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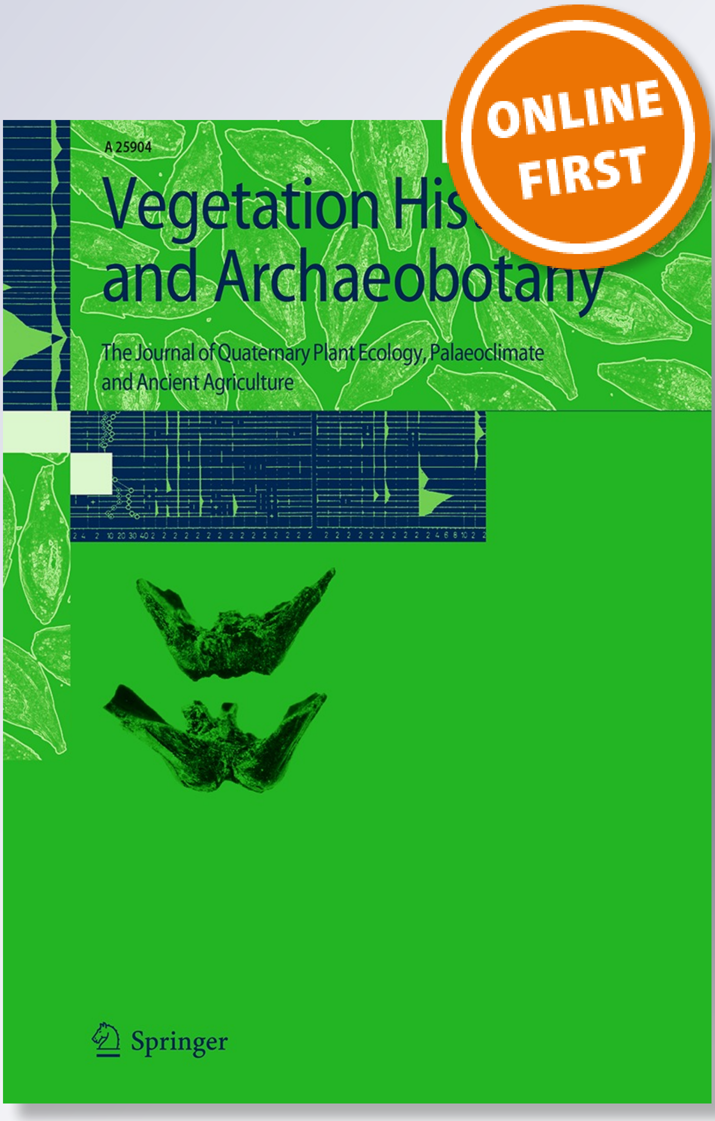

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ORIGINAL ARTICLE

Unravelling the past 1,000 years of history of human–climate–landscape interactions at the Lindu plain, Sulawesi, Indonesia

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Abstract The Lindu plain, located in the northern mountainous region of the Lore Lindu National Park in Sulawesi, Indonesia, provides many ecosystem services for the population inhabiting the area and harbours a unique biodiversity. Palynological, charcoal and diatom analyses of a lake sediment core from Lake Lindu (Danau Lindu) reveal that during the last 1,000 years the Lindu plain has been modified by human activities. Evidence of frequent burning and possible shifting cultivation from an earlier phase from ca. AD 1000 to 1200 might be related to the metal age population which erected the megaliths in the province of Central Sulawesi. From ca. AD 1200–1700 there followed 500 years of wetter climate conditions, corresponding to the southward movement of the Intertropical Convergence Zone. At the same time, decreases of macro-charcoal concentrations and pioneer vegetation indicators show that the use of the landscape of Lindu plain had become more permanent. Following a phase of forest recovery from ca. AD 1730 to 1910, the most recent part of the Lake Lindu record shows a trend towards deforestation that started in the late 20th century, lasting until now. The lake level started to fall at the beginning of the 20th century, as shown by the increase of sedimentation rate and supported by low pollen concentration and palaeomagnetic data. Such a change was unprecedented for the last 1,000 years covered by the record, and it has no link to the climate variability as reconstructed for the last hundred years. If deforestation increases and a larger amount of water is channelled away from the lake for irrigation purposes, the lake level will continue to fall. This suggests that there is a need for better management of the forests surrounding the plain and of the irrigation systems in the area open for cultivation.

Keywords Palynology · Charcoal · Diatoms · Lore Lindu National Park · Megaliths · Magnetostratigraphy

Introduction

Present-day tropical montane rainforests in the area of the Lore Lindu National Park (LLNP) in the province of Central Sulawesi, Indonesia, are rich in biodiversity and an important source of ecosystem services for the local population inhabiting the area. The montane rainforests within the LLNP, a UNESCO Man and Biosphere reserve since 1977, are mostly untouched old-growth forests (Cannon et al. 2007). However, during the last three decades, a growing population and political and economic initiatives have increased the pressure on previously relatively isolated communities, leading to conflicts for land and the opening up of further forested areas for

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agriculture (Acciaioli 2001). Within the context of sustainable management of conservation areas and agrolandscapes, palaeoecological and palaeoenvironmental studies provide a valuable contribution by showing how the vegetation and the environment have changed as a consequence of long-term climate variability and human-landscape interactions. In order to understand the present and future landscape dynamics, it is important to have a historical perspective when analysing the effects of environmental changes caused by human activities. However, little is known about the prehistory and history of the LLNP.

Megaliths found in the area of the park indicate that well-organized human societies have been present there for at least the last 2,000 years. Closer investigations have only been conducted in the Besoa valley in the southern part of the park (Fig. 1), where pollen analysis has revealed that the valley has been deforested for 2,000 years (Kirleis et al. 2011, 2012).

Isolated from the valley to the north and south, the present-day economy of the four villages on the shore of Lake Lindu, Anca, Tomado, Langko and Puroo, is based on the trading of rice cultivated in the plains surrounding the lake and fish caught in the lake itself. Little is known of the prehistory of the Lindu plain where megaliths are also found.

We present the results of a multi-proxy palaeoenvironmental study of a 123 cm long sediment core taken from Lake Lindu (1°19′16″S, 120°04′36″E at 960 m a.s.l.), spanning the past ca. 1,000 years. Palynological, charcoal and diatom data are used to reconstruct the vegetation and fire history of the Lindu plain, as well as the history of eutrophication of the lake. The aim is to characterize the timing and intensity of human activities during prehistoric and historic times. Results from the Lindu sediment core will shed light on the history of human-landscape interactions on the Lindu plain, a well-known fish reserve, and contribute to the understanding of the complex but still poorly known history of Central Sulawesi.

Study area

The Lindu valley is located in the highlands of Central Sulawesi and has an area of ca. 1,000 km^2 in the Takoekadju mountain range. In the northwest portion of the valley lies Lake Lindu, an ancient permanent freshwater lake, which is 10 km in length and 5–6 km in width (Fig. 1a). Small streams originating from the surrounding mountains drain into the lake. At the north-eastern corner,

