. Harrison, C. Huang, M. Ke, Z. Kong, S. Li, W. Li, P. Liew, G. Liu, J. Liu, Q. Liu, K.-B. Liu, I.C. Prentice, W. Qui, G. Ren, C. Song, S. Sugita, X. Sun, L. Tang, E. Van Campo, Y. Xia, Q. Xu, S. Yan, X. Yang, J. Zhao and Z. Zheng. 2000. Palaeovegetation of China: a pollen data-based synthesis for the mid-Holocene and last glacial maximum. *Journal of Biogeography* **27**, 635-664.

8 Download Area

The presented maps are available for download at:

<http://lqb.unige.ch/lgmvegetation>

9 Table of Figures

Figure 1. LGM extended coastlines (sea-level drop of 120m) computed from global bathymetry (Smith and Sandwell, 1997).

Figure 2. Global LGM vegetation map (-180;+180 decimal degrees extent).

Figure 3. Legend accompanying the maps.

Figure 4. North and central America.

Figure 5. South America.

Figure 6. Africa.

Figure 7. Europe.

Figure 8. Eurasia.

Figure 9. Australasia.

Table 1. Vegetation categories and their description. The corresponding vegetation type(s) from Olson et al. (1983) are also indicated.

ID#	Vegetation Type	Description	Corresponding Olson's vegetation type
1	Tropical rainforest	Broadleaved, tall, evergreen forest. Drip tips and buttress roots common on trees.	Main Tropical/Subtropical Forest; Broad-Leaved Humid Forest
2	Monsoon or dry forest	Largely or entirely deciduous closed forest in tropics.	No Olson analogue
3	Tropical woodland	More open, deciduous woody vegetation (more than 6m tall). Open canopy; less than 60% canopy cover.	Main Tropical/Subtropical Forest; Dry Forest and Woodland
4	Tropical thorn scrub and scrub woodland	Lower woody vegetation (less than 6m tall), generally open with wide gaps between the bushes/low trees, in frost-free climate	No Olson analogue
5	Tropical semi-desert	Very open. Between 2% and 10% vegetation cover. Scattered clumps of grass or small shrubs.	Nonpolar desert or semidesert (Sparse (rocky) vegetation, Other Desert and Semidesert, Cool Semidesert Scrub)
6	Tropical grassland	Greater than 20% vegetation cover. Mainly grassy, very few woody plants (less than 5% cover).	Tropical savanna or montane; Tropical Savanna and Woodland
7	Tropical extreme desert	Less than 2% vegetation cover. Almost entirely barren.	Nonpolar desert or semidesert (Sand Desert)
8	Savanna	Greater than 20% vegetation cover, mainly grassy but with 5-20% tree cover.	Tropical savanna or montane; Tropical Savanna and Woodland

9	Broadleaved temperate evergreen forest	Mainly broadleaved and mainly evergreen trees, closed canopy (>60% crown cover). Without drip tips or buttress roots. Frosts occasionally occur	Mostly mid-latitude broad-leaved and mixed (Woods, Temperate broad-leaved forest), Tropical/subtropical humid forest, Temperate/boreal forest;
10	Montane tropical forest	Broadleaved evergreen trees. Closed forest canopy. Shorter than lowland forests, tending not to have drip tips or buttress roots.	No Olson analogue
11	Open boreal woodlands	Open woody vegetation (less than 60% canopy cover). Highly frost tolerant trees.	Northern or Maritime Taiga, subalpine
12	Semi-arid temperate woodland or scrub	Low woody vegetation (less than 6m tall), generally open with wide gaps between the bushes/low trees, in a climate in which frosts occur	Other dry woods mosaics
13	Tundra	Greater than 2% cover by low shrubs (<1m) or grasses in a lowland climate with extremely cold winters and cool summers.	Tundra
14	Steppe-tundra	A vegetation type widespread during the Last Glacial Maximum, which combined plants of tundra and steppe environments. Probably around 50% ground cover by plants; bare ground abundant but patchy.	No Olson analogue

