Ecological Indicators 85 (2018) 932–943

Contents lists available at ScienceDirect

Ecological Indicators

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

The assessment of the changes of biomass and riparian buffer width in the terminal reservoir under the impact of the South-to-North Water Diversion Project in China

Shengtian Yang[a,1], Juan Bai[b,c,*,1], Changsen Zhao[a], Hezhen Lou[a], Chunbin Zhang[b], Yabing Guan[b], Yichi Zhang[b], Zhiwei Wang[b,d], Xinyi Yu[b]

[a] College of Water Sciences, Beijing Normal University, Beijing Key Laboratory for Remote Sensing of Environment and Digital Cities, Beijing 100875, China
[b] State Key Laboratory of Remote Sensing Science, Faculty of Geographical Science, Beijing Normal University, Beijing Key Laboratory for Remote Sensing of Environment and Digital Cities, Beijing 100875, China
[c] College of Geographical Science, Shanxi Normal University, Linfen 041004, China
[d] Key Laboratory of Radiometric Calibration and Validation for Environmental Satellites, National Satellite Meteorological Center, China Meteorological Administration, Beijing, China

ARTICLE INFO

Keywords:
Riparian buffer width
Biomass
Inter-basin water transfer
Remote sensing
Unmanned aerial vehicle (UAV)

ABSTRACT

Reservoir and lake levels are susceptible to interference from inter-basin water transfer projects that are intended to alleviate increasing serious water resource crises. However, the impact of these transfers on riparian buffers as well as to water security is not clear. This paper considers the world's largest inter-basin water transfer, the South-to-North Water Diversion (SNWD), as an example for assessing changes in riparian buffer width and biomass in order to indicate the influence of the project on the ecological system of the receiving reservoir. The riparian buffer width is determined by Landsat NDWI. Basing on in situ survey, the method that combing unmanned aircraft vehicle (UAV) and remote sensing (Landsat) was employed to calculate riparian biomass.
Results: show that water arriving from the SNWD directly decrease the existing buffer width due to the rising water level, and riparian biomass shows a negative response to elevated water levels. Therefore, the transferred water will impair the ecological functions of that buffer and increase risk to the security of the water resource. The vegetation cover in extant riparian buffer zones should be restored if the buffers are to be effective as usual. This study provides information useful to assess riparian impact from artificial inter-basin water projects prior to implementation.

1. Introduction

Inter-basin water transfer projects are increasingly used worldwide to alleviate the serious water resource crises. Well-known projects include the Central Arizona Project and the California State Water Project in the United States (Cantor, 1980; Gastelum and Cullom, 2013), the Siberian Rivers Diversion in Russia (Voropaev and Velikanov, 1984), the Indira Gandhi Canal in India (Gardiner, 1987), the Eastern National Water Carrier in Namibia (Davies et al., 1992), and the Snowy Mountains Scheme in Australia (Domicelj, 1980). At present, the largest inter-basin transfer scheme in the world is the South-to-North Water Diversion (SNWD) project in China, whose east and middle routes have already been built, and which currently delivers 25 billion m^3 of fresh water per year (Liu and Zheng, 2002). Many researchers take the SNWD as a model of large inter-basin water transfers, and increasing attention is being directed to the ecological and environmental problems associated with this project (Stone and Jia, 2006; Zhang et al., 2008; Cheng and Song, 2009; Gu et al., 2012; Liang et al., 2012; Tang et al., 2014; Barnett et al., 2015; Yang et al., 2016).

Water transfer projects can be divided into three parts: the water source, conveyance canal and terminal reservoir, and the ecological and environmental problems associated with each are different. For example, in the water source area, the water shortage and pollution of the clean water supply are of greatest concern (Zhang, 2009; Gu et al., 2012; Tang et al., 2014; Zeng et al., 2015; Yang et al., 2016). In the conveyance canal, maintenance of water quality and prevention of the migration of invasive species and spread of diseases as a result of the diversion process are the main issues (Cheng and Song, 2009; Zhang,

* corresponding author at: No.19 Xinjiekouwai Street, Haidian district, Beijing.
E-mail address: baijuanaction@163.com (J. Bai).
[1] These authors contributed equally to this article.

https://doi.org/10.1016/j.ecolind.2017.11.011
Received 24 July 2017; Received in revised form 10 October 2017; Accepted 6 November 2017
1470-160X/

2009; Zhuang 2016). In the terminal reservoir, maintenance of riparian functions is the major ecological and environmental problem, because the reservoir's water level will obviously rise due to the water transfer (Zhang et al., 2008; Zhang, 2009; Zhuang, 2016).

The riparian zone, which is the interface between land and water, is essential in protecting the security of the water resource (Gregory et al., 1991; Naiman and Decamps, 1997; Wang et al., 2011; King et al., 2016). Well-maintained riparian zones are crucial for maintaining ecological functions in downstream rivers and other water bodies (Fernández et al., 2014; Fu et al., 2015). However, when water delivered from water resource reaches the terminal reservoir, the original riparian buffer will be inundated extensively and increase risk to the terminal water. It may render the riparian zone ineffective at intercepting and retaining excess particulates and dissolved nutrients originating from the surrounding uplands, and alter the riparian zone from a nutrient sink into a nutrient source (Schilling et al., 2006). There is therefore a need to monitor, understand and predict ecological responses to the risk to the entire riparian zone, and riparian condition is an important index of ecological quality in terminal reservoir.