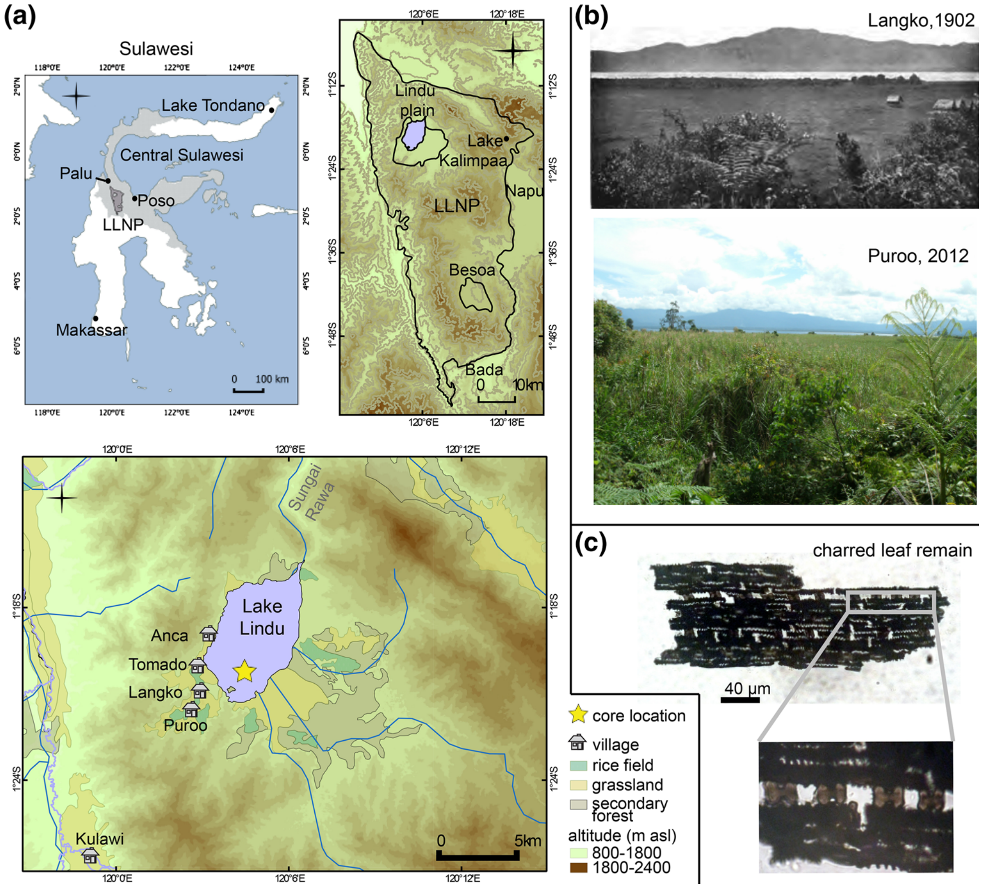


Fig. 1 **a** Map of the study region showing the location of the Lake Lindu sediment core (*star*). *Upper left* location of the Lore Lindu National Park (LLNP, *dark grey*) in Central Sulawesi (*light grey*); *upper right* location of the Lindu plain, Bada, Besoa and Napu valleys, borders of the LLNP and other places mentioned in the text; *bottom* locations of the villages of the Lindu plain and the coring site. Data source, Land Cover 2011, the Ministry of Forestry, the Republic of Indonesia (http://appgis.dephut.go.id/appgis/download.aspx); **b** *upper photo* view of the Langko village and grassland on the southwestern shore of the Lindu lake in 1902 (from Sarasin and Sarasin 1905). *Bottom photo*; view of the *alang-alang* (*Imperata cylindrica*) grassland from the village of Puroo in 2012, photo by S. Biagioni; **c** example of charred leaf remain from grass found at 120 cm (ca. AD 1100) and details of dumb-bell silica body

the river Sungai Rawa is the only outlet and it flows northwards to join a tributary to the Palu valley (Sudomo et al. 1990). High mountain peaks and steep topography within a short distance characterize the area, as the result of the uplift that started in the Pliocene, following the juxtaposition of the east and north arms of Sulawesi (Moss and Wilson 1998). At an altitude of ca. 960 m a.s.l., the lake basin covers an area of 32 km^2. It is the eighth largest lake in Sulawesi and the largest water body within the area of the LLNP. The Lindu plain is the only large wetland habitat in the National Park.

Climate and vegetation

Central Sulawesi is characterized by high humidity and temperatures. Mean annual precipitation ranges between 1,800 and 2,100 mm, and mean annual temperature decreases with elevation from 21 °C at 1,000 m to 14 °C at 2,400 m (Hijmans et al. 2005; WorldClim 2006; Culmsee et al. 2010). The modern climate of Indonesia is controlled by the seasonal movement of the Intertropical Convergence Zone (ITCZ) across the equator and interannual changes in the phase of the El Niño Southern Oscillation (ENSO) (Gunawan 2006). As the ITCZ moves southwards during the austral summer, the northwest monsoon delivers humid air and heavy rainfall to Indonesia, while during the austral winter the southeast monsoon brings relatively cool, dry conditions when the ITCZ is positioned over mainland Asia. According to Gunawan (2006), in the montane areas of Central Sulawesi, the rainfall is strongly determined by the local topography. The air masses reaching the area from the northwest and southeast are lifted orographically, leading to the formation of clouds and rainfall throughout the year. As a consequence, the monthly amount of rainfall during the dry southeast monsoon is only slightly less than that of the wet northwest monsoon. The modern intra-annual climate of the montane areas of the LLNP can be described as perhumid with at most 2 months of slightly lower precipitation, corresponding to the southeast monsoon peak in August (Gunawan 2006). The inter-annual variability of rainfall is influenced by the coupled ocean–atmosphere phenomenon ENSO: during El Niño (La Niña) warm (cold) phases, Indonesia experiences lower (higher) rainfall than in other years (Philander 1990; Cane 2005). When El Niño occurs, the Lake Lindu catchment has experienced yearly low water and mean discharge despite the high retention capacity (Leemhuis and Gerold 2006), negatively affecting the fish population and the fishing market established by the local villages (Acciaioli 2000).

The eastern, northern and northwest corners of the lake are covered with low-lying areas of marshy grassland. These open swamps are used by the local population for cultivating rice and grazing cattle. The mountain areas surrounding the lake are dominated by lower montane vegetation, in which the dominant tree families are Lauraceae, Fagaceae, Sapotaceae, Moraceae and Euphorbiaceae (Culmsee and Pitopang 2009). The higher peaks range from 2,000 to 2,400 m a.s.l. and are covered with upper montane vegetation, in which Podocarpaceae, Myrtaceae and Fagaceae are the dominant tree families (Culmsee et al. 2011).

Prehistory and history of Central Sulawesi (Table 1)

Central Sulawesi is rich in metal age megaliths, large worked stones in the shape of cylindrical vats, statues, urns and mortars (Kaudern 1938; Bellwood 1979; Sukendar 1976, 1980a, b; Kirleis et al. 2012). The majority are located in the Napu, Besoa and Bada valleys, but megaliths are also found on the Lindu plain. The absolute age of the megaliths has not been determined with precision, but archaeological estimates range from 3000 BC to AD 1300. At the Pokekea site in the Besoa valley Kirleis et al. established a *terminus ante quem* for the erection of the large stone vats called *kalambas* of ca. AD 830 (Fig. 1a; Kirleis et al. 2011, 2012). The authors further suggested a link between the opening of the forest in the valley when continuing burning started from ca. 2,000 years ago and the early construction phase of the monuments. The relationship between the megalithic culture and the indigenous people who live around the park today remains open to speculation. It seems likely that Proto-Malay and Palaeo-Mongoloid people migrated into the area, but much more research is needed in order to answer this fundamental question about the megaliths and their creators.

The first Europeans who visited Central Sulawesi were the Portuguese in the middle of the 16th century, followed by the Spanish, who arrived via the Philippines. They never settled in large numbers, but their influence is still visible. They introduced maize, tomato, chili peppers and horses (Davis 1976). A more important impact was the arrival of the Dutch, who opened up the areas in the lowlands starting from the 17th century. Before the Dutch arrival, there was little wetland rice growing, and agriculture activities were mostly focused on upland dryland rice, maize, and tubers grown under a shifting system. Population density in Central Sulawesi was very low. The small communities were ruled by kings and were relatively isolated from each other, and they were mainly located in the surrounding mountains, with no permanent settlements existing at that time (Kreisel et al. 2004). In contrast to the inhabitants of the Poso region, methods of wet rice cultivation were

Table 1 Overview of prehistory and history of Central Sulawesi and Lindu plain, as discussed in the text

Phases	Time	Central Sulawesi	Lindu plain
Japanese rule and independence	1970s-80s	Lore Lindu National Park	Declaration of Lore Lindu National Park led to increased migration to the Lindu plain
	1950s		Bugis start fish market and clove gardens and open new areas for wet rice plantations
	1949	Final admission of independence	
	1945	Independence of Indonesia, Dutch wars of re-conquest	
	1942	End of the Dutch rule and start of the Japanese colonial rule	
Dutch colonial period	1930		Discovery of schistosomiasis, the Dutch colonial administration maintained a policy of isolating the lake
	1905	Start of direct impact on the cultural landscape	Sarasin brothers visit Lindu plain and report of fishing traps, horses and falling lake level
	End of 19th cent.		First Europeans in the area, south of Palu
	1891	Christianization of the Poso region (Central Sulawesi)	Remote mountain populations of western Central Sulawesi including the Lindu plain, remained relatively isolated
	1710	Central Sulawesi comes under the rule of Makassar (South Sulawesi)	
	17th century	Palu becomes an important sea trade harbour, the interior of the island remains isolated	Lindu plain inhabited by an ethnic group named after Lindu
	1668	The Dutch conquer Makassar, Bugis flee from Makassar to Central Sulawesi	
	1648	Central Sulawesi comes under the rule of the Dutch East India company, but stays as a liege under the sultanate of Ternate (Moluku)	
	1605	Dutch East Indian company (DEI) in Palu	
Pre-colonial period	16th century	Portuguese and Spanish visit Central Sulawesi, introduction of maize, tomato, chili pepper and horses	
	5,000-700 yrs ago (?)	Metal age population inhabits Central Sulawesi and builds a large number of megaliths	Megaliths also found on the plain

already well known to the inhabitants of western Central Sulawesi before the arrival of the Dutch, as reported by Valentyn (1724–1726).

