Science of the Total Environment 634 (2018) 550–560

Contents lists available at ScienceDirect

Science of the Total Environment

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

# Conversions between natural wetlands and farmland in China: A multiscale geospatial analysis

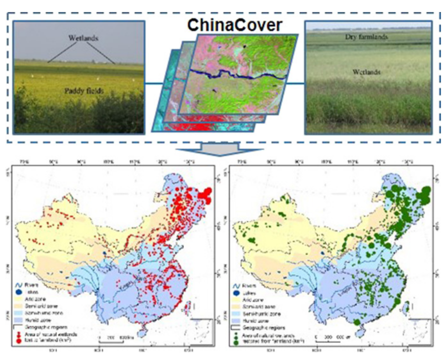
Dehua Mao [a,b], Ling Luo [a], Zongming Wang [a,*], Maxwell C. Wilson [b], Yuan Zeng [c], Bingfang Wu [c], Jianguo Wu [b,d,e]

[a] Key Laboratory of Wetland Ecology and Environment, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun, 130102, China
[b] School of Life Sciences, Arizona State University, Tempe, 85287, USA
[c] Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, 100094, China
[d] School of Sustainability and Julie A. Wrigley Global Institute of Sustainability, Arizona State University, Tempe, 85287, USA
[e] Center for Human-Environment System Sustainability (CHESS), Beijing Normal University, Beijing, 100875, China

## HIGHLIGHTS

- Conversions between natural wetlands and farmland in China were quantified.
- About 60% of China's lost natural wetlands were due to agricultural encroachment.
- Natural wetland conversion to farmland was highest in Northeast China (85.4%).
- A total of 1369 $km^2$ of natural wetlands were restored from farmland during 1990–2010.
- China must develop place-based sustainable management policies for natural wetlands.

## GRAPHICAL ABSTRACT




## ARTICLE INFO

*Article history:*
Received 14 January 2018
Received in revised form 8 March 2018
Accepted 1 April 2018
Available online xxxx

Editor: D. Barcelo

*Keywords:*
Natural wetlands
Farmland
Agricultural encroachment
Wetland restoration
ChinaCover

## ABSTRACT

Agricultural activity is widely recognized as a leading driver of natural wetland loss in many parts of the world. However, little is known about the spatiotemporal patterns of conversion between natural wetlands and farmland in China. This information deficiency has limited decision-making for the sustainable management of natural wetland ecosystems. In this study, we explicitly quantified bidirectional natural wetland-farmland conversions during the periods of 1990–2000 and 2000–2010 at multiple spatiotemporal scales. Our results revealed that about 60% (15,765 $km^2$) of China's lost natural wetlands were due to agricultural encroachment for grain production, 74.7% (11,778 $km^2$) of which occurred from 1990 to 2000. Natural wetland conversion to farmland was highest in Northeast China (13,467 $km^2$ or 85.4%), whereas the natural wetlands in Northwest China demand extra attention because of a notable increase of agricultural encroachment. Natural wetlands in the humid zone experienced tremendous agricultural encroachment, leading to a loss of 10,649 $km^2$, accounting for 67.5% of the total agriculture-induced natural wetland loss in China. On the other hand, a total of 1369 $km^2$ of natural wetlands were restored from farmland, with 66.3% of this restoration occurring between 2000 and 2010, primarily in Northeast China and the humid zone. Although a series of national policies and population pressure resulted in agricultural encroachment into natural wetlands, there are also policies and management measures protecting and restoring natural wetlands in China. The spatial differences in natural wetland-farmland conversions among

* Corresponding author.
*E-mail address:* zongmingwang@iga.ac.cn. (Z. Wang).

https://doi.org/10.1016/j.scitotenv.2018.04.009

different geographic regions and climatic zones suggest that China must develop place-based sustainable management policies and plans for natural wetlands. This study provides important scientific information necessary for developing such policies and implementation plans.



## 1. Introduction

Agricultural activity is the leading anthropogenic force driving the loss of natural ecosystem (Ramankutty and Foley, 1998;Qiu, 2011; Asselen et al., 2013), causing serious ecological consequences, such as habitat degradation (Zhao et al., 2006; Wimberly et al., 2018), biodiversity loss (An et al., 2007; Cramer et al., 2017; Yang et al., 2017), water quantity and quality declines (Fang et al., 2005; Scanlon et al., 2007), and reduced carbon sequestration (Saunders et al., 2012; Man et al., 2017). To respond to these emerging environmental problems, the first necessary step is to quantify the spatiotemporal patterns of agricultural encroachment into natural areas.

Wetlands cover approximately 6% of the terrestrial surface and provide important and diverse benefits to people around the world (MA, 2005; Zedler and Kercher, 2005; Keddy, 2010). However, significant wetland loss due to human activity, including agricultural encroachment (Rebelo et al., 2009; Reis et al., 2017), urbanization (Li et al., 2014; Hartig and Bennion, 2017), and aquaculture (Richards and Friess, 2016), has occurred in recent decades. Despite efforts to restore natural wetlands for human well-being (Wang et al., 2012; MA, 2005), more than half of the global wetlands have disappeared during the last century (Davidson, 2014). Agricultural encroachment is dominantly responsible for wetland loss, undermining the capacity of natural wetlands to deliver ecosystem services (Asselen et al., 2013; Wang et al., 2015; Beuel et al., 2016). Therefore, spatially explicit assessments of the natural wetland loss due to agricultural conversion are extremely important for wetland conservation and restoration.

