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Relationship between landscape structure metrics and wetland nutrient retention function: A case study of Liaohe Delta, China

Xiuzhen Li [a,*], Rob H.G. Jongman [b], Yuanman Hu [a], Rencang Bu [a], Bert Harms [b], Arnold K. Bregt [b], Hong S. He [a,c]

[a] *Institute of Applied Ecology, Chinese Academy of Sciences, P.O. Box 417, Shenyang 110016, China*
[b] *ALTERRA, Wageningen University and Research Center, P.O. Box 47, 6700 AA, Wageningen, The Netherlands*
[c] *School of Natural Resources, University of Missouri-Columbia, Columbia, MO 65211-7270, USA*

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Abstract

The relationship between landscape pattern and the function of nutrient reduction in the natural reed marsh of Liaohe Delta is studied with the help of some landscape metrics. The results discovered that not all the metrics selected are explanative in representing the function of nutrient reduction. Network connectivity, area size, and source to centre metrics are closely related to the simulation results from different pattern scenarios, while other metrics like area-weighted mean shape, fractal, contagion and aggregation are not related with the reduction process at all. Different metrics should be chosen according to the purpose of the study, based on the criteria of simplicity, generality and ecological meaning.

Keywords: Landscape metrics; Liaohe Delta; Nutrient reduction; Wetland

1. Introduction

An important task in landscape ecology is to quantify the structure of land mosaics with mathematical metrics (Turner and Gardner, 1991; Forman and Godron, 1981; Forman, 1995; McGarigal and Marks, 1995). Various metrics quantify different aspects of landscape pattern (O'Neill et al., 1988). A large number of landscape metrics have been defined and proposed (Pielou, 1975; Forman and Godron, 1981; O'Neill et al., 1988; Baker and Cai, 1992; Gustafson and Parker, 1992). Many of the existed landscape metrics have been implemented into the software package, such as FRAGSTATS[1] (McGarigal and Marks, 1995) and APACK (Mladenoff and Dezonia, 1997). Most of the metrics are based on

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* Corresponding author. Tel.: +86 24 83970350;
fax: +86 24 83970351.
E-mail address: Landscape2001@sina.com (X. Li).

[1] http://www.umass.edu/landeco/research/fragstats/fragstats.html; http://www.innovativegis.com/products/fragstatsarc/demo.htm.

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statistical analysis over the spatial attributes of landscape elements, namely, area, perimeter and length, and redundancy is inevitable. According to Giles and Trani (1999), six factors are considered to be important in describing a mapped area, which are the area, the number of classes, proportion of dominant class, number of polygons, polygon size variance and elevation range. Even these six factors are not equivalently important in different research situation.

However, the studies on how these metrics can be used to inference the underlying ecological processes are lacking (Collinge and Forman, 1998). But what is more important is the ecological meaning of these metrics, or to which extent the metrics can reflect the reality. Compared to the documentation of landscape metrics, much less work has been done in the correlation between these metrics and the functionality of the underlying ecosystems (Loehle, 1990; McGarigal and McComb, 1995).

Not all the pattern metrics are closely related to the ecological processes as we have expected. According to a study on the consistency of correlations between a set of landscape indices and some response variables from a simulated dispersal process across heterogeneous landscapes, 68% of the statistical relationships were highly inconsistent and sometimes ambiguous for different landscape structures and for differences in dispersal behaviour (Tischendorf, 2001). With and King (1999) studied the dispersal success on fractal landscapes, and concluded that gap structure of landscapes is a more important determinant of dispersal than patch structure, though both are required to predict the ecological consequences of habitat fragmentation. The metrics for patch structure was not sensitive at thresholds of habitat abundance, according to their simulation data.

This paper will report the consistency between some landscape metrics and purification function of a reed marsh in the Liaohe Delta based on a spatial simulation model (Xiuzhen et al., 2002), and some pattern scenarios designed to study the effect of certain landscape elements combination on the nutrient reduction, according to the simulated results from this model (Li et al., 2002). A brief description of the model and pattern scenarios will be given in the following section.

2. Methods

2.1. The spatial model and scenarios study on which this study is based

The natural wetland of Liaohe Delta is a reed-dominated landscape with canals criss-crossing internally (Fig. 1). The combination of reed area, canals and pumping stations can affect the nutrient reduction function in the wetland system differently (Li, 2000; Li et al., 2002).

