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# A new late Quaternary palaeohydrological record from the humid tropics of northeastern Australia

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ABSTRACT

High resolution X-ray fluorescence (XRF) is presented as a robust palaeoclimatic proxy, suitable for use on Late Pleistocene to Holocene sediments located in a volcanic crater on the Atherton Tableland in northeastern Queensland, Australia. The proxy allows identification of wet and dry shifts in a complex sedimentary sequence comprised of peat, gyttja, laminated organic rich muds and fine clastic silt-rich sediments. Significant correlation is found between the XRF record and other proxies including magnetic susceptibility, humification, grain size, macrocharcoal, $\delta^{13}C$ and C/N and pollen.

Sixteen wetter periods are identified in the 37 ka sedimentary record for Bromfield Swamp. Three wetter periods commence in late Marine Isotope Stage 3, nine in the early glacial, one in the late de-glacial and four in Holocene. Nineteen drier periods are identified, four in late MIS 3, seven in the early glacial, one during the LGM, one in the late de-glacial period and six in the Holocene.

The XRF record for Bromfield Swamp is specifically used to identify periods of abrupt climate change. Marked changes in effective precipitation are detected at 32,690, 30,080, 24,660, 21,870, 11,880, 10,020, 9170 and 5120 cal. yr BP. The detection of these abrupt climate events may allow correlation with records from terrestrial sites across the Southern Hemisphere and potentially, the Northern Hemisphere.



## 1. Introduction

Palaeoclimate records for the Southern Hemisphere tropics, specifically the wet tropics of northeastern Australia, have historically focused on the results obtained from a small number of field sites (Reeves et al., 2013a, 2013b; Turney et al., 2006c; Williams et al., 2009). As countries of the Western Pacific strive to better understand more recent changes in climate (particularly in the Anthropocene), it is imperative that climate researchers have a comprehensive and complete history of regional climate forcing through the Late Pleistocene and Holocene.

Palaeoenvironmental studies from the wet tropics of northeastern Australia have identified wetter and drier phases over differing time scales. In the past decade, there has been an observable shift towards attaining more high-resolution records and a search for shorter duration global climate events such as Heinrich events (Denniston et al., 2013; Muller et al., 2008a). These palaeoclimate studies suggest that there are many more regional climate changes occurring and that they are unrelated to global climate drivers (Muller et al., 2008b). A small number of regional syntheses have also been produced reporting on a range of sites including some outside northeastern Australia (Denniston et al., 2013; Reeves et al., 2013a, 2013b; Turney et al., 2006c). Together, the temporal range of these records is significant, with several reporting on detected changes in climate over the last 30,000–50,000 years (Kaal et al., 2014; McGowan et al., 2008; Muller et al., 2008a, 2008b; Reeves et al., 2013a, 2013b; Turney et al., 2006a, 2006b; Williams et al., 2009).

The Atherton Tableland in the wet tropics of northeastern Queensland has been the focus of many palaeoenvironmental studies due to the preservation of temporally long and continuous sediment archives, located principally within volcanic crater basins. Correlation of pollen records from Lynch's Crater (Kershaw et al., 2007) and marine Core ODP 820 in the Coral Sea (Moss and Kershaw, 2007) has allowed a picture of environmental change on the Tableland to be produced for the last two glacial–interglacial cycles (Kershaw and van der Kaars, 2012). Pollen and other complementary palaeoenvironmental and palaeo-hydrological proxy indicators (including diatoms and humification) applied to these long sedimentary sequences have allowed inferences to be made on changes in local and regional climate from the last deglaciation approximately 18,000–11,000 yr BP through to the Late Holocene (Haberle, 2005; Hiscock and Kershaw, 1992; Kershaw, 1970, 1971, 1973, 1975, 1994; Kershaw et al., 2007; Kershaw and Nanson, 1993; Kershaw and Nix, 1988; McGlone et al., 1992; Moss and Kershaw, 2000; Tibby and Haberle, 2007; Turney et al., 2004; Walker, 2007). The only studies to have focused explicitly on the identification of wetter and drier phases in the wet tropics are Turney

