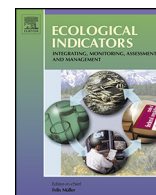




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Analysis of landscape fragmentation processes and driving forces in wetlands in arid areas: A case study of the middle reaches of the Heihe River, China



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ARTICLE INFO

Article history:

Received 3 September 2013

Received in revised form 30 April 2014

Accepted 18 June 2014

Keywords:

Wetlands

Fragmentation

Driving forces

Heihe River

Landscape indices

ABSTRACT

Landscape fragmentation in wetlands usually implies degradation of its ecological functions. Landscape fragmentation divides wetlands into isolated islands, which disturbs the energy flow and nutrient cycling within the wetland. Research into the development and causes of landscape fragmentation in wetlands is urgently needed for effective monitoring and protection of wetlands. We use a combination of techniques including remote sensing, a landscape index model, and redundancy analysis to analyze landscape fragmentation and its driving forces in the middle reaches of the Heihe River from both temporal and spatial perspectives. A new mathematic morphological method that enhances the credibility of landscape fragmentation analysis without changing the original pixel size of the interpreted data is proposed for the calculation of landscape indices. The combination of this new mathematic morphological method and traditional landscape pattern indices enhances the evaluation strategy for landscape fragmentation. Our results demonstrate that the fragmentation processes that affect the wetland landscape of the study area are primarily represented as the shrinking of core wetland area and decrease in mean size of wetland patches. Our results also show an increase in the fragmentation index (*FS*) of the landscape in recent decades. The impacts of natural factors on wetland landscape fragmentation processes are typically reflected in changes in climate and hydrology. In the study area, temperature, which is more important than precipitation in driving wetland landscape fragmentation processes, cannot be omitted. In addition, our analysis proves that unnecessary human activity is a major threat for sustainable development and maintenance of wetlands.

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1. Introduction

Wetlands are unique ecosystems formed as a result of interactions between the forces affecting land and water (Zhang et al., 2010). As key parts of the global ecological system and carbon pool, wetlands offer important ecological functions and effects that cannot be replaced: they mitigate pollution, provide habitats for wildlife, regulate climate, and preserve biodiversity, among other

things (Mander and Mitsch, 2009; Copeland et al., 2010; Sulman et al., 2013). However, the Organization of Economic Cooperation and Development has estimated that approximately 50% of global wetlands could have been lost since 1900, with the remainder experiencing increased fragmentation in recent years (Lienert et al., 2002; Erwin, 2008; Khaznadar et al., 2009; Zhang et al., 2010; Wang et al., 2011). Similarly, incomplete statistics suggest that two thirds of wetlands in France were lost during 1900–1993 (Westerberget al., 2010). In general, climatic change accompanied by increased disturbance caused by human activity has placed wetlands at greater risk, particularly in arid zones (Zhao et al., 2009). Wetlands in arid zones are key nodes and represent critical areas in the landscape patterning that is crucial to the functioning of arid environments; they also play a key role in providing water, energy, and other resources to sustain human life (Zhou, 2005;

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Mwakaje, 2009). However, owing to a lack of consideration of their role in sustainable resource use, wetlands in arid areas continue to fragment, resulting in decreased wetland biodiversity (Soomers et al., 2013; Walz and Syrbe, 2013).

Wetland landscape fragmentation plays a major role in the degradation of ecological systems (Liu et al., 2014) and the reduction of wetland biodiversity; in particular, this fragmentation results in complex spatial distributions of vegetation and reduced functioning of wetlands (Alexandridis et al., 2009; Liu et al., 2009; Song et al., 2012). As such, fragmentation can be considered as one of the most significant expressions of wetland degradation and has been recognized as a core component of landscape ecology and landscape conservation because it affects cycles of material and energy directly (Wiens, 1994; Cerian and Keys, 2009). As a key factor exerting pressure on biodiversity, wetland fragmentation also has a negative effect on the functioning of wetland ecosystems (Opdam and Wascher, 2004). In most cases, fragmentation represents the first step in the process of wetland degradation. Accordingly, research into the processes underlying wetland landscape fragmentation should improve our understanding of typical wetland evolution and help advance techniques to protect wetlands. The underlying processes and driving forces of wetland landscapes are core research topics in current wetland science (Liu et al., 2009).