In the spatial model (Xiuzhen et al., 2002), a non-linear regression model was used to simulate the nutrient reduction process in the canal system, while a linear model was adopted for the reed system. The above mathematical models are incorporated into GIS with the Grid module of Arc/Info. The general idea is that, given input concentration values of nutrient species like total nitrogen (TN) or soluble reactive phosphorus (SRP) at the pumping station, the nutrient reduction at a certain point on the canal or reed field can be calculated. The total reduction in the whole reed-canal system controlled by this pumping station can also be calculated accordingly. Validation against field measurement data indicated that the model was strong enough to make estimations for the Liaohe Delta ($p < 0.05$).

Based on the above model, four scenarios of reed-canal patterns were designed for one of the reed farms in the Liaohe Delta to study the effect of spatial pattern on the nutrient reduction in the wetland: canal density (Fig. 2), reed-area size, reed-area shrinking pattern (Fig. 3), and pumping station position (Li et al., 2002). According to the simulation results, each factor brings less than 10% change on the total reduction rate. The aggregately distributed small reed area is good enough to remove large amount of nutrients. More canals do not contribute significantly in nutrient removal in the reed fields. Pumping station should be positioned away from the centre of the reed field for a higher removal rate.

Apart from the reed area, canal length and pumping station position, are there any other factors closely related to the nutrient reduction of the system? For example, the connectivity of the canal network and the different spatial character of the reed field arrangement may also affect the reduction process. This paper will go further with the relationship

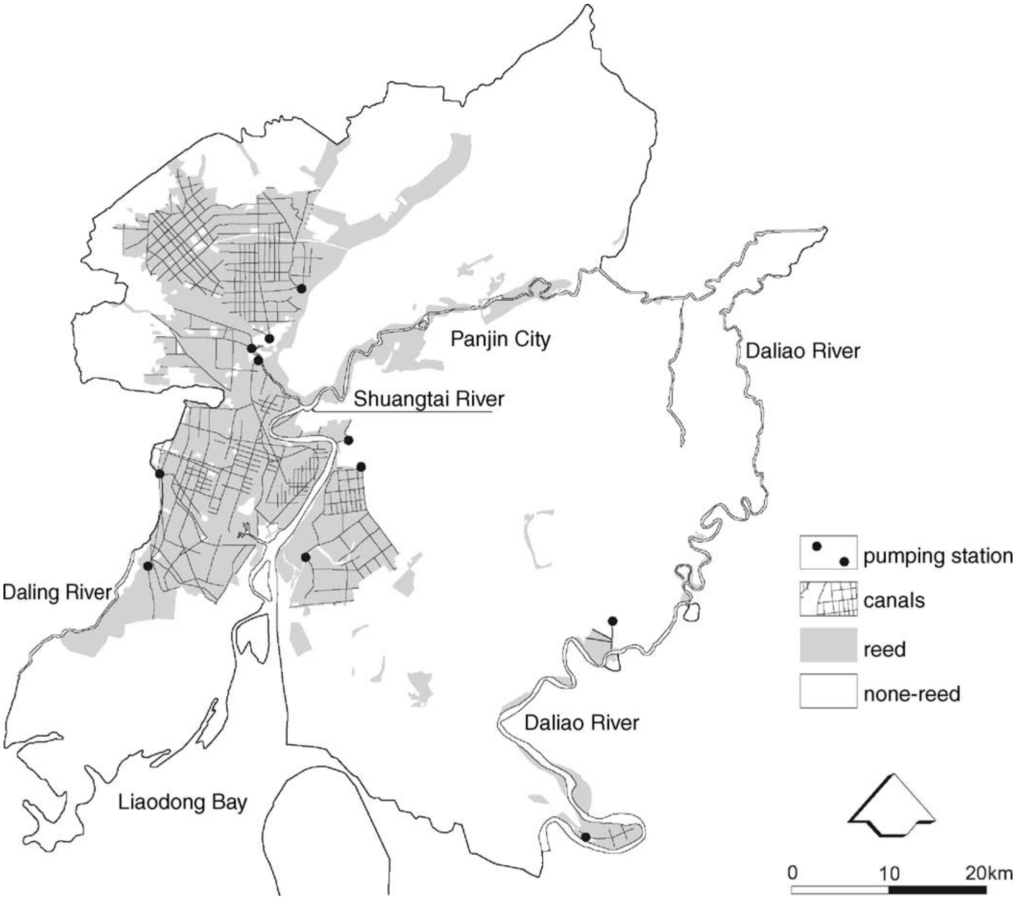

Fig. 1. The distribution of reed, canal and pumping stations in the Liaohe Delta.

between different patterns and nutrient retention rates quantitatively, with the help of some landscape pattern metrics.

