Relationship between landscape fragmentation and oasis evolution: a case study of Suzhou Oasis in arid China

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Abstract: Landscape fragmentation in arid area under the global Land Use/Cover Change has drawn more attention in research of arid landscape ecology recently. In this study, the evaluated oasis evolution and its landscape fragmentation in Suzhou Oasis, a typical agricultural oasis in the middle reach of the Heihe River watershed. Oasis maps were obtained from Landsat TM images for 1990, 1999 and 2010, respectively. The results indicated that during 1990 to 2010, the change of oasis area was dominated by an increase of farmland, grassland and constructed land. The oasis area had increased mainly due to the conversion of farmland, unused land to grassland, and rapid urbanization. Landscape fragmentation index changed over time in the 15 towns, and there was a decrease of number of patches (NP), patch density (PD) and largest patch index (LPI), and an increase in division index (DIV) and Shannon’s density index (SHI), suggesting that the change of landscape fragmentation degree had slowed down gradually. An improved method is used to describe the villages and towns scales of landscape fragmentation of the oasis evolution and fragmentation process.

1. Introduction
Science Land Use/Land Cover Change (LUCC) have become a global change research in the 1990s, more efforts have been devoted to the evolution process, landscape pattern, driving forces and future modeling of LUCC[1-3]. In arid areas of western China, LUCC of oases is influenced by natural and humanities factors and is restricted by resource conditions[4-5]. Landscape structure of continental river basin in arid zone of northwest China is simple, land use change in the process of oasis is bound to arouse changes in watershed landscape structure and the component[4], leading to regional landscape pattern change further, and this process will lead to regional ecological and environmental change.

Landscape fragmentation of landscape structure, function and ecological processes has different degree of influence[5]. Carry out human activities and landscape fragmentation research has always been a hot topic in landscape ecology[6-8]. With the rapid development of the "3S" technology, the quantitative research of landscape fragmentation also successively carried out both at domestic and abroad. Ülo Mandera took Estonia for example to explore the correlation analysis of connection degree and landscape fragmentation[9]. Simon Blanchet through to the research of landscape fragmentation to explore reasonable land use management strategies[10]. Darla k. Munroe explored the impact of land-use policies on urbanization and landscape fragmentation in Bloomington[11]. Many domestic researchers believe that landscape fragmentation show a certain distribution[12], and studied landscape fragmentation under the oasis development process in different geographical units[5,13-14].
Studies have found that as the oasis development (or oasis expansion), oasis landscape fragmentation have intensified trend. However, these studies focused on the analysis of landscape indexes, studies of spatial relationship between oasis development and landscape fragmentation have reported relatively uncommon.

Landscape index research is more than the combination of quantitative and qualitative analysis\textsuperscript{[15-16]}. For example, a commonly used degree of landscape fragmentation is the plaque number on unit area\textsuperscript{[17-19]}. However, in this study concluded that plaque broken degree is not only the size of the patch number density, also should consider the diversity of plaque type. So the Shannon’s diversity index (SHI) were introduced of the new patch fragmentation index calculation, tries to explore the patch fragmentation and the relationship between the oasis evolution process. Suzhou in Hexi Corridor, western of China, gestated many landscapes of oasis agriculture on Beidahe River watershed, and formed two land-use modes, Farm-based Land Use and Construction land. This study tries to address these issues by examining the land change from 1990 to 2009 for the oasis. Use GIS platform and a new landscape method to carry out the spatial and temporal distribution of oasis landscape fragmentation in 20 years and its variation law in Suzhou, preliminary explore the interaction influence and relationships between oasis development process and landscape fragmentation and its influence factors.

2. Materials and methods

2.1. Study area

Study area is located at the center of Hexi Corridor in NW China 39°10′-39°59′N, 98°12′-99°18′E (Figure 1). In study area, the landscape consists of farmland, grassland, water, forestland, construction land and unused land. The region has a temperate continental dry climate with a mean temperature of 7.3°C. The amount of annual precipitation is only 85.3 mm. Suzhou Oasis is important for human survival space with development by irrigated agriculture in this region, two irrigated methods supports this area’s agriculture, as the region consist by two parts: Piedmont alluvial fan and along the banks of the stream in Beidahe River.