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et al. (2004) and more recently Burrows et al. (2014a, 2014b), both using peat humification. With the long, near-continuous sediment record of Lynch's Crater available for peat humification (supported by extensive pollen records), Turney et al. (2004) were able to record millennial-scale dry periods from the Late Pleistocene to the Middle Holocene, together with cycles of climate at a semi-precessional timescale of approximately 11,900 years. Results of the study led the authors to state that the identified climate variations applied to northeastern Australia (Turney et al., 2004). We seek supporting evidence for this statement through an examination of sediment cores extracted from the central swamp area on Bromfield crater basin.

The present study aims to show the strength of X-ray fluorescence (XRF) as a proxy for relative precipitation in the humid tropics of north Queensland and to provide a near-continuous XRF record spanning 37,000 years for the Atherton Tableland. XRF has been successfully employed to determine Holocene coastal environmental changes in southwest Florida (USA), allowing inferences to be made on climate variability (van Soelen et al., 2012). XRF has also proved a valuable palaeoclimate proxy at Laguna Rabadilla de Vaca in the southeastern Ecuadorian Andes, where Niemann et al. (2009) identified periods of wet and dry using relative influx of Ti as an indicator of greater fluvial input into the lake. Particularly relevant to the present study are the continuous, high-resolution, multi-element XRF core scanning analyses of the Les Echets sedimentary sequence used to determine changes in lake status and ultimately, changes in climate (Kylander et al., 2011). Using a similar methodology to Kylander et al. (2011) the present study examined particular associations between different elements (Ti, Fe, Rb, Sr, Si, Ca, K, Mn). Validation of the XRF record is achieved through comparison with data collected from a suite of other established proxies (magnetic susceptibility, pollen, humification, grain-size, macrocharcoal, $\delta^{13}C$, C/N, pollen).

## 2. Site description

### 2.1. Location/regional setting

Bromfield Swamp (17°22′44″S, 145°32′27″E) is located 55 km south-southwest of Cairns in northeastern Queensland (Fig. 1). The Swamp, measuring 1.0 km × 0.8 km, occupies the base of a large maar (Bultitude et al., 1999; de Keyser and Lucas, 1968) on the Atherton Tableland. With a diameter of more than 1.7 km and steeply inclined slopes (covered by weathered basaltic rocks and pyroclastics) rising 45–60 m (Bultitude et al., 1999; Kershaw, 1975) above the present swamp surface, the crater appears as a bowl-shaped feature on an undulating plateau of Late Cainozoic volcanics of the Atherton Basalt Province (Bultitude et al., 1999; Whitehead et al., 2007). The vegetated swamp surface at 754 m asl is easily differentiated from the inner walls and slopes of the crater, presently covered with a mixture of pasture grasses and pockets of remnant and secondary rainforest.

A v-shaped valley breaches the eastern wall of Bromfield crater allowing water from the surface of Bromfield Swamp to pass into a tributary of the North Johnstone River. Today there is a near-continuous flow of water from the Swamp into the tributary, which is also noted by Denmead (1971) and Kershaw (1975); however, a 1907 survey plan of the Swamp does not illustrate a permanent stream line from the south-eastern edge of the wetland (Malanda Parish Plan No. 335, 1907). This difference in observed water flow is perhaps not surprising, the land survey being completed in the years subsequent to the major nation-wide 'Federation Drought' of 1895–1902 (Haberle et al., 2006; Heinrich et al., 2008; Whetton, 1997). Available annual and monthly rainfall data for Atherton township (14 km NNW of the Swamp) for 1906–1907 illustrates yearly precipitation close to the mean value of 1414 mm, calculated for the period 1895–1972 (Bureau of Meteorology, 2015b) and monthly totals very similar to long-term values. From this and associated meteorological data, it is inferred that rainfall contributions to the surface of the Swamp for the period 1906–1907 were similar to the long-term average. The observed absence of water flowing from the Swamp into the tributary of the North Johnstone River in 1907 may instead be attributed to loss of groundwater recharge in the years of the major drought.