The wetlands distributed along the middle reaches of the Heihe River have great significance for the eco-environmental protection of northwestern China. In particular, as the primary westward route for migratory birds of China, the wetlands in the middle reaches of the Heihe River also act as a staging point along the East Asia–India section of the eight global migratory channels. Additionally, these wetlands act as an environmental barrier that prevents the southward invasion of the Badain Jaran desert and play a key role in maintaining the ecosystem balance of the Heihe River basin. However, the wetlands have been partially destroyed by human activity and climate change in recent years, with fragmentation and ecosystem degeneration of these wetlands

becoming increasingly pronounced over time. Such degeneration has induced the southward expansion of the Badain Jaran desert, exposing large expanses of grassland and oasis to the threat of desertification, and endangering the survival and development of the Heihe River basin. At worst, such changes could have a profound influence on the ecological security of the Hexi Corridor and northwestern China as a whole. Consequently, research into the wetlands of the Heihe River basin is urgently required. Previous studies of the Heihe River focused on various aspects of the environment, including landscape evolution, hydrological change and its ecological effects, water consumption, evapotranspiration, vegetation cover, and carbon sequestration (Lu et al., 2003; Kang et al., 2007; Kong et al., 2009; Wang et al., 2009; Zhao et al., 2010; Li et al., 2012; Wang et al., 2012; Li et al., 2013). However, many features of these wetlands remain unknown; in particular, knowledge of landscape fragmentation in the region remains insufficient (Li and Zhao, 2010).

Here, we adopt remote sensing (RS), geographical information system (GIS), redundancy analysis (RDA), and techniques of morphological image processing to explore the processes and driving forces of wetland landscape fragmentation in the Heihe River basin. The primary aims of this study are: (1) to characterize the processes of wetland fragmentation in the middle reaches of the Heihe River during 1975–2010 at the landscape and pixel levels; and (2) to analyze the driving forces that promote wetland landscape fragmentation, distinguishing between the effects of human activity and natural environmental changes in the middle reaches of the Heihe River.

2. Study area

The middle reaches of the Heihe River (98°57'–100°52' E, 38°39'–39°59' N) are located in the western part of Gansu Province, northwestern China, spanning three counties (Ganzhou, Gaotai, and Linze) and covering an area of 10,753 km² (Fig. 1). The climate of the region is characterized by cold winters, hot summers, and

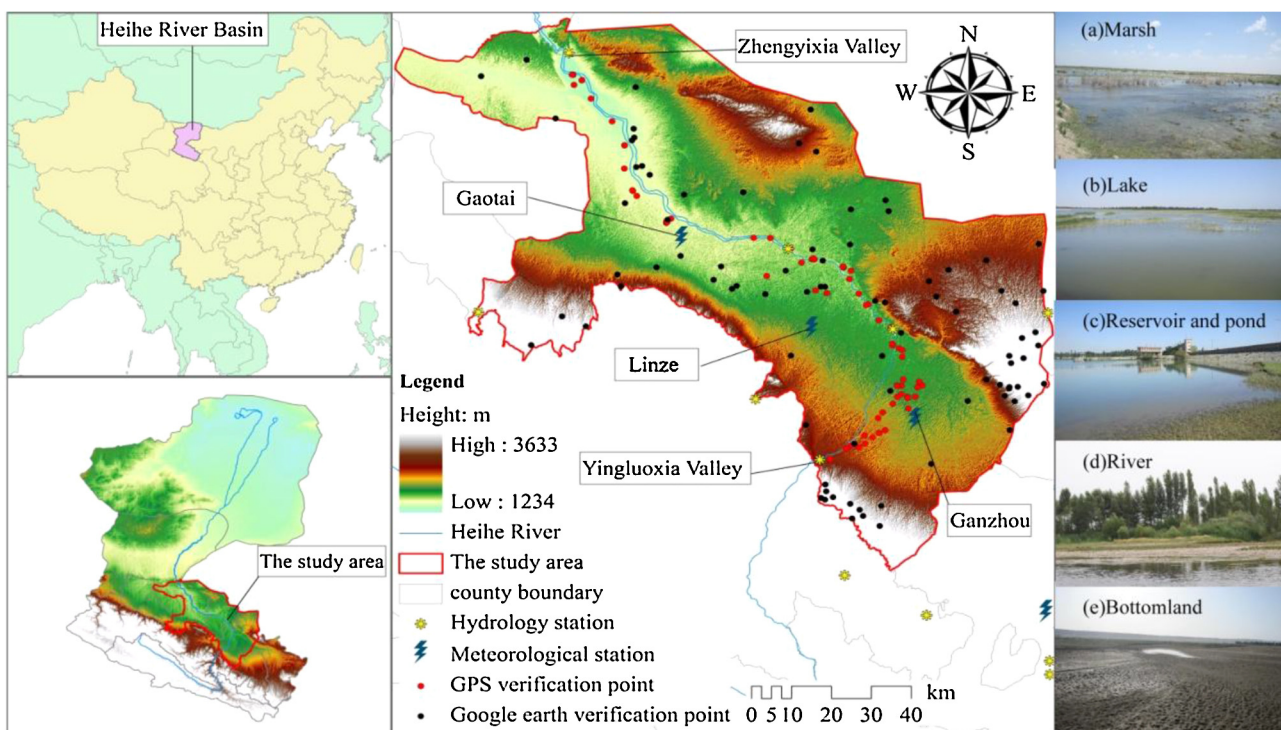


Fig. 1. Location of the study area.

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