The response to the Referee #1:

(1) Comments from Referee #1

In general, the review of the article is positive, but major improvements are necessary before the manuscript can be considered for publication: Line 017: Why to mention: “This paper is one of the studies: : :..” This paper and the results must be able to stand alone, it sounds like an excuse! Line 031: I’m a bit astonished that from 9,250 cal. Yr BP to present no major changes were highlighted although Fig. 2documents noteworthy changes. Line 042: lie seems a not-quite correct term Line 073-076: The statement could be proven within the entire manuscript! Clear evidences are missing. Line 103: “densata Mast.” are “also present” Line 153: Results – this is the weakest part of the manuscript in terms of interpretation!! Line 157: there is no “chronological control against which to decipher the vegetation and climate history”. There is only a listing what might have happened within the different Pollen Zones, but an interpretation and/or a comparison to recent conditions is missing!!! Line 278: The discussion and the conclusions have to be improved deeply. The visual differences between Zone 1 and Zone 3 are not so clear, but the “interpretation” of the climate conditions are quite different. Zone 2, in between, shows completely different climatic and vegetative conditions, but there is no interpretation or any comparison to other published studies. According to this, chapter 5 (from Line 278 onwards) has to be improved tremendously. The results and this paper must be able to stand alone in contrast to the authors predication that they “published the first of a series of studies: : :.” Major revisions of the manuscript are necessary.

(2) Author's response

Line 017: We agree with Referee #1 that this paper and the results can stand alone.

Line 031: Fig. 2 documents noteworthy changes and major changes from 9,250 cal yr BP to the present should be highlighted.

Line 042: We agree that “lie” is not a suitable term.

Line 073-076: One aim of this paper is to develop insights into the changing floristic diversity and to draw inferences about past climate and anthropogenic influences based on palynological investigation. The other aim is to compare study sites at different altitudes in the region. We agree that clear evidences are missing in this regard.

Line 103: We also think the sentence “*P. densata* Mast. also present” is incorrect.

Lines 153, 157, 278: We agree with Referee #1 that the results, discussion and conclusions need to be improved in terms of interpretation.

(3) Author's changes in manuscript

Line 017: The sentence “is one of the studies covering a range of altitudes within this hotspot” has been removed (**Line 17 in the revised Ms**).

Line 031: From 9,250 cal. yr BP to the present, the vegetation has been dominated by needle-leaved forest (comprising mainly *Pinus*, *Abies* and *Tsuga*), interspersed with broad-leaved *Quercus* and *Betula*, reflecting a significant decline of humidity from the early to late Holocene (**Lines 50-53 in the revised Ms**).

Line 042: The term “lie” has been changed to “are located” (**Line 61 in the revised Ms**).

Line 073-076: We aim to use pollen data to develop insights into the changing floristic diversity and to draw inferences about past climate and anthropogenic influences in the region during the Late Quaternary (**Lines 110-112 in the revised Ms**).

Line 103: *P. densata* Mast. are also present (**Line 158 in the revised Ms**).

Lines 153, 157, 278: In the results section, we have deleted “chronological control against which to decipher the vegetation and climate history” (**Line 241 in the revised Ms**) and made a comparison of pollen assemblage between each pollen zone and the surface samples (representing recent condition) (**Lines 338-346, 364-371, 386-392, 406-415, 431-437 in the revised Ms.**) In the discussion and conclusion section, we have made a detailed comparison with previous studies, particularly in terms of the Last Glacial Maximum and the Younger Dryas (**Lines 477-645 in the revised Ms**).

The response to the Referee #2:

(1) Comments from Referee #2

General Comments

The authors present results of a pollen core dating back to at least 20,000bp. I would congratulate the authors for their growing body of work in the region. The data they collect will surely be an important contribution to scientific discussion in the region. However, a major goal of the manuscript is to make inferences on past climate, based on their palynological findings. Regrettably, I found this aspect of the paper questionable, and generally poorly argued. The authors climate inferences are restricted to "cold", "warm", "humid", and "dry", terms which are so open to personal interpretation that they are more likely to serve as a source of confusion than clarity. There seems to be no attempt to place these relative terms in context. For example, climatic inferences are not discussed in relation to well known climatic phenomena, such as the LGM, or even modern climate. Furthermore, climate inferences are based on few indicator taxa with questionable indicator value. The authors also do not adequately describe how modern vegetation and climate varies along mountain slopes, making at least this reader suspect the adequacy of the authors’ ecological understanding of vegetation change along elevation gradients, and thus the ability to make climate inferences based on the vertical migrations of taxa on mountain slopes as determined by the pollen record. In general, while I deeply encourage the author’s to get this information published, I cannot say that in its current form, the manuscript possesses the quantitative rigor that readers of BG might have come to expect.

Specific Comments

Line 21-26 - Climate at _22,000 BP is initially inferred to be cool, presumably based on the dominance of broad-leaved taxa, and dry, based on the presence of Artemisia. At _20,000 BP, again based on the dominance of similar broad-leaved taxa, climate is inferred to be warm , and, (presumably) based on the presence of aquatic taxa, humid. I found the apparent capacity for broad-leaved taxa to indicate both cool and warm climates confusing and unrealistic.

line 27 - Again, while the dominance of broad-leaved taxa is initially associated with cold conditions (line 21-23), in this line the dominance of broad-leaved taxa is associated to warm climate. In the methods section (line 110), broad-leaved taxa are described to "cloak" mountain sides at higher elevations, suggesting that dominance of broad-leaved taxa indicates cooler temperature. Thus, the author’s climate inference does not seem to be consistent with their own descriptions of vegetation zonation along the elevation gradient. It also seems opposite to the expectation that conifers dominate at higher altitudes than broad-leaved trees. I’m a bit confused.

line 32 - The term "coupled" suggests that broad-leaved and needle-leaved taxa coexist together rather than alternate in dominance with changing climate conditions, which seems to be the idea the authors are trying to indicate.

line 35 - The strength of conviction the authors relate here concerning indications of human disturbance does not match the rather tentative mood in the discussion.

line 38 - Based on the figure provided, I cannot visualize the marked decline in Quercus pollen in the first 30cm of the core. Rather, I see a trending decline in Quercus that began much earlier (around 60cm, or arguably around 230cm when Pinus becomes dominant). One interesting aspect of the first 30cm I do see is that the nearly perfect negative correlation between Pinus and Quercus seems to break down. The dramatic decrease in Pinus beginning around 20cm is not matched by an expected (based on the rest of the profile) increase in Quercus. At any rate, I think that if the authors wish to base arguments of human impact on the vegetation then these specific aspect of the profile should be made more visually apparent to the readers so that we are able assess the statements independently.
line 52-53 - My initial reading of this sentence had me wondering why comparison between sites was predicated on altitudinal zonation of vegetation, as any two sites could be compared in theory. Maybe changing the word "and" ("compare between sites and build up....") to "in order to" or something equivalent might help.
line 97 - One of main objectives of the paper is make past climate inferences. The ability to make inferences on past climates from the vertical migration of taxa along mountain slopes, as evident from the palynological record, is ultimately based on our knowledge of how the present vegetation is distributed along the elevation gradient.
That said, I think the authors must do a better job of describing how present day vegetation changes with vertical ascent on these mountains. First, besides one citation at the beginning of the paragraph I notice that there are virtually no citations, especially to the botanical literature where vegetation zonation is likely to be well described. Second, the authors only describe the gradient from 3,100, where the study site is located, to 4000 masl. Considering that vertical migration can be up or down, a characterization of the type of forests below the site location seems critical. Third, based on the portion of the elevation gradient that has been described by the authors, it is very difficult for the reader to understand the main trends that are evident. For example, the distinction between broad-leaved and needle-leaved compositions seems to be critical to the climate inferences the authors make at later points, suggesting that broad-leaved and needle leaved forests dominate at different elevations, and by extension, different climates. However, this is not evident in their descriptions. For example, begining line 97, "The study area is located within a vegetation “sub-domain” characterized by Pinus yunnanensis Franch. forest and Picea-Abies forest typical of northwestern-central Yunnan (WGYV, 1987). The local vegetation displays a distinct vertical zonation. On the mountains surrounding Wenhai Lake (3,100–3,500 m), the vegetation is dominated by oaks (Quercus pannosa Hand.-Mazz) and pines."
Then...at line 109
"At higher elevations, between 3,500 and 3,800 m, the Jade Dragon Snow Mountain is cloaked in evergreen broad-leaved forest consisting of Quercus pannosa and Cyclobalanopsis glauca (Thunb.) Oerst, together with coniferous trees such as Abies delaveyi Franch., Picea likiangensis (Franch.) E. Pritz and Larix potanini Batalin." Resuming, the authors have described a situation where at low and high elevations forests are dominated by oaks (broad-leaves) and conifers (needle leaves). The major distinction between broad and needle leaves does not seem to capture any vertical zonation of vegetation communities along the elevation gradient, at least as the authors have described it. This is important because the broad/needle distinction later serves as one the main arguments for inferring climate change.
And lastly, based on my reading of the authors description, I’m led to believe that dominance of broad-leaved taxa indicates higher elevations and, by inference, colder climates. This is opposite to my own expectations of needle-leaved taxa dominating at higher elevations.
line - 148 - 151 - Were the groupings determined by the tilia software based on the groupings of taxa, or the

taxa themselves?
line 168 - 172 - The grouping described here is later used as a basis to make climate inferences, thus it stands to reason that the groups should be based on their climatic tolerance. While in most circumstances I would generally agree that a distinction between broad and needle-leaved taxa is ecologically important, the authors have failed completely to articulate this (see previous commentary).
Also, it is not clear what the author’s inclusion criteria for the "broad-leaved" category was. For example, the inclusion, of herbaceous taxa such as Cyperaceae seems without foundation. It is also not clear whether the "broad-leaved" category was restricted to Quercus, Alnus, Artemisia, Cyperaceae, Ericaceae and Polygonaceae, or also included other angiosperms (Meliaceae, Flacaourts, Rosaceae, Rutaceae, Salix, etc).
Also, it is not clear what the author’s inclusion criteria for the aquatic category was.
Mainly, I ask why not all aquatics are included, such as pediastrum?
Also, it seems that grouping should be exclusive, in the sense that one taxa should not appear in different groups that are used to infer climate. Cyperaceae, for example, is grouped into the broad-leaved group, as well as the hygrophilous group.
line 188-190 - "A greater diversity of palynomorphs was recovered from the core samples than from the surface samples, which might suggest that surface samples fail to capture the local vegetation completely." This seems a bit of a strange thing to say for two reasons. First, the core reflects 20,000 years of historical plant migrations up and down the slope as well as from other regions, while surface samples reflect only the most modern vegetation community. It seems intuitive that species should accumulate in the pollen record with time, thus the author’s conclusion that it is due to the possibility that surface samples don’t capture local vegetation pattern seems baseless. Second, palynological inference is ultimately based on the ability of surface samples, which are later fossilized under anoxic conditions, to capture trends in local vegetation pattern. If the authors contest that palynological samples adequately reflect local vegetation then they seem to have eroded the logical basis for their study.
line 195 - The presence of Palmae is interesting as it is a clear warm climate indicator. I didn’t see it in the figure of pollen profile. Why not?
line 280-288 - The discussion opens with a paragraph where the authors outline what they believe to be indicator taxa for temperature and moisture. Generally, I found the section to be unconvincing. I am wary of any climate inferences based on the author’s data for the following reasons.
1) Temperature and moisture co-vary in complex ways along the elevation gradient. The authors provide no description of how climate variables vary on the modern elevation gradient, thus it is impossible for the reader to understand how it has changed relative to modern conditions. How does precipitation vary along the elevation gradient in the authors’s region? What are conditions in the lowlands? The relative terms such as warm, cold, humid, and dry, that the authors used to describe the climate are generally not useful. They are open to so much personal interpretation that these terms are more likely to confuse, rather than contribute to further scientific inquiry.
2) On a physiological level, all land plants are faced with the competing demands of taking up CO2 from the atmosphere while limiting water loss, thus, the assumption that plant species move vertically to remain within either their temperature or moisture tolerance independently does not account for these coupled environmental constraints on growth and survival (Crimmins et al 2011). Because ambient temperature and moisture availability both influence plant water-energy balance, distributional shifts of plant species apparent from the pollen record may not be adequately explained by considering changes in past temperature or moisture in isolation. By extension, the idea that vertical migration of few taxa could indicate change in either one or the other climate variable seems naive based on our understanding of modern plant physiology. Climate

