Diversity indices and spatial scales greatly effect the conclusions of relationships between biodiversity and ecosystem functions

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Abstract

The relationships between biodiversity and ecosystem functions such as stability and productivity has long been debated and has no final conclusion until now. But it is ignored that the debate should be firstly based on the same diversity index, which should be theoretically complete, and on same observation scale. For the issue on the scale of ecotope observation, ecosystems should be distinguished according to intensity of human disturbance. For the issue on the scale of species observation, either number diversity or biomass diversity should be identified. This paper takes grassland ecosystems located within the Bayin Xile grassland of Xilin Gol League of Inner Mongolia Autonomous Region as an example and analyzes effects of different diversity indices and of various spatial scales on the relationships between biodiversity and ecosystem functions. The calculation results show that different diversity indices lead to different conclusions. The analysis to land cover data based on Landsat TM images by up-scaling process demonstrates that spatial scale of data has a great effect on the conclusion of the relationships between biodiversity and ecosystem functions.

Keywords: Biodiversity; Ecosystem function; Relationship; Diversity index; Spatial scales

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1. Introduction

Prior to 1970s, ecologists attempted to develop a general theory linking stability and diversity on the scale of species observation (Odum, 1953; MacArthur, 1955; Elton, 1958; Hutchinson, 1959). Since Gardner and Ashby (1970) and May (1972) challenged the conventional wisdom that stability increases with species diversity, the thinking of some scientists started to change gradually. There appeared two camps on the diversity-stability hypothesis. Some scientists argued that their research results did not support the conventional wisdom of natural historians: diversity begets stability (Gilpin, 1975; Woodward, 1994; Beeby and Brennan, 1997; Naeem, 2002; Pfisterer and Schmid, 2002; Lhomme and Winkel, 2002). However, many scientists still believe that diversity begets stability (Odum, 1971; Watt, 1973; McNaughton, 1978; Glowka et al., 1994; Pennist, 1994; McGrady et al., 1997; Naeem and Li, 1997; Tilman et al., 1997). In particular, many recent advances have indicated that diversity can be expected, on average, to give rise to ecosystem stability (Wolfe, 2000; Chapin III et al., 2000; Tilman, 2000; Bengtsson et al., 2000; McCann, 2000).

The relationship between diversity and productivity has been a central but contentious issue within ecology (Schmid, 2002). In terms of Darwin’s result, the biodiversity of communities is due to niche diversification of the co-occuring species and such diversification will lead to greater community productivity due to more effective resource exploitation (Darwin, 1872). In 1968, the evidence from California grasslands showed that net productivity was inversely related to species diversity (McNaughton, 1978), which challenged Darwin’s result. Since 1990s, there have appeared ardent debates on the diversity-productivity relationships. New York successional analyses suggested that average net productivity was negatively related to species diversity (McNaughton, 1993). Johnson et al. (1996) argued that attempts to unveil the relationships between biodiversity and ecosystem productivity continue to generate contradictory conclusions. Rusch and Oesterheld (1997) claimed that diversity has a negative effect on productivity. Wardle et al. (1997) concluded that species composition, rather than species diversity, is the main determinant of ecosystem productivity. Hooper and Vitousek (1997) in terms of their experiment in a grassland in California debated that primary productivity did not correlate with increasing functional group richness, but composition explained much more variance than did richness. Grime (1997) stated that dominant plants rather than biodiversity control ecosystem productivity. Huston et al. (2000) concluded that species richness per se has no statistically or biologically significant effect on plant productivity. However, many ecologists still believe Darwin's result. The experimental results at eight European field sites showed that each halving of the number of plant species reduced productivity by approximately 80gm^{-2} on average (Hector et al., 1999). Tilman (2000) reviewed recent experimental, theoretical and observational studies and stated that on average greater diversity leads to greater productivity in plant communities, greater nutrient retention in ecosystems and greater ecosystem stability. Purvis and Hector (2000) summarized that 95% of experimental studies support a positive relationship between diversity and ecosystem functioning. Many ecologists (Tilman et al., 2001; Swift and Anderson, 1993; Lehman and Tilman, 2000; Loreau, 2000; Loreau and Hector, 2001) think that productivity may be greater at higher diversity because of niche complementarity among particular combinations of species and the greater chance of occurrence of such combinations at higher diverity. Cardinale et al.'s experiment (2002) showed that bryophyte diversity and productivity have a positive relationship because a greater complexity of vertical structure helps to trap water and facilitate plant survival during drought. Pfisterer and Schimid (2002) in their combinatorial biodiversity experiments found that higher diversity tends to lead to higher productivity.

