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Assessing resilience/sensitivity of tropical mountain rainforests towards climate variability of the last 1500 years: The long-term perspective at Lake Kalimpaa (Sulawesi, Indonesia)

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ABSTRACT

The tropical montane rainforests of the Lore Lindu National Park in Sulawesi, Indonesia provide many ecosystem services for the population inhabiting the area and harbor unique biodiversity in a key area for phytogeography. The mountain regions of Central Sulawesi experience perhumid climate conditions with few seasonal changes in precipitation, making the vegetation a possible sensitive target for future changes of precipitation patterns. The ecological consequences are hard to predict due to the lack of knowledge of the dynamical processes that govern these tropical forests. This research aims to shed light on the long-term response of the montane vegetation of Lore Lindu National Park to stress caused by climate variability and human activities in the past. Palynological data are used to reconstruct forest vegetation dynamics and are compared to centennial time scale data of fire frequencies, palaeorainfall proxies and regional climate reconstructions to assess the drivers of these changes. Results reveal that the Fagaceae family dominates the entire recorded period, as they still do today. Fire episodes occurred locally only ten times in the last 1500 years but two periods were characterized by higher frequencies: between ca. AD 1070 and 1200 and between ca. AD 1450 and 1660. The regional correlation of these events with periods of drought registered in Java suggests that centennial-scale increases in fire frequencies at Lake Kalimpaa were consequences of the vegetation being more prone to fire, probably due to more frequent or more intense El Niño events. In both cases Fagaceae did not decrease, indicating resilience towards droughts and fires of at least one species of that family. Following the first period of increased fire frequencies, the vegetation went through a long secondary forest phase lasting about two and a half centuries (ca. AD 1200–1450). *Weinmannia* was co-dominant together with *Lithocarpus*/*Castanopsis*. The second period of increased fire frequencies corresponds to a phase when records across the tropics show that the Intertropical Convergence Zone (ITCZ) was displaced to the south. High effective rainfall enhanced the growing of swamp taxa like *Pandanus* around the lake. Human–landscape interactions are evident only starting from the 20th century (from ca. 1950 to present) with *Weinmannia* rising probably due to the logging of emergent *Agathis* trees and/or landslides caused by the construction of the road which today passes near the lake. In general, palynological diversity values indicate that within-landscape diversity (Whittaker's gamma diversity) decreased when fires increased. Palynological rate of change and compositional turnover indicate that the vegetation communities were more resilient to fire disturbance during period of high rainfall. A different trend is apparent starting from the second half of the 20th century, suggesting a change in the dynamical response of the vegetation communities to forest fires, possibly as a consequence of increasing human activities around the lake. The emergent tree *Agathis*, while being more responsive to long-term rainfall variability in the past, did not reestablish itself following the years of intensive selective logging in the second part of the last century. These findings improve our knowledge of the long-term ecology of Central Sulawesi, one of the world's hotspots of biodiversity.

1. Introduction

At the dawn of the 19th century Indonesia was one of the richest tropical countries in the world in terms of forest cover and biodiversity (Baas et al., 1990). However, forest cover decreased from estimated 170 million ha around 1900 to 98 million ha by the end of the 20th century. The deforestation process is still accelerating today, due to extensive logging and conversion of forest to agricultural land (Miettinen et al., 2011). Aware of the consequences of these rapid changes, national and international efforts to develop forestry conservation plans started from the 1980s (Wardojo and Masripatin, 2002; e.g. UNESCO Man and

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Biosphere Programme and Biodiversity Action Plan for Indonesia). These efforts include strategies aimed at protecting biodiversity and restoring ecosystem services by monitoring natural forest ecosystems in Indonesia. The Lore Lindu Biosphere Reserve and National Park (LLNP) in Central Sulawesi is part of the UNESCO Man and Biosphere Programme (MAB) and represents one example of these national and international management measures aimed to protect both natural ecosystems and cultural heritage. The protected area of 217,982 ha comprises one of the largest continuous montane rainforests of Sulawesi and shows unique biodiversity (Cannon et al., 2007) representative of Sulawesi's key position for biogeographical questions in Southeast Asia and Malesia (e.g. van Balgooy, 1987; van Welzen et al., 2011). Studies of tree families along altitudinal transects have highlighted the importance of Fagaceae mainly with the genera *Lithocarpus* and *Castanopsis* (Culmsee et al., 2010). However, developing long-term forest ecosystem management plans is not an easy task. Apart from encroachment on the forest by population pressure and largely uncontrolled extraction of forest resources, an additional potential stress factor to consider is climate change.

