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Non-point source pollution dynamics under long-term agricultural development and relationship with landscape dynamics

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ABSTRACT

Long-term agricultural development has an influence on the regional landscape patterns and non-point source (NPS) pollution. The implementation of sustainable landscapes management is a key component in agricultural development together with the reduction of agricultural NPS pollution. In this paper, the interactions of land cover, landscape pattern and NPS pollution were analyzed synchronously. The land cover variation of the agricultural watershed from 1976 to 2006 in Northeast China was analyzed from the Landsat series images, and the landscape pattern was also analyzed with FRAGSTATS. The Soil and Water Assessment Tool (SWAT) was used to identify the NPS pollution response to long-term land cover dynamics. The temporal variation trends of the landscape fragmentation, shape and diversity index demonstrated the response of natural land covers to agricultural development. The six landscape metrics at landscape and watershed scale indicated that the impact of agricultural expansion on regional natural system become slightly in the recent time period. By applying redundancy analyses (RDA), the interactions of the land cover and landscape pattern dynamics with the pollution loading of NPS nutrients at four temporal scales were analyzed. The RDA results also demonstrated the close interactions among them and the proper landscape pattern design can facilitate the prevention of NPS pollution. The responses of seven NPS nutrient indices to the temporal variation of the landscape pattern were also identified, and the influence of agricultural land expansion on NPS nutrient loading was described. The applied method can analyze the interactions of three aspects simultaneously and provide potential solution to agricultural NPS pollution reduction. These results confirm the important role of sustainable landscape management and spatial arrangement during agricultural development and conservation planning.

1. Introduction

Sustainable landscape management is a component of ecological agriculture and facilitates the unvaried ecosystem functions during agricultural land intensification and the increasing demand for crop yield (Noble and Dirzo, 1997; Proulx and Fahrig, 2010). Landscape trajectories are widely applied to express the landscape pattern dynamics during the processes of urbanization or agricultural exploitation (Makki et al., 2013; Ruiz and Domon, 2009). Conflicts related to ecosystem stability, food safety and pollution prevention have boomed around the world. Sustainable landscape managements may represent the proper solution, which is mainly about the long term eco-environment stability and the stable landscape equilibrium under fast changing human-induced disturbance (Blaschke, 2006). However, research with respect to agricultural development, non-point source (NPS) pollution and landscape patterns remains scarce.

Landscape metrics are widely applied tools for sustainable land management, especially in agricultural watershed (Fry et al., 2009; Gulickx et al., 2013). This method offers a pathway through which to assess the interactions between landscape pattern and environmental consequence due to agricultural development (Mander and Jongman, 2000). Therefore, it is necessary to understand the factors that drive the agricultural landscape pattern dynamics and their influence on the regional environment. An improved understanding of landscape change is viewed as a requirement for the assessment of landscape pattern dynamics with reference to various functions. Landscape indicators are an important component of understanding and monitoring of human impact on the ecosystem dynamics (Gergel, 2005). Therefore, detailed descriptions of

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the landscape patterns contribute to the development of management strategies that can prevent further decline and promote the environmental value of agricultural development (Mac Donald et al., 2000).

Long-term and intensive agricultural development creates environmental pressures via land cover variation and the flow of associated NPS nutrients pollution into stream networks (Jain, 2002). Studies that seek a deeper understanding of agricultural pollution prevention have expressed increasing concern with respect to the quantification of pollution loads during agricultural development (Milliman and Syvitski, 1992). Agricultural NPS pollution models are often combined with land cover scenarios generated from remote-sensing data to produce potential scenarios of the impacts of land cover changes on the landscape. These NPS pollution models provide a link between the landscape changes and the pollution yields of NPS nutrients. The Soil and Water Assessment Tool (SWAT) (Nasr et al., 2007) was selected in this study due to its advantages in working with long-term data. The SWAT includes approaches that describe how land cover, precipitation, temperature, and humidity affect different aspects of pollution loading of NPS nutrients and has been often applied as a tool to investigate the effects of land cover change. Several case studies of the impact of land cover changes on pollution via NPS nutrients have been analyzed using this model (Ficklin et al., 2009; Ouyang et al., 2010). The application of SWAT in this study was designed to estimate the overall impacts on the NPS pollution loading of long-term land cover variation due to agricultural development.

