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# Changes in lacustrine environment due to anthropogenic activities over 240 years in Jiuzhaigou National Nature Reserve, southwest China



Shiguang Li <sup>a, b</sup>, Xinxin Hu <sup>a</sup>, Ya Tang <sup>a</sup>, Chengmin Huang <sup>a, \*</sup>, Weiyang Xiao <sup>c</sup>

<sup>a</sup> Department of Environmental Science and Engineering, Sichuan University, Sichuan 610065, China

<sup>b</sup> Sichuan Academy of Environmental Sciences, Sichuan 610041, China

<sup>c</sup> Jiuzhaigou Administrative Bureau, Sichuan 623400, China

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## ABSTRACT

Jiuzhaigou National Nature Reserve in southwest China is listed as a World Natural Heritage Site and has numerous alpine and subalpine travertine lakes. Over the past 240 years, agricultural expansion, tourism enhancement and other human activities have resulted in land use and land cover change. In this study, sediment cores from three lakes in Jiuzhaigou were collected to track the nature and intensity of these human activities in Jiuzhaigou as well as determine the influences of human activities on the lacustrine environment. Total organic carbon (TOC), total phosphorus (TP), total nitrogen (TN), carbon to nitrogen ratio (C/N), biogenic silica (BSi), heavy metal elements and other indicators were used to trace the evolution of the lacustrine sedimentary environment in Jiuzhaigou. The increased intensity in agricultural activities, large-scale deforestation, unsustainable tourism and other activities was clearly identified in the lake sediment records. Ecological restoration and decreased travel disturbance would reduce the levels of the various eutrophic substances and heavy metal elements in the lacustrine environment. Studying and understanding the response of lacustrine environment to human activities is of great significance for the protection and sustainable use of water and landscapes in the mountain lakes of Jiuzhaigou.

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## 1. Introduction

A critical assortment of terrestrial sediments is transported by surface and ground water on a watershed-scale and as airborne dusts. Lacustrine deposits have a number of advantages including continuous sedimentation, a high sedimentation rate, and their ability to record sensitive, high-resolution, and abundant information (Graney et al., 1995; Baker et al., 2001; Ma et al., 2013; McLauchlan et al., 2013), and are an archive for past regional and global environmental changes. Increasing evidence has revealed that major Earth surface processes, ecosystems and biogeochemical cycles are profoundly impacted by anthropogenic activities on both regional and global scales, and a deeper understanding of past long-term human–nature interactions is needed for predicting the future projection of environmental development. With the growing impact of human activities on lake evolution in recent years, more

studies have been conducted on the impact of human activities on the lacustrine sedimentary environment (Zolitschka et al., 2003; Wu et al., 2007; Enters et al., 2008; Thevenon et al., 2012; Niemitz et al., 2013).

Various biogenic elements (C, N, P, Si, etc.) of lacustrine sediments are proxies for comprehensively assessing lake productivity, the changes of which reflect not only the regional hydrothermal conditions but also the mode and intensity of human activities (Cohen, 2003; Kenney et al., 2010). Total organic carbon (TOC) content is the most basic parameter used to describe the quantity of organic matter in sediments, which is an important indicator of lacustrine environment quality (Meyers et al., 1998; Meyers, 2003; Kenney et al., 2010). Nitrogen and phosphorus are important biogenic elements in aquatic ecosystems, but the excessive enrichment of these elements can lead to eutrophication of the water body (Harris, 1994; Conley et al., 2009). Biogenic silica (BSi) is often viewed as an alternative proxy for lacustrine diatom abundance and aquatic primary productivity (Schelske et al., 1986; Arai and Fukushima, 2012). Lacustrine sediments act as major sinks for heavy metals in water environments. The levels of heavy metals can

\* Corresponding author.

E-mail addresses: [huangcm@scu.edu.cn](mailto:huangcm@scu.edu.cn), [cmhuangscu@gmail.com](mailto:cmhuangscu@gmail.com) (C. Huang).

reflect the water pollution status and thus indicate the intensity of human activities (Lyons et al., 1983; Pekey, 2006; Farkas et al., 2007; Niemitz et al., 2013).

Jiuzhaigou National Nature Reserve (hereafter referred to as Jiuzhaigou) is located in Aba Prefecture, Sichuan Province, southwest China (Fig. 1) and is mainly comprised of highland travertine lakes, travertine waterfalls, travertine beach flows and other typical karst landscape. Jiuzhaigou was listed in the “World Natural Heritage” and the “World Network of Man and Biosphere Reserve” in 1992 and 1997, respectively. Recent archaeological excavations have demonstrated that local residents have engaged in farming activities in the Jiuzhaigou area since as early as the Western Han Dynasty, which began approximately 2000 years ago (Lv et al., 2010). The agriculture-husbandry production mode of Jiuzhaigou residents lasted until the mid-19th century. Since the introduction of potatoes, corn and other crops, agriculture activity has dominated the region. Opium cultivation led to an increase in soil erosion from the late 1930s to the early 1950s (Liang et al., 2014). Between 1966 and 1978, Jiuzhaigou forests suffered from massive deforestation. In 1984, tourists began entering Jiuzhaigou. The number of visitors in 1984 was 27,000, and the number dramatically increased to 3.639 million by 2012. Tourism activities are mainly constrained within an area of approximately 55 km<sup>2</sup> at the valley bottom. Although tourism pushes the large-scale development of the local economy, the intense tourism activities produce a series of environmental issues (Gu et al., 2013); for example, paludification and eutrophication were observed in a portion of Jiuzhaigou’s lakes (Zhou, 1998; Wang et al., 2006; Liang et al., 2014).