On the scale of ecotope observation (Naveh and Lieberman, 1994; Forman, 1995), Odum (1969) proposed the strategy of ecosystem development and stated that the most pleasant and certainly the safest landscape to live in is one containing a variety of crops, forests, lakes, streams, roadsides, marches, seashores, and 'waste places'. Haber (1971) applied this strategy into land utilization systems and proposed the concept of differentiated land use (Haber, 1979) and a differentiated land use strategy (Haber, 1990). Numerous authors have stressed the favorable effect of diversity on agroecosystem functions such as ecosystem stability and productivity (Mager, 1985; Kaule, 1986; Barbier, 1990; Francis and Clegg, 1990; Stinner and Blair, 1990; Stocking et al., 1990; Altieri, 1991; Prinsley, 1992; Ryszkowski, 1992; Yue and Jiang, 1993; Nachtigall, 1994; Yue and Kong, 1994; Ripl, 1995; Burel, 1996; Lenz and Haber, 1996; Herzog, 1997; Pfiffner, 1996; OECD, 1997).

However, most of the arguments on the relationships between biodiversity and ecosystem functions do not clear what kind of diversity index is used and how large spatial scale or how high spatial resolution of data their calculations are based on.

2. Methods

2.1 Study region

The investigated region with total area of 97200 hectares is located in $43^o29'44'' - 43^o46'19''N$ and $116^o25'3'' - 116^o49'33''E$, within the Bayin Xile Grassland of Xilin Gol League of Inner Mongolia Autonomous Region. It has a semi-arid and continental grassland climate in temperate zone. The annual average temperature is 0.2°C, with a highest temperature of 38.5°C in summer and a lowest temperature of –42.8°C in winter. The annual average precipitation is 350mm. The most common species are *Aneurolepidium chinensis* (Trin.) Kitag. and *Stipa grandis* P. Smirn., of which biomass accounts for 60.4% of the total amount. Precisely, *Aneurolepidium chinensis* (Trin.) Kitag. accounts for 48.8% and *Stipa grandis* P. Smirn.11.6%. Grass plants return green at the end of April and senescence in early October. Plant growing period lasts about 150 days.

2.2 Data acquisition of land cover

Landsat TM/ETM images, taken on 31 July of 1987, 11 August of 1991, 27 September of 1997, and 23 May of 2000, are analyzed by applying digital image processing techniques to the 6 visible/near-infrared bands (bands 1, 2, 3, 4, 5, and 7). Ancillary data include a vegetation map of Bayin Xile, a soil map of Xilin River Basin, a topographical map, and biomass data sampled in the field. Using the 6 atmospherically-corrected bands as input, 48 spectral classes are generated by unsupervised classification procedure of ISODATA (ERDAS/Imagine 8.4 package). Because cropland and wetland could not be separated out as unique spectral classes, supervised classification is used to define training samples of cropland and wetland. The supervised training samples and the 48 unsupervised spectral classes are combined together and the whole image is classified again by using the maximum likelihood classification procedure. Using the ancillary data as a reference, the spatial relationships between spectral classes and land cover types are established. The final land cover classification map has 14 identical classes: F. *sibiricum* steppe, S. *baicalensis* steppe, A. *chinensis* + *forbs* steppe, A. *chinensis* + *bunchgrasss* steppe, A. *chinensis* + Ar. *frigidas* steppe, S. *grandis* + A. *chinensis* steppe, S. *grandis* + *bunchgrasss* steppe, S. *krylavii* steppe, Ar. *frigida* steppe, cropland, wetland, desertification land, saline-alkaline land, and water area (as seen in Figures 1, 2, 3, and 4).

Fig. 1. Land Cover in 1987 (30m×30m)

Fig. 2. Land Cover in 1991 (30m×30m)

Fig. 3. Land Cover in 1997 (30m×30m)

Fig. 4. Land Cover in 2000 (30m×30m)

2.3 Data acquisition of maximum aboveground biomass in terms of species

The peak value of aboveground biomass of the grass communities appears at the end of August usually, which is considered as the grassland productivity. In order to analyze the relationship between species biomass diversity and the grassland productivity, 57 sampling quadrates that all sizes are $1m \times 1m$ were randomly selected. The sampling process includes 5 steps: (1) cutting grass to the roots at the end of August, (2) classifying the cut grass in terms of species, (3) drying the cut grass in terms of species at 60^{o}C, and (4) weighting the dried grass in terms of species. Inner Mongolia Grassland Ecosystem Research Station, which was founded in 1979 and was listed as a key project demonstrative station by UNESCO’s MAB program in 1988, has been repeating the sampling process in the study region at the end of August every year since 1980. We only pay an attention to the data selected in 1987, 1991, 1997 and 2000 in order to correspond with the land cover data.

