Science of the Total Environment 621 (2018) 18–29

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Human footprint in Tibet: Assessing the spatial layout and effectiveness of nature reserves

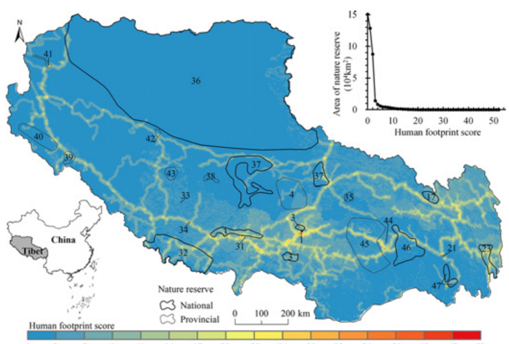
Shicheng Li [a,b,*], Jianshuang Wu [c], Jian Gong [a,d], Shaowei Li [b]

[a] Department of Land Resource Management, School of Public Administration, China University of Geosciences, 430074, Wuhan, China
[b] Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China
[c] Freie Universität Berlin, Institute of Biology, Biodiversity/Theoretical Ecology, Altensteinstraße 34, 14195 Berlin, Germany
[d] Key Labs of Law Evaluation of Ministry of Land and Resources of China, 430074 Wuhan, China

HIGHLIGHTS

- Tibet is not disturbed much by human activities now, but it is threatened by increasing human pressures.
- Grazing and road disturbance intensity contribute significantly to the increase of human footprint.
- The spatial layout of nature reserves is rational overall in terms of human footprint.
- The establishment of nature reserves in Tibet is effective in reducing human activities.
- No leakage phenomenon occurs in the surrounding regions of the Yarlung Zangbo Grand Canyon reserve.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 August 2017
Received in revised form 19 November 2017
Accepted 19 November 2017
Available online 22 November 2017

Editor: Elena Paoletti

Keywords:
Human impact
Spatial layout
Management effectiveness
Nature reserves
Conservation planning
Yarlung Zangbo Grand Canyon

ABSTRACT

Humanity is causing dramatic changes to the Earth, and we may be entering a human-dominated era referred to as the Anthropocene. Mapping the human footprint and assessing the spatial layout and effectiveness of protected areas facilitate sustainable development. As the core region of the third pole, Tibet is an important area for biodiversity and the provision of ecosystem services. In this study, five categories of human pressure were summed cumulatively to map the human footprint in Tibet for 1990 and 2010, and the spatial relationship between the human footprint and national and provincial nature reserves (NRs) in Tibet was analyzed. In addition, the human footprint map was also used to evaluate the effectiveness of national and provincial NRs for reducing the impact of human activities. A comprehensive assessment was undertaken for the Yarlung Zangbo Grand Canyon (YZGC) NR. There were several key findings from this study. First, the human footprint scores (HFS) in Tibet for 1990 and 2010 were low, and increased by 32.35% during 1990–2010, which was greater than the global value of 9% for 1993–2009, indicating that Tibet is seriously threatened by human pressure. Grazing intensity and road disturbance intensity contributed significantly to the increase in the HFS. Second, the average HFS for 1990 in NRs was lower than that for the entire Tibet, but the spatial layout and extent of some reserves (e.g., the Qomolangma NR) needs to be optimized further. Third, the establishment of NRs in Tibet was effective in reducing human activities. No leakage phenomena were identified in the regions surrounding the YZGC reserve. However, the management of NRs in Tibet is still challenging in terms of reducing human activities.

* Corresponding author at: 388 Lumo Road, Hongshan District, Wuhan 430074, Hubei, China.
E-mail addresses: lisc@cug.edu.cn, lisc.10s@igsnrr.ac.cn (S. Li), wujs07s@zedat.fu-berlin.de (J. Wu), gongjian@cug.edu.cn (J. Gong), leesw@igsnrr.ac.cn (S. Li).

https://doi.org/10.1016/j.scitotenv.2017.11.216
0048-9697/

1. Introduction

Human activities have dramatically altered, and thus exposed great pressure to the ecosystems of the Earth (Vitousek et al., 1997). These alterations have been accelerated since the industrial and green revolutions (Motesharrei et al., 2016). The concept of the Anthropocene, which is a new era dominated by human activities, has been proposed (Waters et al., 2016). Many researchers have attempted to map the human footprint, which denotes the total of the ecological footprints of human population, represented by the work of the global human footprint map for the 1990s (Sanderson et al., 2002). This has been updated for 1993–2006 using the latest global satellite images and ground surveys, suggesting that human beings are stewards of nature (Venter et al., 2016). The human footprint could be a useful tool to facilitate conservation planning, and is also significant for ensuring sustainable development (Burton et al., 2014; Correa Ayram et al., 2017; Tapia-Armijos et al., 2017; Woolmer et al., 2008). The human footprint method and the maps of the global datasets have been used widely (Allan et al., 2017; Gonzalez-Abraham et al., 2015; Johnson et al., 2017).

As a category of protected area enabling sustainable development, nature reserves (NRs) are designated to protect biodiversity, especially threatened species, and ecosystem services (Xu et al., 2017). The biosphere reserves of the Man and the Biosphere Program are areas comprising terrestrial, marine, and coastal ecosystems, and have been used to establish a scientific basis for the improvement of the relationships between human beings and their environments (Bridgewater and Babin, 2017). Much attention has been given to assessing the rationality of the layout and the effectiveness of NRs (De Almeida et al., 2016; Geldmann et al., 2013). For example, the creation of Urdaibai Biosphere Reserve in Spain prevented the construction of urban megaprojects that would have dramatically affected the current natural core areas (Castillo-Eguskitza et al., 2017). China's current protected areas are insufficient to prevent the loss of areas of less-disturbed habitat (Chen et al., 2017). However, most studies concerning the assessment of layout rationality and the effectiveness of NRs have been conducted from the perspective of biosphere dimension, including the protection of biodiversity and ecosystem services (Chen et al., 2017). For example, Xu et al. (2017) reported that the layout of NRs in China needs to be strengthened in terms of the protection of important ecosystem service functions, while studies concerning the human dimension are rare.