Today, the Central Sulawesi region is ethnically and culturally heterogeneous and comprises 15 indigenous groups, speaking 24 distinct languages. However, most of the people living today around the National Park are recent arrivals, or their descendants. The majority moved into the area as participants in the government's transmigration programmes which were at a peak in the 1970–1980s, and as a result of conflicts elsewhere (Kreisel et al. 2004).

History of the Lindu plain

According to Kaudern (1925), the Lindu plain has been inhabited since at least the 17th century by an ethnic group known by the same name. Accounts of the land-use strategies of the indigenous groups which lived in the area are derived mostly from reports by Dutch missionaries, in particular Albert Christian Kruyt and Nicolaus Adriani. They explored the mountainous regions in the first half of the 20th century following the Dutch christianisation mission, which began in 1891. The activities of the missionaries were centred in the eastern part of Central Sulawesi and particularly in the region around the river Poso, while the remote mountain populations of Central Sulawesi, including the Lindu plain, remained relatively isolated. This is probably due to the discovery on the Lindu plain in the 1930s of infestations of the snails that harbour the blood flukes causing schistosomiasis (Clarke et al. 1974). Indeed, according to Acciaoli (1989), the Dutch colonial administration maintained a policy of isolating the region after the initial attempts in the 1910s and 1920s to improve wet rice cultivation. After Kruyt and Adriani, the next Europeans to visit the Lindu plain were the Sarasin brothers, two natural scientists, who mapped the watercourses from Palu to Palopo (Sarasin and Sarasin 1905).

The first people who started the exploitation of the resources of the Lindu plain were of Bugis origin from South Sulawesi, in the late 1960s. They first migrated into the area after the Kahar Muzakkar regional rebellion in the 1950s. They expanded the local economy by selling fresh and salted fish and starting the transport of fish from the lake by horse cart. Their arrival marked the opening up of new areas for wet rice cultivation, and clove gardens were established near the shore line (Weber et al. 2003). Soon after the establishment of the Lore Lindu protected area in the late 1970s, the government granted a special status for the Lindu plain. A buffer zone was established in the surrounding forest to allow the Lindu villagers to maintain their fields and to have access to forest products. As a consequence, migration to the Lindu plain increased in the 1980s when arable land in Central Sulawesi became scarce following the establishment of the LLNP (Kreisel et al. 2004).

Materials and methods

A 123 cm long sediment core (LINDU_3) was recovered from Lake Lindu in 2006 using a Kajak corer (Renberg 1991) at a water depth of 46.5 m. The core was split into two halves and transported to the Department of Palynology and Climate Dynamics, University of Göttingen, Germany, where it was photographed and described lithologically and then stored in darkness at 4 °C.

Radiocarbon dating and palaeomagnetic analyses

Altogether eight bulk sediment samples have been sent for radiocarbon dating, four to the Leibniz Laboratory for Radiometric Dating and Isotope Research at the University of Kiel, Germany, three to the AMS ^{14}C Laboratory in Erlangen, Germany and one to the Poznań Radiocarbon Laboratory, Poland (Table 2). Ages were calibrated using the R script CLAM with the SHCal_13 and postbomb_SH1-2.14C calibration datasets. Since some age reversals occurred, only the youngest ages were used to establish the chronology, and the resulting age-depth-model was tested using magnetostratigraphy. The sediment core was sub-sampled with a u-channel and sent to the Sedimentary Paleomagnetism and Marine Geology Laboratory at the Institut des sciences de la mer de Rimouski (ISMER) of the University of Québec at Rimouski, Canada. The natural remanent magnetization (NRM) was acquired at 1 cm intervals on the u-channel using a 2G Enterprises 755 cryogenic magnetometer with stepwise alternating field (AF) demagnetization at peak fields of 0–90 mT with 5 mT increments from 0 to 80 mT. Inclination and declination of the characteristic remanent magnetization (ChRM) were calculated using an Excel spreadsheet developed for that purpose (Mazaud 2005) with AF demagnetization steps from 5 to 90 mT (17 steps). This macro also allows calculation of component magnetizations and maximum angular deviation (MAD) values using principal component analysis (Kirschvink 1980). Due to the response function of the magnetometer pick-up coils some smoothing occurs, and the top and bottom ~7 cm of the u-channel have to be considered cautiously.

Palynological and micro-charcoal analyses

Sediment samples of 0.5 cm^{3} were taken at 4 cm intervals (31 samples) along the core for analysing pollen, spores and non-pollen palynomorphs (NPPs), and at 2 cm intervals for micro-charcoal particles (62 samples). The samples were prepared using standard methods including 70 % HF treatment (Fægri and Iversen 1989). Before sample processing, the spores of the marker *Lycopodium clavatum* were added to the samples for the calculation of the concentrations. Pollen and spore identification is based on the reference collection of tropical pollen and spores at the Department of Palynology and Climate Dynamics at the University of Göttingen, which includes specimens collected from the LLNP in 2011 and 2012, pollen keys and atlases for southeast Asia (Flenley 1967; Powell 1970; Huang 1972; Garrett-Jones 1979; Stevenson 1998) and the online Australasian Pollen and Spore Atlas (APSA) hosted at Palaeoworks, Australian National University, Canberra

Table 2 Accelerator mass spectrometry radiocarbon dates from Lake Lindu, calibrated age ranges at 95 % confidence intervals

Sediment depth (cm)	^{14}C age BP/negative^{14}C	Age AD (mean;2σ range; probability)[a]	δ^{13}C	Laboratory	Lab. code
17	−1,372 ± 20	1988; 1985–1990; 57 %	−28.8	Kiel–2012	KIA47353
20	**−730 ± 40**	**2000; 1998–2004; 93 %**	**−31.9**	**Erlangen-2008**	**Erl-12489**
32	530 ± 30	1430; 1405–1450; 95 %	−30.3	Poznan-2008	Poz-24226
53	350 ± 30	1570; 1490–1645; 95 %	−27.2	Kiel-2012	KIA47354
62	**−482 ± 40**	**1958; 1957.61–1958.37; 5 %**	**−13.1**	**Erlangen-2008**	**Erl-12490**
77	**105 ± 20**	**1900; 1880–1930; 51 %**	**−28.2**	**Kiel-2012**	**KIA47355**
86	542 ± 41	1420; 1390–1460; 94 %	−33.5	Erlangen-2008	Erl-12491
100	**455 ± 20**	**1470; 1440–1500; 94 %**	**−27.3**	**Kiel-2012**	**KIA47356**

[a] Ages used for chronology are in bold; calibration done with R script CLAM, calibration curves SHCal13.14C and postbomb_SH1-2.14C for postbomb dates

(http://apsa.anu.edu.au). Identified pollen grains were counted to a sum of 300 and percentages were calculated relative to the pollen sums. Moraceae and Urticaceae were counted together because pollen grains from these two families are not distinguishable morphologically. The values of Moraceae–Urticaceae are overrepresented in the pollen assemblage due to the high production of pollen from these families (Jantz et al. 2013). Therefore, they are excluded from the total pollen sum for the calculation of the percentages of the remaining taxa. The opposite situation occurred for the Lauraceae, which is today one of the most important tree families in the area, but due to the thin and fragile exine, it is almost completely absent from the pollen assemblage. Concentrations are expressed in the diagrams as counts per cm^3 of sediment. Pollen taxa are grouped into lower montane rainforest, swamp, pioneer and secondary rainforest, anthropogenic indicator, palm and upland long-distance transported according to their altitudinal and ecological distributions, based on field observation and available literature (Kessler et al. 2002; Culmsee et al. 2010; Flora Malesiana collection: http://floramalesiana.org; Prosea collection: http://prosea.nl). Important NPPs are presented as concentrations per unit of volume (counts/cm^3). Poaceae pollen grains larger than 40 µm were counted separately. Although it is not possible to distinguish the grains of *Oryza sativa* from other Poaceae under the compound light microscope, pollen grains belonging to this group are larger than 35–40 µm (Chaturvedi et al. 1998). This group is therefore used, in combination with other anthropogenic proxies, as a possible indicator of rice cultivation.

Micro-charcoal particles that were seen under a normal light microscope as black and completely opaque with sharp edges have been counted (10–150 µm). Following Finsinger and Tinner (2005), at least 200 items, the total of micro-charcoal particles and *L. clavatum* spores, were counted and the concentration per unit of volume was calculated. Concentrations and proportions of the taxa are plotted against depth, and the ages of the record are discussed as time-windows in order to minimize the error due to the uncertainty of the age-depth model. For plotting and calculations, the software C2 was used (Juggins 2007).