2.4 Diversity indices

Twenty-seven diversity indices can be found in literatures (Yue et al., 1998; 2001; 2003). In addition to a scaling index introduced recently,

$$d(t) = -\frac{\ln\left(\sum_{i=1}^{m(\varepsilon)} (p_i(t))^{\frac{1}{2}}\right)^2}{\ln(\varepsilon)}$$

the most widely used diversity indices in ecological literature include Shannon's index,

$$I(t) = -\sum_{i=1}^{m(\varepsilon)} p_i(t) \ln p_i(t),$$

and Simpson's index,

$$S(t) = \left(\sum_{i=1}^{m(\varepsilon)} (p_i(t))^2\right)^{-1}$$

where $p_i(t)$ is probability of the ith investigation object such as species biomass or ecotope; $m(\varepsilon)$ is total number of the investigation objects; *t* represents time variable; $\frac{1}{\varepsilon} = e + \frac{a}{s}$, *a* is area of studied region in hectares, s is spatial resolution of land cover data or area of sampling quadrat, and *e* equals 2.71828.

3. Results

3.1 Different diversity index leads to different conclusions on relationships between biodiversity and ecosystem functions

The calculation results by operating the three diversity indices on the sampling data in the field in 1987, 1991, 1997 and 2000 (as seen in Table 1) shows that correlation coefficients of scaling diversity, Shannon's diversity, and Simpson's diversity (Table 2) with grassland productivity are respectively 0.83, 0.69, and 0.38 (Table 3). In other words, if scaling index is used it could be concluded that species biomass diversity has positive relation with grassland productivity; but if Simpson's index is used it is difficult to be concluded that species biomass diversity has a positive relation with grassland productivity.

Table 1. The sampling data of maximum aboveground biomass (g/m^2)

Table 2. Grassland productivity and species biomass diversity

Table 3. Correlation of productivity with species biomass diversity and ecotope diversity

The calculation results by operating the diversity indices on the land cover data at 30m×30m resolution (Fig. 1-4) show that scaling diversity and Shannon's diversity have no relationship with grassland diversity, but correlation coefficient between Simpson's diversity and grassland productivity is 0.68. Statistically, the calculation results by the three diversity indices have different trends from 1987 to 2000. Shannon's diversity and scaling diversity have an increase trend from 1991 to 1997, but Simpson's diversity has a decrease trend in this period. From 1997 to 2000, Shannon's diversity and Simpson's ecotope diversity have an increase trend, but scaling diversity has no change (Table 4). Correlation coefficient between ecotope diversity and desertification area for scaling index, Shannon's index, and simpson's index are respectively 0.96, 0.93, and 0.71, so that we can conclude that ecotope diversity increase leads to ecosystem unstability.

Table 4. Desertification area and ecotope diversity

3.2 Spatial scale of data has a great effect on the conclusion of the relationships between biodiversity and ecosystem functions

The land cover data set on 30m×30m spatial resolution is transformed into 20 more ones by up-scaling process (Table 5, 6, and 7). The pixel side of every new land cover data set is 30m bigger than the transformed one both in width and height. The land cover type in each pixel of the new land cover data is derived from the dominant land cover type of the transformed pixels. When every new data set is created, it can be export to a vector polygon file such as Coverage of Arc/Info.

Table 5. Effect of different spatial scales on correlation coefficient of scaling diversity with grassland productivity and desertification area

Table 6. Effect of different spatial scales on correlation coefficient of Shannon's diversity with grassland productivity and desertification area

Table 7. Effect of different spatial scales on correlation coefficient between Simpson's diversity and grassland productivity

The analysis results show that pixel size change causes nonlinear change of correlation coefficients of ecotope diversity with grassland productivity and desertification area, in which enlargement of desertification area indicates unstability of the grassland ecosystem. When pixel size is 210m×210m correlation coefficients between ecotope diversity and grassland productivity reach maximum values for all of scaling index, Shannon's index and Simpson's index, which are 0.52, 0.75 and 0.89 respectively. But correlation coefficients between ecotope diversity and desertification area reach maximum values for all of the three indices when pixel size is 30m×30m; correlation coefficient between ecotope diversity and desertification area reaches maximum value for Simpson's index when pixel size is 60m×60m. Therefore, at spatial resolution 210m×210m we conclude that higher ecotope diversity tends to lead to higher productivity; at 30m×30m there is an inverse relationship between ecotope diversity and ecosystem stability.