15	Polar and alpine desert	Less than 2% ground cover by any species of vascular plant. Cold climate virtually year-round.	Polar or Rock Desert
16	Temperate desert	Less than 2% ground cover in climate in which frost occurs.	Cool desert and semi desert types
17	Temperate semi-desert	2-20% vegetation cover in a climate in which frosts occur.	Cool desert and semi desert
18	Forest steppe	5-20% overall tree cover, often as patches of trees, in a mainly grassy landscape. In lowlands.	Wooded tundra
19	Montane Mosaic	Complex topographic mosaics of forest, tundra, grassland and montane desert.	No Olson analogue
20	Alpine tundra	Greater than 2% cover by low shrubs (<1m) or grasses in a mountain climate with cold winters and cool summers.	No Olson analogue
21	Subalpine parkland	5-20% overall tree cover, often as patches of trees, in a mainly grassy landscape.	Cool grassland/scrub. Subalpine.
22	Dry steppe	Greater than 20% vegetation cover, mainly grasses. Relatively short (<75cm) grasses, drier climate.	Cool grassland/scrub.
23	Temperate steppe grassland	Greater than 20% vegetation cover, mainly grasses. Relatively tall grasses and other plants (>75cm), moister climate.	Main Grassland or shrubland; Cool grassland/scrub
24	Main Taiga	Conifer forest with a fairly open canopy	Mostly taiga and other conifer; Main Taiga

25	Lakes and open water	Year-round open water, possibly freezing in winter.	Water Bodies
26	Ice sheet and other permanent ice	Year-round ice or snow on surface.	Ice

Figure 1. LGM extended coastlines (sea-level drop of 120m) computed from global bathymetry (Smith and Sandwell, 1997).



Figure 2. Global LGM vegetation map (-180;+180 decimal degrees extent).

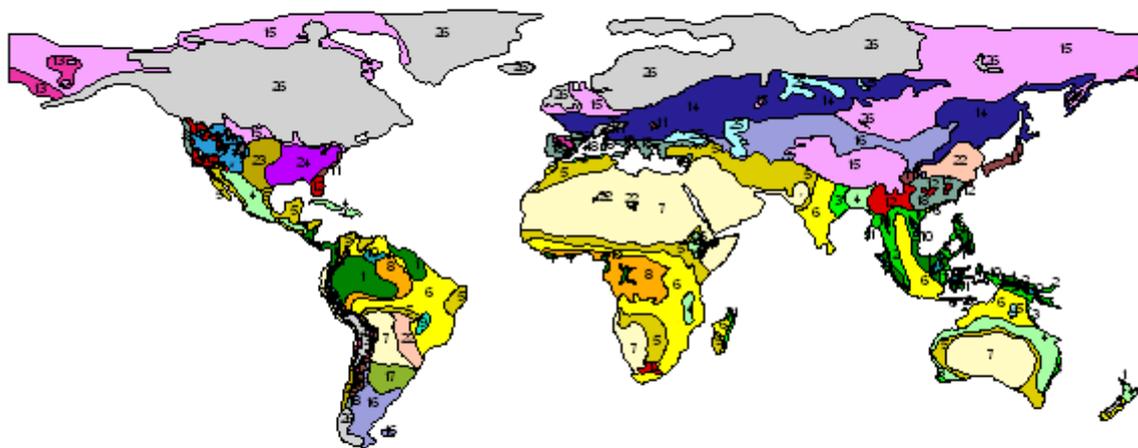


Figure 3. Legend accompanying the maps.



Figure 4. North and central America.

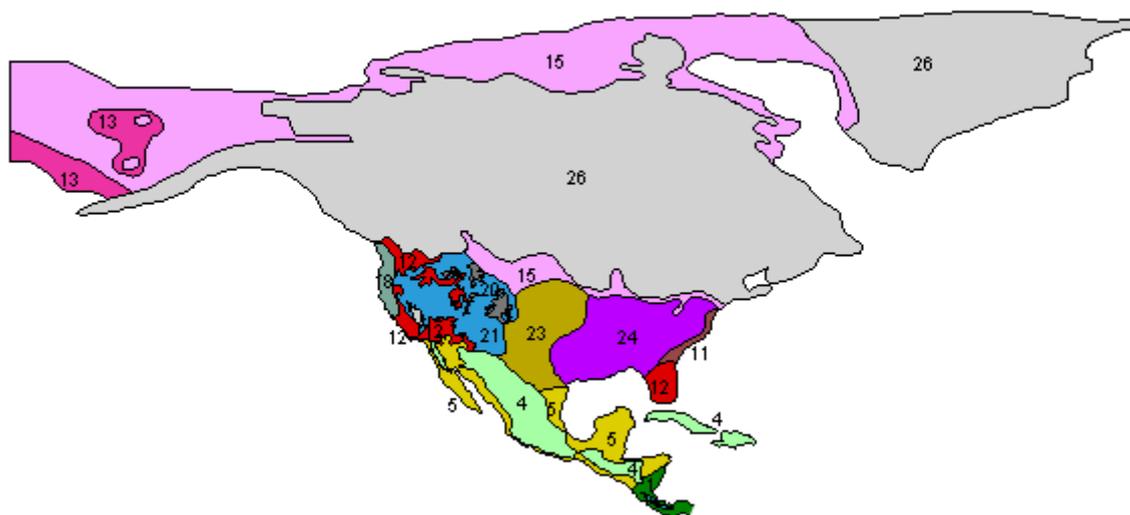


Figure 5. South America.