As the core region of the third pole (Yao et al., 2012), the Tibet Autonomous Region (hereafter Tibet) is an important area for biodiversity (Newbold et al., 2015) and ecosystem services (Ouyang et al., 2016; Song and Deng, 2017). Many unique ecosystems and species are located in this region. It provides water resources for a large number of human population in the world (Xu et al., 2008). Therefore, many protected areas have been established in this region to protect the fragile environment and biodiversity. The area of NRs in Tibet accounts for more than one third of the Tibet land area (Xu et al., 2017). In addition, Tibet is also highly sensitive to human activities, which means a slight human disturbance may cause serious environment degradation. In recent decades, the environment in Tibet has changed due to human activities and climate change (Li et al., 2017a; Yu et al., 2016). However, studies involving the human footprint mapping in Tibet are inadequate (Fan et al., 2015; *Zhao et al.,* 2015b; Zhong et al., 2008), with even fewer studies assessing the layout rationality and effectiveness of NRs in Tibet from the perspective of human activity.

The Ministry of Environmental Protection of China has developed a management practice referred to as "Monitoring and Verification of Human Activities in Nature Reserves Using Remote Sensing" and launched the "Green Shield 2017" inspection over national NRs in July 2017 to monitor and reduce human activities in NRs, including the over-exploitation of mineral resources, illegal construction, and operation of hydropower facilities (Ministry of Environmental Protection of the People's Republic of China, 2017). Recently, the Chinese government punished officials over environmental violations in the Qilian Mountains national NR. These actions of the central government in China indicate that there is an urgent need to assess and reduce human activities in NRs (Ma et al., 2016, Song et al., 2017).

Therefore, the aims of this study are to: 1) map the human footprint in Tibet for 1990 and 2010, and reveal their spatial and temporal characteristics; 2) analyze the spatial relationship between the human footprint and NRs at national and provincial levels in Tibet; and 3) assess their effectiveness in reducing human activities from 1990 to 2000, especially for the Yarlung Zangbo Grand Canyon (YZGC) NR.

2. Study area

Tibet lies between 26°52′N–36°32′N and 78°24′E – 99°06′E, with an area of 1.2 million km^2. The north of Tibet is a plateau consisting of the Kunlun Mountains, González Mountains, and Nianqing Tanggula Mountains. The south of Tibet contains the Yarlung Zangbo River and its tributary valleys, while the southeast is a series of alpine canyons with an almost north-south strike. The altitude generally decreases from more than 5000 m in the northwest to less than 4000 m in the southeast (Fig. 1). The region with an altitude higher than 4000 m accounts for 85.1% of the total land area (Yao et al., 2012).

In Tibet, the incoming solar radiation is strong with an annual value of 140–200 kcal/cm^2. The annual mean temperature ranges from −2.4 to 12.1 °C, and the annual mean precipitation ranges from 66.3 to 894.5 mm (http://www.gov.cn/guoqing/2013-04/08/content_5046170.htm). Both temperature and precipitation decrease from southeast to northwest. In addition, there are many rivers and lakes in Tibet (Xu et al., 2008). The vegetation types in Tibet, from southeast to northwest, are forest, meadow, grassland, desert, and alpine vegetation. Tibet is also a global hotspot of biodiversity conservation. Most of the human activities are distributed in the eastern regions and the midstream of the Yarlung Zangbo River, but the intensity of these activities is increasing (Li et al., 2017b; Zhao et al., 2015a).

By the end of 2015, there were 47 NRs in Tibet, including nine at the national level, 14 at the provincial level, and 24 at the county level (Fig. 1). The total area of NRs is currently 41.37×10^4 km^2, which is the highest among the 31 provincial-level regions in China. The area covered by NRs accounts for 34.47% of the total area of Tibet, while the corresponding figure for China is only 15.1%. According to the protection targets, the 23 national and provincial NRs in Tibet can be classified into six types: inland wetlands, forest ecosystems, wild animals, geological relics, desert ecosystems, and wild plants.

3. Materials and methods

3.1. Human footprint mapping

Taking the regional characteristics of Tibet and data availability into consideration, we tailored the global datasets method (Sanderson et al., 2002; Venter et al., 2016) and considered five categories of human pressure (population density, land use intensity, grazing intensity, road and railways, and the electricity infrastructure) to map the human footprint for 1990 and 2010 in a spatially explicit way. These pressures were weighted according to estimates of their relative levels of influence on nature.

3.1.1. Population density

Using the global datasets method (Sanderson et al., 2002) and considering the nomadic lifestyle of Tibet (Cardillo et al., 2004; Miehe et al., 2009; Woodroffe, 2000), we assigned influence scores to the population density in each grid, where the scores for densities in the range of 0–50 inhabitants/km^2 increased linearly from 0 to 10. We assigned all population densities higher than 50 inhabitants/km^2 a score of 10, which was based on the assumption that the influence of population density reached an asymptote at 50 inhabitants/km^2. The pressure of a nomadic lifestyle on the environment is less than that of a settled