4. Discussions

Unsatisfying diversity indices have been criticized by many specialists. For instance, Odum (1969) stated that Shannon's formula may obscure the behavior of these two rather different aspects of diversity, variety and evenness. Pimm (1994) reviewed the research history of relation between diversity and stability and concluded that theoretical studies of whether interacting sets of species will be stable consider whether the densities of all those species return to equilibrium or not. To ask how long a community persists before it is invaded is to ask how long the community composition lasts. Such a discussion ignores fluctuations in the abundance of species, i.e. equitability, and looks only at the species list itself. Harper and Hawksworth (1996) pointed out that Shannon diversity index and Simpson's index are inadequate for some purposes because it is possible for a species-rich or ecotope-rich but inequitable community to have a lower index than one that is less species-rich or less ecotope-rich but highly equitable. Hooper and Vitousek (1997) stated that species diversity measured by Shannon index ignores species composition. Beeby and Brennan (1997) described that various indices attempt to measure diversity and include some measure of equitability, with varying success. In doing so, the index may make assumptions about the underlying pattern of equitability within the community, which itself can be problematical. Yue et al (1999) found that Shannon index could not express the 'variety' component of diversity and does not imply any information of the size of the area under investigation region; if Shannon index is used the number of every species or every ecotope type should be greater than 100 theoretically. Therefore, the scaling index was introduced on the basis of theoretical demonstration, for which all diversity indices were analyzed (Yue et al., 1998). Although the scaling index has been tested and improved many times (Yue et al., 1999, 2000, 2001, 2002, 2003), its effectiveness under all circumstances does still need to be further tested.

Effects of spatial scale on biodiversity and on relationships between biodiversity and ecosystem functions have been discussed by many specialists. For instance, Noordwijk's results (2002) showed that intensification of crop-fallow system is likely to decrease the average species richness per unit area at field scale, but ecotope diversity may initially increase; while further intensification is likely reduce all aspects of biodiversity. Gotelli (2002) stated that species diversity is a challenging parameter to measure because diversity is organized hierarchically: individual organisms are classified into species, species into genera, and genera into families, and so on. Enquist and Niklas (2001) found that organizing principles are needed to link biodiversity across spatial and temporal scales. Crawley and Harral (2001) demonstrated that different processes might determine plant biodiversity at different spatial scales. Ritchie and Olff (1999) proposed that the spatial scaling of resource use by species of different size may explain many species-diversity patterns across a range of spatial scales, which seems to provide a basis for the development of ecological theories that are trans-scalar in geographical space (Whittaker, 1999). Our results show that species diversity is much smaller than ecotope diversity in the investigated region within the Bayin Xile Grassland. This means that the sampling process might not cover all species in the region. These problems caused by incomplete and uneven sampling expect to be solved by means of remote sensing (Nagendra and Gadgil, 1999; Yue, 2000; Yue and Liu, 2003).

Many specialists noted that relationships between biodiversity and ecosystem functions require particular attention on various scales such as local, landscape and regional ones. For instances, Chase and Leibold (2002) concluded that the shape of the productivity-biodiversity relationship depends on spatial scale; when data were viewed among ponds the relationship between species diversity and productivity was hump-shaped, whereas the same data were viewed among watersheds the relationship was positively linear. Noordwijk’s result (2002) showed that trade-off between productivity and biodiversity depend on the scale of model application. Loreau, et al. (2001) stated that generally the relative effects of individual species and species richness may expected to be greatest at small-to-intermediate spatial scales, but these biological factors should be less important as predictors of ecosystem processes at regional scales, where environmental heterogeneity is greater. Purvis and Hector (2000) found that the relationship between plant diversity and productivity changes with spatial scales. Gaston (2000) stated that observed patterns may vary with spatial scales and processes at regional scales influence patterns observed at local ones. Results of plant diversity and productivity experiments in European grasslandshighlighted the importance of considering scale when studying relationship between diversity and productivity (Hector et al., 1999). Our results showed that spatial resolution of data have a nonlinear effect on the relationships between diversity and ecosystem functions such as productivity and stability (Fig.5 and Fig.6).

Fig.5 Effects of spatial resolution on correlation coefficient between diversity and productivity

Fig.6 Effects of spatial resolution on correlation coefficient between diversity and desertification area

In short, discussions on the relationships between diversity and ecosystem functions should be based on specific diversity index and on specific spatial scale or spatial resolution of data.