inferences should generally be based on many indicator species, not one or two.
3) The indicator taxa probably do not account for the entire extent of climate change experienced at the site. For example, two conifers, Abies and Picea, and Betula are considered to be indicators of cold climates, while Pinus is considered to indicate warm climate. The degree of temperature variation examined by considering only these taxa is relatively small compared to the taxa that are present in the core, such as Palmae, Meliaceae, Flacourtiaceae, etc, etc. Furthermore, Abies (author's indicator of cold) and Pinus (author's indicator of warm) visually tend to show positive correlation throughout the core (see Tilia figure), suggesting an overlapping response to environmental changes and thus are not likely to be able to distinguish between colder and warmer climates.
4) It is not clear whether the authors use the term hygrophilous to indicate plants that grow in and around the damp substrates surrounding the lake, or to indicate plants that are ecologically restricted to climates with high precipitation and/or low precipitation seasonality. Thus, it is unclear whether the authors view these taxa as indicators of the conditions of the immediate lake environment or regional precipitation. It is confusing because the authors have focused, until now, on regional climate inferences. The distinction is important because changes in abundance of aquatics and semi-aquatic taxa (hygrophilous) are likely to reflect changing local site conditions, rather than changes in regional climate (Bush 2004 provide a good discussion on this). For example, most of the taxa that the authors have chosen are predominantly comprised of species of fast growing low shrubs or small emergent herbs that occur in high light environments, such as forest edges surrounding lakes, rather than the forest understories. Thus, their increase and decline probably reflects shifting local processes in the lake rather than large scale change in precipitation. These taxa could only be used as indicators of regional precipitation if a positive correlation between their abundance and regional precipitation is expected. However, I don't see this as a likely scenario, as shifting abundances of these moisture indicators might even produce patterns opposite to what one might expect. For example, if decreasing precipitation lowers average lake levels it can increase suitable colonization sites for emergent hygrophilous taxa, whereas deeper lake levels that flood these colonization sites in response to high precipitation may decrease suitable habitat. In these examples, the amount of pollen of hygrophilous taxa is negatively correlated to regional precipitation. Patterns of hygrophilous taxa will depend as much on local topography of the lake bottoms and the nature of water inputs and outputs from the lake as regional climate. The point, is that once the ecology of hygrophilous taxa is taken into consideration, it is arguable that they are not likely to be good indicators of regional moisture.
5) The authors provide minimal support from the literature or distributional data that support the relevance of thier chosen indicator taxa to climate inference. Many taxa, such as Cyperaceae, Polygonaceae, and Poaceae are extremely diverse taxa and show high degrees of ecological differentiation. Artemisia, a taxa the authors suggest is an indicator for dry environments, for example, has been shown to have wide ecological amplitudes in nearby regions that limit its use for climate inference (Subally & Quezal 2002).
Based on these observations, I am wary of the climate inferences the authors provide.
line 292 - 295 - I fail to understand how, based on fossil pollen, the authors know that certain taxa occurred around the vicinity of the lake and other taxa occurred at higher elevations. While pollen can certainly be transported downslope, it seems impossible to establish which pollen grains were produced at higher elevations and which were produced in situ, as least with the level of confidence that the authors suggest.
line 296 - While I would generally agree that the herbs are probably growing in forest edge conditions around the lake, the authors contention that Artemisa, previously indicated as a taxa indicating dry environments, should prefer the wet conditions around the lake seems inconsistent.
There seems to be some inconsistency in the environmental conditions that taxa indicate. Two other examples

became apparent to me as well. 1) Cyperaceae is considered a broad-leave taxa, which the authors use to make inferences concerning temperature, as well as an indicator of moist conditions. 2) Polygonaceae is an indicator of moist conditions as well as human disturbance. Once again, the ecological diversity of these taxa likely make their utility in making good climate inference very difficult.

line 299 - 300 - Cold and dry relative to what? How does this compare with other pollen studies and known climatic events (i.e. LGM). The authors do not provide a point of reference. The authors to not provide comparisons with other studies. The statement is thus not interpretable. Furthermore, it is not clear on what basis the authors have make their determination. What exactly makes the authors think this time period was cold and dry?

line 301 - 307 - Again, warm and humid relative to what. This statement is not interpretable. Furthermore, it is not clear on what basis the authors have determined the climate to be warm and humid. I assume it is based on the increase in pollen of herbaceous and shrubby taxa that the authors have suggested as hygrophilous. See previous discussion on the ecology of these taxa.

line 308 - 315 - On line 292 a dominance of broad-leaved taxa was associated with cold and dry conditions. Here, the decrease of broad-leaved taxa is associated with cold and dry conditions. I am thoroughly perplexed.

line 331 - Again, cold humid and warm humid relative what? What indicates cold? What indicates warm?

(2) Author's response

General Comments

We accept the suggestions of Referee #2 and have made necessary corrections in the revised Ms. The major aim of the manuscript is to make inferences on past climate based on principal palynomorphs from Wenhai Lake. Some indicator taxa may be questionable in indicator value like what Referee #2 said, but they have special ecological preferences in Southwest China. We have clarified in this regard and have given a detailed and clear statement on their climatic implications in the revised Ms. The climatic inferences have also been discussed in relation to the LGM and YD in the discussion section. Furthermore, we have adequately described how modern vegetation and climate varies along elevation gradients in the Jade Dragon Snow Mountain region.

Specific Comments

Lines 21-26, 27: We agree with Referee #2 that it is impossible for broad-leaved taxa to indicate both cool and warm climates. It is really a bit confusing.

Line 32: The term "coupled" suggests that broad-leaved and needle-leaved taxa coexist together.

Line 35: We agree with Referee #2 that the strength of conviction concerning indications of human disturbance does not match the rather tentative mood in the discussion.

Line 38: The marked decline in *Quercus* pollen in the first 30 cm of the core is compared with the early stage (around 60 cm).

Line 52-53: We agree with Referee #2 that the word "in order to" is more suitable than “and”.

Line 97: We agree with Referee # 2 that it is necessary to describe how the present day vegetation changes along the elevation gradients.

Lines 148-151: The groupings were determined by the tilia software based on the groupings of taxa.

Lines 168-172: The palynomorphs recovered from the surface samples should be summed into trees and shrubs, herbs, pteridophytes, and aquatics, so that they are in agreement with the categories of palynomorphs from the Wenhai core samples. The trees and shrubs include conifers and broad-leaved taxa (trees, shrubs). The aquatics comprise algae and *Myriophyllum.*

Lines 188-190: We agree with Referee #2 that the palynological inference is based on the ability of surface samples.

Line 195: Selected taxa with abundance of more than 1% in at least one sample were shown in Figure 2. However, Palmae pollen occurs in only three samples (with abundance of less than 1%), so we didn't show it in the figure of pollen profile.

Lines 280-288: We agree with Referee #2 that this section is unconvincing, because some taxa may be questionable in indicator value. More detailed information about the indicator taxa is necessary.

Lines 292 - 295: We agree with Referee #2 that it seems impossible to establish which pollen grains were produced at higher elevations and which were produced in situ.

Line 296: It is true that the herbs are usually growing in forest edge conditions around the lake. *Artemisia* is taxon growing in temperate areas of mid to high latitudes of the Northern Hemisphere, in particular in arid or semi-arid environments (Valles and McArthur, 2001). The genus *Artemisia* is considered an indicator of steppe climate (Erdtman, 1952) and moderate precipitation (El-Moslimany, 1990). Cyperaceae is a cosmopolitan family, with many species commonly growing in wetlands and surrounding areas, adapted to an open and sunny condition. The high frequency of Cyperaceae pollen may indicate humid conditions (KIBCAS, 2003b; Sun et al. 2003). Most species of Polygonaceae family is in relation to moist conditions, but the occurrence of some species such as *Rumex* and *Fagopyrum* can be used as the indicator of human activity.

Lines 299 - 300: The suggestions of Referee #2 are very good. We will provide comparisons with other studies and known climatic events. The genus *Quercus* is widely distributed in the fog zone (with higher humidity, at about 3,100 m) on the Jade Dragon Snow Mountain where it forms a montane needle- and broad-leaved mixed forest along with *Tsuga* and *Picea*. *Betula* is viewed as a cold- and drought-tolerant element. Based on the dominance of *Quercus* and *Betula* pollen, we may infer the climate condition was cold and dry followed by cold and wet conditions.

Lines 301 - 307: Generally speaking, we can't infer a warm and humid climate condition during this period, but we can infer a relatively cold and dry climate with several fluctuations in humidity, based on a notable increase in *Betula* pollen and a dramatic decrease in *Quercus* pollen.

Lines 308 - 315: The increase in *Quercus* pollen indicates a cold and wet condition, so the remarkable decrease in *Quercus* pollen together with *Abies* reaching its maximum extent during this period may reflect the climate changed to colder and drier compared to the last stage.

Line 331: The statement of cold humid and warm humid possibly is not suitable. A significant decline in humidity from the early stage (early Holocene) to late stage (late Holocene) can be inferred based on the increase in *Quercus* pollen at the beginning and the decline after that.

(3) Author's changes in manuscript

General Comments

According to the suggestions of Referee #2, we have made a detailed statement on the climatic implications of major palynomorphs recovered from Wenhai Lake (**Lines 440-475 in the revised Ms**). The climatic inferences have been discussed in relation to the LGM and YD (**Lines 477-645 in the revised Ms**). How the modern vegetation and climate varies along elevation gradients in the Jade Dragon Snow Mountain region has been adequately described (**Lines 145-155 in the revised Ms**).

Specific Comments

Lines 21-26, 27: Broad-leaved *Quercus* indicates cold and wet climate in the Jade Dragon Snow Mountain region. Broad-leaved *Betula* reflects cold and dry condition. We have made the necessary corrections (**Lines 22-29 in the revised Ms**).

Line 32: We prefer to use the term "interspersed" instead of “coupled” (**Line 52 in the revised Ms**).

Line 35: We have changed to “During this period, human activity likely increased in this region, with impacts on the vegetation such as a distinct decrease in *Pinus* and *Quercus* pollen and an increase in Polygonaceae pollen in the upper 30 cm of the core” (**Lines 53-55 in the revised Ms**).

Line 38: The marked decline in *Quercus* pollen in the first 30 cm of the core is compared with the early stage (around 60 cm) (**Line 56 in the revised Ms**).

Line 52-53: We have changed the word “and” to "in order to" (**Line 72 in the revised Ms**).

Line 97: The section of how the present day vegetation changes along the elevation gradients is described in **lines 145-155 in the revised Ms**.

Lines 168-172: The palynomorphs recovered from the surface samples were summed into trees and shrubs, herbs, pteridophytes, and aquatics (**Lines 250-298 in the revised Ms**).

Lines 188-190: We have deleted “which might suggest that surface samples fail to capture the local vegetation completely” (**Line 307 in the revised Ms**).

Line 195: Here we use a new figure 2 instead of the old one. In the new figure, all the palynomorphs were shown (**Figure 2 in the revised Ms**).

Lines 280-288: The section of “Climatic implications of the principal palynomorphs from Wenhai Lake” was added to show the detailed information about the indicator taxa (**Lines 440-475 in the revised Ms**).