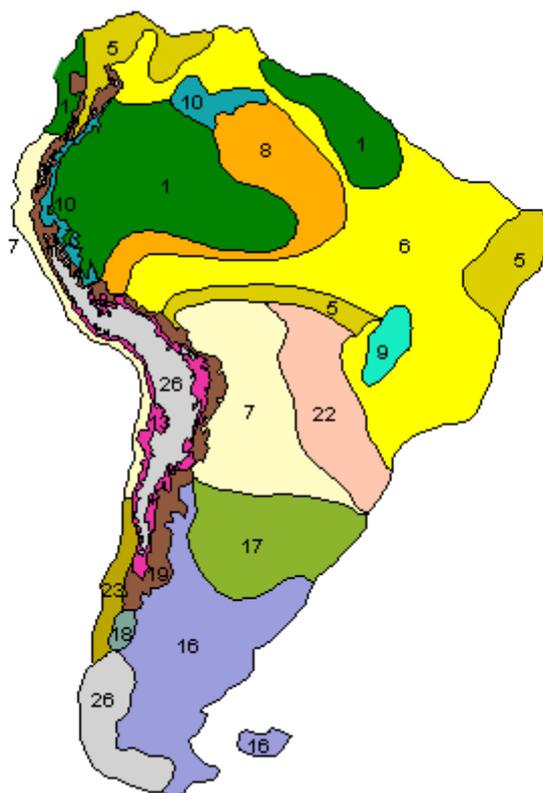


Figure 6. Africa.

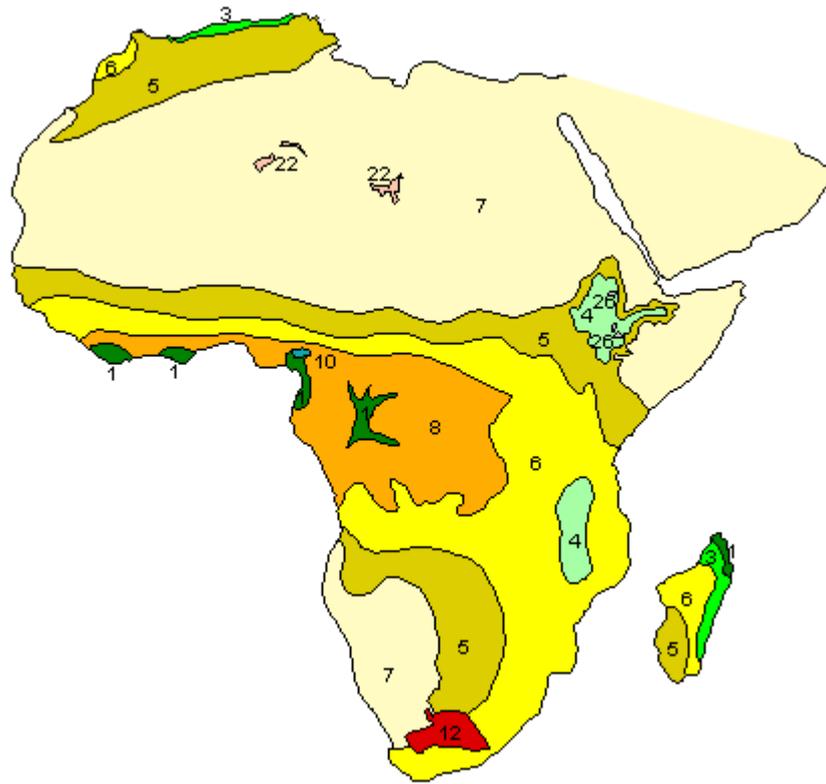


Figure 7. Europe.