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Table 1. The sampling data of maximum aboveground biomass (g/m^2)

Species	1987	1991	1997	2000
Aneurolepidium chinensis (Trin.) Kitag.	60.63	117.27	88.21	129.343
Stipa grandis P. Smirn.	26.57	22.2	7.25	23.8605
Achnathrum sibiricum (L.) Keng	6.55	6.44	1.09	14.503
Caragana microphylla Lam.	13.96	4.39	0	3.398
Agropyron michnoi Roshev	6.12	20.53	0	2.708
Artemisia commutata Bess.	31.87	9.6	0.51	0.846
Carex korshinshyi Kom.	4.44	0.43	6.51	37.725
Artemisia scoparia Wald. et Kit.	0	0	0	0.284
Salsola collina Pall.	0.07	0.16	0	0
Kochia prostrata (L.) Schrad.	3.01	1.5	0.23	8.1155
Serratula centeuroides L.	1.92	0.72	0.72	2.8265
Artemisia frigida Willd.	1.35	1.72	0.67	1.128
Cleistogenes squarrosa (Trin.) Keng	0.54	1.12	2.39	2.863
Koeleria cristata (L.)Pers.	1.28	3.69	0.92	9.4275
Heteropappus altaicus (Willd.) Novopokr.	2.69	1.64	0.48	0.059
Poa palustris L.	0.29	3.73	1.31	1.3835
Allium ramosum L.	0	0.15	4.92	0.225
Allium senescens L.	5.47	6.83	0	6.914
Potentilla tanacetifolia Willd. Ex Schlecht.	0.8	0.15	1.15	2.6355
Melissitus ruthenica (L.) Peschkova	0.5	0.04	1.27	1.1065
Orostachys fimbriatus (Turcz.) Berger	0.36	0.74	0.17	0
Allium tenuissimum L.	0.76	2.78	0	3.0445
Potentilla acaulis L.	0	0	1.41	3.1735
Allium bidentatum Fisch. ex Prokh.	0.18	0.09	0	0.6055
Dontostemon micranthus C. A. Mey	1.25	1.43	0	0
Allium condensatum Turcz.	0	0.58	0.31	0.513
Saposhnikovia divaricala (Turca.) Schischk.	0.35	0	0.21	1.108
Artemisia sieversiana Willd.	6.17	0	0	0
Potentilla bifurica L.	1.27	0	0.53	1.334
Allium anisopodium Ldb.	0.11	1.48	0	3.8515
Oxytropis myriophylla (Pall.) DC.	0.72	0.03	0	0
Elymus dahuricus var. tangutorum Roshev.	0	0	0.25	0
Astragalus adsurgens Pall.	0	0	0	0.001
Thalictrum petaloideum var.	0.77	0.36	0.04	0.002
Chenopodium glaucum L.	0	0.14	0	0
Pulsatilla tenuiloba (Turcz.) Tuz.	0	0.19	0	1.148
Thermopsis lanceolata R. Br.	0	0	0	0.2285
Adenophora stenanthina (Ldb.) Kitag.	0	0	0	2.985
Haplophyllum dauricum Juss.	0.05	0	0	0.0255
Iris tenuifolia Pall.	0	0	0	0.0535
Melandrium brachypetalium (Horn) Fenzl.	0.01	0	0	0
Potentilla verticillaris Steph. ex Willd.	0	0	0	0.695
Cymbaria dahurica L.	0.13	0	0	0
Adenophora crispata (Korsh.) Kitag.	0	0	0.01	0.4995
Gueldenstaedtia verna (Georgi) A. Bor.	0	0	0.06	0
Astragalus galactites Pall.	0	0	0	0.001
Chenonpodium aristatum L.	0	0.12	0	0
Gentiana squarrosa Ldb.	0	0.02	0	0
Others	0.05	0	0	4.98

Table 2. Grassland productivity and species biomass diversity

Year	Biomass (g/m^2)	Species biomass diversity		
		Scaling index	Shannon’s index	Simpson’s index
1987	180.24	0.13	2.21	2.49
1991	210.27	0.12	1.76	1.71
1997	120.62	0.10	1.23	1.35
2000	274.20	0.14	2.08	1.98

Table 3. Correlation of productivity with species biomass diversity and ecotope diversity

Diversity index name	Species biomass diversity	Ecotope diversity (30m×30m resolution)
Scaling index	0.83	-0.08
Shannon’s index	0.69	0.17
Simpson’s index	0.38	0.69

Table 4. Desertification area and ecotope diversity

Year	Desertification area (hectare)	Ecotope diversity (30m×30m resolution)		
		Scaling index	Shannon's index	Simpson's index
1987	357. 12	0.53	8.76	86.35
1991	930. 78	0.54	9.37	422.20
1997	2503. 98	0.55	9.71	298.18
2000	2986. 56	0.55	9.77	585.14

Table 5. Effect of different spatial scales on correlation coefficient of scaling diversity with grassland productivity and desertification area

