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Road construction and landscape fragmentation in China

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Abstract: The landscape fragmentation caused by road construction has many direct and indirect impacts on wildlife and ecosystems. By using the GIS and statistic software of fragmentation computation, a comprehensive index, road-induced landscape fragmentation index (RLFI), is proposed to quantify the degree of landscape fragmentation resulting from different levels of road constructions. The results show that road-induced fragmentation index in China ranges from 0.987 to 3.357, with a mean of 1.846 in 2002. The regional differences of landscape fragmentation are obvious and scoring sequence is: North China (2.65) > East China (2.62) > Central China (2.60) > South China (2.51) > Southwest China (2.34) > Northeast China (2.19) > Inner Mongolia (1.88) > Northwest China (1.67) > Qinghai-Tibet Plateau (1.65). The anisotropic analysis indicates that the variation of fragmentation index in east-west direction is larger than that in south-north direction.
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The phenomenon of habitat fragmentation which was resulted from anthropogenic disturbances for natural landscape or ecosystems such as removing original land cover, creating edge habitat, altering landscape structure and function, and increasing access for human, has attracted a considerable recent interests due to a growing appreciation in biological conservation and ecosystem management. The division and dissection of the landscapes by linear elements such as roads, pipeline corridors and other rights-of-way contributes to the loss and fragmentation of habitat. Landscapes bisected by these elements would be expected to have more and smaller habitat patches, decreased connectivity between patches, decreased complexity of patch shape, and higher proportions of edge habitat (Saunders S C *et al*., 2002).

As linear transportation infrastructure, roads of all kinds have seven general effects: mortality from road construction, mortality from collision with vehicles, modification of animal behavior, alteration of the physical environment, alteration of the chemical environment, spread of exotics, and increased use of areas by humans. "Roads precipitate fragmentation by dissecting previously large patches into smaller ones" and by creating a barrier to movement and dispersal between adjacent habitat patches (Reed *et al*., 1996; Forman and Alexander, 1998). Recent calculations indicate that the ecological influences of USA roads may extend hundreds or thousands of meters from the roadside, suggesting that upwards of 20% of the USA is directly, ecologically affected by roads (Forman, 2000; Forman and Deblinger, 2000; Forman *et al*., 1997). The representatives of 12 European countries such as Austria, Belgium, France, The Netherlands, Spain, and United Kingdom etc. present at the meeting of the European expert group Infra Eco Network Europe (IENE) held in Romania on 9-11 October 1996 have stressed the need for co-operation and exchange of information in the field of habitat fragmentation caused by infrastructure at European level. After the meeting, COST 341 project -- Habitat Fragmentation due to linear Transportation Infrastructure was implemented. The scientists in China have increasingly growing concerns about the impacts of road construction on natural ecosystems, and many researches

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were carried out, focusing on the effects of linear Transportation Infrastructure on LUCC and landscape structure and functions (Zhang *et al*., 2002; Yan *et al*., 2003; Kan and Meng, 1998).

As the national population grows, so does the construction and impacts of new roads. Currently, at least 1.77 million km of public roads crisscross all over China. Roads are conspicuous components of landscapes and play a substantial role in defining landscape patterns. Researches concerning roads and their influence on landscape fragmentation offer sufficient reasons for adopting precautionary measures towards road management. Researches into the relationships between landscape fragmentation and road networks can offer useful information for managing road and adjacent ecosystems.

The objectives of this study are to investigate the role of roads in segmenting landscape patterns and structure, and quantitatively measure the degree of road-induced landscape fragmentation in China.

1 Study area and data

1.1 Study area

China has experienced a tremendous growth in road construction over the past decades. In 2002 its total road mileage approximately reached 1.765 million km, with expressway amounting to 25,100 km. The road density in China has shown a rapid increase since 2000 (Figure 1). The planned national trunk road network, composed of "five verticals" and "seven horizontals", is expected to be completed by 2010, adding another 0.35 million km across the country. By more than 50 years of road construction, road networks will be well established in China (Figure 2).

1.2 Data and preprocess

Based on geographical information systems (GIS), two main data layers from two separate sources are employed in this study: (1) National Geomatics Center of China 1:250,000 scale road map (2002) and (2) Institute of Geographic Sciences and Natural Resources Research, CAS 1: 4,000,000 scale vegetation map (1996). The resolution of this map is high enough to analyze the fragmentation due to vegetation only as a background layer bisected by roads.