Macro-charcoal analysis

Macro-charcoal particles (>150 µm) were counted in samples which were evenly spaced at 1 cm intervals along the sediment core (123 samples). The samples, of 2 cm^3 each, were prepared following the methods of Stevenson and Haberle (2005) and Rhodes (1998). Weak hydrogen peroxide (6 % H_2O_2) was used to partially digest and bleach organic material in the sediment samples when counted under a binocular dissecting microscope. The sample preparation procedure aimed to ensure that little particle fragmentation occurred during preparation. Results are expressed as the number of charred particles per cm^3.

Diatom analysis

Sediment samples for diatom analysis were prepared according to standard methods at 2 cm intervals (62 samples) (Wang et al. 2013). 0.5 cm^3 sediment samples were treated with 30 % H_2O_2 and mounted using mounting media with a high refractive index (Mountmedia, Wako). At least 300 diatom valves were counted for each sample using an optical microscope with 1,000× magnification. The diatom taxa were identified on the basis of reference collections and literature (Krammer and Lange-Bertalot 1986; Wang et al. 2010).

Numerical analysis

Local pollen assemblage zones were defined numerically by constrained cluster analysis using the software CONISS (Grimm 1987, 1993). The dissimilarity matrix was calculated as Cavalli-Sforza's chord distances of squared root transformed percentage data. All pollen and spore taxa were included in the analysis. Unconstrained multivariate statistical analysis was done to characterize the changes in vegetation composition of the past 1,000 years using the software CANOCO 5 (Ter Braak and Šmilauer 2002). The length of the compositional taxa gradient had a value of only 1.2 standard deviation (SD) units, so a linear model was chosen and a principal component analysis (PCA) was carried out with all identified pollen and spore percentage data. Data were centred and square root transformed to downscale the weight of a few dominant taxa.

Results

Lithology and chronology

Sediment core LINDU_3 consisted entirely of sediments with laminations that measured in millimetres. From 123 to 78, 62 to 36 and 6 to 0 cm sediment depths dark blackish colours predominated. Intercalated were light brown to whitish colours between 78 and 62 cm and whitish colours between 36 and 6 cm.

As the sediment–water interface was intact, the top of the record represents the year of coring, 2006. According to a linear extrapolation of the lowermost accepted ages, the base of the Lake Lindu record has an age of AD 1030. Since the radiocarbon dating results were rather heterogeneous and had a number of age reversals, only the youngest ages were linearly interpolated (Table 2; Fig. 2a). Such results for radiocarbon dating seem to be rather common on the island of Sulawesi, where dating has turned out to be a challenge in many sediment archives (Haberzettl et al. 2013).

Palynological results

In total, 209 different pollen taxa were encountered, of which 77 rare taxa remain unidentified. The most representative lower montane forest taxa in the pollen assemblage belong to the Moraceae and Urticaceae families (average 38 %; min 10 %, max 50 %) (Fig. 3). The next most representative taxa of lower montane rainforest are Fagaceae, mostly represented by *Lithocarpus–Castanopsis* (average 20 %; min 9 %, max 36 %, percentages based on a total pollen sum excluding Moraceae–Urticaceae), *Acalypha* (average 6 %, up to 17 %), *Peperomia* (average 6 %; min 2 %, max 13 %), Myrtaceae (average 3 %, up to 9 %), *Engelhardtia* (average 3 %, up to 9 %), Elaeocarpaceae (average 2 %, up to 5 %), *Ilex* (average 2 %, up to 5 %), *Celtis* (average 2 %, up to 6 %), *Myrica* (average 1 %, up to 5 %) and *Freycinetia* (average 1 %, up to 4 %). All these taxa together account for 53 % of the pollen sum on average. The group of swamp plants is represented mostly by *Typha* (up to 4 %) and *Callitriche* (average 2 %, up to 8 %). Pioneer and secondary forest taxa are represented mostly by *Macaranga* (average 4 %, up to 11 %), *Trema* (average 2 %, up to 8 %) and *Neonauclea* pollen (average 2 %, up to 5 %). Anthropogenic indicators are represented mostly by Poaceae (average 13 %, up to 20 %), Mimosoideae (up to 4 %) and *Plantago* (up to 0.8 %). Palms are little represented (average 1 %, up to 6 %). Upper montane pollen taxa are rare and mostly represented by *Phyllocladus* (average 1 %, up to 4 %). Pteridophyta spores are abundant and diverse (average of the total sum of pollen plus spores 29 %, min 12 %, max 45 %, total number of taxa 81), although most of the taxa remain unidentified.

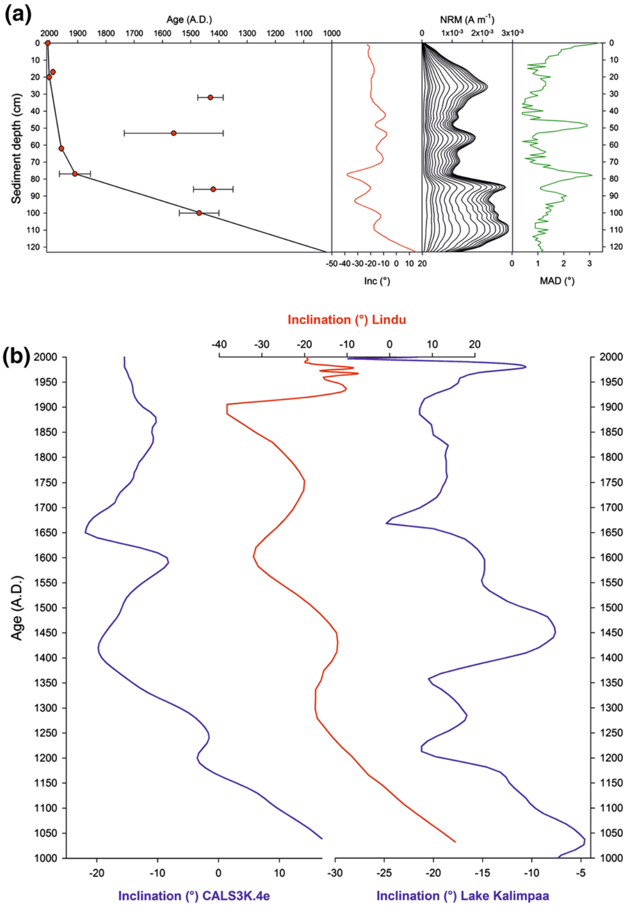


Fig. 2 **a** Chronology of the Lake Lindu sediment record as well as inclination (inc), the natural remanent magnetization (NRM) and maximum angular deviation values (MAD); **b** comparison of the Lake Lindu inclination record to that from Lake Kalimpaa (Haberzettl et al. 2013) and the CALS3 K.4e (Korte and Constable 2011) model output calculated for the location of the sediment core from Lake Lindu

Pollen concentration values are high at the bottom of the sediment core between 123 and 115 cm (average 12×10^4 grains/cm^3), but they decrease from 115 to 75 cm (average 6×10^4 grains/cm^3) and have even lower values in the top part of the core from 75 to 0 cm (average 4×10^4 grains/cm^3).

The record is divided into two large clusters by the CONISS analysis. The first zone is lin-1 from 123 to 76 cm, and the second is lin-2 from 76 to the top of the core. Based on important changes and composition of the palynological, charcoal and NPP data, the two zones are additionally divided into six sub-zones: lin-1a (123–116 cm), lin-1b (116–84 cm), lin-1c (84–76 cm), lin-2a (76–64 cm), lin-2b (64–52 cm) and lin-2c (52–0 cm).

Description of the palynological sub-zones

Lin-1a (123–116 cm; ca. AD 1030–1200)

The basal sub-zone of the record is characterized by low values of *Lithocarpus–Castanopsis* pollen (average 11 %), while other montane rainforest genera like *Freycinetia* and *Acalypha* have the highest values of the record (averages 2 and 16 %). Poaceae pollen grains are well represented and they increase towards the top of the sub-zone (from 13 to 16 %). Within this group, grains larger than 40 µm are found. Swamp pollen taxa have low values (average 2 %) mirrored by high micro-charcoal particles (average 12×10^4 part/cm^3). Pioneer pollen taxa have high values, represented by *Macaranga* (average 7 %) and *Trema* (average 5 %).

Lin-1b (116–84 cm; ca. AD *1200–1730)*

Lithocarpus-Castanopsis pollen values slightly increase (average 18 %) while *Acalypha* decreases. Swamp pollen taxa values increase notably, represented mostly by *Typha* (up to 4 %). Micro-charcoal concentrations decrease while *Glomus* spores increase. *Tilletia* and *Plantago* occur for the first time in this sub-zone. On average, the pollen concentrations decrease.