Lines 292 - 295: We have changed to “the vegetation surrounding the lake catchment was dominated by broad-leaved forest (composed mainly of *Quercus*, *Betula* and *Castanopsis*) and needle-leaved forest (mainly *Pinus* and *Abies*).” (**Lines 481-483 in the revised Ms**).

Line 296: The herbaceous plants *Artemisia*, Labiatae, Compositae and Polygonaceae, and ferns Athyriaceae, Polypodiaceae, Gymnogrammaceae and *Pteris*, grew around the lake or under coniferous or broad-leaved trees (**Lines 483-485 in the revised Ms**).

Lines 299 - 300, 301 - 307, 308 - 315, 331: The necessary corrections can be seen in the section “5.2 Vegetation and climate history at Wenhai” (**Lines 477-645 in the revised Ms**).

A 22,570-yr record of vegetational and climatic change from Wenhai Lake in the Hengduan Mountains biodiversity hotspot, Yunnan, Southwest China

Y. F. Yao [1, 3*], X. Y. Song[2], A. H. Wortley[3], S. Blackmore[3], and C. S. Li[1*]

[1] State Key Laboratory of Systematic and Evolutionary Botany, Institute of Botany, Chinese Academy of Sciences, Xiangshan, 100093 Beijing, PR China

[2] Shanxi Agricultural University, Taigu 030801, Shanxi, PR China

[3] Royal Botanic Garden Edinburgh, 20a Inverleith Row, Edinburgh EH3 5LR, Scotland, UK

[*] Correspondence to: Y. F. Yao (yaoyf@ibcas.ac.cn), C. S. Li (lics@ibcas.ac.cn)

Abstract

The Hengduan Mountains, with their strong altitudinal vegetation zonation, form a biodiversity hotspot which offers the potential for comparison between sites in order to understand how this zonation arose and how it has responded to climate change and human impacts through time. This paper presents a 22,570-yr pollen record of vegetational and climatic change based on a core 320 cm in depth collected from Wenhai Lake on the Jade Dragon Snow Mountain, one of the highest peaks in the Hengduan Mountains region of Yunnan, Southwest China. From 22,570 to 21,140 cal. yr BP, the vegetation was dominated by broad-leaved forest (comprising mainly *Quercus*, *Betula* and *Castanopsis*), accompanied by needle-leaved forest (mainly *Pinus* and *Abies*), indicating a rather cold and dry climate relative to the present followed by cold and wet conditions. In the period between 21,140 and 19,350 cal. yr BP, the vegetation was still dominated by broad-leaved forest and needle-leaved forest as before but with a notable increase in *Betula* pollen and a sharp decrease in *Quercus* pollen, implying a relatively cold and dry climate with several fluctuations in humidity. The period 19,350 to 17,930 cal. yr BP was a transition stage from broad-leaved forest to needle-leaved forest, with a dramatic decrease in *Quercus* pollen and a maximum reading for *Abies* pollen, reflecting the coldest and driest climate since 22,570 cal.

删除的内容: is one of the studies covering a range of altitudes within this hotspot, and

删除的内容: , accompanied by coniferous

删除的内容: and the drought-tolerant herb *Artemisia*

删除的内容: a cool and dry climate

删除的内容: pollen of aquatic plants

删除的内容: a relatively warm and moderately humid climate.

删除的内容: a warm-humid climate at the beginning and a cold-dry one at the end.

yr BP. The expansion in needle-leaved forest dominated by *Pinus* and *Abies* (22,570－17,930 cal. yr BP) along with an increase of *Betula* might correspond to the Last Glacial Maximum (LGM, the start of the LGM perhaps occurred prior to the basal age of the core). Between 17,930 and 9,250 cal. yr BP, needle-leaved forest declined and broad-leaved forest began to increase at first, suggesting increases in temperature and humidity, while towards the end of the period, needle-leaved forest expanded and broad-leaved forest shrank, indicating a colder and drier climate, possibly corresponding to the Younger Dryas. From 9,250 cal. yr BP to the present, the vegetation has been dominated by needle-leaved forest (comprising mainly *Pinus*, *Abies* and *Tsuga*), interspersed with broad-leaved *Quercus* and *Betula*, reflecting a significant decline in humidity from the early to late Holocene. During this period, human activity likely increased in this region, with impacts on the vegetation such as a distinct decrease in *Pinus* and *Quercus* pollen and an increase in Polygonaceae pollen in the upper 30 cm of the core. The marked decline in *Quercus* pollen compared with the early stage of this period, in particular, in the Wenhai core can be correlated with that observed in the Haligu core (situated about 2 km away) between 2,400 cal. yr BP and the present.

1 Introduction

The Hengduan Mountains are located in the north of the Mountains of Southwest China biodiversity hotspot, the most biologically diverse temperate ecosystem in the world (Conservation International, 2008), sandwiched between the Honghe Basin to the east and the Qinghai-Xizang Plateau to the west. They comprise five main ridge systems characterized by vertical vegetation zonation and separated by four deep drainage systems, created during the Himalayan orogeny beginning in the Tertiary Period and continuing into the Quaternary (Myers et al., 2000; Ying, 2001). The floristic diversity of the region is particularly high: the Hengduan Mountains are situated in Yunnan Province which, despite covering just 4% of China’s land area, contains c. 15,000 species of higher plants, almost 50% of the country’s total.

The marked altitudinal zonation of vegetation in the Hengduan Mountains offers the potential to compare between sites in order to build up an understanding of how this zonation

删除的内容: Between 17,930 and 9,250 cal. yr BP, needle-leaved forest and broad-leaved forest alternated in dominance in the early stages, with the former taking the predominant position by the end of the period, suggesting a climate fluctuating between warm-humid and cold-dry.

删除的内容: and

删除的内容: coupled

删除的内容: forest (mainly

删除的内容:)

删除的内容: a

删除的内容: transition in climatic conditions from warm-humid to cold-humid

删除的内容: which may be evidenced by the

删除的内容: lie

删除的内容: and

arose and how it responds, through time, to climate change and human impacts. The Jade Dragon Snow Mountain (rising to 5,596 m a. s. l.) is one of the highest peaks in the Hengduan Mountains region, and is particularly appropriate for the study of past and present diversity using palynological data because it supports a number of natural wetlands and lakes containing abundant, well-preserved palynomorphs, at a range of altitudes. Thus, sampling of core sediments from different sites has the potential to generate pollen data relative to both time and altitude (at a given locality), which will ultimately enable us to estimate changes in both floristic composition and diversity over time and their response to climatic change.

During the past decade, pollen analysis has been employed extensively for understanding Quaternary vegetation and climate history in China (e.g., Xu et al., 2002; Xiao et al., 2004; Zhao et al., 2007; Li et al., 2011; An et al., 2013; Cao et al., 2013; Jiang et al., 2013). However, few such studies have been conducted in the Hengduan Mountains (Jiang et al., 1998; Shen et al., 2006; Jones et al., 2012; Song et al., 2012; Cook et al., 2013; Xiao et al., 2014). Previously, we have investigated changing climate and vegetation over the past 9,300 years based on pollen analyses of a core 400 cm in depth from a wetland site at Haligu (3,277 m) on the Jade Dragon Snow Mountain (Song et al., 2012). This paper presents a 22,570-yr record of vegetational and climatic change from Wenhai Lake (3,080 m), also on the Jade Dragon Snow Mountain. We aim to use pollen data to develop insights into changing floristic diversity and to draw inferences about past climate and anthropogenic influences in the region during the Late Quaternary.

2 Study area

Wenhai Lake (26°58′59″ N, 100°09′54″ E) is located at the southern end of the Jade Dragon Snow Mountain in Yulong County of Lijiang City, northwestern Yunnan, Southwest China (Fig. 1). It forms part of Lashihai Swamp Natural Reserve and is about 23 km northwest of Lijiang City. This area is a key region linking the Qinghai-Xizang Plateau with the Yungui Plateau, and also is a boundary region between the Hengduan Mountains area of northwestern Yunnan and the plateau area of eastern Yunnan. More than a thousand years ago, Wenhai was an important stop on the ancient “Tea-Horse Road,” a route for trading tea and horses

删除的内容: in this series of studies,

删除的内容: in the series

删除的内容: the

删除的内容: of the region

删除的内容: This data will also be used to draw inferences about past climate and anthropogenic influences, and to compare study sites at different altitudes in the region to provide a better understanding of changes in the distinctly vertical vegetation zones that characterize the region. .

between inland agricultural and remote nomadic regions (Luo, 2003). Yulong County is home to several ethnic minority peoples, with the Naxi being most numerous. Wenhai Lake is an open lake surrounded by high mountains, covering an area of about 0.16 km^2. It is a seasonal lake fed mainly by rainfall and glacial melt-water from the nearby mountains.

The study area is strongly influenced by the southwest monsoon coming from the Indian Ocean. Thus the summers are warm and humid and the winters cool and dry. The mean annual temperature (MAT) and mean annual precipitation (MAP) measured at Lijiang (situated below the study site at about 2,200 m), are 12.8°C and 935 mm, respectively. About 90% of the annual precipitation falls in summer, between June and October. The warmest month is July, with a mean temperature of 17.9°C, and the coldest month is January, with a mean temperature of 5.9°C (Feng et al., 2006).

The regional vegetation and climate of the Jade Dragon Snow Mountain area are strongly related to elevation gradients. At increasing elevations on the mountain slopes, MAT shows a decreasing trend, while MAP displays a reverse trend. For example, MAT and MAP are 12.6°C and 772 mm, respectively, at 2,393 m, MAT decreases to 5.4 °C and MAP increases to 1,600 mm at 3,200 m, MAT further decreases to –3.3~ –4.7°C and MAP increases to more than 2,400 mm at the snow line (4,800 m; He et al., 2000a, 2000b). Four main vegetation zones can be recognized: Zone 1, semi-humid evergreen broad-leaved forest–pine forest (about 2,400–3,000 m); Zone 2, needle- and broad-leaved mixed forest- sclerophyllous evergreen broad-leaved forest (about 3,000–3,300 m); Zone 3, cold-temperate needle-leaved forest (about 3,300–4,200 m); and Zone 4, alpine heath scrub and meadow (above 4,200 m; Wu et al., 2006). From our personal observations, the present vegetation around the Wenhai Lake catchment is dominated by oaks (*Quercus pannosa* Hand.-Mazz) and pines, primarily *Pinus yunnanensis*, with *P. armandii* Franch at slightly lower elevations and smaller numbers of *Tsuga dumosa* (D.Don) Eichler and *P. densata* Mast. are also present. Here, the most abundant shrubs are ericaceous, including rhododendron species, especially *Rhododendron mucronatum* (Blume) G. Don, *R. racemosum* Franch., *R. yunnanense* Franch. and *R. delaveyi* Franch., together with *Vaccinium bracteatum* Thunb. and *Pieris formosa* (Wallich) D.Don. Herbaceous taxa are diverse with some of the most speciose genera being *Anemone, Gentiana,*

删除的内容: The study area is located within

删除的内容: a vegetation “sub-domain” characterized by *Pinus yunnanensis* Franch. forest and *Picea-Abies* forest typical of northwestern-central Yunnan (WGYV, 1987). The local vegetation displays a distinct vertical zonation. On the mountains surrounding Wenhai Lake (3,100–3,500 m), the vegetation is dominated by

Primula and *Roscoea*. This area is now heavily influenced by human activities, such as felling of timber and grazing, so some patches are barren of vegetation.

删除的内容: zone

删除的内容: At higher elevations, between 3,500 and 3,800 m, the Jade Dragon Snow Mountain is cloaked in evergreen broad-leaved forest consisting of *Quercus pannosa* and *Cyclobalanopsis glauca* (Thunb.) Oerst, together with coniferous trees such as *Abies delaveyi* Franch., *Picea likiangensis* (Franch.) E. Pritz and *Larix potanini* Batalin. The forests are interspersed with meadows which are grazed by livestock. From 3,800 to 4,200 m, the vegetation is dominated by subalpine bush and meadow composed, among others, of *Rhododendron* spp., *Juniperus* spp., *Berberis* spp. and scattered *Sorbus* spp. Dwarf shrubs are present at this altitude, including *Caragana tibetica* (Maxim. ex C.K. Schenid.) Kom. and *Chesnya nubigena* (D.Don) Ali. Above 4,200 m the vegetation is restricted mainly to herbaceous taxa including *Draba* spp., *Saxifraga* spp. and *Saussurea* spp.