Effective control of NPS nutrient pollution in agricultural catchments requires the use of model system and best management practices (BMP), which are similar to the concept of sustainable landscape management (Pearson and Gorman, 2010). Diverse landscape conservation and sustainability is one of the ten key topics in landscape ecology (Potschin and Haines-Young, 2006). Due to the increasing need for sustainable development worldwide, the integration of landscape ecology and landscape architecture in practice is imperative (Nassauer and Opdam, 2008). Landscapes can be viewed as multifunctional services and be expressed with the landscape metrics at difference spatial scale, particularly in highly productive human-dominated systems such as agricultural zones (Mander et al., 2007).

The objectives of this study were to identify how the land cover and landscape pattern dynamics response to a three-decade period of intensive agricultural development, to assess the NPS N and P loadings response to long-term land cover transformation with SWAT model, and to understand the interactions between land cover variation and landscape pattern using different formats of NPS nutrient pollution.

2. Methodology

2.1. Study area description

The studied watershed is a part of the Sangjiang Plain in the Northeast of China and has a total drainage area of 220,500 ha. The yearly average precipitation is approximately 600 mm, and the yearly mean temperature is approximately 1.91 °C (Yang et al., 2012). The local topography does not vary greatly, with altitudes between 45 m and 836 m. The drainage and use of natural wetlands for agricultural land (paddy fields with rice and uplands with corn, soybean) over the past 50 years has resulted in a decrease of wetlands from approximately 3.53×10^6 ha in 1954 to 0.96×10^6 ha in 2005 (Wang et al., 2010). In 2006, the area of paddy fields and uplands was 2695.9 km^2 and 9068.0 km^2, respectively (Fig. 1).

Table 1
Detailed description of Landsat series images.

Year	Path/row number	Date
1976		7.12, 1976; 7.25, 1975; 7.19, 1976, 7.19, 1976
1989	114/27, 114/28	6.12, 1989; 9.16, 1989, 6.25, 1991, 9.25, 1990
2000	115/27, 115/28	9.25, 2001; 9.20, 2000, 8.12, 2000, 8.12, 2000
2006		9.15, 2006; 10.1, 2006, .9.22, 2006, 9.22, 2006

2.2. General research framework

The general framework of the present study is illustrated in Fig. 2. First, the SWAT database was constructed with the four-term land cover information, and the model parameters were subsequently calibrated. Second, the yearly patterns of the NPS nutrient yield were estimated over the entire watershed in different formats. Third, the landscape pattern dynamics in 1976, 1989, 2000 and 2006 were calculated in the same temporal-spatial scale with FRAGSTATS and the ArcGIS tool. Together with the statistical tools and the redundancy analysis, the correlations of the pollution yield of the NPS nutrients with three types of land covers were first calculated. Furthermore, the spatial relationship of the landscape interaction between the land cover and the NPS pollution loading was identified.

2.3. Land cover interpretation process

The study area has experienced four rounds of massive agricultural development since the 1970s, and these rounds occurred in 1976, 1989, 2000 and 2006. Therefore, the land cover data for these four years were developed from the Landsat series images, which were download from the Remote-Sensing Satellite Ground Station, CAS. The entire studied watershed was covered by four images (Table 1), which were collected with minimal cloud coverage and the images were mostly taken from the similar period.

The remote sensing data is interpreted by supervised classification and manually rectified during field investigation. The land cover was classified into seven first-level categories: paddy fields, uplands, urban, forests, water, grasslands, and wetlands. The classification procedure was the same as the national land cover database scheme and was applied in all four years of the data. This approach minimizes the system errors during interpretation and the landscape metric calculation. No reference data were available for the interpretation of the first three years of images, and therefore, no accuracy estimation was performed. The accuracy assessment of the TM images in 2006 was conducted using a site-specific method that compared the land cover map to the ground control points (Röder et al., 2008). The 320 control points were sampled randomly across the study area for the accuracy assessment, and the overall accuracy of the classification was approximately 91.8%. To highlight the interaction between the land cover variations and the NPS loadings, the linear correlation between these values was analyzed with the SPSS software package.

2.4. Non-point source nutrient pollution estimation

The ArcSWAT 2005 is capable of continuous daily simulation of the NPS nutrient pollution in a large and complex watershed over a long period of time (Chaplot, 2005). In this study, the NPS nitrogen (N) in the forms of organic and nitrate were simulated, and their sum represents the total N (TN). The NPS phosphorus (P) was modeled in the forms of organic, soluble and sediment contributions, and their sum represents the total P (TP).

The SWAT databases were imported and included the topography in Fig. 1 (1:250,000), the four-year land covers in Fig. 3 (1:1,000,000), the climate information, and the soil properties