Lin-1c (84–76 cm; ca. AD *1730–1910)*

In this sub-zone *Lithocarpus–Castanopsis* pollen values continue to increase (average 25 %). Poaceae values decrease slightly (average 10 %) and grains larger than 40 µm are no longer found. Swamp pollen taxa decrease (average 1 %), mirrored again by high micro-charcoal values (average 8×10^4 particles/cm^3) and low *Glomus* concentrations (average 470 spores/cm^3).

Lin-2a (76–64 cm; early 20th century)

In this sub-zone pollen preservation is poor, and grains show corrosion and are often folded. The pollen grains of Moraceae-Urticaceae are particularly badly preserved.

Primary lower montane pollen taxa continue to rise, especially *Lithocarpus-Castanopsis* (average 29 %). However, *Freycinetia* and *Acalypha* values markedly decrease (averages 0.5 and 3 %), while *Celtis* increase (up to 6 %). Pioneer and secondary pollen taxa are mostly represented by *Macaranga* (average 5 %) and *Neonauclea* (average 5 %). As in the previous sub-zone, swamp pollen taxa continue to decrease, mirrored by high micro-charcoal and low *Glomus* concentrations. *Tilletia* values decrease markedly (average 47 counts/cm^3).

Lin-2b (64–52 cm; mid 20th century)

The difference between this and the previous sub-zone is in the increase of swamp pollen taxa (average 4 %), while micro-charcoal concentrations decrease and *Glomus* increases. Peaks in *Plantago* pollen and *Botryococcus* colonies are recorded at the beginning of the sub-zone (1 % and 7,500 colonies/cm^3).

Lin-2c (52–0 cm; late 20th and beginning of 21st century)

This sub-zone marks the start of a decreasing trend for primary lower montane and pioneer pollen taxa, which continues until the top of the record. In contrast, Poaceae pollen values start to increase and grains > 40 µm are found again. *Baccaurea* values increase from 44 to 28 cm, followed by the increase of *Neonauclea* and anthropogenic pollen indicators like Poaceae >40 µm, Mimosoideae and Apiaceae. *Botryococcus* values increase, starting from 14 cm and continuing to the top. Several peaks of *Tilletia* are recorded, starting from 38 cm.

Fig. 3 Summary diagram from the Lake Lindu sediment core divided ▶ into temporal zones and sub-zones. The *black lines* are the locally weighted scatter plot smoothings (LOWESS) fitted to the sample values (*light grey bars*) to highlight trends. X-axes are rescaled for a better visualization of the least abundant taxa. **a** *Upper diagram* Moraceae-Urticaceae (expressed in percentages of the total pollen sum); sum of lower montane rainforest, swamp, pioneer, secondary forest, anthropogenic, palms and long-distance transported pollen taxa (expressed as percentages of total pollen sum excluding Moraceae–Urticaceae); total Pteridophyta spores (expressed as percentages of sum of pollen and Pteridophyta spores); pollen, Pteridophyta and diatom concentrations (counts/cm^3). *Lower diagram*: macro- and micro-charcoal concentrations (counts/cm^3); swamp pollen taxa sum (percentages of the total pollen sum excluding Moraceae-Urticaceae); selected non-pollen palynomorph (NPP) concentrations (counts/cm^3); selected diatoms (counts/cm^3); CONISS dendrogram of the square root transformed proportions of all taxa (dissimilarity coefficient Edwards and Cavalli-Sforza's chord distance); **b** most significant pollen taxa within the groups (percentages of the total pollen sum excluding Moraceae-Urticaceae); selected Pteridophyta taxa (expressed as percentages of sum of pollen and Pteridophyta spores)

Macro-charcoal results

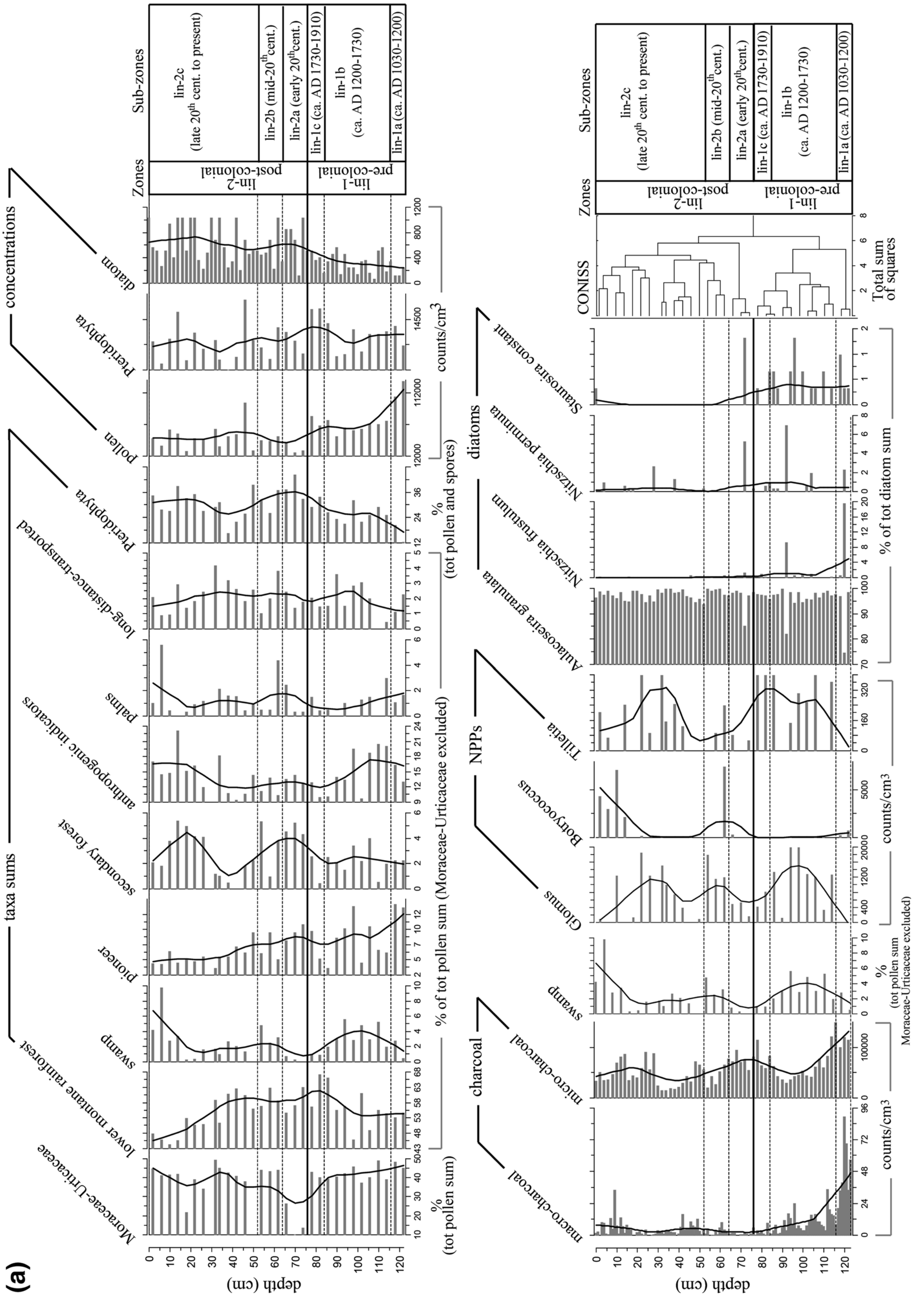
Macro-charcoal particles are found in all the samples along the core. There are exceptionally high concentrations in Sub-zone lin-1a at the bottom of the record, from 123 to 113 cm. At the same depths, charred particles were larger than in the rest of the record and remains of grass leaves were observed (Fig. 1c).

Diatom results

Overall, 42 diatom taxa were identified, of which planktonic diatom, *Aulacoseira granulata* is the most important species with an average of 97 % of the total diatom sum throughout the core. The values of the benthic diatoms, *Nitzschia frustulum*, *N. perminuta* and *Staurosira construens* peak shortly in Sub-zones lin-1a, lin-1b, and lin-2a. In Sub-zones lin-2b and lin-2c, the benthic diatom *Staurosira construens* is no longer present. The diatom concentration is stable with a lower average (3.25×10^8 valves/cm^3) in Zone lin-1, while the mean concentration doubles (6.39×10^8 valves/cm^3) with marked variations in Zone lin-2.