3 Materials and methods

3.1 Coring and sampling

A sediment core 320 cm in depth was obtained from Wenhai Lake in January 2005 using a Russian corer, which consists of a 40 cm long steel chamber (diameter 10 cm) and 1 m long steel rods. Coring was done in 40 cm overlapping steps (0–40 cm, 40–80 cm, 80–120 cm, etc.). To avoid contamination, the chamber was cleaned carefully before starting each new round of coring. The core was labelled in the field, wrapped in plastic foil and placed in halved PVC tubes. A detailed lithological description of the core is presented in Fig. 2.

3.2 Radiocarbon dating

Two samples from the core, at 155 cm and 320 cm in depth, were taken for Accelerator Mass Spectrometry (AMS) radiocarbon dating, which was performed at the Scottish Universities Environmental Research Centre (SUERC) in Glasgow, Scotland, UK. The ^{14}C ages are quoted in conventional years BP (before 1950 AD). Bulk samples from the core were used because fragments of plant material suitable for analysis were not present. Age calibration was set up using the calibration curve from Reimer et al. (2004) by means of the calibration program OxCal v3.10 (Bronk, 2005). Date ranges are cited in calibrated years AD/BC at 95% probability, with end points rounded to the nearest 10 years (Mook, 1986; Foster et al., 2008).

3.3 Pollen analysis

Six surface soil samples near the core were collected for comparison with the preserved pollen assemblage. Thirty-two samples were taken from the core itself, at 10 cm intervals, for pollen analysis. Thirty grams of each sample were processed by the method of heavy liquid separation (Moore et al., 1991; Li and Du, 1999) followed by acetolysis (Erdtman, 1960). Pollen grains and spores were identified using modern pollen slides, palynological literature and monographs (IBCAS, 1976; IBSCIBCAS, 1982; Wang et al., 1995). All samples yielded abundant, well-preserved palynomorphs. Pollen samples were examined using a Leica DM 2500 light microscope at a magnification of 400 × and at least 300 pollen grains and spores were counted in each sample. Pollen grains and spores were divided into four categories: trees and shrubs, herbs, pteridophytes and aquatic taxa. Pollen data were expressed as percentages and graphed using Tilia.Graph, and pollen zones were determined with CONISS in the Tilia program (Grimm, 1997).

4 Results

4.1 Chronology

Two AMS radiocarbon dates, 14,075±40 yr BP (17,150–16,350 cal. yr BP) at depth of 155 cm and 19,075±50 yr BP (22,760–22,380 cal. yr BP) at depth of 320 cm, give a relatively reliable basis for deciphering the vegetation and climate history in and surrounding Wenhai Lake. The sedimentation rates are c. 0.1 mm/yr and 0.28 mm/yr for the depths of 0–155 cm and 155–320 cm, respectively. Ages of other depths are interpolated by assuming that the sedimentation rate is constant between the two dated samples, i.e., 9,250 cal. yr BP at 80 cm depth, 17,930 cal. yr BP at 190 cm, 19,350 cal. yr BP at 230 cm, and 21,140 cal. yr BP at 280 cm.

4.2 Pollen analysis

4.2.1 Surface samples

Fifty palynomorphs were identified from the six surface soil samples collected in close proximity to the core, including 29 families and seven genera of angiosperms, three genera of gymnosperms, nine families and one genus of pteridophytes, and one genus of alga (See the supplementary material). The pollen assemblage is dominated by trees and shrubs, at percentages ranging from 79.5% to 97.0% of the total pollen and spores. *Pinus* pollen (62.3–87.1%) dominates in all six surface samples, followed by *Abies* (3.3–10.7%), *Quercus* (0–5.5%) and Ericaceae (0–4.1%). Herb pollen is present at low percentages (1.8–4.1%), and comprises *Artemisia*, other Compositae, Caryophyllaceae, Chenopodiaceae, Convolvulaceae,

删除的内容: establishing a chronological control against which to

删除的内容: .

删除的内容: The palynomorphs were summed into four groups: conifers, broad-leaved plants, ferns and aquatics. Coniferous trees include *Pinus*, *Abies* and *Tsuga*. The broad-leaved taxa comprise angiosperm trees, shrubs and herbs, including *Quercus*, *Alnus*, *Artemisia*, Cyperaceae, Ericaceae and Polygonaceae. The ferns include Polypodiaceae, Athyriaceae and *Pteris*. The aquatic plants are *Myriophyllum* and *Zygnema*.

删除的内容: coniferous taxa

删除的内容: 66.8

删除的内容: 3.5

删除的内容: , followed by broad-leaved elements (5.3–16.8%), ferns (0.9–15.3%) and aquatics (0–3.0%)

删除的内容: 3

删除的内容: 8.5

删除的内容: accompanied by

删除的内容: 1.1

删除的内容: Polypodiaceae (0–10.6%),

删除的内容: 1.2

删除的内容: 6

删除的内容: ,

删除的内容: Athyriaceae (0.2–2.8%), Polygonaceae (0.2–2.4%), Cyperaceae (0–1.1%), and Gramineae (0–0.3%).

Cruciferae, Cyperaceae, Gramineae, Labiatae, Liliaceae and Polygonaceae. Pteridophyte spores account for 0.3–15.3%, including Athyriaceae, Cyatheaceae, Gymnogrammaceae, Hymenophyllaceae, Loxogrammaceae, Lygodiaceae, Plagiogyriaceae, Polypodiaceae, *Pteris* and Sinopteridaceae. Aquatic plants are recorded at low percentages (0–3%), comprising *Myriophyllum* and *Zygnema*. This pollen assemblage is consistent with the local vegetation of the lake basin and the surrounding mountains, reflecting a needle-leaved forest dominated by *Pinus* and accompanied by some broad-leaved components, e.g. *Quercus* and Ericaceae.

4.2.2 Pollen diagram zonation and description

Pollen analysis of the core samples shows a high degree of taxonomic diversity. The palynoflora comprises 83 palynomorphs, which can be identified to 45 families and 13 genera of angiosperms, one family and seven genera of gymnosperms, 12 families and three genera of pteridophytes and two genera of algae (See the supplementary material). Some of the selected palynomorphs extracted from the core are illustrated in the supplementary material.

A greater diversity of palynomorphs was recovered from the core samples than from the surface samples. However, many of the taxa found in the core but missing from surface samples are not present in the upper part of the core and are no longer present in the immediate area so do not contribute to the local pollen rain. Examples include *Cedrus*, *Dacrydium* and *Taxodium* amongst the gymnosperms and the angiosperm taxa Actinidiaceae, Anacardiaceae, *Carpinus*, Clethraceae, Flacourtiaceae, Icacinaceae, Juglandaceae, *Liquidambar,* Myrsinaceae, Palmae and *Tilia.* Some of these taxa have a subtropical distribution and their closest occurrence to the study site is at much lower elevation near the Jinsha River or considerably further south in Yunnan. Other taxa such as Araceae, Araliaceae, Campanulaceae, Caprifoliaceae, Caryophyllaceae and Umbellifereae are present in the immediate area but are entomophilous plants with relatively lower pollen production which might be expected to be under-represented in the local pollen rain.

删除的内容: , which might suggest that surface samples fail to capture the local vegetation completely

A cluster analysis performed using Tilia (with CONISS) divided the pollen diagram into five distinct zones (Fig. 2). Brief descriptions of each zone are as follows.

Pollen zone 1 (320–280 cm: 22,570–21,140 cal. yr BP):

This zone is characterized by a dominance of tree and shrub pollen (72.9–81.3%), followed by herbs (6.3–20%), ferns (4.2–12.5%) and aquatics (0–4.2%). Among the trees and shrubs, the percentage of broad-leaved elements (42.2–70.8%) is higher than that of conifers (10.4–33.9%). The trees and shrubs are dominated by the broad-leaved taxa *Quercus* (20–62.5%, including *Quercus* sp. 1 and sp. 2), *Betula* (1.8–7.6%), *Castanopsis* (0–6.7%) and the coniferous taxa *Pinus* (6.3–24.4%) and *Abies* (4.2–10.1%). Pollen grains of other coniferous plants such as *Picea* and *Tsuga*, and broad-leaved plants such as *Corylus*, *Ulmus* and Ericaceae are also present in minute quantities. Herbs are represented by *Artemisia* (0–11.5%), coupled with Chenopodiaceae (0–4.4%), Compositae (0–4.4%), Labiatae (0–4.2%), and Polygonaceae (0–3.7%). Fern taxa include Athyriaceae (3.7–6.7%), Polypodiaceae (0–4.6%), Gymnogrammaceae (0–4.2%) and *Pteris* (0–2.1%). Two taxa of aquatic plants, *Myriophyllum* and *Pediastrum,* are recorded, at 0–3.1% and 0–1.0%, respectively.

The pollen assemblages of pollen zone 1 and the surface samples are both dominated by tree and shrub pollen, represented by 72.9–81.3% and 79.5–97%, respectively. *Quercus* pollen (20–62.5%) dominates the trees and shrubs of pollen zone 1, followed by *Pinus*, *Abies*, *Betula* and *Castanopsis*. In contrast, *Pinus* pollen (62.3–87.1%) dominates the trees and shrubs of the surface samples, followed by *Abies*, *Quercus* and Ericaceae. The percentage of herb pollen is comparatively high in pollen zone 1 (6.3–20%) compared to the surface samples (1.8–4.1%). Similar percentages of pteridophyte spores (pollen zone 1: 4.2–12.5%, surface samples: 0.3–15.3%) and aquatics (pollen zone 1: 0–4.2%, surface samples: 0–3%) are recorded in pollen zone 1 and the surface samples.

Pollen zone 2 (280–230 cm: 21,140–19,350 cal. yr BP):

In this zone, two distinct characteristics are observed: firstly a sharp increase in the aquatic pollen percentage, reaching a maximum (16.7%) for the entire profile at a depth of 270 cm, which is attributed to the prevalence of *Myriophyllum* and *Pediastrum*. Secondly, trees and shrubs continue to dominate in this zone. The percentage of trees and shrubs ranges from 52.3% to 79.6%. As in pollen zone 1, broad-leaved trees (34.4–65.2%) still occupy a higher percentage than conifers (8.6–45.2%). Among the conifers, it should be noted that *Pinus* pollen reaches its lowest value (2.1%) for the whole profile at a depth of 230 cm. Broad-leaved trees, i.e. *Quercus* (4.1–56.5%), *Betula* (3.4–13.7%), *Castanopsis* (0–8.5%) and *Corylus* (0–6.3%), together with herbaceous taxa, i.e. *Artemisia* (0–12.8%) and Polygonaceae (2.2–6.9%), continue to play an important role in this zone. In addition, some new broad-leaved elements, *Alnus*, *Carpinus*, Actinidaceae, *Ilex*, Leguminosae, *Tilia*, Cruciferae and Plantaginaceae, are found sporadically for the first time. The percentage of fern spores (1.3–13.8%) remains at almost the same level as in pollen zone 1. Athyriaceae spores show a slight increase (up to 10.9%), but Gymnogrammaceae (0–0.4%), Polypodiaceae (0–1.1%) and *Pteris* (0–1.1%) display minor decreases.