2.2. Data sources and Method

Study data in this research include were (1) Three periods of remote sensing images of Suzhou Oasis, including Landsat TM images from August in 1990, 1999 and 2010 (Resolution:30 m), which images oasis consist and change in the last 20 years. Based on the real auction, the oasis landscape was classified into five categories, including farmland, grassland, water, forestland and construction land\textsuperscript{[19]} (2) The socio-economic data, oasis and landscape pattern change factors from 1990 to 2010 is synthesized from the socio-economic statistical year book of Suzhou.

2.3. Description of oasis processing

The oasis dynamic degree\textsuperscript{[20-21]}, relative change rate\textsuperscript{[22]} of oasis were used to describe the oasis spatial-temporal processing. The oasis dynamic degree, respectively, represent the general change rate and per year change rate during the period, which can be respectively expressed as

\[
K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \tag{2.1}
\]

Where \(K\) represent dynamic degree, for a certain LUCC type during the period; \(U_a\) and \(U_b\) represent the areas for a certain land type at the start and end time; and \(T\) is time.
Figure 1. The location and oasis landscape pattern for study area

The relative change rate of a certain land type reveals spatial difference. It is expressed as

\[ R = \frac{|U_b - U_a| \times C_a}{U_a \times |C_b - C_a|} \]  \hspace{1cm} (2.2)

Where \( R \) is the relative change rate of a certain land type, \( K_a \) and \( K_b \) are the areas for a certain land type in a specific region at the start and end time, respectively, \( C_a \) and \( C_b \) are areas for the land type in the entire region at the start and end time, respectively.

Geographic information system (GIS) platform is used to land use type classification and analysis of land use type conversion, and data statistics in space. Time superimposed analysis to describe the evolution of oasis in time and space process.

2.4. Landscape fragmentation metrics

Landscape pattern on the basis of the previous studies\(^{22-25}\), six landscape metrics were selected to measure the spatial pattern of oasis change over time, including number of patches (NP), patch density (PD), largest patch index (LPI), division index (DIV) and Shannon’s diversity index (SHDI).
Landscape fragmentation refers to the divided degree of landscape, reflecting the interference degree of landscape influenced by human activities. Landscape fragmentation index (F) is positively related to the number of patches and negatively related to the average patch area. The index is calculated by the following formula:

\[ F = \sum_{i=1}^{n} N_i / A \]  

(2.3)

Where \( F \) is the landscape fragmentation, \( N_i \) is the number of land use patches of type \( i \), \( A \) is the total area.

Shannon's diversity index (SHDI) is represented by:

\[ SHDI = -\sum_{i=1}^{n} P_i \ln(P_i) \]  

(2.4)

Where SHDI is stand for the Shannon’s diversity index. \( P_i \) is the area proportion of land use type \( i \), \( n \) is the total number of land use type.

In this study, landscape fragmentation is not only contain by the number of patch, but also the different type in each path. The different as follows:

\[ F_{new} = F \times SHDI = \sum_{i=1}^{n} [P_i \ln(P_i)] \cdot N_i \cdot 100 / A \]  

(2.5)

Where \( N \) is the total number of patches; and \( A \) is the total area of landscapes. \( P_i \) is the area proportion of land use type \( i \), \( n \) is the total number of land use type.

