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Oasis dynamics change and its influence on landscape pattern on Jinta oasis in arid China from 1963a to 2010a: Integration of multi-source satellite images

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ABSTRACT

As one of the vital research highlights of global land use and cover change, oasis change and its interaction with landscape pattern have been regarded as an important content of regional environmental change research in arid areas. Jinta oasis, a typical agricultural oasis characterized by its dramatic exploitation and use of water and land resources in Hexi corridor, northwest arid region in China, was selected as a case to study the spatiotemporal oasis change and its effects on oasis landscape pattern. Based on integration of Keyhole satellite photographs, KATE-200 photographs, Landsat MSS, TM and ETM+ images, we evaluated and analyzed the status, trend and spatial pattern change of Jinta oasis and the characteristics of landscape pattern change by a set of mathematical models and combined this information with landscape metrics and community surveys. During the period of 1963a–2010a, Jinta oasis expanded gradually with an area increase of 219.15 km^2, and the conversion between oasis and desert was frequent with a state of "imbalance–balance–extreme imbalance conditions". Moreover, most of the changes took place in the ecotone between oasis and desert and the interior of oasis due to the reclamation of abandoned land, such as Yangjingziwan and Xiba townships. Furthermore, the area, size and spatial distribution of oasis were influenced by human activities and resulted in fundamental changes of oasis landscape pattern. The fractal characteristics, dispersion degree and fragmentation of Jinta oasis decreased and the oasis landscape tended to be simple and uniform. Oasis change trajectories and its landscape pattern were mainly influenced by water resource utilization, policies (especially land policies), demographic factors, technological advancements, as well as regional economic development. We found that time series analysis of multi-source remote sensing images and the application of an oasis change model provided a useful approach to monitor oasis change over a long-term period in arid area. It is recommended that the government and farmers should pay more attention to the fragility of the natural system and the government should enhance the leading role of environmental considerations in the development process of oasis change, particularly with respect to the utilization of the limited water and land resources in arid China.

1. Introduction

Human-induced land use and land cover change (LUCC) is one sentinels of research on socioeconomic development and global environmental change (Turner, 1997). LUCC has profoundly influenced natural landscapes via a combination of physical, ecological and socio-cultural factors (Verburg et al., 2002; Nagendra et al., 2004), and this issue has received worldwide attention since the mid-1990s (Turner, 1997). The context, direction, and rate of landscape change have increasingly attracted the planners and researchers' interest recently. In arid areas, oasis change and its implications for landscape structure are not only the most visible type of LUCC, but also fundamental for developing a better understanding of the relationships and interactions between human activity and environmental change (Lambin and Geist, 2006; Gong et al., 2013), especially at the regional scale.

Oasis change can be observed as the sprawling and shrinking of the oasis boundary over time, namely, oasification and desertification. Oasification and desertification are the two basic but

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opposite geographic processes in arid area (Shen et al., 2000). Oasification (the antonym of desertification) has often been defined as the conversion process of desert to oasis, corresponding to the expansion in oasis area and scale, a process affected by human activities and human-nature interactions (Wang, 2009). And then, oasification has impacted on human well-being and social development directly (Jia et al., 2004; Luo et al., 2010) through a series of measures, such as expanding cultivated land, land consolidation and dam construction on inland rivers. Hence, understanding and analyzing the processes, status and trends of oasification procession, especially in the long-term oasis landscape change dynamics were urgently needed for the control and governance of human activities and protection of natural systems in arid China.

Spatially explicit time-series studies represent an important starting point to improve understanding of oasis change and its effect on landscape pattern. Historical insights on LUCC processes, actors, driving forces and resulting changes could provide a valuable basis to efficiently control or direct future changes (Brink et al., 2014). The scientific interest of satellite observations of oasis change over long periods of time has been recognized. However, there is a lack of longer time scale satellite data available from the same source, especially for more than 40 years. Lack or inaccessibility of appropriate data sets across multiple time scales may be a great challenge for the study of long-term oasis changes. In addition, oasis land use patterns have also created dynamic, short-term land cover transitions that are difficult to capture with available data. Hence, to monitor the complexities of oasis change of long duration effectively, multi-type, time-serial remote sensing data are needed (Luo et al., 2008; Ruelland et al., 2010). For instance, Zhou et al. (2010) quantitatively investigated the processes and trends of land use change in Aksu watershed in arid China based on topographic data, Landsat MSS, TM and ETM+ images. Ruelland et al. (2010, 2011) used Corona, Landsat and SPOT satellite images to contrast land-cover changes in Mali. Brinkmann et al. (2012) used multi-source satellite images to analyze the extent of land cover changes and major landscape transformation processes of four West African cities over the latest 50 years.