Prior to analyzing the landscape fragmentation that was resulted from road construction, two data layers are preprocessed in ArcGIS 8.3 (ERSI Inc. 1999-2002). On the purposes of calculating landscape fragmentation statistics, the vegetation types on vegetation map are combined and reclassified into five types: forest, grassland, cropland, desert and water body. All kinds of roads, i.e., expressway, primary highway, secondary-class highway, third-class highway, forth-class highway and substandard road, are extracted from road map and converted to single vector layer. To account for the fragmenting effects of road network, six 1:250,000 scale road vector layers are respectively superimposed upon reclassified vegetation data set by using merge function in ArcGIS8.3.

2 Quantifying the degree of landscape fragmentation

2.1 Statistic unit

In order to explicitly delineate the patterns of landscape fragmentation, we define our units of analysis, termed grid units, using Gridmaker function in MPAINFO7.0 (MPAINFO Corporation, 1985-2002). The original size of each grid with longitude/latitude projection is 25 km $\times$ 25 km and the total grid number is 16,642 in China. The grid units layer is constructed to summarize the calculation results of landscape fragmentation, and display its spatial patterns.

2.2 Patch analysis software

The spatial analysis program Patch Analyst 3.1(beta) (Rob Rempel, 2003), an extension to the ArcView GIS system, is used to quantify the landscape fragmentation because it facilitates the spatial analysis of landscape patches, and modelling of attributes associated with patches.

Roads are coded as background cover, so that they are not treated as patches themselves

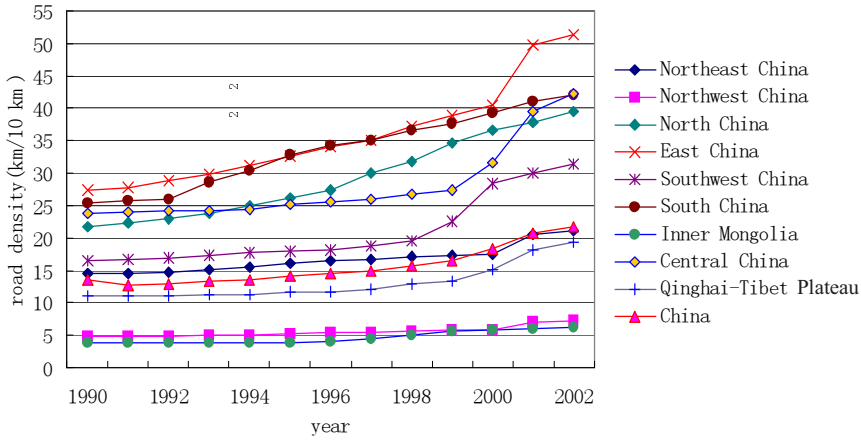

Figure 1 The development process of road density in China

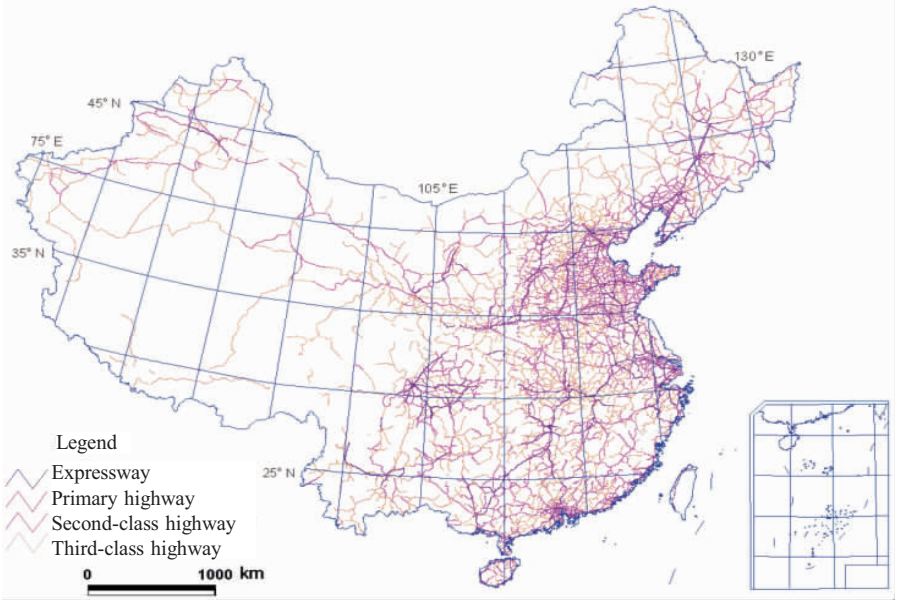

Figure 2 Spatial patterns of road network in China (2002)

(Heilman *et al*., 2002). Patch Analyst calculates a set of pattern metrics for each patch within a landscape, each cover class within a landscape, and the entire landscape.