3. Results and Analysis

3.1. Oasis evolution

Oasis is mainly distributed in the mainstream of Beidahe River basin and piedmont alluvial plains, with scattered small oasis rely on groundwater irrigation (Figure 1). Farmland is an absolutely main body with proportion of the oasis area greater than 80.93%. Grassland, water is an organic component, the proportion of forest land is minimal in Suzhou Oasis, only accounts from 0.03% to 0.11%. The main content of oasis evolution is the expansion of the oasis area. Over the past 20 years, the oasis area is increased by 362.9 km², growth rate of 35.4%. Among them, the farmland, grassland, construction land area increased by 7.48%, 1.53% and 1.39%, respectively, unused decreased by 10.83%, the body of the oasis area of growth are farmland, grassland and construction land. Oasis from 1990 to 2010, the dynamic change of construction land to the maximum, the size is much higher than the rest of the oasis changes to classes. Farmland area changes is the largest, but at the same time,
the subjects of oasis consists of farmland, therefore, dynamic rendering of the minimum value. Showing that nearly 20 years the rapid advance of urbanization process, it is 1999-2010, city area is expanding rapidly (Table 1). Oasis evolution process changes assume a periodic in 1990-1999 and 1999-2010. The magnitude and scale of oasis growth in the first decade is bigger than the second (Table 1). As the 1990-1999, The farmland in Suzhou Oasis was increases by the proportion of 2.81%, which growth an area of 94.04 km²; Followed by the grassland, the increasing area with 23.79 km² (with the increase proportion of 0.71%); Proportion of water of 4.02 km², up by 0.12%, this because of the result by Water level recovery in tidal flats wetlands around the reservoir and Seasonal rivers water levels rise in the northwest corner of the oasis (Table 1); Area of forestland in study area increased only 0.93 km² (with the increase area proportion of 0.03%); Construction land contains with urban areas and township for residential areas, it is the fastest expansion to the stage area class, characterized by increased construction land area of 25.07 km² (with the increase proportion by 0.74%), what suggesting the influence of rapid urbanization in oasis area in Northwest China; The area of unused land decreased 137.83 km², which converted to oasis land use types, it shows the strengthen impact of human activities on oasis land cover change. During 1999-2010, the growth of the farmland land area with 156.69 km²(proportion increase 4.67%), mainly in internal padding and margin expansion; Grassland area has increased 27.49 km² (its proportion with a change 0.82%), mainly shows with grassland expansion of the eastern Yinda township ; water increased by 10.06 km² (0.30% growth), this is mainly due to the influence of seasonal melt water supplies and rainfall, precipitation, and the irrigation water which is not stable; Forest land area showed a trend of decrease (decreased 0.58 km²), mainly caused by the forest land turn into grassland (or brush); The area of construction land area increased 21.6 km²(proportion increase0.65%); In the meantime the unused land still reduce (with the decreased area of 215.08 km², fell by the proportion 6.42%).

| Type          | 1990  | 1999  | 1990-1999 | 2010   | 1999-2010 | 1990-2010 |
|---------------|-------|-------|-----------|--------|-----------|-----------|
|               | Area (km²) | Percent (%) | Area (km²) | Percent (%) | Area (km²) | Percent (%) | Area (km²) | Percent (%) | Area (km²) | Percent (%) | K  |
| Farmland      | 872.21 | 26.03 | 966.25 | 28.84 | 94.04 | 2.81 | 1122.74 | 33.51 | 156.49 | 4.67 | 0.01 |
| Grassland     | 98.96 | 2.95 | 122.75 | 3.66 | 23.78 | 0.71 | 150.24 | 4.48 | 27.50 | 0.82 | 0.03 |
| water         | 36.15 | 1.08 | 40.17 | 1.20 | 4.01 | 0.12 | 50.23 | 1.50 | 10.06 | 0.30 | 0.02 |
| Forestland    | 0.38 | 0.01 | 1.31 | 0.04 | 0.93 | 0.03 | 0.73 | 0.02 | -0.58 | -0.02 | 0.05 |
| Construction  | 16.61 | 0.50 | 41.68 | 1.24 | 25.07 | 0.75 | 63.28 | 1.89 | 21.60 | 0.64 | 0.14 |
| Unused land   | 2326.28 | 69.43 | 2178.45 | 65.02 | 147.83 | -4.41 | 1963.37 | 58.60 | 215.08 | -6.42 | 0.02 |