2.2. *Metrics selected for different scenarios*

It is unfeasible to test all the landscape metrics with our limited data set. Here, only a few of them are selected, assuming that they may have close relationship with the nutrient reduction function of the reed-canal system (Table 1). The criteria for the selection are: (1) easy to interpret; (2) applicable to general situations; (3) ecologically meaningful in the specific situation of wetland nutrient reduction.

The ability of these metrics in reflecting the nutrient reduction will be tested with the simulated results obtained in Li et al. (2002).

Detailed description of these metrics can be found in the literature (Forman and Godron, 1981; Baker and Cai, 1992; Forman, 1995; McGarigal and Marks, 1995). Distance of source to centre, proposed in this study, is the ‘‘distance from source point to the spatial centre of an area’’. In this study, it is the distance from the pumping station to the spatial centre of the reed field controlled by this station. The purpose is to testify if there is any close relationship between the quantity of nutrient removal and the distance from source point (pumping station) to the spatial centre of concerned area. As described in Li et al. (2002), the simulation results for the same reed-canal system can be different if the position of pumping station changes.

For comparison, correlation coefficient (*R*) between nutrient reduction and landscape metrics is calculated for each scenario. The sample set size for

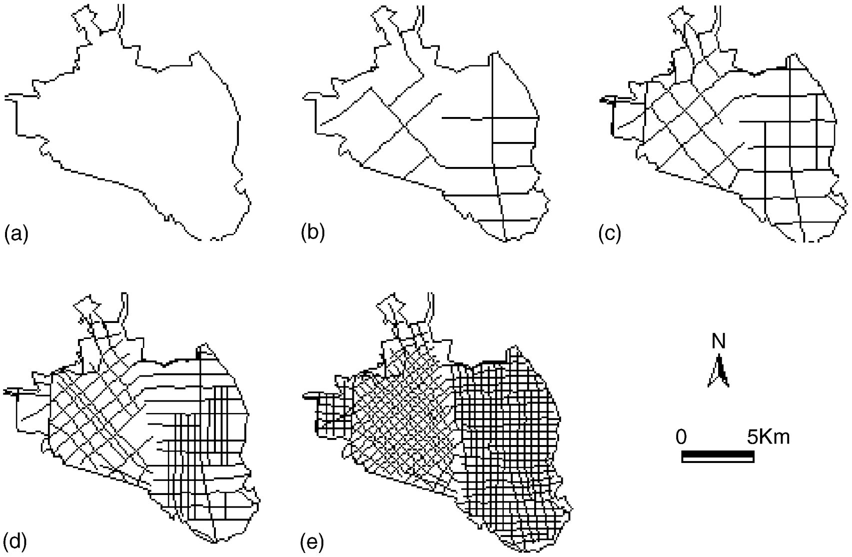

Fig. 2. Different canal densities designed to study the effect of canal on wetland nutrient removal: (a) no canal; (b) one-fourth of the present canal density; (c) one-half of the present canal density; (d) present canal situation; (e) double the present canal density (adopted from Li et al., 2002).

each scenario is four to five only. According to Pearson and Hartley (1966), the lowest *R*-value for significant correlation between a data pair is 0.900, when $n = 4$; and 0.805 when $n = 5$, with 95% confidence. If correlation coefficient value is lower than this standard, the landscape index is considered to be not related to the nutrient reduction function.

Most of the metrics are calculated in the GIS package of Arc/Info, or FRAGSTATS. Some of the AML program files are adopted from Li (1999).

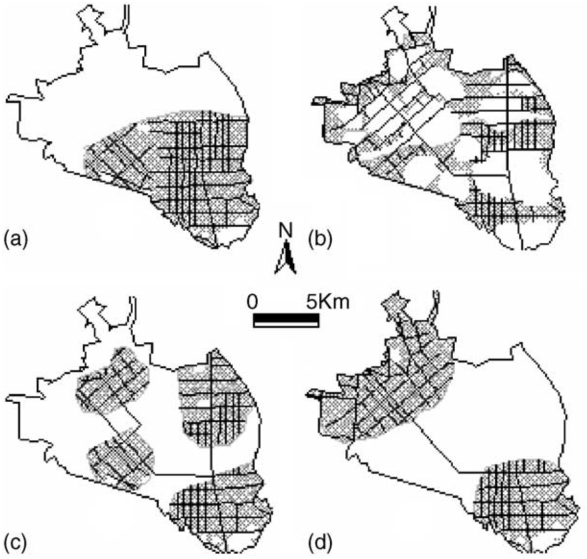

Fig. 3. Different reed-area shrinking patterns if the area is reduced to half of the present situation: (a) shrinkage; (b) perforation; (c) fragmentation; (d) bisection (adopted from Li et al., 2002).

