Nestedness analysis of land use change on pedodiversity under the intensive urbanization process

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The nestedness analysis method has been used in biological studies for many decades and is thought to have greatly expanded ecologists capacities to deal with complex biotic patterns within archipelagos or "islands" of terrestrial or aquatic habitat. Diverse biotic and abiotic processes are believed to generate nested distributions, including non-random extinction, differential colonization, and nestedness of critical resources. Biodiversity research is the keystone of conservation biology and natural reserves design. One of the most obvious causes of variation in the distribution of plant species and communities is the underlying soil variation. Usually ecologists use soil variables, but do not consider soil types in the same way as they consider bio-species. It was not until the beginning of the 1990s that soil data were analyzed with mathematical tools developed for the study of biodiversity. Only recently, has the extensions of nested subset analysis to other taxa, regions, and spatial scales just begun. Rapid urbanization has caused many social and environmental problems including a clear loss of certain soil types or unique soil units to urbanization. Our recently published research results in Nanjing indicate that 2 soil types, Clay loamy fimic-ferriudic argosol and Loamy car-mottlic-fimic-orthic anthrosol as classified in the Chinese Soil Taxonomy, may be in danger of disappearing under urban/suburban structures because they have been decreased by 41.4% and 62.4%, respectively in the past 20 years. Seven soils decreased by more than 10%, and 8 others decreased by more than 5%. Land use changes, especially resulting from the rapid urbanization process, have often had a great impact on pedodiversity. The loss of soil types may therefore represent loss of whole biological communities unique to those soil types. The conservation of pedodiversity also brings into question the wisdom of converting to agriculture those soils that have not previously been cultivated. This paper tries to share the nestedness analysis method from biological studies to examine the spatial-temporal change of pedological assemblages and pedodiversity characteristics (Nested pattern) due to the influence of the fast urban expansion of Nanjing in the past 20 years.

Study site, data and method

The data used in the study is a set of Landsat satellite TM images overlaid with the digital soil database map (at scale 1:200,000) in which 19 soil mapping unit delineations forming 869 polygons excluding 16 non- soil polygons were linked with their attribute databases of natural conditions and different soil properties of the studied area. Nanjing is located in the Yangtse delta (Jiangsu province, east China, Figure 1), and known as a famous historic city, which was home to a large community of human beings in the late period of the mid-Pleistocene epoch 350,000 years ago and has experienced extensive development in the past 2-3 decades with 9 new economic development zones established around the city.

The methodology consists of analyzing data with a geographic information system (GIS) to combine urban land use maps of different times derived from satellite images with data on soil characteristics contained in the established soil databases before a nested subset analysis is conducted. The integration of satellite remote sensing and GIS technology proved to be an efficient method for mapping and analysis of urban land use change. Some ideas from SOTER methodology were borrowed to build a database for spatial analysis and evaluation. In a perfectly nested matrix, the hypothetical line that separates the occupied area of the matrix from the unoccupied portion is called “boundary line”. Taxa absences above and to the left of the line are defined as unexpected, the same as the taxa presented below and to the right. When randomness is low, unexpected presences and absences cluster near the boundary line. In contrast, when it increases, both unexpected presences and absences move further away from it. The “entropy” of the matrix is a result. The “Temperature Calculator” of Atmar and Patterson used in this paper seems ideally suited to explore various features of nestedness (Figure 2).

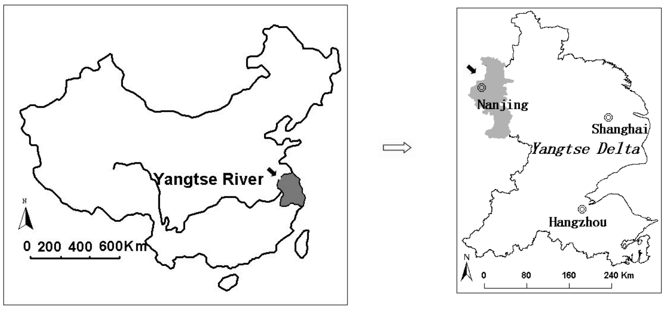

Figure 1. Location of the study area.