Multivariate statistical analysis

Principal component analysis (PCA) of all identified pollen and spore taxa was used to compare and characterized the


(a)
depth (cm)
0 10 20 30 40 50 60 70 80 90 100 110 120
taxa sums
Moraceae-Urticaceae
lower montane rainforest
swamp
pioneer
secondary forest
anthropogenic indicators
palms
long-distance-transported
Pteridophyta
concentrations
pollen
Pteridophyta
diatom
% (tot pollen sum)
% of tot pollen sum (Moraceae-Urticaceae excluded)
% (tot pollen and spores)
counts/cm3
Zones
lin-2 post-colonial
lin-1 pre-colonial
Sub-zones
lin-2c (late 20th cent. to present)
lin-2b (mid-20th cent.)
lin-2a (early 20th cent.)
lin-1c (ca. AD 1730-1910)
lin-1b (ca. AD 1200-1730)
lin-1a (ca. AD 1030-1200)
charcoal
macro-charcoal
micro-charcoal
counts/cm3
NPPs
swamp
Glomus
Botryococcus
Tilletia
% (tot pollen sum Moraceae-Urticaceae excluded)
counts/cm3
diatoms
Aulacoseira granulata
Nitzschia frustulum
Nitzschia perminuta
Staurosira constant
% of tot diatom sum
CONISS
Total sum of squares

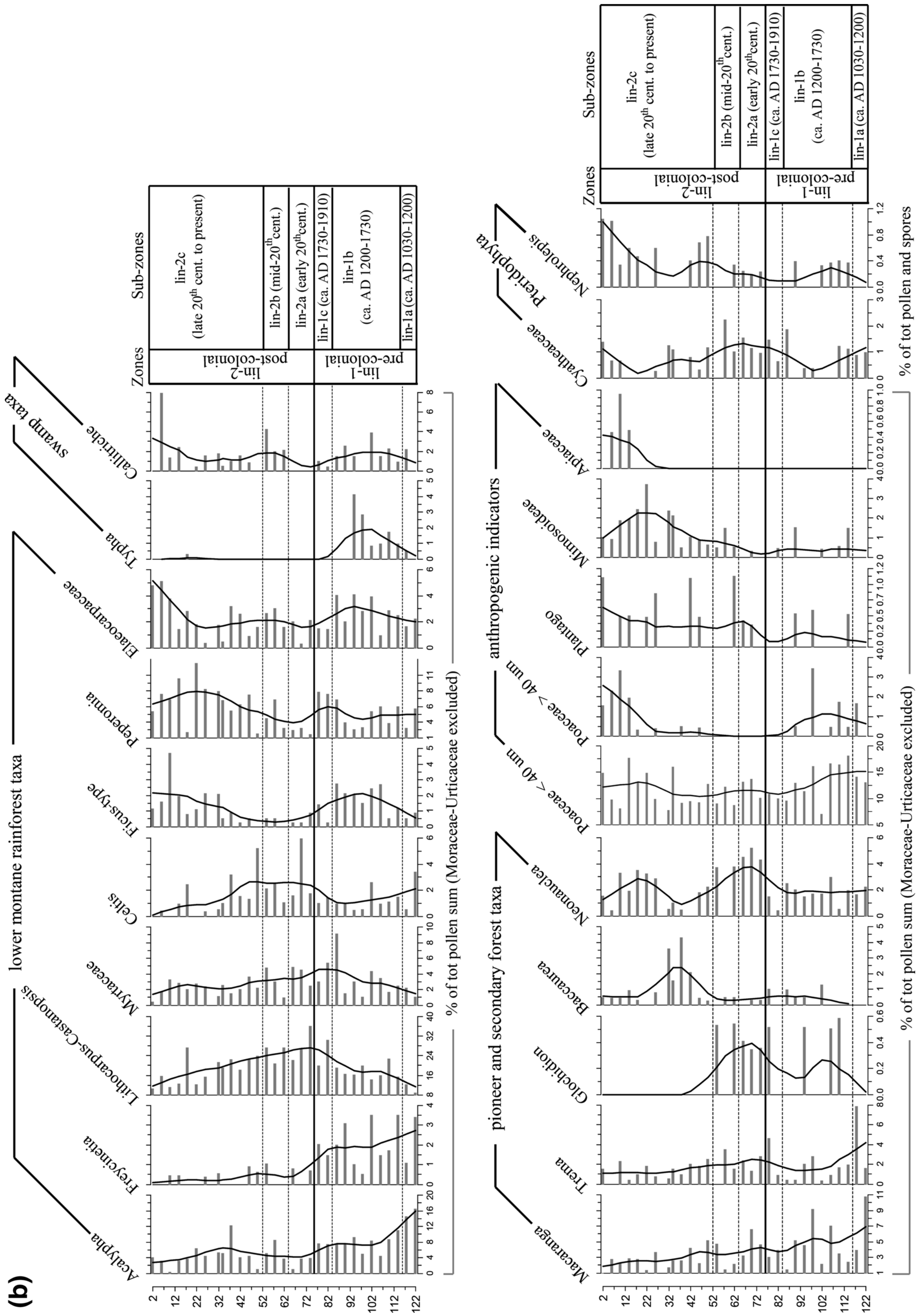


Fig. 3 continued

patterns of palynological composition variation across the different prehistoric and historic phases in the Lindu results from ca. 1,000 years ago (Fig. 4). The first and second axes of the ordination diagram explain 22 % of the variance. The samples in the middle Sub-zones lin-1c and lin-2a score mostly positively on the first axis, while the remaining samples score negatively (Fig. 4a). The scores of the second axis separate the assemblages into two groups (Fig. 4b). Samples in Zone lin-1 score negatively (pre-colonial period), while those in Zone lin-2 (post-colonial period) score positively.

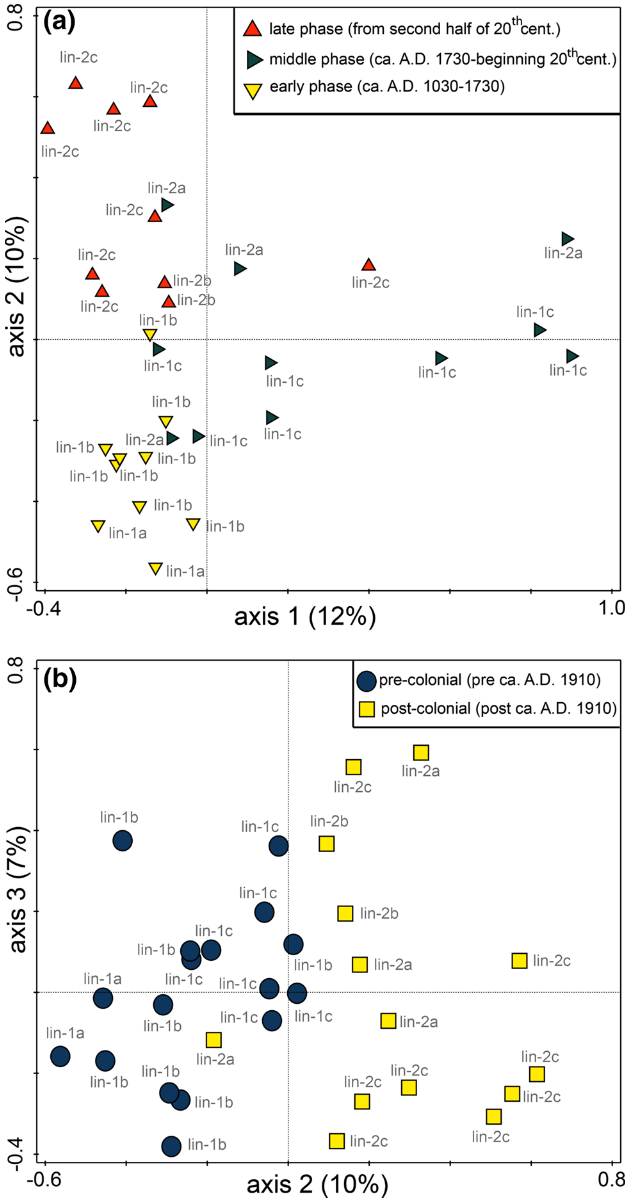


Fig. 4 Principal component analysis (PCA) of all percentage data of identified pollen and spore taxa. Percentages calculated on the total sum of all taxa square root transformed. First, second and third axes are shown (cumulative explained variation 29 %). Scatterplots represent the sample scores. Results are centred by taxa. Group of adjacent samples are marked differently to highlight the different groups corresponding to different prehistoric and historic phases. Palynological sub-zones are given in light grey; **a** first and second axes scatterplots; **b** second and third axes scatterplots