The main variable of Indonesia's climate is not temperature, which is rather constant throughout the year, but rainfall (Aldrian et al., 2004). The inter-annual variability of rainfall is influenced by the coupled ocean–atmosphere phenomenon El Niño-Southern Oscillation (ENSO): during El Niño (La Niña) warm (cold) phases, Indonesia experiences lower (higher) rainfall than in other years (Philander, 1990; Cane, 2005). Predictions of changes in ENSO variability are uncertain, as it is not clear how this phenomenon is related to climate forcing factors and to what extent the increasing anthropogenic greenhouse gas emission will influence ENSO variability. Climate models predict a wide range of responses of ENSO from weaker to stronger, from more El Niño-like to more La Niña-like average conditions (e.g. Collins, 2005; van Oldenborgh et al., 2005; Guilyardi, 2006; Merryfield, 2006). The tropical regions of Southeast Asia could experience a shift in precipitation patterns leading to more frequent and/or more severe droughts in the future (Christensen et al., 2007; Sheffield and Wood, 2008). The ecological consequences of these scenarios for forests of the LLNP are hard to predict. Palaeoecological and palaeoenvironmental studies in Sulawesi are still rare, but they are important as they show vegetation, fire and climate history and add to the understanding of vegetation response to climate variability and human disturbance. In conservation science, palaeoecological data are invaluable for making well-founded predictions on how the biological component of ecosystems may respond to future perturbations such as climatic changes (Willis et al., 2010; Cole, 2012). The last 2000 years are of particular interest as they include marked regional to global scale climate variations that can be reconstructed at decennial to centennial resolution. However, the few available studies in Sulawesi (Gremmen, 1990; Dam et al., 2001; Hope, 2001) discuss long-lasting variations in the climate regime and have a relatively low temporal resolution for the last few thousand years. The aim of this study is to evaluate the response of the montane rainforests of LLNP to past stress caused by climate variability and human activities at the decennial to centennial time scale for the last 1500 years. We present results of palynological analysis of a sediment core taken from Lake Kalimpaa, located in the center of the Fagaceae dominated montane rainforest of LLNP.

2. Study area

The study area is located in the northern part of the LLNP in Central Sulawesi (Fig. 1). Sulawesi is the biggest island of the Wallacea biogeographical region, a relatively young, geologically highly complex island world (Hall, 2009). The crossroad position between the Sunda shelf (part of East Asia) to the west and the Sahul shelf (part of Australasia) to the east and the biogeographic complexity makes it a global biodiversity hotspot for plants and animals, with high levels of endemism (Myers et al., 2000).

Lake Kalimpaa (1°19′35″S, 120°18′32″E, also known as Lake Tambing) lies at 1660 m asl and was chosen because of its small catchment and its remote position far from the valleys in the north and south of LLNP which are more strongly impacted by human activities. The lake has an area of ca. 6.5 ha and a maximum water depth of 6.6 m and is therefore likely to record local vegetation changes in the past. About 200 m northeast of the shoreline the main asphalt road through the National Park passes and separates the lake area from the steeper mountainous area leading up to the peak of Mt. Rorekautimbu (ca. 2400 m asl). A small inflow reaches the lake mainly through a small swamp forest area in the northeast, dominated by *Pandanus* and palm species, and a small outflow is located in the southwest.

2.1. Modern vegetation

The rainforests of the LLNP are species-rich tropical forests. Most of the forests are still in good or old-growth condition and are situated in mountain areas (Cannon et al., 2007). The vegetation gradient ranges from upper montane rainforest, above 2000 m asl, dominated by conifers and Myrtaceae to lower montane rainforest between 1000 and 2000 m asl. Tree transect studies along an altitudinal gradient in the LLNP revealed that Fagaceae, mainly represented by the genera *Lithocarpus* and *Castanopsis*, are important at all elevations but are dominant in the lower montane rainforest between 1200 and 1800 m asl, followed by Myrtaceae, Theaceae, Symplocaceae, Magnoliaceae, Melastomataceae and Juglandaceae (Culmsee et al., 2011).

Around Lake Kalimpaa, *Castanopsis acuminatissima* (Fagaceae) was found to be the dominant species, followed by *Bischofia javanica* (Phyllanthaceae), *Calophyllum soulattri* (Clusiaceae), *Castanopsis argentea* (Fagaceae), *Prunus arborea* (Rosaceae) and *Ficus* sp. (Moraceae) (Febriliani et al., 2013).

Fagaceae play a key role in these forests in terms of aboveground biomass, which maintains a steady value despite altitudinal changes in forest structure and composition as opposed to the decline of biomass with increasing elevation usual for non-Fagaceous montane forests. Therefore, the Fagaceae dominated forest of LLNP is of particular interest in light of climate mitigation initiatives, which aim to reduce CO_2 emissions via forest preservation and restoration (Culmsee et al., 2010). The modern distribution of *Lithocarpus* and *Castanopsis* (Soepadmo, 1971) indicates that these two tropical genera avoid seasonal climates. Their actual presence in Central Sulawesi seems to represent no exception.

2.2. Climate

The modern climate of Indonesia is controlled by the seasonal migration of the ITCZ across the equator and interannual changes in ENSO (Fig. 2). As the ITCZ migrates southward during the austral summer, the northwest monsoon delivers humid air and heavy rainfall to Indonesia, whereas during austral winter the southeast monsoon brings relatively cool, dry conditions while the ITCZ is positioned over mainland Asia (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. However, the monthly amount of rainfall formed during the southeast monsoon is slightly less than that of the northwest monsoon, as the former brings humid air masses, while the latter brings dry air from the Australian continent and the rainfall is therefore purely orographic. The modern intra-annual climate of the montane areas of the LLNP can be described as perhumid with at most two months of slightly lower precipitation, corresponding to the southeast monsoon peak in August (Gunawan, 2006). Mean annual precipitation ranges between 1800 and 2100 mm, whereas mean annual temperature decreases with elevation from 21 °C at 1000 m asl to 14 °C at 2400 m asl (Hijmans et al., 2005; WorldClim, 2006; Culmsee et al., 2010).