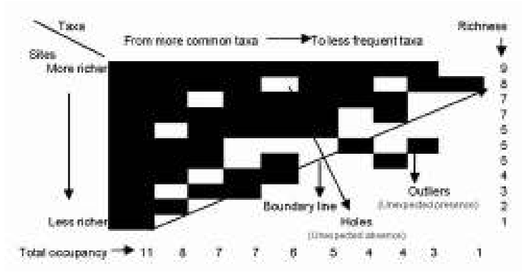

Figure 2. Typical realistic nested matrix.

Results and discussion

Land use change under fast urbanization process from 1984 to 2003

The urban sprawl data from 1984 to 2003 was obtained by interpretation of Landsat TM satellite images from different dates (1984, 1995, 2000 and 2003) (Figure 3). The images show Nanjing undergoing rapid urbanization in the past 20 years. The city urban area increased 16,776 ha from its starting area 31,634 ha in 1984 to 48,410 ha in 1995 with a 1525 ha yearly increase (4.8%). During the next two periods, 1995–2000 and 2000–2003, all values were clearly higher than the previous annual increase: 2470 ha y^{-1} or 5.1% during 1995–2000 and an annual increase of 4804 ha y^{-1} or 7.9% during 2000–2003. In the past 20 years, there has been an absolute urban area increase of 43,544 ha in Nanjing area, which is now 2 times larger than before (Table 1). More urban areas including the city, attached county seat and township areas expanded each year at an annual rate of 6.9%. Trends in urbanization of the city show that the city is more urbanized southward than other directions since the city economy was naturally stopped in its growth by the Yangtse River to the northwest. It is considered to be the geographic line dividing north and south China and the mountainous area east of the city. People in this area traditionally preferred to live or do business on the south side of the Yangtse River that played an important role in shaping the city structure in its recent history. The newly established Jiangning economic development zone (Jiangning District) south of the original Nanjing city is another reason for the current city urban/suburban growth pattern. A satellite-based calculation shows that 11.3% of the total land area of Nanjing city is now in urban use (2003) compared with only 4.8% in 1984. It is clear that the best soils are being developed first even though the percentage of urbanized area relative to the city total land surface is not very high. There is evidence, however, that some preservation of the very best soils has been taking place.

Table 1 The extended urban area of Nanjing city from 1984 to 2003 (ha).

Time	1984-1995	1995-2000	2000-2003
Starting area	31634.61	48410.93	60764.49
Extended area	16776.32	12353.56	14414.48
Increased area per year	1525.12	2470.71	4804.83
Yearly increase rate (%)	4.82	5.10	7.91

An increased nestedness of land use pattern under urbanization growth

Ecologists and pedologists are both aware that not all taxa that occur within a region are widespread within that entire region. For a set of sites, one can envisage a presence–absence, or incidence, matrix of resident taxa. Rows represent the sites, and columns represent names of all the taxa. Each site-taxon combination is represented by a one or a zero depending on whether the taxon is present or absent at that site. Summing across rows give the taxa richness recorded in a given site. Summing across columns for a given taxon give the number of locations where its presence has been recorded. These matrices provide a simple graphic illustration of the interrelationships between patterns of taxa and occupancy. The site sample describes the assemblages (pedologic or biologic) of the landscape in a probabilistic manner.

In this case study, all the calculated town level units are respectively defined as ones for “urbanized” or zeros for “not urbanized”. Analyzing the expansion of Nanjing in the last 20 years, results (Table 2) show that the fill of urbanized area analyzed by a professional software tool (Nested Temperature Calculator) has been doubled (from 3.5 in 1984 to 7.2 in 2003), and the nested degree has been getting higher and higher (T value at 18.68, 16.96, 16.40 and 15. 17 in the four periods). The pattern of land use is all nested in 1984, 1995, 2000, 2003, and the nested degree has been getting higher and higher; Geographical changes can be found by the distribution of the fill value of different towns. Some towns or districts show very clear increases in fill due to the more rapidly growing urbanization. Jiangning DZ ranks the first since it is completely a new development zone cratered only in the past ten years while the others are less changed.

Table 2. Nestedness analysis of landuse pattern under urbanization from 1984 to 2003.