A large number of regional studies have reported that the loss of natural wetlands worldwide is largely caused by crop cultivation for food production, such as in southwestern Australia (Davis and Froend, 1999), the Sanjiang Plain in China (Wang et al., 2011; Song et al., 2014), North and South Dakota in the United States (Johnston, 2013), and Kampala in the Uganda (Isunju and Kemp, 2016). However, these studies varied in both temporal scale and wetland definition, indicating that new evidence for natural wetland loss due to agricultural encroachment at larger scales is needed. Compared to other human threats (e.g., urbanization), it is easier to restore natural wetlands lost to agricultural encroachment because the soil seed bank is conserved (Neff et al., 2009; Wang et al., 2017). Therefore, an accurate quantification of the conversion between natural wetlands and farmland at large scales is critical to understanding the sustainability of global wetland ecosystems.

China holds approximately 10% of global wetlands (Niu et al., 2009, Hu et al., 2017) and one-fifth of the world population (about 1.4 billion people), but only 7% of global farmland (Liu and Diamond, 2005; Lu et al., 2015). For both food production and economic growth, extensive natural wetlands have been cultivated due to negligence and underestimation of their tremendous ecological values (Gong et al., 2010; Song et al., 2012; Chen et al., 2015). Despite the consensus that dramatic farmland expansion has destroyed substantial natural wetlands (Niu et al., 2009), knowledge gaps exist in mapping and quantifying agricultural encroachment into natural wetlands across the country. We still do not know how much natural wetlands have been cultivated to farmland in China. Additionally, we know little about the spatiotemporal patterns of natural wetland reclamation or restoration. This information deficiency has limited spatially explicit decision-making for wetland conservation and rehabilitation (Wang et al., 2012; Reis et al., 2017). A more generalized understanding of the patterns and processes underlying the conversion between China's natural wetlands and farmland will be helpful in designing sustainable national policies for protecting and restoring natural wetlands (Nguyen et al., 2017).

In this study, we aim to document the spatiotemporal patterns of both China's agricultural encroachment into natural wetlands and the restoration from farmland to natural wetlands from 1990 to 2010. Specifically, we intend to reveal the hotspot areas of these conversions, and to examine how these conversions vary across geographic regions and climatic zones. We also identify key socioeconomic driving forces of natural wetlands-farmland conversions and make recommendations for sustainable wetland management.

## 2. Data and methods

### 2.1. Remote sensing datasets

Remote sensing can both help us characterize the current status of land cover and, through the use of time series data, help us to determine changes on the land surface (Ozesmi and Bauer, 2002; Tian et al., 2017). These advantages make remote sensing the best way to identify the conversion between different land cover categories. After the establishment of China' socialist market economic system in the early 1990s, China began to develop rapidly and experienced dramatic land cover changes (Zhang et al., 2014a). To investigate the ecological changes, the Chinese Academy of Sciences (CAS) has established the China National Land Cover Database (ChinaCover) based on multi-source and multi-seasonal satellite images (Zhang et al., 2014a; Ouyang et al., 2016). And the ChinaCover was published as atlas in 2017 (Wu et al., 2017). Datasets for natural wetlands and farmland in 1990, 2000, and 2010 used in this study were extracted from the ChinaCover. In this study, the natural wetlands refer to the wetlands consisting of vegetation cover types including forested swamp, shrub swamp, and marshes. Natural water bodies (i.e., rivers and lakes) were excluded from our analysis. This database does not separate inland and coastal wetlands because there is no generally accepted boundary between them, and satellite images do not always cover low tidal areas for the entire coast line. Farmland was classified into dry farmland and paddy field.

The detailed information for classification and validation of ChinaCover was introduced in Zhang et al. (2014a). An object-oriented classification approach was used to differentiate various classes of land cover. In the process, a hierarchical classification tree (i.e., Fig. 1a) and various rules (i.e., Fig. 1b) were designed to identify natural wetlands and farmland. The normalized difference vegetation index (NDVI) and normalized difference water index (NDWI) played important roles in the identification of natural wetlands, whereas the phenologic features and object shape/texture contributed largely to the recognition of farmland. Additionally, the geographic and climatic features (Fig. 1c) were considered to establish different rules (Fig. 1b) for identifying natural wetlands and farmland across the country. Visual editing based on the knowledge of natural wetlands in various research teams of CAS largely contributed to the classification. In addition, a great number of field samples carried out by CAS and samples from Google Earth images were used to improve the classification accuracy. The overall accuracy of ChinaCover is greater than 94%. Specifically, producer's accuracy is 89% for natural wetlands and 90% for farmland, while user's accuracy is 86% for natural wetlands and 89% for farmland. The dataset of ChinaCover represents the most accurate mapping of China's land cover during the past decades and thus were used in this study. Fig. 2 shows the distribution of China's natural wetlands and farmland in 2010.