Ordinal number	Pixel size	Year			Correlation coefficient		
		1987	1991	1997	2000	With productivity	With desertification area
1	30m×30m	0.53	0.54	0.55	0.55	-0.08	0.96
2	60m×60m	0.49	0.49	0.50	0.50	0.08	0.90
3	90m×90m	0.44	0.46	0.46	0.46	0.32	0.82
5	120 m×120m	0.41	0.43	0.43	0.43	0.39	0.79
6	150m×150m	0.39	0.41	0.40	0.41	0.46	0.76
7	180m×180m	0.37	0.39	0.38	0.39	0.43	0.75
8	210m×210m	0.35	0.37	0.37	0.38	0.52	0.73
9	240m×240m	0.34	0.36	0.35	0.36	0.42	0.72
10	270m×270m	0.32	0.35	0.34	0.35	0.43	0.69
11	300m×300m	0.31	0.34	0.33	0.34	0.41	0.70
12	330m×330m	0.30	0.33	0.32	0.33	0.35	0.69
13	360m×360m	0.29	0.32	0.31	0.32	0.38	0.75
14	390m×390m	0.28	0.31	0.30	0.31	0.36	0.66
15	420m×420m	0.27	0.30	0.29	0.30	0.46	0.64
16	450m×450m	0.27	0.29	0.29	0.30	0.37	0.69
17	480m×480m	0.26	0.28	0.29	0.29	0.25	0.79
18	510m×510m	0.25	0.29	0.28	0.28	0.38	0.62
19	540m×540m	0.25	0.28	0.27	0.28	0.48	0.62
20	570m×570m	0.24	0.27	0.26	0.27	0.40	0.64
21	600m×600m	0.24	0.27	0.26	0.27	0.38	0.48

Table 6. Effect of different spatial scales on correlation coefficient of Shannon's diversity with grassland productivity and desertification area

Ordinal number	Pixel size	Year				Correlation coefficient	
		1987	1991	1997	2000	With productivity	With desertification area
1	30m×30m	8.76	9.37	9.71	9.77	0.17	0.93
2	60m×60m	8.13	8.78	8.88	9.02	0.28	0.85
3	90m×90m	7.30	8.09	7.91	8.31	0.52	0.73
5	120 m×120m	6.73	7.57	7.30	7.78	0.58	0.69
6	150m×150m	6.32	7.17	6.75	7.33	0.67	0.59
7	180m×180m	5.91	6.85	6.39	6.97	0.64	0.57
8	210m×210m	5.64	6.55	5.96	6.73	0.75	0.51
9	240m×240m	5.42	6.29	5.85	6.44	0.67	0.58
10	270m×270m	5.21	6.12	5.50	6.22	0.74	0.46
11	300m×300m	4.96	5.94	5.35	6.05	0.70	0.50
12	330m×330m	4.77	5.78	5.24	5.82	0.63	0.52
13	360m×360m	4.67	5.57	5.02	5.63	0.69	0.48
14	390m×390m	4.50	5.52	4.87	5.37	0.60	0.37
15	420m×420m	4.44	5.38	4.73	5.37	0.70	0.41
16	450m×450m	4.23	5.26	4.64	5.23	0.65	0.44
17	480m×480m	4.07	5.07	4.69	5.15	0.55	0.61
18	510m×510m	4.08	5.16	4.47	5.05	0.63	0.39
19	540m×540m	4.08	5.04	4.32	4.91	0.68	0.31
20	570m×570m	3.89	4.89	4.11	4.79	0.71	0.31
21	600m×600m	3.86	4.95	4.10	4.67	0.63	0.22

Table 7. Effect of different spatial scales on correlation coefficient between Simpson's diversity and grassland productivity