Tree and shrub pollen dominates the pollen assemblages of both pollen zone 2 and the surface samples, but its percentage in pollen zone 2 (52.3–79.6%) is lower than in the surface samples (79.5–97%). *Quercus* pollen dominates the trees and shrubs of pollen zone 2 (4.1–56.5%), compared to the dominance of *Pinus* pollen (62.3–87.1%) in the surface samples. The percentages of herb pollen (pollen zone 2: 2.2–21.2%, surface samples: 1.8–4.1%) and aquatics (pollen zone 2: 4.1–16.7%, surface samples: 0–3%) are comparatively high in pollen zone 2 compared to the surface samples. Pteridophyte spores account for 1.3–13.8% and 0.3–15.3%, respectively, in pollen zone 2 and the surface samples.

Pollen zone 3 (230–190 cm: 19,350–17,930 cal. yr BP):

In this zone, tree and shrub pollen maintains a dominant status (79.7–92.2%), followed by herbs (5.2–13.7%), ferns (0.7–7.1%) and aquatics (0–5.8%). The percentage of trees and shrubs reaches its highest value (92.2%) of the profile, at a depth of 200 cm. The conifers (28.4–66.8%) show a higher percentage than broad-leaved trees (19–51.4%). *Pinus* (19.2–50.0%) and *Abies* (9.0–43.4%) pollen shows a sharp increase, and *Abies* pollen in particular maintains a peak value (43.4%) throughout the profile. The broad-leaved trees *Quercus* (9.5–31.1%) and *Betula* (1.3–9.6%), and herbaceous *Artemisia* (0–11.2%), also play an important role. The ferns are dominated by Athyriaceae, ranging from 0.2% to 7.1%. Six other types of ferns, i.e. Polypodiaceae, Selaginellaceae, Sinopteridaceae, Hymenophyllaceae, *Pteris* and Lygodiaceae, occur at low percentages, less than 2%. The prevalence of *Myriophyllum* (0–2.8%) and *Pediastrum* (0–5.8%) declines sharply and one new aquatic taxon, Potamogetonaceae, appears in this zone at a low percentage (0–0.1%).

The percentage of tree and shrub pollen in pollen zone 3 (79.7–92.2%) is more similar than the previous zones to that of the surface samples (79.5–97%). As in the surface samples, *Pinus* pollen dominates in pollen zone 3, followed by *Abies* and *Quercus*. The percentages of herb pollen (pollen zone 3: 5.2–13.7%, surface samples: 1.8–4.1%) and aquatics (pollen zone 3: 0–5.8%, surface samples: 0–3%) in pollen zone 3 are higher than in the surface samples. However, a comparatively lower percentage of pteridophyte spores is recorded in pollen zone 3 (0.7–7.1%) than in the surface samples (0.3–15.3%).

Pollen zone 4 (190–80 cm: 17,930– 9,250 cal. yr BP):

Tree and shrub pollen dominates in this zone (75.8–90.4%). Herbs rank second (7.5–18.4%), followed by ferns (0–12.1%) and aquatics (0–4%). Coniferous *Pinus* (12.6–46.9%) and *Abies* (1.8–30.3%), and broad-leaved *Quercus* (9.1–37.8%) and *Betula* (0–13.5%) are the dominant elements of trees and shrubs. Additionally, three other coniferous taxa, *Picea*, *Tsuga* and Taxodiaceae, and 28 broad-leaved tree species including *Corylus*, *Castanopsis*, *Liquidambar* and Myrsinaceae are recorded at low percentages. Herbs are represented by *Artemisia* (0–9.9%), Labiatae (0–6.1%) and Polygonaceae (0.4–4.7%), accompanied by Chenopodiaceae, Cyperaceae, Plantaginaceae and Gramineae in minute quantities. Nine types of ferns are found in this zone, among which Athyriaceae and Polypodiaceae possess relatively high percentages of 0–12.1% and 0–2.2%, respectively. Three aquatic plants occur: *Myriophyllum* (0–3.7%), *Pediastrum* (0–0.6%), and *Zygnema* (0–0.2%).

Tree and shrub pollen maintains a dominant status in pollen zone 4 (75.8–90.4%) and in the surface samples (79.5–97%). *Pinus* pollen dominates the pollen assemblage of pollen zone 4 (12.6–46.9%), but its percentage is much lower than in the surface samples

(62.3–87.1%). The percentages of *Quercus* (pollen zone 4: 9.1–37.8%, surface samples: 0–5.5%) and *Abies* pollen (pollen zone 4: 1.8–30.3%, surface samples: 3.3–10.7%) in pollen zone 4 are generally higher than in the surface samples. A comparatively higher percentage of herb pollen is documented in pollen zone 4 (7.5–18.4%) relative to the surface samples (1.8–4.1%). Pteridophyte spores (pollen zone 4: 0–12%, surface samples: 0.3–15.3%) and aquatics (pollen zone 4: 0–4%, surface samples: 0–3%) occur in similar percentages in pollen zone 4 and the surface samples.

Pollen zone 5 (80–0 cm: 9,250 cal. yr BP – present):

This zone is dominated by tree and shrub pollen (47–84.2%), followed by herbs (4.9–37.4%), ferns (7.8–24.8%) and aquatics (0–3%). The pollen percentage of conifers (31.3–79.9%) is higher than that of broad-leaved trees (4.3–37.6%). From the beginning to the end of this zone, *Pinus* (14–56.8%) shows a decrease then increases sharply, while *Quercus* (1–29.1%) and *Betula* (0–7.4%) show a decreasing trend, and *Abies* (7.4–27.2%) an increasing one. *Tsuga* (1.1–7.5%) reaches its highest percentage in this zone. Pollen of other trees and shrubs such as *Picea*, *Alnus*, *Corylus*, *Carpinus*, Ericaceae, Anacardiaceae, Dipsacaceae, Flacourtiaceae and Meliaceae are found in some samples, at percentages of less than 1%. Herbs are characterized by a distinct decrease in *Artemisia* (0–3.4%) and an increase in Polygonaceae (2–20.8%) and Labiatae (0.7–15.4%). Among the fern spores, Polypodiaceae (4.5–17.9%) shows a remarkable increase and Athyriaceae (0–6.3%) a notable decrease. The percentage of aquatics changes little compared to pollen zone 4, but *Myriophyllum* disappears in this zone. Thus only two types are recorded, *Pediastrum* (0–0.6%) and *Zygnema* (0–3%).

Tree and shrub pollen dominates the pollen assemblages of both pollen zone 5 and the surface samples, represented by 47–84.2% and 79.5–97%, respectively, among which *Pinus*, *Abies*, and *Quercus* are the dominant taxa. The percentages of herb pollen (pollen zone 5: 4.9–37.4%, surface samples: 1.8–4.1%) and pteridophyte spores (pollen zone 5: 7.8–24.8%, surface samples: 0.3–15.3%) are generally greater in pollen zone 5 than in the surface samples. Aquatics occur at the same percentage (0–3%) in pollen zone 5 and the surface samples.

5 Discussion and conclusions

5.1 Climatic implications of the principal palynomorphs from Wenhai Lake

The palynoflora found in the Wenhai core includes a large number of potential climate indicators. For example, *Pinus* is currently distributed below 3,200 m elevation in Southwest China and is commonly found in slightly warm and moderately dry habitats. *Pinus yunnanensis* Franch., *P. densata* Mast. and *P. armandi* Franch. are the dominant species on the mountains of northwestern Yunnan (KIBCAS, 1986). *Tsuga* is a cold-tolerant and hygrophilous conifer, requiring a MAT of 8.4 to 10.5°C and a MAP of about 1,000 mm for favorable growth in Yunnan (WGYV, 1987). One species, *Tsuga dumosa* (D. Don) Eichler, and one variety, *T. chinensis* (Franch.) E. Pritz. var. *forrestii* (Downie) Silba are recorded in northwestern Yunnan (KIBCAS, 1986; Wang et al., 2007). *Abies* is strongly associated with cold and dry habitats with a MAT of 2–8°C and MAP ca. 600 mm in the mountains of Southwest China (CCCV, 1980; Jarvis, 1993). Five species, viz. *Abies delavayi* Franch, *A. forrestii* C. Rogers, *A. georgei* Orr, *A. nukiangensis* W. C. Cheng & L. K. Fu, *A. ferreana* Bordères & Gaussen, and two varieties, *A. ernestii* Rehd. var. *salouenensis* (Borderes et Gaussen) W. C. Cheng et L. K. Fu, and *A. georgei* Orr var. *smithii* (Viguie et Gaussen) W. C. Cheng et L. K. Fu, occur in northwestern Yunnan (KIBCAS, 1986). *Betula* is viewed as a cold- and drought-tolerant element. Eleven species and two varieties occur in Yunnan, among which five species and two varieties grow in Lijiang, including *B. calcicola* (W. W. Smith) Hu, *B. delavayi* Franch, *B. platyphylla* Suk., *B. utilis* D. Don, *B. potaninii* Batal, *B. utilis* D. Don var. *sinensis* (Franch.) H. Winkl, and *B. delavayi* Franch var. *polyneura* Hu ex. P. C. Li (KIBCAS, 1991). *Alnus* usually grows on riverbanks or at village margins, in moist temperate habitats. One species, *A. nepalensis* D. Don is found in northwestern Yunnan (KIBCAS, 1991). Evergreen sclerophyllous *Quercus* displays considerable ecological adaptability, and can grow in either dry or humid environments. This genus is widely distributed in the fog zone (with higher humidity, at about 3,100 m) on the Jade Dragon Snow Mountain, where it forms a montane needle- and broad-leaved mixed forest along with *Tsuga* and *Picea* (WGYV, 1987). From our personal observations, some small *Quercus* trees are present up to about 3,800 m. *Artemisia* is mainly distributed in temperate areas of mid to high latitudes of the

Northern Hemisphere, usually in arid or semi-arid environments (Valles and McArthur, 2001). The genus *Artemisia* is considered an indicator of steppe climate (Erdtman, 1952) and moderate precipitation (El-Moslimany, 1990). There are 54 species and eight varieties growing in Yunnan (KIBCAS, 2003a). Cyperaceae is a cosmopolitan family with ca. 5,000 species and 104 genera. Many species of this family commonly grow in wetlands and surrounding areas, adapted to open and sunny conditions. About 26 genera and 272 species occur in Yunnan. The high frequency of Cyperaceae pollen may indicate humid conditions (KIBCAS, 2003b; Sun et al. 2003).

5.2 Vegetation and climate history at Wenhai

Based on the climatic preferences of the major taxa recovered from the Wenhai core, the palynological record reveals a detailed history of shifting vegetation and climate change in this region during the past 22,570 yrs (Fig. 3). From 22,570 to 21,140 cal. yr BP (Pollen zone 1), the vegetation surrounding the lake catchment was dominated by broad-leaved forest (composed mainly of *Quercus*, *Betula* and *Castanopsis*), accompanied by needle-leaved forest (mainly *Pinus* and *Abies*). The herbaceous plants *Artemisia*, Labiatae, Compositae and Polygonaceae, and ferns Athyriaceae, Polypodiaceae, Gymnogrammaceae and *Pteris*, grew around the lake or under coniferous or broad-leaved trees. This pollen assemblage indicates a rather cold and dry climate relative to the present followed by cold and wet conditions. Between 21,140 and 19,350 cal. yr BP (Pollen zone 2), the vegetation was dominated by broad-leaved forest and needle-leaved forest as before, with a notable increase in *Betula* pollen and a sharp decrease in *Quercus* pollen, reflecting a relatively cold and dry climate with several fluctuations in humidity during this period. From 19,350 to 17,930 cal. yr BP (Pollen zone 3), the coniferous trees *Pinus* and *Abies* showed a distinct increase, with *Abies* especially reaching its maximum proportion during this period. In contrast, broad-leaved *Quercus* displayed a remarkable decrease compared to the previous stage. This pollen assemblage suggests a transition from broad-leaved forest to needle-leaved forest, pointing to the coldest and driest climate conditions since 22,570 cal. yr BP. In the period from 22,570 to 17,930 cal. yr BP, needle-leaved forest dominated by *Pinus* and *Abies* gradually expanded and reached a maximum extent, and at the same time, the extent of *Betula* increased. This

删除的内容: Polygonaceae is found in a wide range of habitats from the Arctic to the tropics, from montane to lowland regions, and from arid to aquatic situations (Schuster et al. 2013). In subtropical region of Southwest China, most members in Polygonaceae grow in the grassland and wetland on the slope and valley, indicating a warm and humid condition (Zhou et al. 2003).