Generally, oasis change has been studied through analysis of changes in land use type of the oasis, such as, farmland, forestry, water area, and grassland. However, at the scale of the entire arid region, an oasis could be considered as a single landscape patch. But, till now, few studies have taken the oasis as a single geographical landscape unit that without consideration of the internal structure change in oasis to quantitatively analysis oasis change and its effect on landscape pattern. In addition, landscape features are sensitive to the spatiotemporal processes involved in LUCC (Nagendra et al., 2004; Luo et al., 2010) due to the fact that most landscape features are scale dependent and have self-similar, fractal structures (Alhamad et al., 2011). Thus, case studies are needed to ascertain and study the relationship of oasis dynamics change and its effects on oasis landscape pattern without consideration of the internal structure change in oases, especially under the influence of increasing human activity and global climate change (Qi et al., 2012).

In China oases are mainly distributed in temperate and warm temperate desert and gobies areas surrounding mountains. Although oases took up only 4–5% of the total area of arid China, more than 90% of the population and 95% of social wealth were concentrated within these oases (Jia et al., 2004; Wang, 2009). Here, an oasis is defined as a unique geographical landscape that has allowed flourishing vegetation and human settlements due to a stable water supply in an arid region (Ling et al., 2013). On the geographical pattern of the arid land, the mountainous forest grassland – plain oasis in basins and watersheds which is co-existed with desert is the most obvious characters. On the watershed scale, fresh groundwater and surface runoff from the nearby mountains had profoundly influenced the location and the size of an oasis (Wang et al., 2011; Ling et al., 2013). Furthermore, the abundance or shortage of water resources is relation to landscape pattern change of the oases located in the upper, middle and lower watershed, respectively (Zhang et al., 2012), evenly determines the stability of the oasis ecosystem. Especially, the temporal-spatial pattern of lower oasis landscape is more sensitive than others.

In this paper, Jinta oasis, a typical artificial and agricultural oasis in the lower reaches of Beida River Basin (the largest anabranch of Heihe River) of arid China, was selected as a case to study the oasis dynamics. We used multi-source satellite images to ascertain the change of the oasis over a long-term time scale and to apply landscape metrics to analyze its effects on the landscape pattern. The analysis was performed in the context of the background of the social factors associated with oasis change between 1963a and 2010a. Our specific objectives were to: (i) detect and explore the dynamics of oasis change over a 47 year period by developing quantitative models for characterizing status, directions, and trends of oasis change; and (ii) reveal the relationship between oasis change and landscape metrics. We concluded with a short discussion on the driving forces of oasis change and landscape pattern of Jinta oasis in arid China.

2. Study area

Jinta oasis (98°39′–99°08′ E, 39°48′–40°17′ N), located in the middle of the Heihe River Basin in Northwest China (Fig. 1), with a total area of 1652 km^2, a population of 124,032 people residing in eight townships in 2010a. It is not only an alluvial fan in the desert-oasis ecotone, but also is a typical agricultural oasis, a representative of the non-homogeneous oases in arid China. There were various soil types including mud soil, meadow soil, aeolian sandy soil and typical gray-brown soil (Ma et al., 2003; Qi et al., 2007). The total annual average precipitation is about 59.5 mm which mainly stretches from July to September, and annual potential evaporation is about 2567 mm. The main vegetation types included crops, such as cotton, hops, wheat, fennel and corn, and the desert vegetation and saline vegetation included Persican Saxoul (*Haloxylon persicum Bunge ex Boiss*. et), Tamarix chinensis, Calligonum (*Calligonum leucocladum*), and salt-living Anabasis (*A. salsa Benthex Volkens*).

3. Materials and methods

3.1. Remote sensing and data processing

Nine time periods of multi-source images were acquired to detect the spatiotemporal change of Jinta oasis from 1963a to 2010a. They were Keyhole photographs (nominal resolution is 2.7 m × 2.7 m) of 1963a and 1968a, Landsat MSS of 1973a (nominal resolution is 79 m × 79 m), KATE-200 photographs of 1980a (nominal resolution is 8.9 m × 8.9 m), Landsat TM images from 1986a, 1993a, 2005a, 2010a and ETM+ from 1999a (nominal resolution is 30 m × 30 m). These data were selected in either summer and/or autumn for it is the best time to study the oasis. Other map data included a topographic map of 1:50 000 made in 1960a and 1972a, a topographic map of 1:100 000 made in 1984a, and a land use map at a scale of 1:100 000 of 1990a, 2007a, all the maps came from Gansu Department of Land and Resources.

The images were geo-referenced to obtain optimal superimposition and minimize geographical deviation (Ruelland et al., 2010). With reference to topographic data, geometric correction and mosaic of the satellite images were implemented using ERDAS version 9.3 (Zhou et al., 2010). The ETM+ image (1999) was geo-referenced using ground control points with a root mean square error (RMSE) of two pixels (Table 1). The KATE-200 photographs, Keyhole photographs, MSS and TM images were geo-referenced