Year	Matrix results		System temperature(Monte Carlo simulation)		Statistical significance
	T value	Fill value	Average	S.D	
1984	18.68	3.5	14.81	0.53	<0.001
1995	16.96	5.4	24.20	0.66	<0.001
2000	16.14	6.1	27.35	0.67	<0.001
2003	15.17	7.2	32.62	0.73	<0.001

More and more nested soil composition and distribution after land use change

Similarly to the method design above, all the calculated soil mapping units at soil family level are respectively defined as ones for urbanized soil families or zeros for still agriculturally used units. In all 32 soil families, only two were not occupied by the urbanization process in the past 20 years, they were Loamy mollic-car-udic-orthic primosol and clay loamy typic-dark-aqui cambosol. Among all the soil families, Loamy typic-Fe-leachic-stagnic anthrosol, clay loamy fimic-ferri-udic argosol and clay loamy car-typic-hapli-stagnic anthrosol occupied by urban land use were the first largest ones, with occupied areas of 4900 ha, 4660 ha and 3010 ha, respectively. According to the composition of pedotaxa (Figure 4), we recognized classification classes (dominant, normal, rare and endangered) in the Nanjing area, 4 of 32 soil families are classified as dominant (D), 16 as normal ones (N), 10 as rare (R) and 2 as endangered (E) based upon frequencies of both presence and remaining areas. The most frequently appearing soil families are Clay loamy typic-arp-udic argosol, Loamy typic-Fe-leachic-stagnic anthrosol and Clay loamy eutric-arp-udic argosol with their frequencies of presence at 56, 52 and 41, respectively. The least frequent soil families are Clay car-vertic-gleyic-stagnic anthrosol and Clay loamy typic-dark-aqui-cambosol with their frequencies of presence at 2 and 3. The urbanization sprawl already turned 1 soil family from dominant into normal, 2 from normal into rare and 1 from rare into endangered. Running the Nested Calculator program for the data from 1984 to 2003 shows that data sets are nested. The pattern of the composition and distribution of soil is all nested in 1984, 1995, 2000, 2003, and the nested degree has been getting higher and higher. The nested metric T of soil composition is 16.88, 13.91, 13.62, 12.88, respectively (Table 3). Area size and geographical conditions are considered to be the main factors forming the nested pattern in Nanjing area.

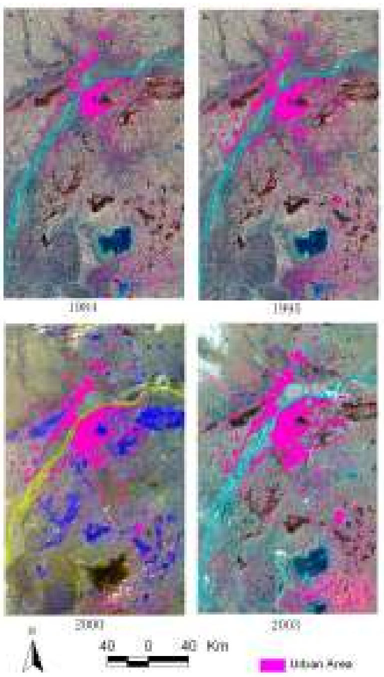

Figure 3. Urban growth pattern.

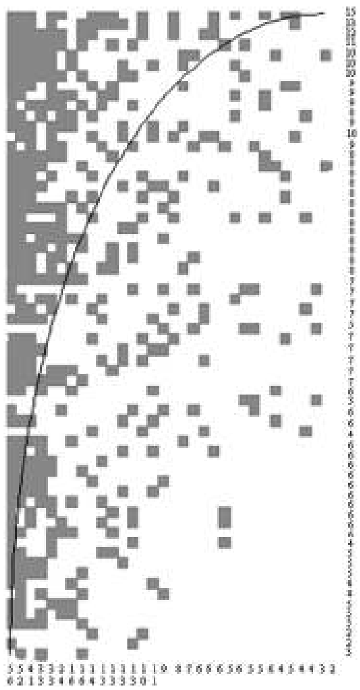

Figure 4. Occurrence of soil family presence.

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Table 3. Nestedness analysis of soil spatial pattern in Nanjing from 1984 to 2003.