删除的内容: **22,570-yr v**

删除的内容: This present study provides a preliminary investigation into the vegetation and climate history ... [1]

删除的内容: on the lower mountains ... [2]

删除的内容: was distributed on the ... [3]

删除的内容: *Picea* and *Ephedra* ... [4]

删除的内容: Aquatic *Myriophyllum* ... [5]

删除的内容: dry

删除的内容: climate

删除的内容: during this period

删除的内容: . . ... [6]

删除的内容: was marked by

删除的内容: increase

删除的内容: aquatic

删除的内容: continuing dominance of ... [7]

删除的内容: last

删除的内容: *Tsuga*, *Alnus*, ... [8]

删除的内容: reflects

删除的内容: transition from

删除的内容: to

删除的内容: . The climate of the ... [9]

删除的内容: y

删除的内容: at the end

删除的内容: .

period might correspond to the cold Last Glacial Maximum (LGM). However, the exact start and end dates of the LGM in Southwest China has been the subject of much debate. For example, Chen et al. (2014) reported that the LGM occurred between 29,200 and 17,600 cal. yr BP, based on the expansion and maximum extent of cold-temperature coniferous forest (mainly *Abies*/*Picea*) in the Xingyun Lake catchment of central Yunnan. Long et al. (1991) identified that the LGM occurred from 30,000 to 15,000 yr BP, with coverage of conifer and broad-leaved mixed forest in the Qilu Lake catchment of central Yunnan. Jiang et al. (2001) concluded that the LGM occurred from 33,000 to 16,000 yr BP, with vegetation comprising montane mixed coniferous and broad-leaved forest and sclerophyllous evergreen oaks in the Heqing Basin of northwestern Yunnan. Thus, previous palynological records from Yunnan tend to provide broader estimates for the LGM. In the present paper, because the basal age of the Wenhai core reaches only to 22,570 cal. yr BP, we cannot deduce the date of the start of the LGM, which perhaps occurred prior to the inferred basal age, as evidenced by the relatively low pollen sum compared with pollen zones 4 and 5. Between 17,930 and 9,250 cal. yr BP (Pollen zone 4), coniferous forest and broad-leaved forest began to decline and increase, respectively, until 140 cm depth of the core, reflecting increases in temperature and humidity relative to pollen zone 3. From 140 cm to 110 cm, coniferous forest expanded, but broad-leaved forest gradually shrank, which indicates colder and drier climate conditions, likely corresponding to the Younger Dryas cold event (YD). The YD is also recorded by other studies in Yunnan. For example, Shen et al. (2006) pointed to the relatively cold period of 12,950 to 11,750 cal. yr BP as the YD, based on the dominance of *Betula* and deciduous oaks in the Erhai Lake catchment. Xiao et al. (2014) identified a relatively cold phase between 12,230 and 11,510 cal. yr BP, based on the dominance of open alpine meadow around Tiancai Lake. From 9,250 cal. yr BP to the present day (Pollen zone 5), *Pinus* underwent a process of decrease at the depth of 50–80 cm (from 38.1% to 14%), increase from 30 to 50 cm (from 14% to 56.8%, this shows a trend consistent with the Haligu core between 4,000–2,400 cal. yr BP), and decrease again at 0–30 cm (from 56.8% to 14.5%), while *Tsuga* displays an opposite trend. *Abies* shows a distinct increase during this period. *Quercus* increased at the beginning of the stage, then decreased after that. This pollen assemblage indicates that needle-leaved forest (comprising mainly *Pinus*, *Abies* and *Tsuga*) dominated the areas surrounding Wenhai

删除的内容: and broad-leaved trees dominated alternately to begin with, but coniferous trees become predominant by the end. This implies that the climate fluctuated between warm-humid and cold-dry, as evidenced by decreases and increases in conifers and *Quercus*, as well as the discontinuous occurrence of *Tsuga*, *Liquidambar*, Polygonaceae, Cyperaceae, *Myriophyllum*, *Pediastrum* and pteridophytes. .

删除的内容: The drought-tolerant herb *Artemisia* had a very low percentage. The hygrophilous herb Polygonaceae and fern Polypodiaceae experienced an increase, decrease and increase.

删除的内容: the vegetation was dominated by

删除的内容: and

Lake during the Holocene, interspersed with broad-leaved elements (mainly *Quercus* and *Betula*), reflecting a significant decline in humidity from the early to late Holocene, which might be related to a strong Asian summer monsoon over Southwest China during the early Holocene and a reduced monsoon intensity in the mid-late Holocene (Dykoski et al., 2005; Kramer et al., 2010).

删除的内容: coupled

删除的内容: forest (

删除的内容: a transitional climate condition from warm-humid to cold-humid.

5.3 Palynological signals of human activity detected in the Wenhai core

删除的内容: 2

Based on pollen and other evidence, human influences on postglacial vegetation have been inferred in Europe and North America (e.g., Brugam, 1978; Hirons and Edwards, 1986; Smith and Cloutman, 1988; Russell et al., 1993; Parker et al., 2002), as well in China (e.g., An et al., 2002; He et al., 2002; Xu et al., 2002; Song et al., 2012). The present authors have previously published another palynological investigation within the Hengduan Mountains (Song et al., 2012). The altitude of the previous study site, Haligu, is 3,277 m, where there is no current human settlement. The present study area (3,080 m), about 2 km far from Haligu, is close to a Naxi ethnic minority settlement at Wenhai village. Moreover, Wenhai was an important stop on the ancient “Tea-Horse Road” (Luo, 2003), making it likely that a wide variety of cultivated plants were introduced into the agricultural system around the lake, as evidenced by an ethnobotanical survy of traditional edible plants (including 45 cultivated plants) used by Naxi people in Wenhai village (Zhang et al., 2013).

删除的内容: the

删除的内容: first of a series of studies covering a range of altitudes

In the Wenhai core, several observations may be interpreted in terms of increasing anthropogenic impact in the region. First, *Pinus* and *Quercus* pollen decreased distinctly at the depth of 0–30 cm, which is probably linked with the fact that local people felled the trees for house construction or fuel wood. We detected that *Quercus* pollen decreased steadily in the Haligu core during the period from 2,400 cal. yr BP to the present day and observed heavy present-day coppicing of *Quercus* for firewood, resulting in much reduced pollen production. The comparison of both cores may substantiate the existing human impacts in the region. Second, the occurrence of abundant Labiatae pollen also indicates increasing human activity. From our personal observation, the Naxi people in Wenhai village currently cultivate several Labiatae species, including *Perilla frutescens* (L.) Britton and *Mentha* spp. as edible herbs and for medical utilization. Third, the increase in Polygonaceae pollen (likely to be *Fagopyrum*) could be an important indicator of human activity in the region, as the Naxi people continue to plant buckwheat as an important crop today. Although we have no absolute way to confirm these signals correlated with increased human settlement in the region, we believe a further ongoing study of two soil pit profiles with high resolution of dating and sampling from the village of Wenhai will give us even more information about human activity on the Jade Dragon Snow Mountain.

Acknowledgements

The authors thank Prof. Nai-Qiu Du from the Institute of Botany, Chinese Academy of Sciences, and Dr. Shao-Hua Yang from the Institute of Alpine Plants in Yunnan Academy of Agricultural Sciences, for their help with this study. This study was supported by the China National Key Basic Research Program (No. 2014CB954201), National Natural Science Foundation of China (No. 41271222), and a visiting scholarship funded by the China Scholarship Council (No. 201204910043).

References

An, C. B., Chen, F. H., and Feng, Z. D.: Study on the relationship between the vegetation change and the human activities in the Gangsu-Qinghai region during the period from mid- to late-Holocene, Arid Land Geogr., 25(2), 160–164, 2002 (in Chinese with English abstract).

An, C. B., Tao, S.C., Zhao, J. J. , Chen, F. H., Lv, Y. B., Dong, W. M., Li, H., Zhao, Y.T., Jin, M., and Wang, Z. L.: Late Quaternary (30.7–9.0 cal ka BP) vegetation history in Central Asia inferred from pollen records of Lake Balikun, northwest China, J. Paleolimnol., 49(2), 145–154, 2013.

Bronk, R.: OxCal Program v3.10, University of Oxford Radiocarbon Accelerator Unit, 2005.

Brugam, R. B.: Pollen indicators of land-use change in southern Connecticut, Quat. Res., 9(3), 349–362, 1978.

Cao, X., Ni, J., Herzschuh, U., Wang, Y., and Zhao, Y.: A late Quaternary pollen dataset from eastern continental Asia for vegetation and climate reconstructions: Set up and evaluation, Rev. Palaeobot. Palyno., 194, 21–37, 2013.

CCCV (Compilation Committee of Chinese Vegetation): Vegetation of China, Science Press, Beijing, 1980 (in Chinese).

Chen, X. M., Chen, F. H., Zhou, A. F., Huang, X. Z., Tang, L. Y., Wu, D., Zhang, X. J., and Yu, J. Q. Vegetation history, climatic changes and Indian summer monsoon evolution during the Last Glaciation (36,400–13,400 cal yr BP) documented by sediments from Xinyun Lake, Yunnan, China, Palaegeogr. Palaeoclimatol. Palaeoecol., 410, 179–189, 2014.

Conservation International: Biodiversity Hotspots, Retrieved 9 September 2008, From http://www.biodiversityhotspots.org/, 2008.

Cook, C. G., Jones, R. T., and Turney, C. M.: Catchment instability and Asian summer monsoon variability during the early Holocene in southwestern China, Boreas, 42, 224–235, 2013.

Dykoski, C. A., Edwards, R. L., Cheng, H., Yuan, D. X., Cai, Y. J., Zhang, M. L., Lin, Y. S., Qing, J. M., An, Z. S., and Revenaugh, J.: A high-resolution, absolute-dated Holocene and deglacial Asian monsoon record from Dongge Cave, Earth Planet. Sci. Lett., 233, 71–86, 2005.

El-Moslimany, A. P.: Ecological significance of common non-arboreal pollen: examples from dry lands of the Middle East, Rev. Palaeobot. Palyno. 64, 343–350, 1990.

Erdtman, G.: Pollen morphology and plant taxonomy (Angiosperms. an introduction to palynology-I), Almqvist and Wiksell, Stockhome, 1952.

Erdtman, G.: The acetolysis method, revised description, Svensk Botanisk Tidskrskrift 54, 561–564, 1960.

Feng, J. M., Wang, X.P., Xu, C.D., Yang, Y.H., and Fang, J.Y.: Altitudinal patterns of plant species diversity and community structure on Yulong Mountains, Yunnan, China, J. Mt. Sci., 24 (1), 110–116, 2006 (in Chinese with English abstract).

Foster, G. C., Chiverrell, R. C., Harvey, A. M., Dearing, J. A., and Dunsford, H.: Catchment hydro-geomorphological responses to environmental change in the Southern Uplands of

Scotland, Holocene, 18, 935–950, 2008.

Grimm, E.: TILIA version 1.11, Illinois State Museum, Springfield, USA, 1997.

He, X. B., Tang, K. L., Tian, J. L., and Matthews, J. A.: Paleopedological investigation of three agricultural loess soils on the Loess Plateau of China, Soil Sci., 167, 478–491, 2002.

He, Y. Q., Yao, T. D., Yang, M. X., and Shen, Y. P.: Contemporary significance of snow and ice indicated by the record in a shallow ice core from a temperate glacier in southwestern monsoon region, J. Glaciology Geocryology, 22(3), 235–242, 2000a (in Chinese with English abstract).