Ordinal number	Pixel size	Year				Correlation coefficient	
		1987	1991	1997	2000	With productivity	With desertification area
1	30m×30m	86.35	422.20	298.18	585.14	0.68	0.71
2	60m×60m	85.32	284.89	312.16	444.36	0.48	0.89
3	90m×90m	69.25	227.20	124.91	322.94	0.82	0.60
5	120 m×120m	60.78	182.26	72.16	248.79	0.89	0.47
6	150m×150m	53.57	162.16	51.76	167.87	0.85	0.26
7	180m×180m	46.16	147.56	43.75	125.68	0.76	0.12
8	210m×210m	43.18	126.99	24.72	134.59	0.89	0.18
9	240m×240m	40.81	108.86	37.66	126.70	0.89	0.33
10	270m×270m	38.01	102.35	20.30	101.85	0.88	0.12
11	300m×300m	33.57	93.39	19.37	93.57	0.88	0.14
12	330m×330m	29.89	84.60	19.74	80.04	0.85	0.12
13	360m×360m	31.13	77.65	16.52	60.21	0.76	-0.09
14	390m×390m	24.55	82.62	15.86	47.67	0.57	-0.19
15	420m×420m	27.31	70.79	16.47	55.59	0.76	-0.06
16	450m×450m	21.48	67.28	13.75	45.40	0.66	-0.11
17	480m×480m	19.51	58.13	17.52	49.07	0.76	0.09
18	510m×510m	18.93	67.99	13.65	47.78	0.68	-0.05
19	540m×540m	19.43	63.17	12.71	38.19	0.60	-0.17
20	570m×570m	18.20	55.95	9.88	35.45	0.64	-0.17
21	600m×600m	17.20	59.43	10.60	32.23	0.54	-0.22

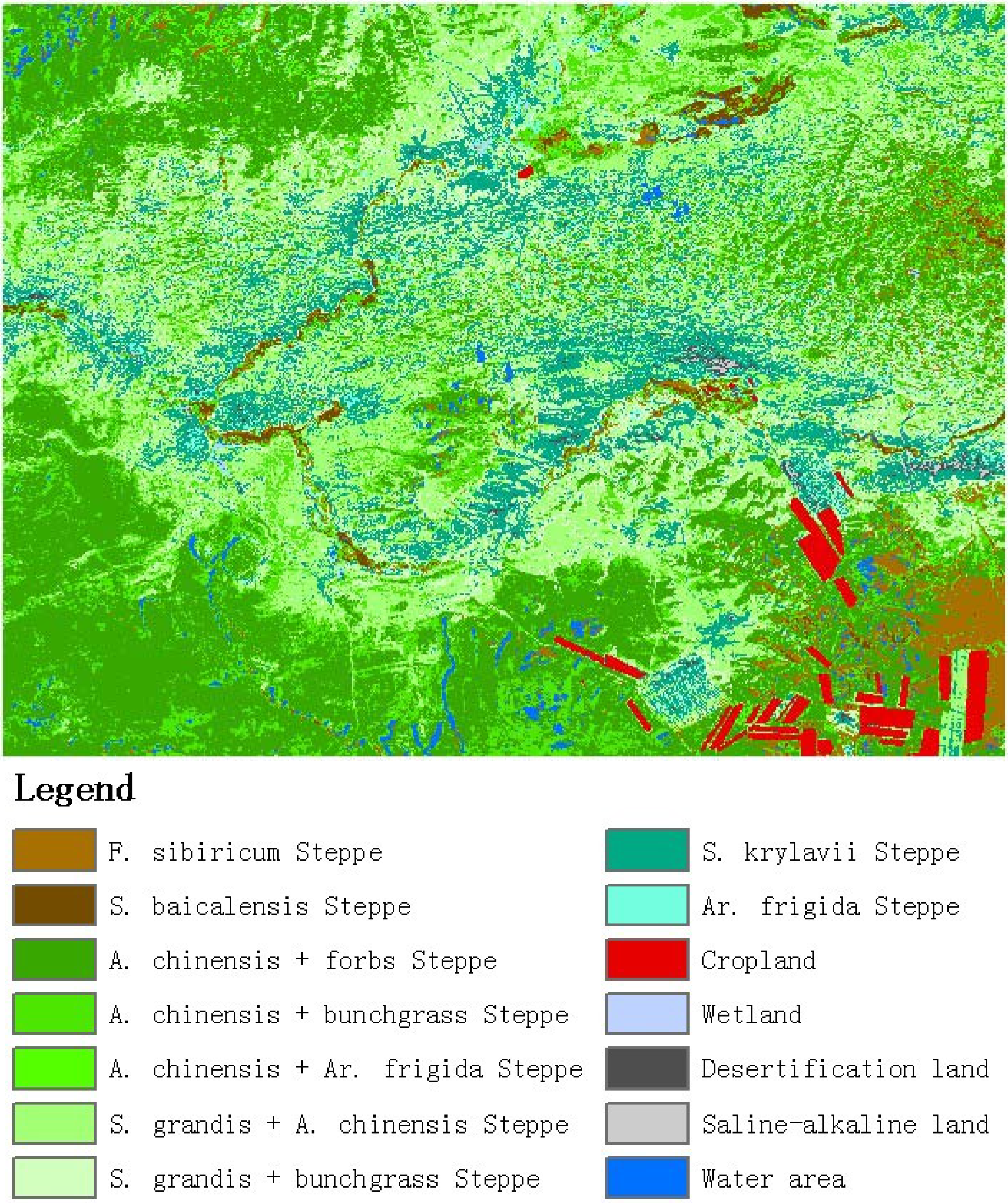
Legend
F. sibiricum Steppe
S. baicalensis Steppe
A. chinensis + forbs Steppe
A. chinensis + bunchgrass Steppe
A. chinensis + Ar. frigida Steppe
S. grandis + A. chinensis Steppe
S. grandis + bunchgrass Steppe
S. krylavii Steppe
Ar. frigida Steppe
Cropland
Wetland
Desertification land
Saline-alkaline land
Water area