Table 1
Landscape metrics selected for different pattern scenarios

Factors	Metrics selected	Range	References
Canal density	Connectivity	0–1	Forman and Godron (1981)
	Circuitry	0–1	Forman and Godron (1981)
	Line density (m/ha)	>0	
Reed-area size	Area size (ha)	>0	
	Circuitry	0–1	Forman and Godron (1981)
Reed-area shrinking pattern	Circuitry	0–1	Forman and Godron (1981)
	Area-weighted mean shape index	>1	Baker and Cai (1992)
	Fractal dimension	1–1.5	Milne (1991)
	Contagion	0–1	Baker and Cai (1992)
	Aggregation index	0–1	He et al. (2000)
Pumping station position	Distance source to center (m)	>0	

3. Results

3.1. Canal density scenario

The metrics chosen for the scenario of different canal density (Fig. 2) are connectivity, circuitry and line density (canal density in this case). The calculated values of the metrics as well as their relationships to the simulation results of total reduction for nitrogen and phosphorous are given in Tables 2(a and b) and 3(a and b).

From these tables, some general conclusions can be drawn regarding to the nutrient reduction function and the network metrics:

(1) The three network metrics are more sensitive to the reduction of total nitrogen than to soluble reactive phosphorous. Connectivity and circuitry have shown significant correlations ($R > 0.90$, $n = 4$, Table 2b) to the reduction of nitrogen, but not significant for phosphorous ($R < 0.9$, $n = 4$, Table 3b).

(2) The reduction of nutrients is more closely related to the canal connectivity than to the line density. Neither nitrogen nor phosphorous has shown significant correlations with line density. In Li et al. (2002), it is concluded that the canal contributes 2–5% to the total nutrient reduction rate by doubling the density of canals. But

Table 2
The results of (a) total nitrogen reduction and network metrics and (b) correlation coefficient between nitrogen reduction and network metrics, in the canal density scenario

Cases of canal	Total reduction (t)	Percent removed	Line density (m/ha) ($n = 4$)	Connectivity (γ) ($n = 4$)	Circuitry (α) ($n = 4$)
Part (a)					
No canal	138.1	51.9	0.00	–	–
1/4 present	145.3	54.6	4.40	0.3492	0
1/2 present	154.2	58.0	8.68	0.4143	0.1151
Present	154	58.8	17.34	0.4938	0.2389
Double	159.2	59.8	34.67	0.5762	0.3639

	R				
	Total reduction (t)	Percent removed	Line density (m/ha) ($n = 4$)	Connectivity (γ) ($n = 4$)	Circuitry (α) ($n = 4$)
Part (b)					
Total reduction	1	0.99996	0.8449	0.9245	0.9367
Percent removed		1	0.8404	0.9187	0.9314
Line density			1	0.9711	0.9634
Connectivity				1	0.9994
Circuitry					1

Table 3
The results for (a) soluble reactive phosphorous reduction and some network metrics and (b) correlation coefficient between phosphorous reduction and network metrics in the canal density scenario

Cases of canal	Total reduction (t)	Percent removed	Line density (m/ha) ($n = 4$)	Connectivity (γ) ($n = 4$)	Circuitry (α) ($n = 4$)
Part (a)					
No canal	3.99	80.6	0	–	–
1/4 present	4.00	80.8	4.40	0.3492	0
1/2 present	4.20	84.8	8.68	0.4143	0.1151
Present	4.20	84.9	17.34	0.4938	0.2389
Double	4.24	85.7	34.67	0.5762	0.3639

	R				
	Total reduction (t)	Percent removed	Line density (m/ha) ($n = 4$)	Connectivity (γ) ($n = 4$)	Circuitry (α) ($n = 4$)
Part (b)					
Total reduction	1	0.9999	0.8071	0.8358	0.8534
Percent removed		1	0.8114	0.8403	0.8576
Canal density			1	0.9711	0.9634
Connectivity				1	0.9994
Circuitry					1

this positive correlation has proved to be very weak.

(3) Circuitry (α index) is a better index than connectivity (γ) in reflecting the nutrient reduction of the reed-canal system. But the difference is small. Therefore, redundancy exists between these two network metrics. According to our data set, the correlation coefficient between these two network metrics is 0.9994, which is extremely high. To make the comparison of metrics among different scenarios more explicit, only circuitry will be used as network connectivity index in the later scenarios.