Since 2001, a vigorous step has been taken in Jiuzhaigou, that of “touring in, but living out of Jiuzhaigou”, to reduce environmental pollution and other negative effects caused by human activities. Therefore, exploring the reaction–response relationship between human activities and the Jiuzhaigou lacustrine environment is of important significance to protect the Jiuzhaigou landscape and determine the best mode of tourism for the sustainable development of this scenic spot.

An integrated analysis on the environmental proxies of lacustrine sediments in Jiuzhaigou was executed, and this paper reconstructed a high-resolution history of lacustrine sedimentary environment changes in Jiuzhaigou during the past 240 years. This study aimed to (1) infer the timing and magnitude of different type of human activities from lacustrine sediments and (2) evaluate the effects of human activities (land use change, agricultural expansion, and tourism) on the lacustrine sedimentary environment in Jiuzhaigou over the past 240 years.

## 2. Materials and methods

### 2.1. Geographic settings

Jiuzhaigou Nature Reserve is located in the transition zone from the Qinghai–Tibet Plateau to the Sichuan Basin between 32°55′–33°16′ N; 103°46′–104°05′ E (Fig. 1), accounting for an area of 620 km<sup>2</sup>. The principal bedrock units found in Jiuzhaigou are composed of soluble carbonate rocks ranging in age from the Devonian to Triassic, which are widely distributed and exposed

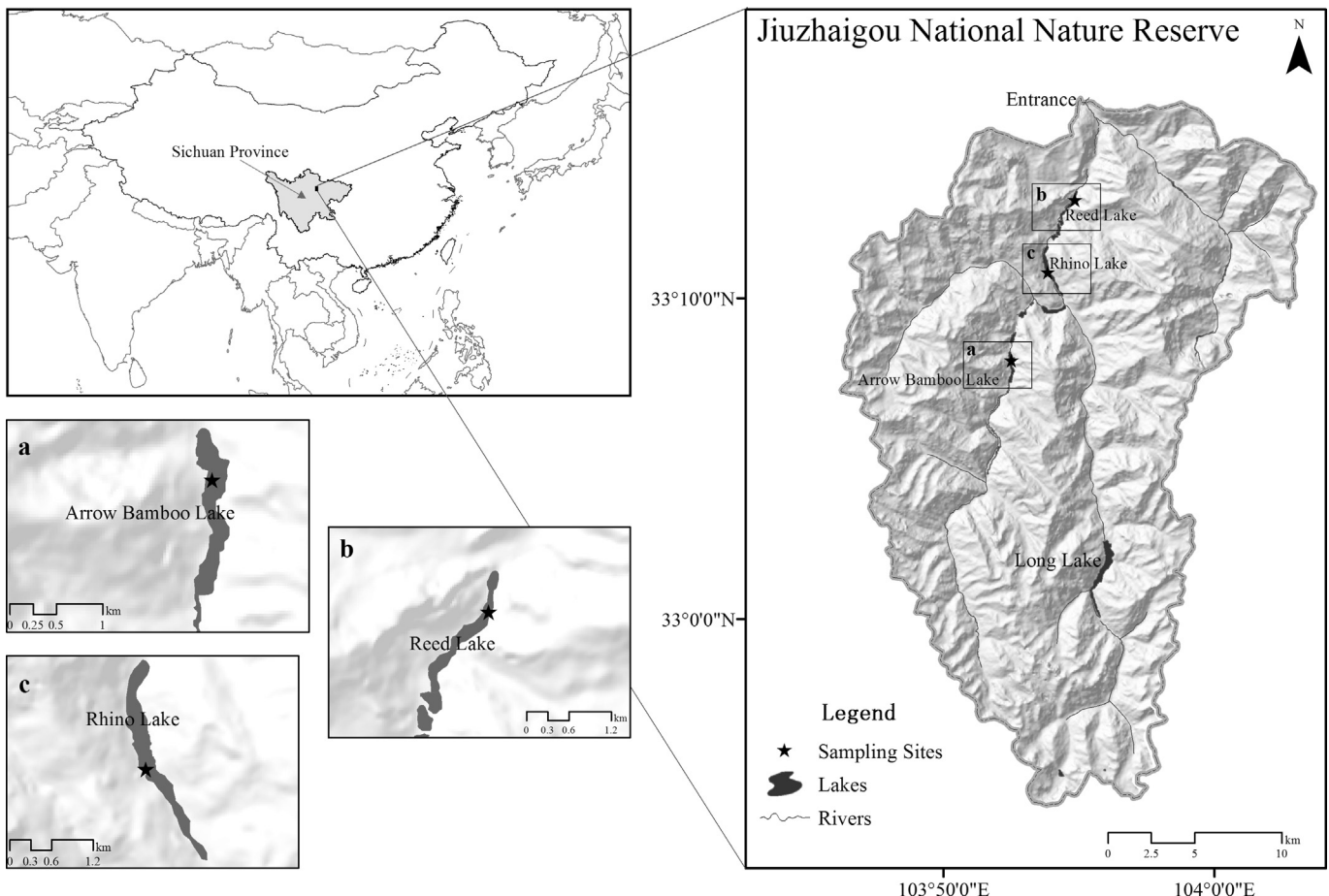


Fig. 1. Map of the sampling sites.

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