Buffer width and biomass are the two of the most important indicators of riparian condition, because sedimentation and nutrients in the terminal reservoir decrease with increasing buffer width and production (Owers et al., 2012; Weissteiner et al., 2013; Klemas 2014). Changes in water levels affect the condition of the riparian zone and may lead to ecological crises in the adjacent waters (Ducros and Joyce, 2003; Rheinhardt et al., 2012). Measurement of riparian buffer width and biomass become important in assessing the success of buffer conservation and restoration (Klemas, 2014).

Precise monitoring of riparian buffer width and biomass requires multi-source remote sensing data. Although quantifying riparian buffer width is relatively easy, and many remote sensing data techniques can provide the required mapping accuracies (Johansen et al., 2010a; Johansen et al., 2010b), quantifying plant biomass accurately at the scale of whole riparian zones is challenging (Husson et al., 2014). Traditional biomass assessment based on field sampling is labour intensive and limited in sample plot scale (Husson et al., 2014; Macfarlane et al., 2017). Biomass-related indexes such as the normalized difference vegetation index (NDVI), which uses data from optical and radar remote-sensing, have been widely used to estimate the amount and temporal variability of biomass (Adam et al., 2009; Mutanga et al., 2012; Luong Viet et al., 2016). However, these methods are restricted in the low spatial resolution of accessible remote sensing data and have difficulties in distinguishing different types of vegetation. Recently, unmanned aircraft vehicles (UAVs) have provided methods for quantifying plant biomass more precisely. Use of a UAV improves the spatial resolution and cost efficiency of the remote sensing data-collection process (Colomina and Molina, 2014; Zarco-Tejada et al., 2014; Džubáková et al., 2015). A method coupling UAV and in-situ measurements is an efficient way to evaluate plant biomass (Kachamba et al., 2016; Selsam et al., 2017), and has been used in combination with field surveys to assess riparian biomass in river riparian zones (Husson et al., 2014).

The purpose of the present study was to assess the impact of the inter-basin water transfer project on riparian conditions in the terminal reservoir of the SNWD project through following steps: ① monitoring riparian buffer width changes using Landsat data, ② employing the method combing in situ, UAV and Landsat to predict riparian biomass, ③ confirming the relation between water level and riparian biomass.

2. Methods and materials

2.1. Study area

The Miyun Reservoir is the largest reservoir in north China (Fig. 1), and is situated in the mountainous area of Miyun County, Beijing (116°47′E ~ 117°05′E, 40°26′N ~ 40°35′N). It has a maximum surface area of 188 km^2 with total storage volume of 4.375 billion m^3. The study area features temperate continental monsoon climate, with mean annual precipitation of 628 mm and mean annual air temperature of 11.3 °C. Uneven seasonal distribution of precipitation results in more than 70% of the annual precipitation occurs between June and September. The principal land uses in the watershed include dry land, woodland, grassland, water body, floodland and residential land. The riparian buffer mainly consists of the area encompassed by the highway surrounding the reservoir including other adjacent water zones that designated by the government. It is divided into three phases: water, reservoir and terrestrial phase. The water phase is the narrow zone between the low-water mark and the reservoir bank, the reservoir phase contains the zone between the low-water mark and high-water mark, and the terrestrial phase extends from the edge of the reservoir phase to the perimeter of the primary source water protection area.

Since the Miyun Reservoir became the drinking water source for Beijing in 1981, it has provided the "life water" for twenty million people and it is vital to the social and economic development of the capital, so its water quality has received increasing attention. The SNWD consists of three routes (i.e., East, Middle and West route). The Miyun Reservoir is the terminus of the middle route, and it stores the surplus water transferred from the Dangjiangkou Reservoir. The middle route of the SNWD was finished subsequent to the east route in 2014, and Beijing began to receive fresh water from the Yangtze River through a 1241 km canal, along which route water "climbs" 133 m to enter the Miyun Reservoir through the Jingmi diversion canal with the help of 9 pumping stations. Storage in the Miyun Reservoir will be improved from 1.2 billion to 2 billion m^3 in 2020, which will increase the water level from 136 m to 150 m. However, one of the most important functions of the riparian zone is to act as a water quality filter, and this function is largely dependent upon the condition of vegetation in the buffer (Klemas, 2014). The additional water will inundate parts of the original riparian zone and vegetation in the remaining part will be affected by the rising water level, leading to inevitable ecological risk for the reservoir.

2.2. Methods

The impact on riparian conditions from changes in water level was evaluated by comparing riparian buffer width and biomass during five years (1999, 2000, 2009, 2010 and 2015). The middle route of the SNWD was finished in late 2014 and Miyun Reservoir began to receive the transferred water in 2015, so we chose 2015 as the current year. As the SNWD will increase Miyun Reservoir's water level to 150 m which almost equals the water level in 1999, so 1999 is chose as the objective year. The water level in these adjacent years (1999 and 2000, 2009 and 2010) were quite different (149 m in 1999 and 142 m in 2000, 137 m in 2009 and 134 m in 2010) and the corresponding riparian zone had significant difference. So we chose these five years. The framework of this study (Fig. 2) includes data preparation, data processing procedures and changes assessment. The database required satellite data (Landsat), UAV data and in situ survey data. In data processing, Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) were calculated from the Landsat data, and variation of NDWI can indicate expansion or constriction of riparian buffer width, and NDVI was used as a reference index for monitoring vegetation. The riparian vegetation volume was obtained by UAV and biomass was measured in situ at the times of UAV flight. A statistical relationship between NDVI and vegetation volume was built by matching Landsat and UAV data, and the relationship between vegetation volume and biomass was built by matching UAV and in situ survey data. Then these two relationships were employed to calculate the biomass of the entire riparian zone. In changes assessment, the impact of riparian buffer width and biomass was evaluated due to rising water levels.