Discussion and interpretation

According to the age-depth model, a clear increase in the sedimentation rate from 0.52 to 40 mm a^{-1} can be observed from the base to the top of the Lake Lindu record (Fig. 2). This is an even more distinct change than what was observed at the much smaller lacustrine system of Lake Kalimpaa, where the sedimentation rate increased from 0.8 to 9.2 mm a^{-1} due to human disturbances in its surroundings (Haberzettl et al. 2013; Wündsch et al. 2014; Biagioni et al. 2015). At Lake Tondano, a modern age was obtained at 100–90 cm (Dam et al. 2001). This date was explained as the probable result of the admixture of recent soil organic matter into the sediment, since its properties did not suggest a radical change in depositional activity (Dam et al. 2001). However, if this age is assumed to be correct, a similar change in sediment accumulation occurred as at Lake Lindu. This is in accordance with the observation that Lake Tondano is seriously threatened by increasing silting up, which according to references dating back to 1979 has been reaching values of 200 mm a^{-1} (Lehmusluoto 1997; Dam et al. 2001). These comparisons make such a drastic change in sediment accumulation conceivable. However, since such a change without the occurrence of mass wasting events is unusually high, the chronology has been tested using magnetostratigraphy and comparison to geomagnetic field model output, since palaeomagnetic secular variations (PSV) can be used as a significant tool to correlate Holocene regional records (Yang et al. 2009; Barletta et al. 2010; St-Onge and Stoner 2011; Ólafsdóttir et al. 2013).

A strong and stable ChRM (characteristic remanent magnetization) was isolated between 5 and 90 mT (Fig. 2a). A viscous remanent magnetization was hardly observed and, when present, was easily removed at 5 mT. MAD values of the ChRM of the Lake Lindu palaeomagnetic record are entirely below 3.5°, indicating a very well preserved magnetization (Stoner and St-Onge 2007). Unfortunately, declination seems to suffer from core twisting, which has often been observed with soft sediments (Ali et al. 1999; Haberzettl et al. 2013) and hence is not plotted. The inclination shows a trend from 15.4° to −38.2° from 123 to 78 cm, intersected by two high amplitude maxima in between. Values close to the ones expected, based on a geocentric axial dipole model (GAD = 2.64°S for Lake Lindu) for the site latitude, are only reached at the base of the core. After the decreasing trend, a change to −10.4° at

69 cm is observed. Thereafter, the amplitude of the variations is much lower, although distinct differences ranging between −7.4 and −16.4° (=9° difference) can be observed. From 32 cm to the top of the record, the amplitude further decreases to values between −17 and −23.7° (=6.7° difference) (Fig. 2a). This change in amplitude is consistent with the observed increase in the sedimentation rate. The lower the sedimentation rate, the higher the amplitude in inclination variations, because a longer period of time is recorded during intervals of lower sedimentation rate. During this longer period, larger variations in the inclination can occur. In contrast, high sedimentation rates only record short time intervals with minor variations in the inclination. Therefore the synchronous occurrence of higher amplitudes during phases with lower sedimentation rates, and lower amplitudes when there are higher sedimentation rates, is in agreement with the chronology. Further support for the chronology comes from the comparison of the inclination record from Lake Lindu with the data obtained from Lake Kalimpaa (Haberzettl et al. 2013) and the CALS3 K.4e spherical harmonic geomagnetic model output for the coring site (Fig. 2b; Korte and Constable 2011). While individual swings in the inclination curve of Lake Lindu are also found in the Lake Kalimpaa record, a similar general trend is found in the CALS3 K.4e model. If one takes into account the error of the radiocarbon dating method itself of ±70 years for the accepted ages (Table 2) and the error in the chronology determined by age-modelling artefacts owing to linear interpolation, as well as the uncertainties contained in the CALS3 K.4e model, an even better fit might be conceivable.

Although the radiocarbon-based chronology is conservative, the palaeomagnetic analyses support this approach and indicate that the age-depth model is a good first order approximation as a basis for palaeoenvironmental reconstruction. In addition, the inclination data extend palaeomagnetic knowledge into an area where such information is very scarce.

According to the age-depth model, the palaeoecological analyses of the Lindu core illustrate the vegetation, climate and fire history of the Lindu plain for the past ca. 1,000 years. The following discussion divides the record into a pre-colonial period corresponding to Zone lin-1 starting from ca. AD 1030 and a post-colonial period, lin-2 after ca. AD 1910, which also includes the post-independence period from 1949 and more recent history.

The change in the sedimentation rate from lin-1 to lin-2 matches the change in pollen concentrations. The first zone is characterized by a low sedimentation rate and fits the higher than average pollen concentrations. The opposite is observed in Zone lin-2, where a high sedimentation rate corresponds to an average lower concentration of pollen. The increase in sedimentation rate can be linked to the fall in lake level at the beginning of the 20th century as observed by the Sarasin brothers in 1902 during their visit to the Lindu plain (Sarasin and Sarasin 1905).

The stable high percentage values of *Aulacoseira granulata*, a widespread planktonic diatom, common in carbonate-rich, eutrophic lakes (Van Dam et al. 1994; Gomez et al. 1995), indicates that Lake Lindu continued to have a high nutrient content. However, an increase in human activities in Zone lin-2 can be inferred from the unstable and higher diatom concentrations, corresponding to cultural eutrophication and increasing amounts of nutrients being washed into the lake (Horner et al. 1990; Kirilova et al. 2010).

Pre-colonial period (lin-1, 123–76 cm, ca. AD 1030–1910)

At the beginning of the record (lin-1a, ca. AD 1030–1200), a well-developed montane rainforest surrounded the lake, as suggested by high values of *Freycinetia*, a climber found in old-growth montane rainforests. The grassland plain which today surrounds the lake shore was already developed, as indicated by high values of Poaceae. Also, indicators of human activities suggest a long history of landscape exploitation on the Lindu plain. Large Poaceae grains (>40 µm) which might include pollen of *O. sativa* type were already encountered. Local fires were very frequent or intense in this period, as shown by the high concentration of macro-charcoal. Large charred particles of grass were found, suggesting that fires burned the grassland on the lake shore. If humans caused the fires, it is possible that the opening of the forest was following a shifting system of cultivation, as a more permanent occupation would not have allowed pioneer fast growing taxa like *Macaranga* and *Trema* to proliferate around the lake. High values of micro-charcoal indicate high regional biomass burning, suggesting that the climate then was drier and/or periods of droughts were frequent. This is further confirmed by the low values of swamp taxa, indicating that the river discharge was low. The same period of drought and disturbance of the vegetation was recorded at Lake Kalimpaa, 15 km southeast (Wündsch et al. 2014; Biagioni et al. 2015) and in the Besoa valley, 30 km south of the lake (Kirleis et al. 2011, 2012).

The increase in fungal spores of *Glomus*, starting from ca. AD 1200 to 1730 (lin-1b), is a good indicator of soil erosion in the lake catchment (Scott Anderson et al. 1984). Increasing soil erosion and the development of larger swamp areas around the lake point toward an increase in run-off and precipitation in this period and/or less frequent periods of drought, as also indicated by low micro-charcoal values. The reconstruction at Lake Lindu matches with the reconstructions of the average position of the ITCZ.

Palaeorecords from the Southern Hemisphere, anticorrelated with palaeorecords from the Northern Hemisphere (Haug et al. 2001; Tierney and Russell 2007; Tierney et al. 2010), show that the ITCZ moved southwards, reaching its southernmost position of the past 2,000 years during the period commonly known as the Little Ice Age (LIA), ca. 15th–17th century. Such a changed position of the ITCZ to being more centred on the LLNP area would have caused seasonality to decrease and average annual precipitation to increase. Similar results were also found at Kalimpaa and Besoa (Wündsch et al. 2014; Biagioni et al. 2015; Kirleis et al. 2011, 2012). Characteristic swamp taxa were *Typha* and *Callitriche*, indicating that stagnant swampy depressions spread around the lake.

Tilletia is a genus of smut fungi in the Tilletiaceae family, species of which are plant pathogens that affect various grasses including rice (Duran and Fischer 1961; Carris and Castlebury 2006). Their occurrence for the first time in Sub-zone lin-1b and the decrease of pioneer taxa and macro-charcoal particles might indicate that a change occurred towards a more permanent and organized use of the plain, starting from around AD 1200. It is possible that increased precipitation had allowed wet rice cultivation to start on the shores around the lake. The high values of *Freycinetia* indicate well-developed montane rainforests surrounding the lake, however Euphorbiaceae decreased, especially *Acalypha*, suggesting that disturbance of the forest also occurred.