He, Y. Q., Yao, T. D., Yang, M. X., and Sun, W. Z.: The new results of $\delta^{18}O$ studies on the system of precipitation, snow, ice and glacial runoff at the glacier Baishui No. 1 region in Mt. Yulong, China, J. Glaciology Geocryology, 22(4), 391–393, 2000b (in Chinese with English abstract).

Hirons, K. R., and Edwards, K. J.: Events at and around the first and second *Ulmus* declines: Palaeoecological investigations in Co. Tyrone, Northern Ireland, New Phytol., 104, 131–153, 1986.

IBCAS (Institute of Botany, Chinese Academy of Sciences): Spore pteridophytorum sinicorum, Science Press, Beijing, 1976 (in Chinese).

IBSCIBCAS (Institute of Botany and South China Institute of Botany, Chinese Academy of Sciences): Angiosperm pollen flora of tropic and subtropic China, Science Press, Beijing, 1982 (in Chinese).

Jarvis, D. I.: Pollen evidence of changing Holocene monsoon climate in Sichuan Province, China, Quat. Res., 39, 325–337, 1993.

Jiang, Q. F., Ji, J. F., Shen, J., Ryo, M., Tong, G. B., Qian, P., Ren, X. M., and Yan, D. Z.: Holocene vegetational and climatic variation in westerly-dominated areas of Central Asia inferred from the Sayram Lake in northern Xinjiang, China, Sci. China Ser. D, 56(3), 339–353, 2013.

Jiang, X. Z., Wang, S. M., and Yang, X. D.: Paleoclimatic and environmental changes over the last 30,000 years in Heqing Basin, Yunnan Province, J. Lake Sci., 10(2), 10–16, 1998 (in Chinese with English abstract).

Jiang, X. Z., Yang, X. D., Wang, S. M., and Tong, G. B.: The Last Glacier Maximum pollen record in the lake sediments from ancient Heqing Lake and its significance for palaeomonsoon, Acta Micropalaeontol. Sin., 18(3), 263–267, 2001 (in Chinese with English abstract).

Jones, R. T., Cook, C. G., Zhang, E. L., Langdon, P. G., Jordan, J., and Turney, C.: Holocene environmental change at Lake Shudu, Yunnan Province, southwestern China, Hydrobiologia, 693, 223–235, 2012.

KIBCAS (Kunming Institute of Botany, Chinese Academy of Sciences): Flora Yunnanica (Tomus 4), Science Press, Beijing, 1986 (in Chinese).

KIBCAS (Kunming Institute of Botany, Chinese Academy of Sciences): Flora Yunnanica (Tomus 5), Science Press, Beijing, 1991 (in Chinese).

KIBCAS (Kunming Institute of Botany, Chinese Academy of Sciences): Flora Yunnanica (Tomus 13). Science Press, Beijing, 2003a (in Chinese).

KIBCAS (Kunming Institute of Botany, Chinese Academy of Sciences): Flora Yunnanica (Tomus 15). Science Press, Beijing, 2003b (in Chinese).

Kramer, A., Herzschuh, U., Mischke, S., and Zhang, C. J.: Holocene treeline shifts and monsoon variability in the Hengduan Mountains (southeastern Tibetan Plateau), implications from palynological investigations, Palaeogeogr. Palaeoclimatol. Palaeoecol., 286, 23–41, 2010.

Li, X. Q., Zhao, K. L., Dodson, J., and Zhou, X. Y.: Moisture dynamics in central Asia for the last 15 kyr: new evidence from Yili Valley, Xinjiang, NW China, Quat. Sci. Rev., 30, 3457–3466, 2011.

Li, X. Q., and Du, N. Q.: The acid-alkali-free analysis of Quaternary pollen, Acta Bot. Sin., 41(7), 782–784, 1999 (in Chinese with English abstract).

Long, R. H., Li, B. F., Brenner, M., and Song, X. L.: A study of late Pleistocene to Holocene vegetation in Qilu Lake of central Yunnan, Geol. Yunnan 10(1), 105–118, 1991 (in Chinese with English abstract).

Luo, S. W.: The historical route of the ancient “Tea-Horse Road” and the current value of its tourism development, J. Chongqing Norm .Uni. (Nat. Sci. Ed.), 20(3), 54–57, 2003 (in Chinese with English abstract).

Mook, W. G.: Recommendations/resolutions adopted by the Twelfth International Radiocarbon Conference, Radiocarbon, 28, 799, 1986.

Moore, P. D., Webb, J. A., and Collinson, M. E.: Pollen analysis, 2nd edn, Blackwell Scientific Publications, London, 1991.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., and Kent, J.: Biodiversity hotspots for conservation priorities, Nature, 403, 853–858, 2000.

Parker, A. G., Goudie, A. S., Anderson, D. E., Robinson, M., and Bonsall, C.: A review of the mid-Holocene elm decline in the British Isles, Prog. Phys. Geog., 26(1), 1–45, 2002.

Reimer, P. J., Baillie, M. G. L., Bard, E., Bayliss, A., Beck, J. W., Bertrand, C. J. H., Blackwell, P. G., Buck, C. E., Burr, G. S., Cutler, K. B., Damon, P. E., Edwards, R. L., Fairbanks, R. G., Friedrich, M., Guilderson, T. P., Hogg, A. G., Hughen, K. A., Kromer, B., McCormac, G., Manning, S., Ramsey, C. B., Reimer, R. W., Remmele, S., Southon, J. R., Stuiver, M., Talamo, S., Taylor, F. W., van der Plicht, J., and Weyhenmeyer, C. E.: IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP, Radiocarbon, 46, 1029–1058, 2004.

Russell, E. W. B., Davis, R. B., Anderson, R. S., Rhodes, T. E., and Anderson, D. S.: Recent centuries of vegetational change in the glaciated north-eastern United States, J. Ecol., 81(4), 647–664, 1993.

Shen, J., Jones, R. T., Yang, X. D., Dearing, J. A., and Wang, S. M.: The Holocene vegetation history of Lake Erhai, Yunnan Province southwestern China: the role of climate and human forcings, Holocene, 16(2), 265–276, 2006.

Smith, A. G., and Cloutman, E. W.: Reconstruction of Holocene vegetation history in three dimensions at Waun-Fignen-Felen, an upland site in South Wales, Philos. Trans. R. Soc. London, Ser. B Biol. Sci., 322, 159–219, 1988.

Song, X. Y., Yao, Y. F., Wortley, A. H., Paudiyal, K. N., Yang, S. H., Li, C. S., and Blackmore, S.: Holocene vegetation and climate history at Haligu on the Jade Dragon snow mountain, Yunan, SW China, Climatic Change, 113, 841–866, 2012.

Sun, X. J., Luo, Y. L., Huang, F., Tian, J., and Wang, P. X.: Deep-sea pollen from the South China Sea: Pleistocene indicators of east Asian monsoon, Mar. Geol., 201, 97–118, 2003.

Valles, J., and McArthur, E. D.: *Artemisia* systematics and phylogeny- cytogenetic and molecular in sights. In: McArthur, E. D., and Fairbanks, D. J. (eds.), Shrubland ecosystem genetics and biodiversity: proceedings. June 13–15, 2000, US Department of Agriculture Forest Service, Rocky Mountain Research Station, Provo, UT Ogden, USA, pp. 67–74, 2001.

Wang, F. X., Chien, N.F., Zhang, Y. L., and Yang, H. Q.: Pollen flora of China, Science Press, Beijing, 1995 (in Chinese).

Wang, H., Zhang, C. Q., Li, D. Z., Xue, R. G., and Yang, Q. E.: Checklist of seed plants of Lijiang Alpine Botanic Garden, Yunnan Science and Technology Press, Kunming, 2007 (in Chinese).

WGYV (Writing Group of Yunnan Vegetation): Vegetation of Yunnan, Science Press, Beijing, 1987 (in Chinese).

Wu, Z. K., Zhang, C. Q., Huang, Y., Zhang, J. L., and Sun, B. L.: Analysis on the formation of plant species diversity in the Yulong Mountains, upper reaches of Yangtze River, Resour. Environ. in the Yangtze Basin, 15(1), 48–53, 2006 (in Chinese with English abstract).

Xiao, J. L., Xu, Q. H., Nakamura, T., Yang, X. L., Liang, W. D., and Inouchi, Y.: Holocene vegetation variation in the Daihai Lake region of north-central China: a direct indication of the Asian monsoon climatic history, Quat. Sci. Rev., 23, 1669–1679, 2004.

Xiao, X. Y., Haberle, S. G., Shen, J., Yang, X. D., Han, Y., Zhang, E. L., and Wang, S. M.: Latest Pleistocene and Holocene vegetation and climate history inferred from an alpine lacustrine record, northwestern Yunnan Province, southwestern China, Quat. Sci. Rev., 86, 35–48, 2014.

Xu, Q. H., Kong, Z. C., Yang, X. L., Liang, W. D., and Sun, L. M.: Vegetation changes and human influences on Qian'an Basin since the middle Holocene, J. Integr. Plant Biol., 44(5), 611–616, 2002.

Ying, J. S.: Species diversity and distribution pattern of seed plants in China, Biodivers. Sci., 9(4), 393–398, 2001.

Zhang, L. L., Zhang, Y., Wang, L., and Wang, Y. H.: An ethnobotanical study of traditional edible plants used by Naxi people in northwest Yunnan, China –a case study in Wenhai village, Plant Divers. Resour., 35(4), 479–486, 2013.

Zhao, Y., Yu, Z. C., Chen, F. H., Ito, E., and Zhao, C.: Holocene vegetation and climate history at Hurleg Lake in the Qaidam Basin, northwest China, Rev. Palaeobot. Palyno., 145, 275–288, 2007.

Figure legends

Figure 1. a. The location of Wenhai Lake in northwestern Yunnan, China, b. The position of core and surface soil samples, c. The location of Wenhai Lake in the Hengduan Mountains, d. The location of Wenhai Lake on the Jade Dragon Snow Mountain, e. An enlarged photograph of Wenhai Lake (c, d and e are cited from Google Earth)

Figure 2. Pollen percentage diagram from Wenhai Lake, northwestern Yunnan, China

删除的内容: of selected taxa

Figure 3. Inferred vegetation succession over the past 22,570 yrs at Wenhai

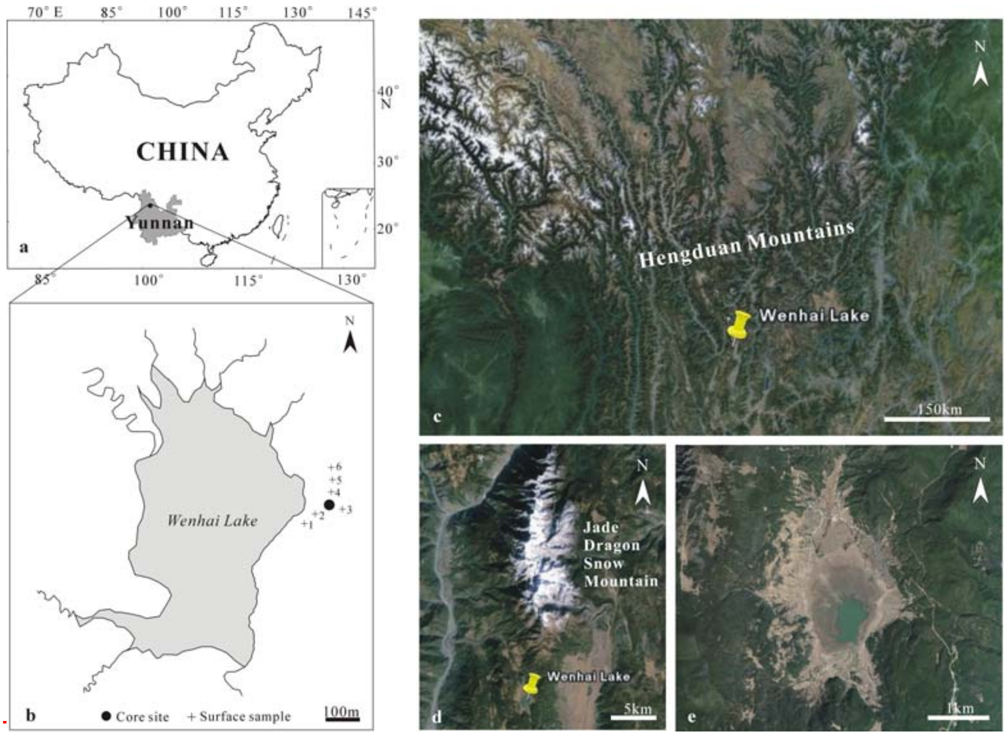
70° E
85°
100°
115°
130°
145°
40° N
30°
20°
CHINA
Yunnan
a
85°
100°
115°
130°
N
Wenhai Lake
+6
+5
+4
+3
+2
+1
b
Core site
+ Surface sample
100m
N
Hengduan Mountains
Wenhai Lake
c
150km
N
Jade Dragon Snow Mountain
Wenhai Lake
d
5km
N
e
1km

