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Shrinkage of the Ruoergai Swamp and changes to landscape connectivity, Qinghai-Tibet Plateau

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ABSTRACT

The Ruoergai Swamp (Zoige) at the eastern margin of the Qinghai-Tibet Plateau in western China is the world's largest plateau peat wetland. Rapid shrinkage of the swamp since the 1950s has endangered the local terrestrial and aquatic ecosystems and the water supply of the upper Yellow River. The causes of the swamp shrinkage were evaluated based upon field investigations in 2011–2013 and analyses of remote sensing images and meteorological and hydrological data. Although a slight rise in the temperature was evident, there was no obvious decrease in the precipitation, indicating that climate change was not the primary cause of the recent swamp shrinkage. Remote sensing images indicated that roughly 920 km of artificial ditches excavated from the 1960s to 1990s have affected around 648 km^2 of swamp, accounting for 27% of the total shrinkage area (approximately 2400 km^2). Bed incision of the upper Yellow River was considered to be the primary cause for the long-term degradation of the Ruoergai Swamp. Ensuing headcut erosion of countless tributaries has induced drainage network extension, draining large areas of the swamp and lowering the groundwater levels. Headcut erosion and construction of the artificial channels have markedly increased the flow and sediment movement in this landscape.

1. Introduction

Wetlands provide vital habitat for diverse wildlife, act as carbon sinks that mitigate the effects from climate warming, and perform important ecosystem services through their role as the natural "filters" that protect water supply and buffer nutrient loads (Barbier et al., 1997; Brinson and Malvarez, 2002; Verhoeven et al., 2006). Across the world, widespread loss and degradation of these terrestrial and aquatic ecosystems was intensified in the twentieth century. Niu et al. (2012) reported that the area of wetlands in China in 2008 was around 324,097 km^2, a reduction of about 33% since 1978. The rapid shrinkage of wetland areas in China is mainly attributed to fill, drainage, and agricultural development associated with population growth and rapid economic development and climate warming (Qiu et al., 2009; Zhou et al., 2009).

The Ruoergai Swamp within the Ruoergai Basin is the largest plateau peat swamp in the world. It is located in the source zone of the Yellow River, at the eastern margin of the Qinghai-Tibet Plateau in western China (Fig. 1). The basin covers a total area of 16,000 km^2, of which about 80% is in Sichuan Province and 20% lies within Qinghai and Gansu Provinces. The swamp acts as a natural reservoir that regulates the water supply to this section of the upper Yellow River, supplying 30% of the annual runoff at the Maqu hydrological station (located along the trunk stream near the outlet of the swamp; Fig. 1).

Prior to the 1950s, the Ruoergai Swamp covered an area greater than 4600 km^2. Its present area is just 2200 km^2—a loss of around 52.2%, seriously degrading the functionality of this system (Li et al., 2011; Liu and Bai, 2006; Xiang et al., 2009; Xiao et al., 2010; Yan and Wu, 2005). Historical records and documents indicate that, prior to the 1930s, the swamp was a near-pristine landscape with negligible human activities, such as herding adjacent to the Riganqiao, Kaerkaqiao, Nanuoqiao, and Naneqiao swamps (Fig. 1). Access to the main swamp was restricted because of the perennial water storage, which was more than 1 m deep. The Ruoergai Swamp has an infamous place in history as more than 23300 members of the Chinese Red Army died while trying to walk through/across the swamp during the rainy season in August 1935 and July 1936 (Baidu Encyclopaedia, 2014). The wet conditions

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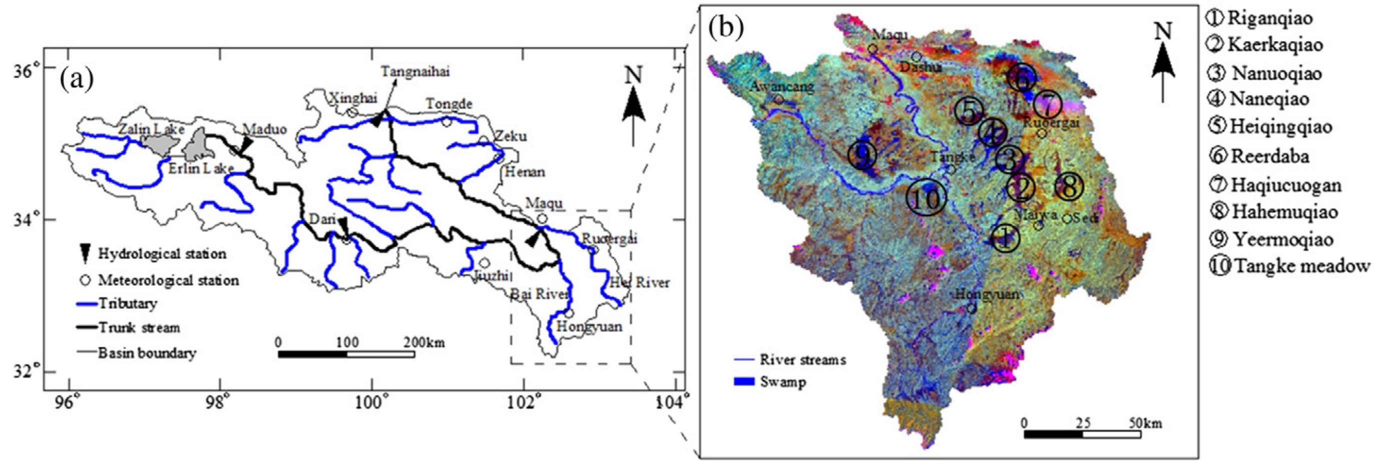