Because many landscape structure metrics are correlated and redundant (Haines-Young and Chopping M, 1996), we choose the patch density, edge density and fractal dimension as indicators of landscape fragmentation.

2.3 Fragmentation index

Road density, road length per unit area, is a convenient measure of human presence on a landscape and may, in some cases maybe appropriately used as a proxy for the suite of changes to landscape structure that are associated with human fragmentation of a landscape (Saunders S C *et al*., 2002).

Patch density equals the number of patches of the corresponding patch type divided by area of grid unit if 'analyze by landscape' is selected, or number of patches for each individual class, if 'analyze by class' is selected.

Edge density equals the sum of the lengths of all edge segments involving the corresponding

patch type, divided by area of grid unit. Edge density equals to zero when no roads are mosaicked onto vegetation patch and only one vegetation type in a specified grid unit.

Fractal dimension represents the complexity of patch shape. A fractal dimension greater than 1 for 2-dimensions indicates a departure from Euclidean geometry (i.e., an increase in shape complexity). The value of fractal dimension approaches 1 for patch shape with very simple perimeters such as circles or squares, and approaches 2 for patch shape with highly convoluted, plane-filling perimeters.

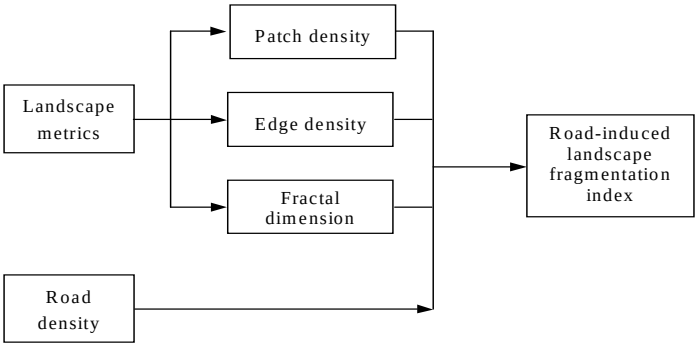

Figure 3 Flow diagram of the GIS process to derive RLFI

The landscape fragmentation is a complex and subtle concept, especially as it relates to the road network whose effects differ in many circumstances. Although several indices are employed to measure the degree of landscape fragmentation such as patch number, patch density, edge length, core area, patch fractal dimension etc., it is insufficient, however, to comprehensively quantify the landscape fragmentation by using the above simplex index.

By integrating Patch Analyst-derived landscape metrics and GIS-derived road density into a single index, a road-induced landscape fragmentation index (RLFI), is developed in this study, which can be used to indicate the degree of landscape fragmentation.

The procedure to determine the RLFI for the study area is as follows: (1) three landscape metrics, i.e., patch density, edge density and fractal dimension, are computed for all 16,442 grid units by using Patch Analyst. Similarly, road density for each grid unit is calculated by using the function of tabulated area in ArcView. (2) Each index is normalized to a range between 0 to 1. (3) Four normalized indices are summed up and integrated into a comprehensive index (RLFI) with a range between 0 to 4 (Figure 3).

RLFI is defined as

$$RLFI = \sum_{i=1}^{4} W_i A_i \qquad (0 \le A_i \le 1)$$

where A_i represents road density, patch density, Edge density, and fractal dimension respectively. W_i is a weighted factor and the weighted value of each index equals to 1 in this research.

3 Results

Statistics reveals differences in the amount of variability and skewness of the fragmentation index of five indices. Fragmentation index in China ranges from 0.987 to 3.357, with a mean 1.846 and standard deviation 0.415 in 2002 (Table 1).