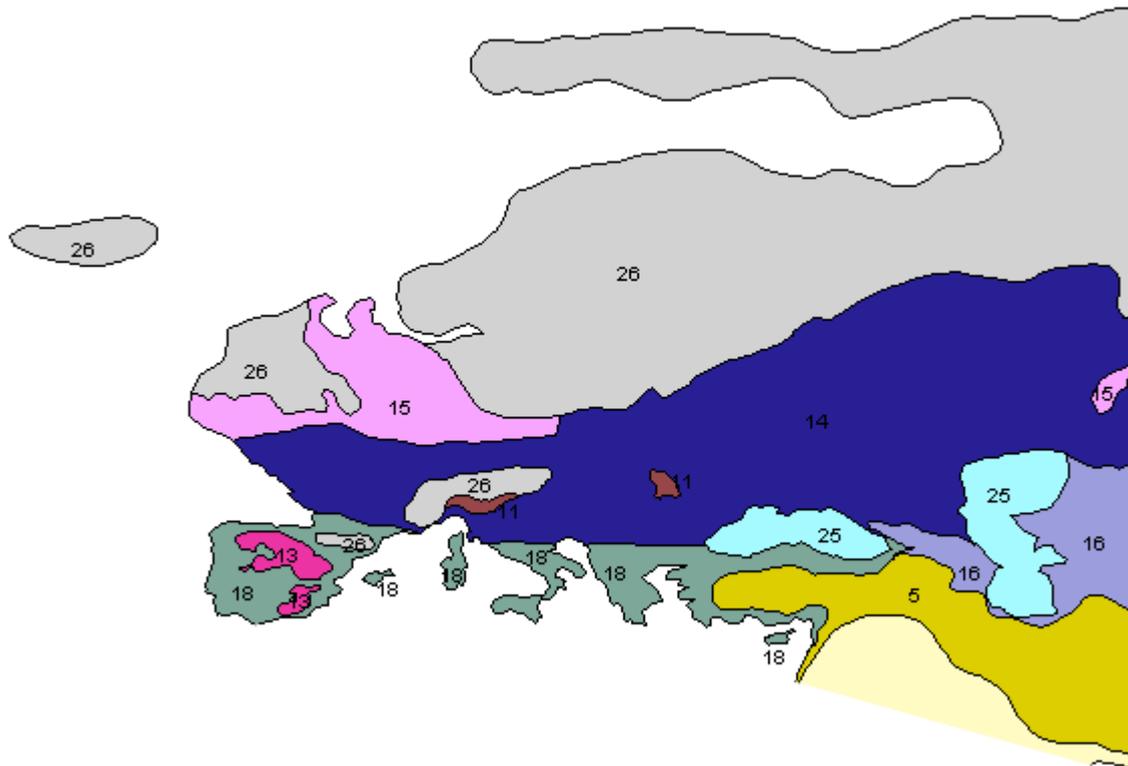


Figure 8. Eurasia.

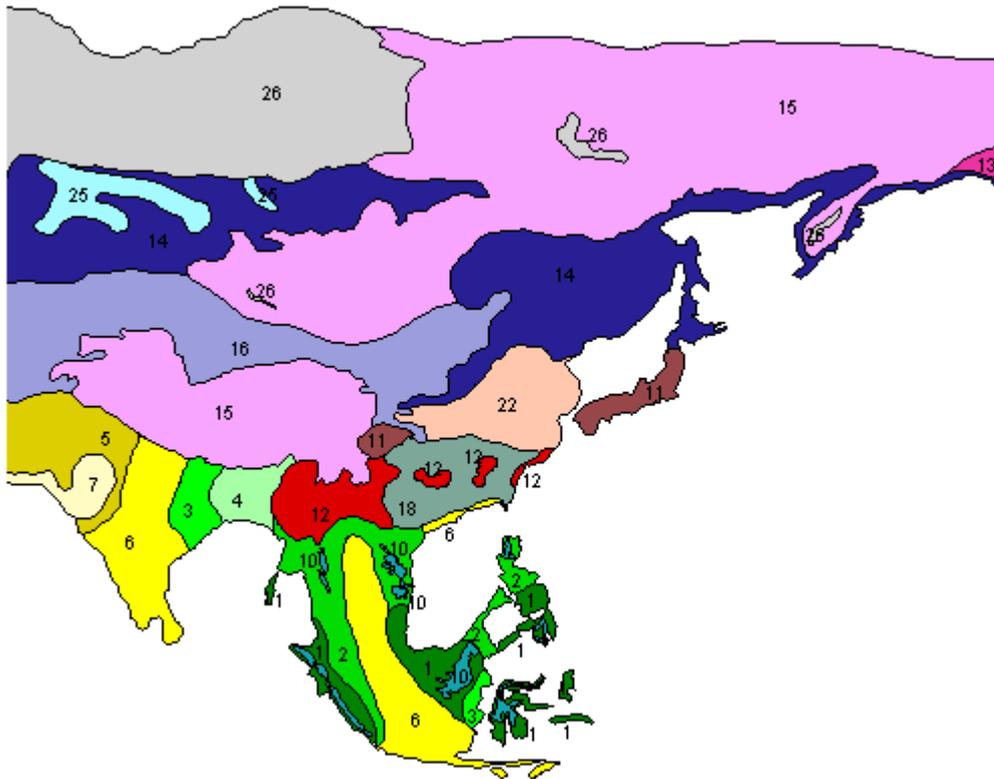


Figure 9. Australasia.