Fig. 1. (a) Location of the Ruoergai (Zoige) Swamp in the upper Yellow River. (b) Remote sensing image of Ruoergai Basin and the dispersal of ten typical swamps.

of the swamp alongside food shortage and starvation attest to the harsh environment at that time.

Today, much of the swamp has been converted into grasslands, and a marked reduction in the area of the surface water has occurred since the 1960s. Rapid acceleration of degradation has occurred since the 1980s such that the area was transformed into a "wet grassland" after 2000, with no distinct surface water across the swamp even during the rainy season other than the large area of lakes and swamps along the upper and middle sections of the Hei River (Bai et al., 2013; Shen et al., 2003). Serious desertification is now evident along both banks of the upper Yellow River and along the tributaries to the Hei and Bai rivers (Fig. 2). Dong et al. (2010) pointed out that the aeolian desertification of the Ruoergai basin expanded at a mean annual rate of 4.1% during 1975–2005 based on remote sensing images. Altered hydrological conditions impact local livelihood, especially livestock farming (Zhang and Lu, 2010). As noted elsewhere, enhanced protection and restoration of the wetlands is an important component of the programs to support the maintenance of aquatic and terrestrial ecosystems, mitigate flood, and improve water quality (Cao and Fox, 2009; Niu et al., 2011; Zhang et al., 2012).

To date, no comprehensive analysis of the underlying causes of the swamp degradation has been undertaken. This study uses field observations and measurements along with remote sensing analyses and analyses of the hydrological and meteorological data to quantify and assess the impacts from climate warming, runoff change, artificially excavated ditches, and river headcut incision as the factors which could account for the shrinkage of the Ruoergai Swamp.

Fig. 2. Desertification at the margins of Ruoergai Swamp.

2. Study area and methods

The Ruoergai Basin (31° 51′–34° 48′ N, 100° 46′–103° 39′E) is located in the source zone of the Yellow River at elevations ranging from 3400 to 3900 m a.s.l. (Fig. 1). Swamps, meandering rivers, terraces, and lakes are widely distributed around various low mountains and small hills in the northeastern part of the Qinghai-Tibet Plateau (Nicoll et al., 2013). The peatland covers five counties: Hongyuan, Ruoergai, and Aba counties in Sichuan Province, and Maqu and Luqu counties in Gansu Province.

Although the initial uplift of the Qinghai-Tibetan Plateau to near its present elevations was completed 13–14 million years ago, deformation within this area continues today in response to the ongoing northward movement (approximately 50 mm yr^{-1}) of the Indian continental plate (DeMets et al., 1994). The uplift of the plateau was accompanied by the development of a series of large strike-slip faults and associated extensional normal faulting. The current slip rates on these faults averages 1–20 mm yr^{-1} (Tapponnier et al., 2001). Many of the sedimentary basins on the plateau, such as the Ruoergai Basin, are related to these fault systems (Fu and Awata, 2007) and are currently separated from each other by actively growing mountain ranges (Craddock et al., 2010; Perrineau et al., 2011). The contemporary low-relief landscape of the Ruoergai Basin was created through gradual infilling of the basin over time, accumulating over 300 m of lacustrine and fluvial silts over the past 900 kyr (Wang et al., 1995).

The transition from a gradually infilling internally drained basin to the present external drainage occurred in the recent geologic past. Fluvial incision of the upper Yellow River began at the northeastern plateau margin 1.8 Myr ago (Li et al., 1997). The headward erosion continued upstream at a rate of roughly 350 km per Myr (Craddock et al., 2010; Harkins et al., 2007), with mean incision at the Longyang Gorge section within the Gonghe Basin occurring at a rate of 4 mm yr^{-1} (Perrineau et al., 2011). The upper Yellow River dissected the ancient lake at Ruoergai around 38 ~ 35 kyr ago (Wang et al., 1995). These marked adjustments to landscape setting have been accompanied by significant long-term climate changes. Craddock et al. (2010) concluded that the climatic conditions during the Quaternary promoted lake expansion, resulting in lake spillover. The conditions were mainly dry and cold around 30 ~ 10 kyr ago, transitioning into cool and humid conditions in the early Holocene, with precipitation decreasing slightly (promoting dry conditions) since 7.9–5.5 kyr ago (Wang et al., 1996).