(4) The correlation coefficient of the metrics with relative reduction rate (percent removed) is a little bit higher than with absolute reduction value. But the difference is also very small. For the percent of nutrients removed is based on the absolute reduction quantity, the correlation coefficient between them almost equals to 1 (Tables 2b and 3b). To make the comparison more general among different metrics in different scenarios, only relative removal value (percent removed) will be used in later discussions.

(5) The line density is also highly related to connectivity metrics in this case. But it only varies in this scenario. In other scenarios, such as reed-area size, shrinking patterns and pumping station positions, the density of the canals does not change so much among different cases. Therefore line density will not be used in later scenarios.

When more canals appear in the reed field, the network becomes more connected, while the area is cut into smaller pieces. Water and nutrient input at a certain point of reed field becomes easier. Therefore the system becomes more efficient in nutrient removal.

3.2. Reed-area size scenario

There are two alternatives in the reed-area size scenario to simulate the quantity of nutrient reduction (Li et al., 2002). One is to keep the water and nutrient input at the pumping station at the present level. Therefore, when the area of reed shrinks, the water and nutrient load per unit area increases. The other alternative is to decrease the water input load proportionally at the pumping station, in order to keep water and nutrient input load per unit area at present level. The simulation results of these two alternatives are entirely different in terms of absolute reduction quantity, but the relative reduction rates have a similar trend. That is, the small areas are more effective in nutrient reduction than large ones.

Only two metrics are selected for this scenario: reed-area size, and the circuitry of the canals. Tables 4 and 5 provide the calculation results of the nutrient reduction rate and the metrics, as well as the relationships between reduction and metrics.

Table 4
The result of (a) total nitrogen reduction and area, circuitry metrics and (b) the correlation coefficiency between nitrogen reduction and area, circuitry metrics in the reed-area size scenario

Cases of area	Total reduction rate[a] (%)	Total reduction rate[b] (%)	Area size (ha)	Circuitry (α)
Part (a)				
1/4 present	67.9	63.2	4250	0.1986
1/2 present	64.3	61.1	8500	0.2191
3/4 present	61.3	59.7	12750	0.2401
Present	58.8	58.8	17000	0.2389
Part (b)				
Total reduction[a]	1	0.9949	−0.9967	−0.9576
Total reduction[b]		1	−0.9834	−0.9757
Area			1	0.9356
Circuitry				1

[a] Total input load at the pumping station is kept at present level.
[b] Total input load at the pumping station decrease proportionally with area shrinking.

Results of Tables 4 and 5 indicate that the total reduction rate for nitrogen and phosphorous is very closely related to the area of reed fields in both alternatives, especially in the first alternative ($|R| > 0.99$). The circuitry index for the canal network is also highly related to the reduction rate, but more sensitive when the input water and nutrient load per unit area is kept at the present level (alternative 2) than when the total input load remains the stable (alternative 1).

In addition, the nutrient reduction rate is negatively related to the area and circuitry index in this scenario. In the canal density scenario, the relationship between nutrient reduction and circuitry index is positive. The reason could be that the area size has a much stronger effect on nutrient reduction, while the connectivity of canal system is also highly affected by area size ($R = 0.9356$, $n = 4$). In other words, larger area has more canals and therefore a higher circuitry value. The effect of circuitry on nutrient reduction rate is overruled by the effect of area size in this situation.

Another interesting phenomenon from Tables 4b and 5b is that the relative nutrient reduction for the two alternatives of input load is highly correlated, though the absolute reduction is totally different (Li et al., 2002).

3.3. Reed-area shrinking pattern scenario

The landscape metrics selected for the reed-area shrinking pattern scenario (Fig. 3) include circuitry of canal network, area-weighted mean patch shape index

Table 5
The result of (a) soluble reactive phosphorous reduction and area, circuitry metrics and (b) the correlation coefficiency between phosphorous reduction and area, circuitry metrics

Cases of area	Reduction rate[a] (%)	Reduction rate[b] (%)	Area (ha)	Circuitry (α)
Part (a)				
1/4 present	89.2	88.7	4250	0.1986
1/2 present	87.9	87.5	8500	0.2191
3/4 present	87.0	86.8	12750	0.2401
Present	86.3	86.3	17000	0.2389
Part (b)				
Reduction[a]	1	0.9983	−0.9902	−0.9673
Reduction[b]		1	−0.9803	−0.9735
Area			1	0.9356
Circuitry				1

[a] Total input load at the pumping station is kept at present level.
[b] Total input load at the pumping station decrease proportionally with area shrinking.