Figure 1

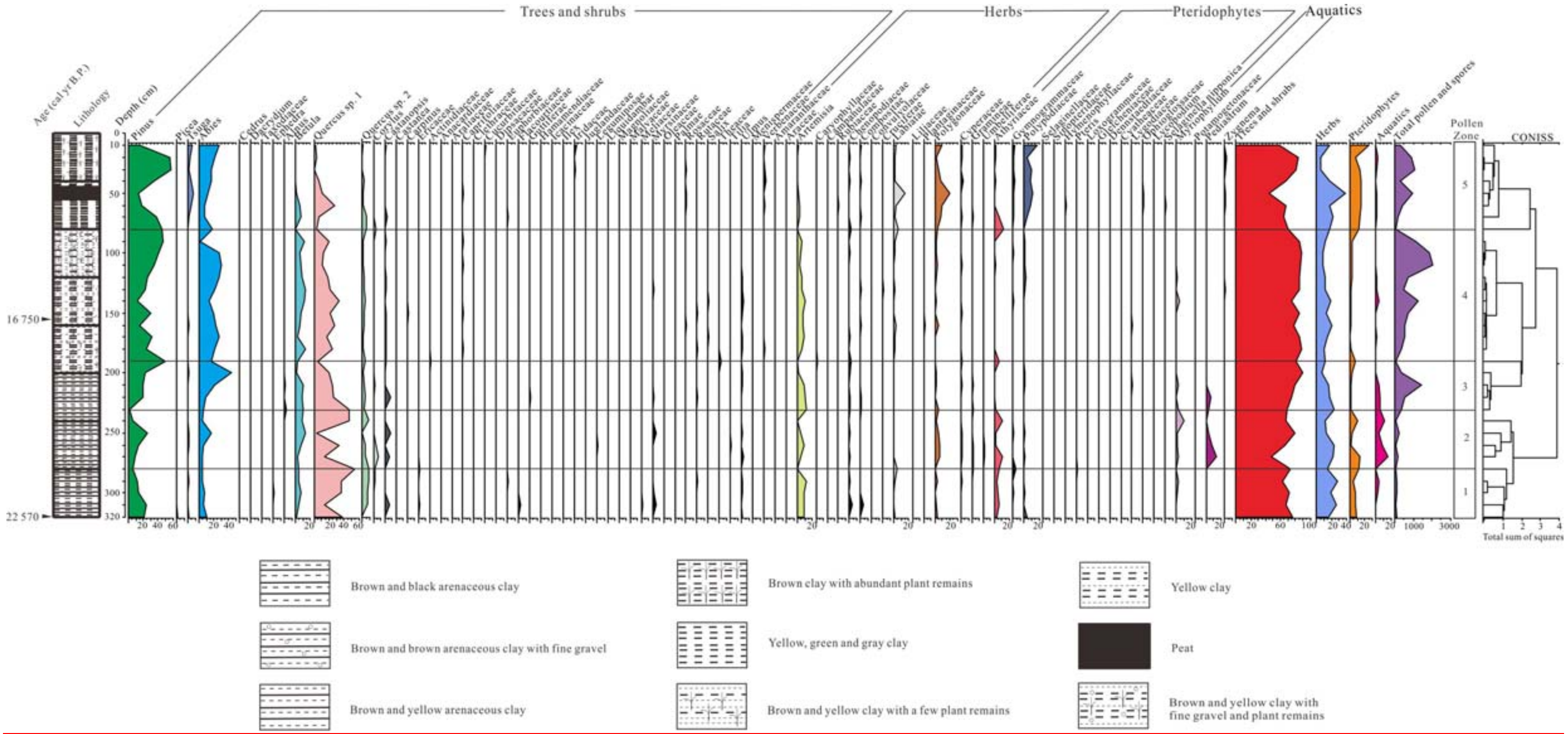
Trees and shrubs
Herbs
Pteridophytes
Aquatics
Age (cal yr B.P.)
Lithology
Depth (cm)
Pollen Zone
CONISS
16 750
22 570
Total sum of squares
Brown and black arenaceous clay
Brown and brown arenaceous clay with fine gravel
Brown and yellow arenaceous clay
Brown clay with abundant plant remains
Yellow, green and gray clay
Brown and yellow clay with a few plant remains
Yellow clay
Peat
Brown and yellow clay with fine gravel and plant remains

Figure 2

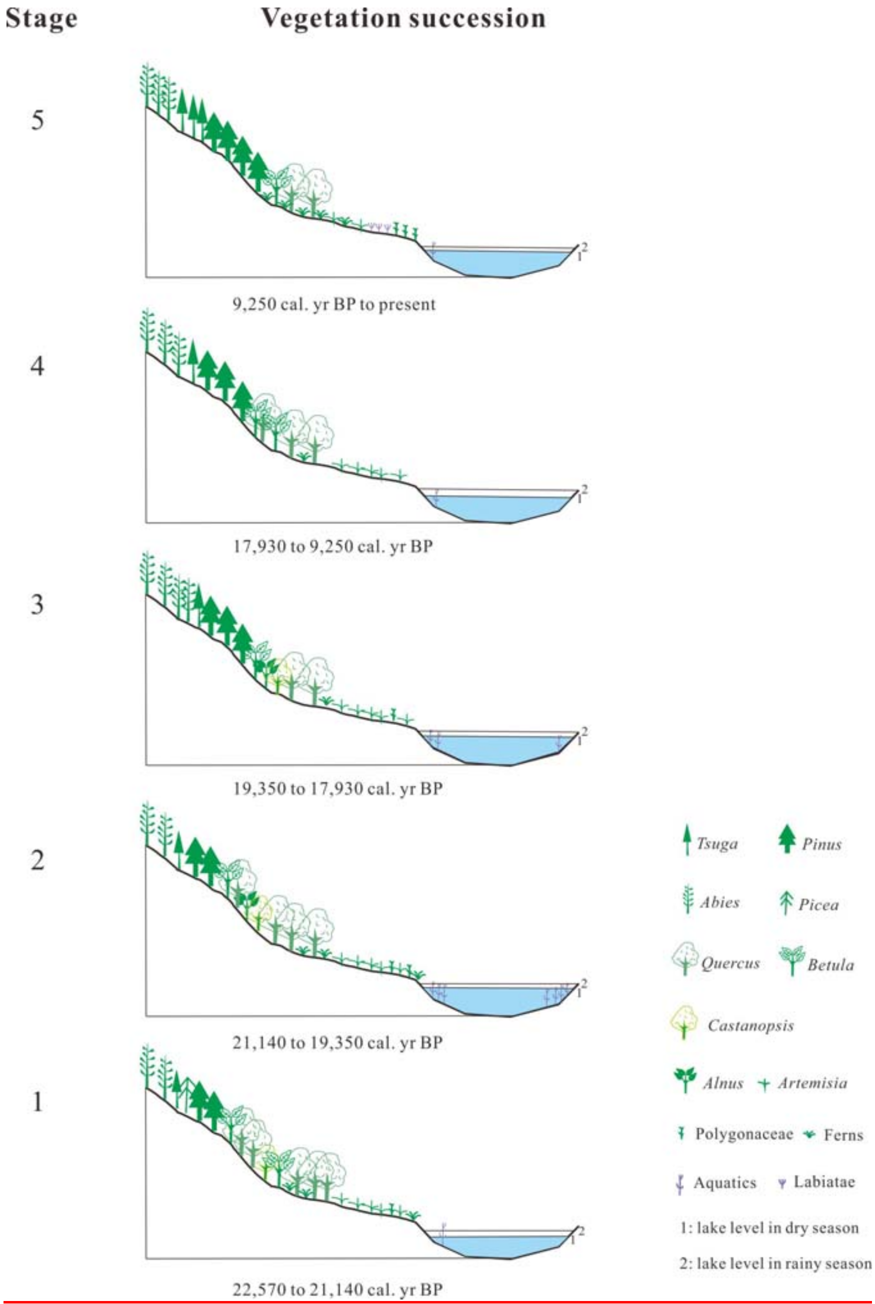
Stage
Vegetation succession
5
9,250 cal. yr BP to present
4
17,930 to 9,250 cal. yr BP
3
19,350 to 17,930 cal. yr BP
2
21,140 to 19,350 cal. yr BP
1
22,570 to 21,140 cal. yr BP
Tsuga
Pinus
Abies
Picea
Quercus
Betula
Castanopsis
Alnus
Artemisia
Polygonaceae
Ferns
Aquatics
Labiatae
1: lake level in dry season
2: lake level in rainy season

Figure 3

页 13: [1] 删除的内容 Lenovo User 2014-11-12 9:02:00

This present study provides a preliminary investigation into the vegetation and climate history at Wenhai Lake. The palynoflora found in the Wenhai core includes a large number of potential climate indicators. For instance, *Abies*, *Picea* and *Betula* are typically regarded as cold-tolerant taxa. *Pinus* usually grows in slightly warmer and moderately dry habitats. *Tsuga*, *Alnus*, Polygonaceae, Poaceae and Cyperaceae are considered to be hygrophilous plants. The occurrence of *Ephedra*, *Artemisia* and Chenopodiaceae normally indicates a dry environment. Evergreen sclerophyllous *Quercus* displays considerable ecological adaptability, and can adapt to dry or humid habitats (WGYV, 1987; Jarvis, 1993; Sun et al., 2003; Jiang et al., 2013).

页 13: [2] 删除的内容 Lenovo User 2014-12-3 14:55:00

on the lower mountains surrounding the lake, with a few *Corylus*, *Ulmus* and Ericaceae trees also dispersed in the forest. N

页 13: [3] 删除的内容 Lenovo User 2014-12-3 14:56:00

was distributed on the upper mountains.

页 13: [4] 删除的内容 Lenovo User 2014-12-3 14:56:00

Picea and *Ephedra* were also found in minute quantities.

页 13: [5] 删除的内容 Lenovo User 2014-12-4 8:48:00

Aquatic *Myriophyllum* and *Pediastrum* grew in the water at low concentrations.

页 13: [6] 删除的内容 Lenovo User 2014-12-3 15:05:00

.

The period b

页 13: [7] 删除的内容 Lenovo User 2014-12-3 15:26:00

continuing dominance of broad-leaved trees in the pollen sum of trees and shrubs. In showed a slight increase. This pollen assemblage suggests that the vegetation was dominated by broad-leaved forest as before, accompanied by needle-leaved forest, indicating a relatively warm and moderately humid climate condition with several climatic fluctuations during the period.

页 13: [8] 删除的内容	Lenovo User	2014-12-3 15:27:00

Tsuga, *Alnus*, Polygonaceae, Athyriaceae, *Myriophyllum* and *Pediastrum* were still visible, but their percentages gradually declined.

页 13: [9] 删除的内容	Lenovo User	2014-12-3 15:32:00

. The climate of the period was warm and humid at the beginning, but shifted to