Year	Matrix results T value	System temperature(Monte Carlo simulation) Fill value	Average	Statistical significance
1984	16.88	48.35	7.84	<0.001
1995	13.91	48.57	7.91	<0.001
2000	13.62	46.59	8.08	<0.001
2003	12.88	44.45	7.86	<0.001

Meanwhile there is a good fit between the two factors (taxa-area, Figure 5) for this data set for the Nanjing area (z=0.5023; R^2=0.8162) with the best fit formula:

$S=0.1096A^{0.5023}$ $F=126.64$, $P<0.001$, $R^2=0.8162$

Results of taxa-range size distributions show that the data set of the studied area conforms to a concave curve (Figure 6), as is also the case of most biological and pedological inventories. Furthermore, this distribution conforms to a power law confirming what the ecological literature predicts.

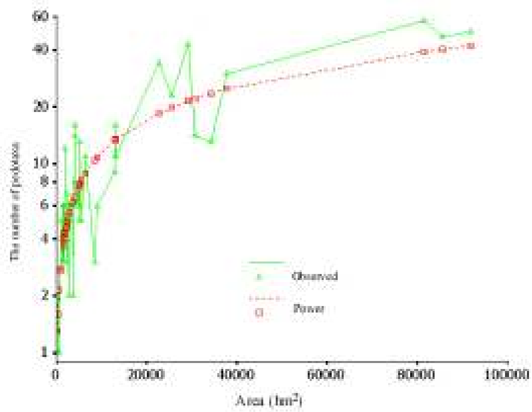

Figure 5. Pedotaxa-area relationship in Nanjing.

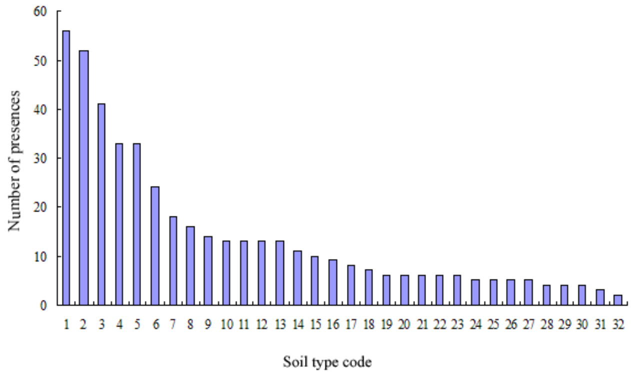

Figure 6. Hollow curve for pedotaxa frequency in Nanjing.

Conclusions

Rapid expansion of urbanization in the Yangtse delta area is still progressing. There has been an absolute increase of 6124 km^2 of urban area in the whole Yangtse delta (from 4873 km^2 in 1984 to 10997 km^2 in 2003) in the past 20 years. Urban area expansion of 322 km^2 each year was at an annual rate of 6.6%. Nanjing city has lost from 4.8 % in 1984 to 11.3 % in 2003 of its surface land to urban use. Results show that the fill of urbanized area calculated by a professional software tool (Nested Temperature Calculator) has been doubly increased (from 3.5 in 1984 to 7.2 in 2003), and the nested degree has been getting higher and higher (T value at 18.68, 16.96, 16.40 and 15. 17 in the four periods). The pattern of the land use is all nested in 1984, 1995, 2000, 2003, and the nested degree has been getting higher and higher. Geographical changes can be found by the distribution of the fill value of different towns. Only two among all the 32 soil families were not occupied by the ongoing urbanization process in the past 20 years while the others were more or less affected. Those distinct soil types (at least two soil families), with their unique physical structure and history of formation, may be in danger of elimination, likely resulting in a substantial loss of below ground and above ground biodiversity. A power law fit is satisfactory for a pedotaxa-area relationship in Nanjing. Thus, in Nanjing there exist taxa-area positive correlations. The pattern of the composition and distribution of soil is all nested in 1984, 1995, 2000, 2003, and the nested degree has been getting greater and greater. Area size and geographical conditions are considered to be the main factors forming the nested soils distribution pattern in the Nanjing area. Soil assemblage regularities appeared to be similar to those described in ecological literature. Cumulative pedotaxa distribution curves, rank–abundance curves, richness and diversity indices, and others diversity tools also show patterns similar to diversity in ecological systems.

Acknowledgements

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