Starting from ca. AD 1730 (lin-1c), average precipitation decreased and/or periods of drought increased, as indicated by low values of swamp taxa and *Glomus* spores and high micro-charcoal values. *Lithocarpus–Castanopsis* increased, Poaceae decreased with no more evidence of large grains from this family, suggesting abandonment or decrease of human activities around the lake. When the Sarasin brothers visited the Lindu plain in 1902, they found that a small group of people were living on the shore line of the lake (Sarasin and Sarasin 1905). The grassland plain which is visible today was already present, but no wet rice cultivation was encountered, the plain being grazed by horses (Fig. 1b). The inhabitants lived off garden products and fishing. In fact, Lake Lindu has been well known for a long time for the abundance of its fish. When Adriani and Kruyt first visited the lake in 1897, they reported that the indigenous people used fish traps to provide for local consumption in the village of Langko near the southwestern shore (Adriani and Kruyt 1898). The cultural difference observed from ca. AD 1730 might have been caused by decreased precipitation and/or occurrences of long periods of drought. The people living around the lake might have been forced to limit their activities to fishing and cattle grazing in consequence of the no-longer favourable climatic conditions. However, additional causes of cultural changes might have played a role. For instance, conflicts and/or spread of diseases can severely affect both human populations and cultivated plants, but such events are not detectable with pollen and palaeoecological analyses.

Post-colonial period (lin-2, 76–0 cm, from ca. AD 1910)

Taxa from montane rainforest continued to increase at the beginning of the 20th century (lin-2a), in particular *Lithocarpus–Castanopsis*. Moraceae–Urticaceae decreased, but this was possibly an artefact of the bad preservation of the pollen grains in this sub-zone. At the same time, secondary forest taxa increased, indicating recovery of the forest, while macro-charcoal values remained low and anthropogenic indicators like *Tilletia* concentrations decreased. Dutch missionaries arrived in this area following the submission of the Kulawi *raja* in 1905. According to Acciaioli (1989), the area around Lake Lindu remained relatively isolated, despite the substantial modifications to the surrounding lowlands, introduced by the Dutch.

A clear increase in the sedimentation rate started at the beginning of the 20th century as indicated by the age-depth model, the change in amplitude of palaeomagnetic inclination and decreased pollen concentrations. Such a change in the sedimentation rate can be linked to the falling lake level observed by the Sarasin brothers in 1902 during their visit to the Lindu plain (Sarasin and Sarasin 1905).

Low values of *Glomus* and swamp taxa as well as high micro-charcoal values were also recorded in the previous sub-zone, lin-1c, suggesting that rainfall decreased and/or droughts increased before the increase in sedimentation rate observed from the early 20th century onwards. However, a link between human activities and the initial lowering in lake level could not be established, as this sub-zone records the recovery of the forest.

The *Botryococcus* colonies in lake sediments are related to periods with a high delivery of nutrients, and their presence is often used as a palaeoenvironmental proxy (Guy-Ohlson 1992). The arrival of Bugis communities in the area during the second part of the 20th century marked the beginning of new landscape opening around the shore of wet rice fields (Acciaioli 2001).The peak in colonies in Sub-zone lin-2b in the mid 20th century might be a consequence of increasing nutrients washed into the lake, as human activities increased around it. At the same time, *Glomus* and swamp taxa increased and micro-charcoal decreased, suggesting increased rainfall. However, the sedimentation rate remained high and the silting of the lake continued despite the changes in the rainfall regime. In this period, there is a clear lack of correlation between the change in the lake level and rainfall variability as reconstructed from the palynological assemblage. It seems likely that the trend towards a falling lake level continued from the mid 20th century until now, as a consequence of the diversion of larger amounts of water away from the lake for irrigation purposes (Acciaioli 2001) and erosion/sedimentation increased due to intensification of land use practices.

Clear palynological evidence for increasing human activities are recorded, starting from the late 20th century (lin-2c) with the re-occurrence of Poaceae pollen >40 µm and the gradual decrease in primary lower montane rainforest taxa up to the present time. Secondary forest taxa like *Neonauclea* and anthropogenic indicators like Mimosoideae, Apiaceae, *Tilletia* and *Botryococcus* increase markedly, starting from very recent time. The palynological evidence for an increase in human activities matches the increase in people migrating to the Lindu plain in search of available land to cultivate after the 1970s, following the establishment of the LLNP (Acciaioli 2001; Weber et al. 2003).

Phases of prehistoric and historic human-landscape interactions on Lindu plain and the link to climate variability in Central Sulawesi

Various phases of cultural use of the Lindu plain are evident from the Lake Lindu record (Figs. 3, 4). In particular, changes occurred from ca. AD 1200 to ca. 1730 showing a more permanent use of the landscape. At the same time, the reconstructed rainfall regime indicates wetter conditions. Such a cultural change can be explained in two different ways. The first hypothesis is that the builders of the megaliths changed their strategies on the Lindu plain by establishing more permanent settlements, taking advantage of the wetter climatic conditions for wet rice cultivation. Accordingly, the disappearance of the metal age culture that produced the megaliths would be recent, ending on the Lindu plain only in the 16th–17th century. These populations might have persisted in isolation from South Sulawesi and Palu, with which the contacts with other populations from South Sulawesi, Europe and mainland Asia were established long before. Alternatively, the changes recorded at ca. AD 1200 might represent the end of the activities of the megalith builders on the Lindu plain. A different ethnic group with knowledge of wet rice cultivation techniques might have replaced the people of the megalith culture.

There is not yet a clear chronology for the megalithic culture in Central Sulawesi. At the megalithic Pokekea site, the dating of the bottom sediments of one of the large stone vats called *kalambas* established that the site was at least 900 years old (Kirleis et al. 2011, 2012). However, in contrast to the Lake Lindu record where there was a phase of forest recovery, the pollen analysis of the Besoa valley shows that open grassland persisted uninterrupted from 2,000 years ago when deforestation started. It is not known when the megalithic culture in Central Sulawesi ended, therefore in order to confirm the validity of these hypotheses, more research is needed on these megalith sites.

The forest recovery phase recorded from ca. AD 1730 to the early 20th century matches with historical reports of a different use of the plain by the so-called Lindu people, whose activities there were mostly limited to fishing and cattle grazing (Sarasin and Sarasin 1905). Although different causes might explain such a radical cultural change, climate might have been one important factor. Indeed, drier conditions characterized this period as indicated by the low values of swamp taxa and high micro-charcoal concentrations.

Starting from the mid 20th century, the arrival of Bugis communities and the more recent population encroachment onto the Lindu plain following the establishment of the LLNP caused major changes (Acciaioli 2000; Kreisel et al. 2004), as also shown by the change in palynological composition of the Lake Lindu record (Fig. 4). The lake level fall began already in the early 20th century, possibly a consequence of long-term drier conditions. However, such a trend has continued until now, although the increase in swamp taxa and decrease in micro-charcoal indicate wetter conditions characterizing the mid 20th century. This suggests that the silting of the lake is not being caused by natural climatic conditions, but rather by increasing human activities. Indeed, local inhabitants of the Lindu plain recently declared that migrants to the area, who cut down forests for coffee and cocoa plantations, were responsible for the increasing shallowness of the lake and the streams feeding into it (Acciaioli 2001). It is possible that, as deforestation increases, and larger amounts of water are used to irrigate new gardens and fields, river discharge will further decrease, damaging the cultivation and fishing activities on the Lindu plain and aggravating the effect of droughts caused by the occurrence of El Niño. A better management of the forested areas around the plain and the water resources of the basin would decrease the erosion and the sedimentation that have been decreasing the depth of Lake Lindu, as shown by its receding shoreline.

Conclusions

Palaeoecological analyses of a sediment core from Lake Lindu reveal a long history of human-landscape interaction on the Lindu plain, which has been modified by human activities during the past 1,000 years. Although further investigations are needed, evidence of intense burning and possible shifting cultivation from an earlier phase from ca. AD 1030 to 1200 might be related to the metal age population which built megaliths in Central Sulawesi. From ca. AD 1200 to 1730, the climate became wetter as a consequence of the southward movement of the ITCZ. At the same time, fires decreased, and a more permanent effect on the landscape began. It remains open to speculation whether the architects of such a cultural change were the megalith people, or a different ethnic group. A phase of abandonment or less intense activities characterized the period from ca. AD 1730 to 1910. Following this phase of forest advancement, the more recent part of the Lake Lindu record shows a trend towards deforestation which started in the late 20th century until the present. The increase in sedimentation rate and lowering of lake level started at the beginning of the 20th century and these have continued until now, despite changes in the rainfall regime which occurred in the last hundred years, as reconstructed from the palynological record.

In conclusion, the Lindu record represents one further step in the increase of the knowledge of human and landscape history in Central Sulawesi and it highlights the potential for further palaeoecological and archaeological investigations in the area.

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