Table 6
The results of (a) nutrient reduction and pattern metrics and (b) the relationship between nutrient reduction and pattern metrics in the reed-area shrinking pattern scenario

Pattern	Total TN reduction (%)	Total SRP reduction (%)	Circuitry	AWMS[a]	Fractal dimension	Contagion	Aggregation
Part (a)							
Shrinkage	61.1	87.5	0.2191	2.4792	1.087	0.601	0.991
Perforation	58.8	86.3	0.0803	2.8382	1.511	0.455	0.988
Fragmentation	58.4	85.9	0.1150	1.7649	1.203	0.635	0.990
Bisection	56.0	84.3	0.1606	1.9895	1.119	0.703	0.995

	R						
	Total TN reduction (%)	Total SRP reduction (%)	Circuitry	AWMS[a]	Fractal dimension	Contagion	Aggregation
Part (b)							
Total TN	1	0.9962	0.3658	0.4845	−0.0060	−0.4597	−0.5855
Total SRP		1	0.2865	0.5281	0.0797	−0.5317	−0.6511
Circuitry			1	−0.1206	−0.8516	0.5308	0.5403
AWM-shape				1	0.6218	−0.8489	−0.5440
Fractal					1	−0.8764	−0.7369
Contagion						1	0.8786
Aggregation							1

[a] AWMS, area-weighted mean shape index.

(AWMS) of the reeds, fractal dimension, contagion and aggregation index for the whole mapped area. As discussed in Li (1999), grid-based pattern metrics like contagion are very much dependent on the resolution or cell size of the landcover grid. Here the cell size is chosen as 30 m × 30 m, the same resolution as that of the model simulation grid. Calculation results for nutrient reduction rates, pattern metrics and correlation coefficients between each pair of values are shown in Table 6a and b.

The results show that none of the pattern metrics chosen for this scenario has a significant relationship with the reduction rate of both nitrogen and phosphorous. Unlike in the scenarios of canal density and reed-area size, the network circuitry index has no relationship with the nutrient reduction rate in the reed-area shrinking pattern scenario. This further indicates that the relationship between the index of network connectivity and landscape functionality is unstable and prone to changes of different situation scenarios.

Table 7
The results of (a) nutrient reduction and distance from the pumping station to the spatial center of the reed field and (b) the relationship between nutrient reduction and distance index

Cases of pumping station	TN reduction (%)	SRP reduction %	Distance source to centre (m)
Part (a)			
Present position (a)	58.8	86.3	9574
Position (b)	56.1	83.4	2095
Position (c)	56.3	83.6	2979
Position (d)	59.2	86.7	10274
Position (e)	56.6	85.1	4100

	R		
	Nitrogen reduction	Phosphorous reduction	Distance source to centre
Part (b)			
Nitrogen reduction	1	0.9437	0.9974
Phosphorous reduction		1	0.9598
Distance source to centre			1

Table 8
The results of (a) soluble reactive phosphorous (SRP) reduction in the canal/reed system and distance from the source to spatial center and (b) the relationship between phosphorous reduction rate and distance factor

	Canal (%)	Reed (%)	Total (%)	Distance source to center (m)
Part (a)				
Present position (a)	54.9	31.4	86.3	9574
Position (b)	46.5	37.0	83.4	2095
Position (c)	47.1	36.6	83.6	2979
Position (d)	54.9	31.7	86.7	10274
Position (e)	47.7	37.4	85.1	4100
Part (b)				
Canal	1	−0.9854	0.9303	0,9940
Reed		1	−0.8544	−0,9636
Total			1	0,9598
Distance source to centre				1

In conclusion, as far as nutrient reduction is concerned, landscape pattern metrics are not very informative in describing landscape functionality. Probably they are more useful in describing landscape structures themselves (Li and Reynolds, 1993; O'Neill et al., 1988), or in describing other phenomena, such as habitat change. Further study is needed concerning the explanation of landscape metrics in the application domain.

3.4. Pumping station position scenario

The distance from source point to spatial centre refers to the distance from the pumping station to the spatial centre of the irrigated reed field. The measurements of the distances of each pumping station (with (a and d) located on the border of the reed fields (b, c and e) located somewhere inside the area) and the nutrient reduction are shown in Table 7a and b.

In general, the reductions of nitrogen and phosphorous are both closely related to the distance index ($R > 0.95$), especially for nitrogen.