It is obvious that the spatial patterns of landscape fragmentation are caused by road construction (Figure 4). Eastern regions in China have the higher fragmenting index with mean value 2.297 and standard 0.437, while western regions have the lower fragmenting index with mean value 1.600 and standard deviation 0.445. From finer scale, the Tarim Basin and central and northern parts of the Qinghai-Tibet Plateau are the lowest value centers of fragmentation index in western China, while Da Hinggan Ling, Xiao Hinggan Ling, Changbai Mountains, as well as mountains in Fujian and Zhejiang provinces are the lowest value centers in eastern China. Being closely correlated with intensity of the anthropogenic disturbances, Liaodong Peninsula, Shandong Peninsula, North China Plain, Jianghuai Plain, Middle and Lower Yangtze Plain, and Zhujiang River Delta have a high index, in other words, a severe landscape fragmentation.

Table 1 Statistics for selected indices in China (2002)

Statistics	Road density	Patch density	Edge density	Fractal dimension	Fragmentation index
Minimum value	0.000	0.010	0.074	0.837	0.987
Maximum value	0.853	1.000	1.000	1.000	3.357
Mean value	0.490	0.454	0.595	0.895	1.846
Median value	0.516	0.463	0.615	0.896	2.506
Standard deviation	0.157	0.191	0.088	0.009	0.415
Skewness	-0.707	-0.164	-1.674	-0.934	-0.783
Kurtosis	3.160	2.260	7.005	8.386	3.229
1st Quartile	0.395	0.314	0.564	0.891	2.189
3rd Quartile	0.606	0.604	0.651	0.901	2.758

Note: all indices are normalized but fragmentation index, not original value

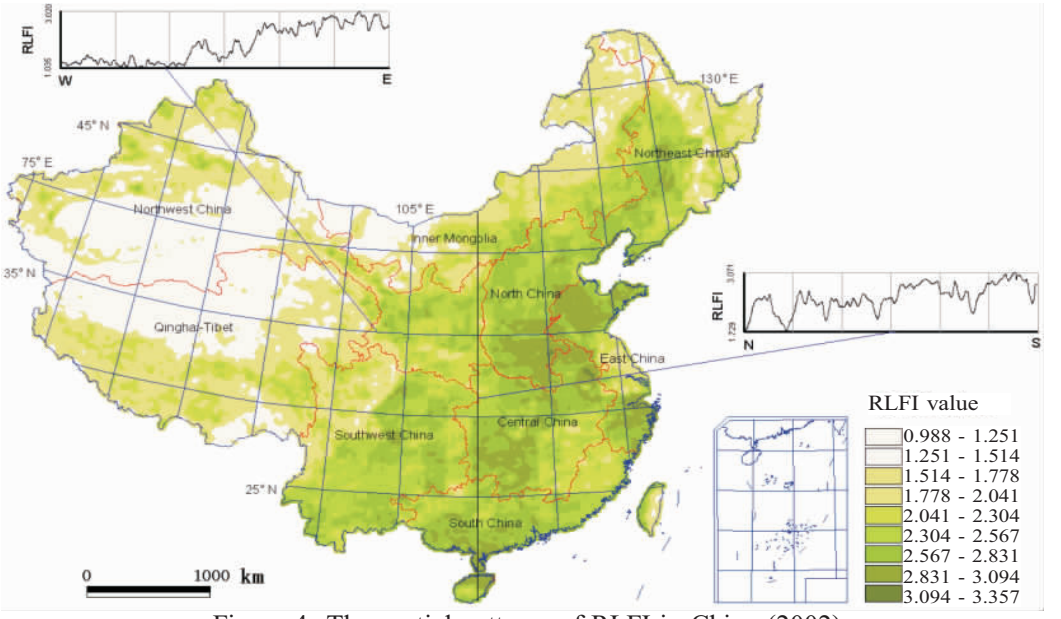

Figure 4 The spatial patterns of RLFI in China (2002)

In order to explicitly show the spatial variation of fragmentation degree, profiles of the index along 110°E longitude and 35°N latitude directions are made using profiling function in ArcView, which exhibit lower values in west and north regions, and higher values in east and south regions (Figure 4). Both profiles show obvious spatial differences, the variations in east-west direction, however, are far greater than those in south-north direction.

To analyze the regional differences of fragmentation degree, we summarize the statistic results according to the modified rationalization.

Nine regions in China have different road-induced landscape fragmentation indices, and the subsequence of index from high to low is: North China (2.65) > East China (2.62) > Central China (2.60) > South China (2.51) > Southwest China (2.34) > Northeast China (2.19) > Inner Mongolia (1.88) > Northwest China (1.67) > Qinghai-Tibet Plateau (1.65) (Table 2).