### 2.2. Climate

The Atherton Tableland is situated in the wet tropics of northeastern Queensland, where precipitation is highly dependent on the austral summer monsoon system of the western Pacific Ocean (Muller et al., 2008a), alternatively identified as the Quasi-Monsoon (Gentilli, 1986; Kershaw and van der Kaars, 2012), the seasonal migration southward of the Intertropical Convergence Zone or ITCZ (Muller et al., 2008a). Northward movement of the ITCZ and a northeast movement of the South Pacific Convergence Zone (SPCZ) indicate the dominance of an El Niño event (Haberle et al., 2010). During these periods, summer precipitation is 150–300 mm below the seasonal average (Haberle et al., 2010). The wet season, running through December to April, accounts for approximately 80% of annual precipitation (Maggs and Hewett, 1993) recorded for the Tableland; this rainfall pattern is replicated at Yungaburra (17° 16′ S, 145° 35′ E), 12 km NNE of Bromfield Swamp.

Average annual rainfall totals are not uniform across the Atherton Tableland. The highest rainfall values are recorded on the eastern side of the Tableland adjacent to the Bellenden Ker Range and decline rapidly to the north and west across the Tableland. Bromfield Swamp, located on the western side of the Tableland adjacent to the Bellenden Ker Range, possibly receives 1700 mm rainfall per annum (Kershaw, 1975); this is approximately two-thirds of the total annual rainfall for Lynch's Crater, estimated to be 2570 mm rainfall per annum (Bushby, 1991). This estimate for Bromfield Swamp appears accurate as Malanda Post Office, located only 6 km NE of the Swamp, records mean average rainfall of 1676 mm $yr^{-1}$ for the period 1916–2010 (Bureau of Meteorology, 2015a).

Data logger and photographic records of changes in water depth for Bromfield Swamp for 2010–2011 show intense rainfall events of short duration to raise the lake-level in the crater basin (Burrows, 2016). Large rainfall events, some associated with cyclonic activity, are recorded in the daily rainfall data for Malanda Alert weather station for the period 21/01/2010–29/11/2011 (Fig. 2, Top). A data logger mounted on the surface of Bromfield Swamp over the same time period recorded swift rises in lake-level in response to each rainfall event (Fig. 2, Bottom). A large rainfall event that commenced 21 January 2010, is seen to raise lake-levels on Bromfield Swamp >0.40 m over a nine day period, reaching a peak level on 30 January 2010 (Date A). From the 23–28 December 2010, moist easterly airflows moving over north Queensland brought high rainfall to the Atherton Tableland, the gauge at Malanda alert recording 103 mm (23 December) and 28 mm (24 December). Atmospheric circulation associated with Cyclone Tasha, a category 1 cyclone that made landfall on the coast south of Cairns on Christmas morning, delivered additional moisture to the Tableland; rainfall totalling 147 mm was recorded at Malanda Alert on 25 December. Lake-level responses on Bromfield Swamp to these rainfall events were extremely rapid, a rise of >0.22 m recorded for the period 23–25 December 2010.

It is perhaps necessary to note that lake-level changes recorded on the Bromfield Swamp data-logger, coincided with the strongest La Niña event to impact northeastern Australia throughout the satellite record (Evans and Boyer-Souchet, 2012). While it has been stated that the above-average rainfall recorded is associated with the La Niña event (Bureau of Meteorology, 2012), a series of Regional Climate Model experiments lead Evans and Boyer-Souchet (2012) to suggest that the additional high rainfall may be attributable to high sea surface temperatures (SSTs) around northern Australia. These higher SSTs, it is further suggested, may be the result of global warming or the consequence of an extreme La Niña event (Evans and Boyer-Souchet, 2012).