It is worth noticing that, the reduction of nitrogen and phosphorous is also closely related ($R = 0.94$). In the former scenarios not all the correlation coefficients between the reduction of these two nutrient elements was presented. But, they are also highly correlated to each other ($R = 0.9137$, $n = 22$). This is because they follow similar reduction rules in the simulation model, with only difference in the magnificence of removal efficiency in the wetland.

If we further examine the results of phosphorous reductions in the canal and reed fields separately (Table 8a and b), we can see that the distance index is also very sensitive to the reduction of canal system. There is a negative relationship between the reduction in the reed system and the distance of pumping station to the reed field centre. This can be understood because the distance between a canal point and the pumping station is an important factor in calculating the nutrient reduction in the canal system, while the reduction in the reed field is not related to the distance factor (Xiuzhen et al., 2002).

From Table 8b, we can also notice that the reduction rates in the canal and reed systems are highly correlated, though it is a negative relationship. They are also significantly related to the total reduction rate as well ($|R| > 0.85$).

4. Discussion

It is easy to calculate large amount of landscape metrics with available software packages (Baker and Cai, 1992; McGarigal and Marks, 1995). However, it is not so easy to link the calculation results to the ecological explanations. One of the objectives of this paper is to test the ecological relationship between the landscape metrics used and wetland nutrient reduction function. Our results do indicate some kind of correlation between the metrics values and nutrient reduction rates in the reed-canal system of Liaohe Delta. However, the following issues need to be clarified.

The simulation results used for testing the metrics may not be good enough because the model and the pattern scenarios used for this study have many assumptions (Li et al., 2002; Xiuzhen et al., 2002). The correlation coefficiency values derived from the simulated data sets can be higher than those derived from real values. In other words, if the simulated results have no close relationship with those landscape metrics, chances are that the relationship between field data and those metrics can be even worse.

The sample set might be too small ($n = 4–5$) to make good statistics on correlation coefficient. Each scenario has only four or five cases to compare the effect of some landscape patterns on nutrient reduction function. It is enough to derive a general trend according to this small data set, but may not be enough to make good correlations for statistics. Therefore, the R (correlation coefficient) values can be over- or underestimated because of the small data set.

A significant correlation should also be interpreted with caution. The correlation may not be caused by the direct influence of one variable on the other, but by the influence from unknown factors on both variables (Elliott, 1993). For example, the high correlation coefficient between nutrient reduction and circuitry in the cases of canal density and reed-area size, is questionable, since both cases are quite high but in the former it is positive, while in the latter it is negative. The reason could be that the effect of canal circuitry is over-ruled by the effect from reed-area size.

Many landscape metrics proposed may be applicable to limited aspects. For example, contagion and aggregation index may be effective in characterising the habitat of some species, but not the nutrient element movement involving physical, chemical, and biological processes.

High correlation or redundancy exists among many landscape metrics. For example, network connectivity (γ) and circuitry (α) are found highly correlated in this study. We should choose carefully among a large group of metrics in order to be concise in describing the structure and function of a landscape.

Different purpose of study, such as species, material, or energy flow, may need different metrics. The index of ''distance from source to spatial centre'' has never been documented before. But it is quite closely related to the nutrient reduction rate in the pumping station scenario, while other metrics may not demonstrate such a close relationship in this case. Therefore, it is the purpose of study that decides the method of description.

It is better to stick on a small number of ecologically expressive landscape metrics according to the objective of the study. The six parameters (area, class, proportion of dominant class, number of polygons, polygon size variance and elevation range) suggested by Giles and Trani (1999) are fundamental in describing a mapped area, but may not be enough in complicated situations like functional study. The combination of these factors could also be important in characterizing the pattern of a landscape.

5. Conclusion

According to the results and discussions above, several conclusions can be made regarding to the relationship between nutrient reduction function and landscape pattern metrics:

1. In the scenario of canal density, the nutrient reduction is more closely related to the connectivity and circuitry of the canal system than the density of canals.
2. The negative relationship between nutrient reduction and area size is so strong that the effect from other pattern factors (such as connectivity of canals) is over-ruled by this factor.
3. None of the landscape pattern metrics are informative in describing the nutrient retention change caused by landscape pattern change.
4. The distance from pumping station to the spatial centre of reed field is strongly related to the nutrient reduction rate.
5. Redundancy exists among different landscape metrics, such as connectivity and circuitry metrics for network.
6. Different metrics should be chosen according to the purpose of the study, based on the criteria of simplicity, generality and ecological meaning.

Although limitations of small data sets exist in this study, the conclusions derived above are still informative to many of the cases in landscape ecology. Instead of defining new complicated landscape metrics, we should concentrate more on existed simpler ones and make good explanation for them.