Table 2 Statistics for landscape fragmentation index in different regions of China in 2002

Region Name	Min	Max	Range	Mean	Std
Northeast China	1.0637	3.0912	2.0275	2.1946	0.4251
North China	1.9196	3.1891	1.2695	2.6548	0.2119
Northwest China	0.9932	2.8991	1.9059	1.6672	0.4859
Central China	1.5076	3.1817	1.6740	2.6018	0.2582
East China	1.5120	3.3570	1.8450	2.6242	0.3488
Southwest China	1.0881	3.0159	1.9278	2.3415	0.3138
South China	1.2599	3.2160	1.9561	2.5128	0.2928
Inner Mongolia	1.0000	2.9596	1.9596	1.8872	0.4186
Qinghai-Tibet	0.9910	2.8191	1.8281	1.6492	0.3670

4 Conclusions and discussion

At national scale, 1:250,000 scale road vector map offers outstanding potential for analysing the landscape fragmentation. In this article we outline a methodology and propose a comprehensive index for measuring the degree of landscape fragmentation that was resulted from road construction. Our preliminary researches have the following conclusions:

(1) The road constructions in China have caused significant landscape fragmentation. Quantitatively measuring the fragmentation degree is the precondition for managing the road and adjacent ecosystems.

(2) The primary contribution of this paper is to provide a unified assessing framework with GIS platform. We have shown how to mosaic and merge vegetation types and different level roads and how to compute landscape metrics after all road patches being removed. We developed a comprehensive index, RLFI, for assessing road-induced landscape fragmentation, which consists of road density, patch density, edge density and patch fractal dimension, and then used it to calculate the China's fragmentation degree caused by different level road constructions.

(3) The patterns of road-induced landscape fragmentation exhibit obvious anisotropic variabilities in China, especially in east-west direction, which are consistent with spatial distributions of socioeconomic factors such as GDP, housing area, population density, etc.

(4) The landscape fragmentation due to road construction has been widely acknowledged. Numerous attempts have been made worldwide to prevent, mitigate or compensate for the adverse effects. The most important work in counteracting habitat fragmentation due to transportation infrastructure is to prevent fragmentation or to reduce the existing levels of fragmentation.

Some work remains to be done: (a) probing into the relationships between landscape fragmentation and its natural and socioeconomic factors; (b) analysing the scaling effects in landscape fragmentation; and (c) choosing finer scale as the study area to show more detailed patterns of road-induced fragmentation.

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References

Forman R T T, 2000. Estimate of the area affected ecologically by the road system in the United States. *Conservation Biology*, 14: 31-35.

Forman R T T, Alexander L E, 1998. Roads and their major ecological effects. *Annual Review of Ecological Systems*, 29: 207-231.

Forman R T T, Deblinger R D, 2000. The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. *Conservation Biology*, 14: 36-46.

Forman R T T *et al*., 1997. Ecological effects of roads: toward three indices and an overview for North America. In: Canters K (ed.), Habitat Fragmentation & Infrastructure. Minist. Transp., Public Works & Water Manage., 40-54. Netherlands.

Haines-Young R, Chopping M, 1996. Quantifying landscape structure: a review of landscape indices and their application to forested landscapes. *Progress in Physical Geography*, 20(4): 418-445.

Heilman Jr G E *et al*., 2002. Forest fragmentation of the conterminous United States: assessing forest intactness through road density and spatial characteristics. *Biosciences*, 52(5): 411-422.

Kan Shuyu, Meng Zhiyong, 1998. Study on sustainable development of railway and highway engineering construction and rationality of land-occupation. *J. of Northern Jiaotong Univ*., 1998, 22(2): 45-49. (in Chinese)

Reed R A, Johnson-Barnard J, Baker W L, 1996. Contribution of roads to forest fragmentation in the rocky mountains. *Conservation Biology*, 10(4): 1098-1106.

Saunders S C *et al*., 2002. Effects of roads on landscape structure within nested ecological units of the Northern Great Lakes Region, USA. *Biological Conservation*, 103: 209-225.

Yan Jianzhong, Zhang Yili, Liu Linshan *et al*., 2003. Main effect of plateau traffic on land use and landscape pattern change: from Lanzhou to Golmud. *Acta Geographica Sinica*, 58(1): 34-42. (in Chinese)

Zhang Yili, Yan Jianzhong, Liu Linshan *et al*., 2002. Impact of Qinghai-Xizang Highway on land use and landscape pattern change. *Acta Geographica Sinica*, 57(3): 253-266. (in Chinese)