3.2. The analysis on Oasis fragmentation
Beidahe River coast in 1990. A small range of high value soccur in Fengle river and piedmont alluvial area around, its overall change is below Beidahe River coast. The Beidahe River coast and reclamation of fringe area make the oasis area larger. DIV index change occurs mainly in the process when unused land transfers into grassland and farmland, exacerbating the fragmentation degree of unused land. But in the piedmont alluvial area oasis are characterized by a relatively single landscape isolation index. As is shown in high values of landscape diversity index are mainly distributed in the Beidahe River coast, the main value is 0.712-1.316, which due to the diversity existence of land use and the high value concentrated in Sandun town The landscape diversity index of Hongshuihe River and Fenglehe River located in piedmont alluvial ranges from 0.561 to 0.742 with a single land utilization way. High value area of Shannon diversity index in 2010 are mainly distributed on the edge of the oasis, including the eastern areas affected by the sprawl across Suzhou, Huangnipo township and Sandun town.
3.3. Relationship between oasis evolution and landscape fragmentation

In the villages and towns as the sample, is calculated for each township in 1990 and 2010, landscape index difference and dynamic and relative rate of change of each township oasis (Figure 3). Landscape difference directly reflects the villages and towns landscape index variation and situational, positive and negative to represent the state of plaque index increase and decrease. The change of town landscape index is obvious. Including the np-poor performance of negative silver quality, the qingshuixiang and village under jinfushi ranked second, while the other villages and towns all experienced minor changes. PD basic characterized by negative difference, difference is larger negative Xifeng township and silver of difference, township village town, huasheng pointed times, also show the negative difference, change the rest of the villages and towns is very low. LPI difference change in basic is not big, but in a town, presents the biggest positive difference under the silver of the town and the Qingshui township, negatively to change, the rest of the villages and towns small changes. DIV showed a town on the biggest negative difference, under the silver of the town and the Qingshui township negative difference. SHDI difference on performance for a town township and semple negative changes, other towns change for positive change. Oasis each dynamic change, you can see that every point of positive change, the expansion trend oasis in every township, silver edge of villages and towns of the town, three town pier, Huangnipo and Xiaheqing township quite dramatically. Relative change rate showed three piers town, under the Qingshui township, silver and Huangnipo is the change in the study area as a whole more violent.

Through adoption of the new method, the accuracy of landscape broken flower index description is improved. Also found that the evolution of the oasis of intensity and change and landscape fragmentation degree is not necessarily associated, the influence of landscape heterogeneity and the space-time difference of impact factor, fragmentation and the oasis words present different characteristics and coexist with each other.
Figure 3. Relationship between oasis evolution and landscape fragmentation in township scale for different fragmentation methods. (F stand for fragmentation in old way, F\textsubscript{new} is the method this study used)

4. Conclusion

Temporal and spatial distribution of oasis landscape analysis shows the expansion trend across Suzhou Oasis in the past 20 years, the oasis area is increased by 362.9 km\(^2\) with the growth rate of 35.4\%. The farmland, grassland, construction land and water are the body composition of oasis. Space expansion and area growth of farmland are dominant for oasis increase, the variation extent of oasis area is shown as farmland > grassland > construction land > water > forestland.

The analysis on landscape fragmentation and spatial conversion for oasis indicate that oasis expansion way (especially the expansion of the farmland) is shown as the internal filling and edge expansion. Based on the density of landscape fragmentation analysis, the results show that human activities and process of oasis development have profound effects on the development of landscape fragmentation, which is closely related to the overall stability of the oasis. There exists obvious difference between the main body and piedmont oasis and the stability of piedmont oasis is particularly important.

The oasis process is accompanied by landscape fragmentation increase or slow down, which is mainly influenced by oasis expansion methods and regional differences, and there is no direct response relationship with the process of oasis. Overall, the oasis development and landscape fragmentation differences is different by regional diversity. The infill development in Beidahe River promotes the continuous and overall ability of nearshore zone and slows down the fragmentation trend of oasis happened in the inner regions of the oasis.

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