More importantly, they should be put into application, such as landscape designing. Otherwise, landscape metrics will become a huge pile of meaningless mathematical game.

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References

Baker, W., Cai, Y., 1992. The r.le programs for multiscale analysis of landscape structure using the GRASS geographical information system. Landsc. Ecol. 7 (4), 291–302.

Collinge, S.K., Forman, R.T.T., 1998. A conceptual model of land conversion processes: predictions and evidence from a microlandscape experiment with grassland insects. Oikos 82 (1), 66–84.

Elliott, J.M., 1993. Some methods for the statistical analysis of samples of benthic invertebrates. Freshwater Biological Association Scientific Publication No. 25. Fourth Impression, p. 159.

Forman, R.T.T., 1995. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press, Cambridge.

Forman, R.T.T., Godron, M., 1981. Patches and structural components for a landscape ecology. Bioscience 31, 733–740.

Giles, R.H., Trani, M.K., 1999. Key elements of landscape pattern measures. Environ. Manage. 23 (4), 477–481.

Gustafson, E., Parker, G., 1992. Relationships between landcover proportion and indices of landsscape spatial pattern. Landsc. Ecol. 7 (2), 101–110.

He, H.S., DeZonia, B., Mladenoff, D.J., 2000. An aggregation index (AI) to quantify spatial patterns of landscapes. Landsc. Ecol. 15 (7), 591–601.

Li, H., Reynolds, J.F., 1993. A new contagion index to quantify spatial patterns of landscapes. Landsc. Ecol. 8 (3), 155–162.

Li, X., 1999. Assessment of Landuse Change Using GIS: A Case Study in the Llanos de Orinoco. Wageningen University Press, p. 88.

Li, X., 2000. Purification Function of Wetlands: Spatial modelling and pattern analysis of nutrient reduction in the Liaohe Delta. Wageningen University Press, p. 123.

Li, X., Jongman, R., Xiao, D., Harms, W.B., Bregt, A., 2002. The effect of spatial pattern on nutrient removal of a wetland landscape. Landsc. Urban Plan 60 (1), 27–41.

Loehle, C., 1990. Home range: a fractal approach. Landsc. Ecol. 5 (1), 39–52.

McGarigal, K., McComb, W.C., 1995. Relationship between landscape structure and breeding birds in the Oregon Coast Range. Ecol. Monogr. 65 (3), 235–260.

McGarigal, K., Marks, B., 1995. FRAGSTATS, spatial pattern analysis program for quantifying landscape structure. General Technical Report PNW-GTR-351. USDA, Forest Service, Pacific, Northwest Research Station, Portland.

Milne, B.T., 1991. Lessons from applying fractal models to landscape patterns. In: Turner, M.G., Gardner, R.H. (Eds.), Quantitative Methods in Landscape Ecology: The Analysis and Interpretation of Landscape Heterogeneity. Springer-Verlag, NY, pp. 199–235.

Mladenoff, D.J., Dezonia, B., 1997. APACK 2.0 user's guide. In: Department of Forest Ecology and Management, University of Wisconsin-Madison, Madison, WI, USA.

O'Neill, R.V., Krummel, J.R., Gardner, R.H., Sugihara, G., Jackson, B., DeAngelis, D.L., Milne, B.T., Turner, M.G., Zygmunt, B., Christensen, S.W., Dale, V.H., Graham, R.L., 1988. Indices of landscape pattern. Landsc. Ecol. 1, 153–162.

Pearson, E.S., Hartley, H.O., 1966. Biometrika Tables for Statisticians, third ed. Cambridge University Press, Cambridge.

Pielou, E.C., 1975. Ecological Diversity. John Wiley & Sons, NY.

Tischendorf, L., 2001. Can landscape indices predict ecological processes consistently? Landsc. Ecol. 16, 235–254.

Turner, M.G., Gardner, R.H. (Eds.), 1991. Quantitative methods in landscape ecology. The Analysis and Interpretation of Landscape Heterogeneity. Springer-Verlag, NY.

With, K.A., King, A.W., 1999. Dispersal success on fractal landscapes: a consequence of lacunarity thresholds. Landsc. Ecol. 14, 73–82.

Xiuzhen, L., Jongman, R., Harms, W.B., Bregt, A.K., 2002. Spatial modeling of nutrient reduction in the natural wetlands of the Liaohe Delta, China. In: Mander, Ü., Jenssen, P.D. (Eds.), Natural Wetlands for Wastewater Treatment in Cold Climates. WIT Press, Southampton, Boston, pp. 47–74.