Fig. 1. Land Cover in 1987(30m×30m)

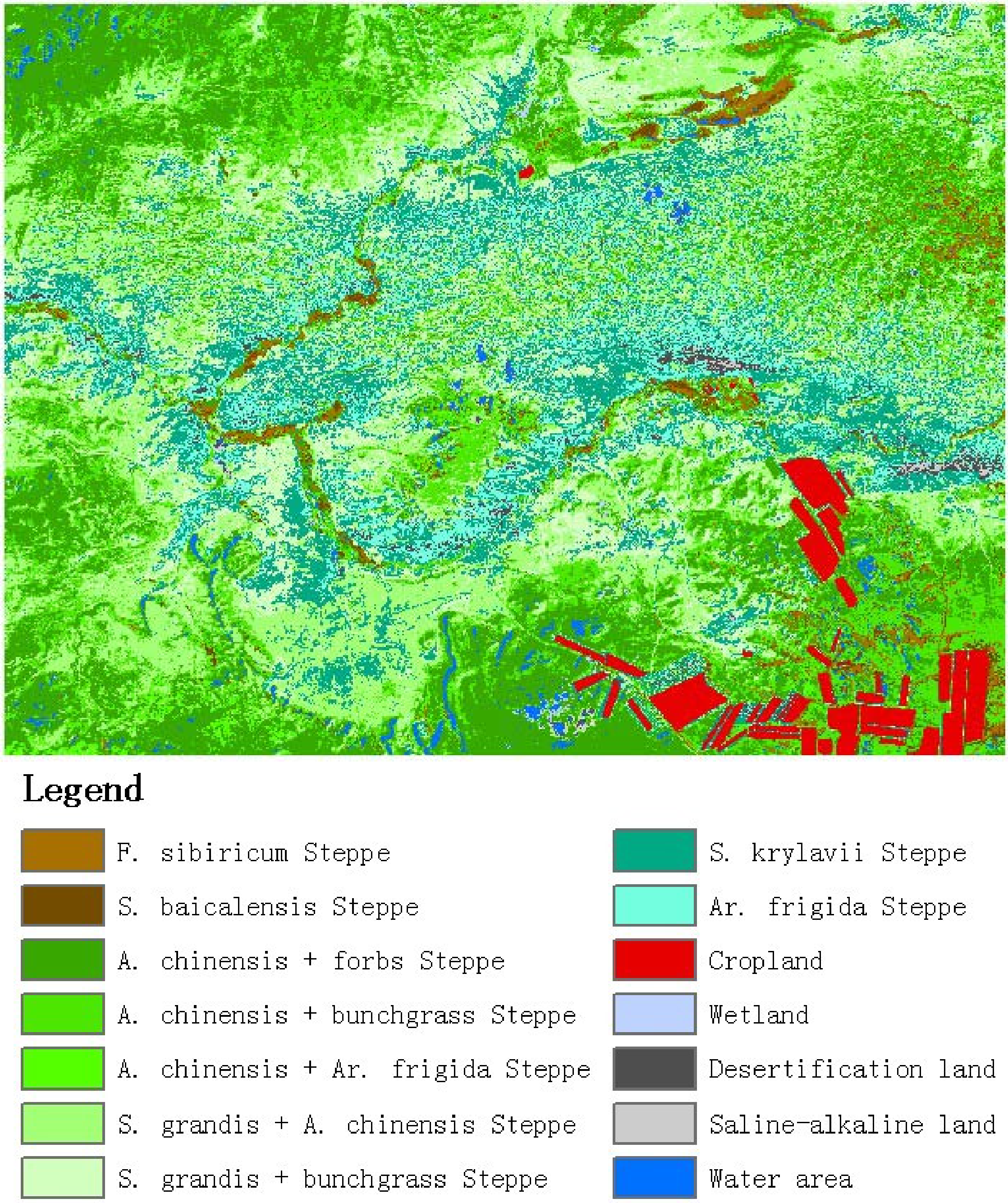

Fig. 2. Land Cover in 1991 (30m×30m)

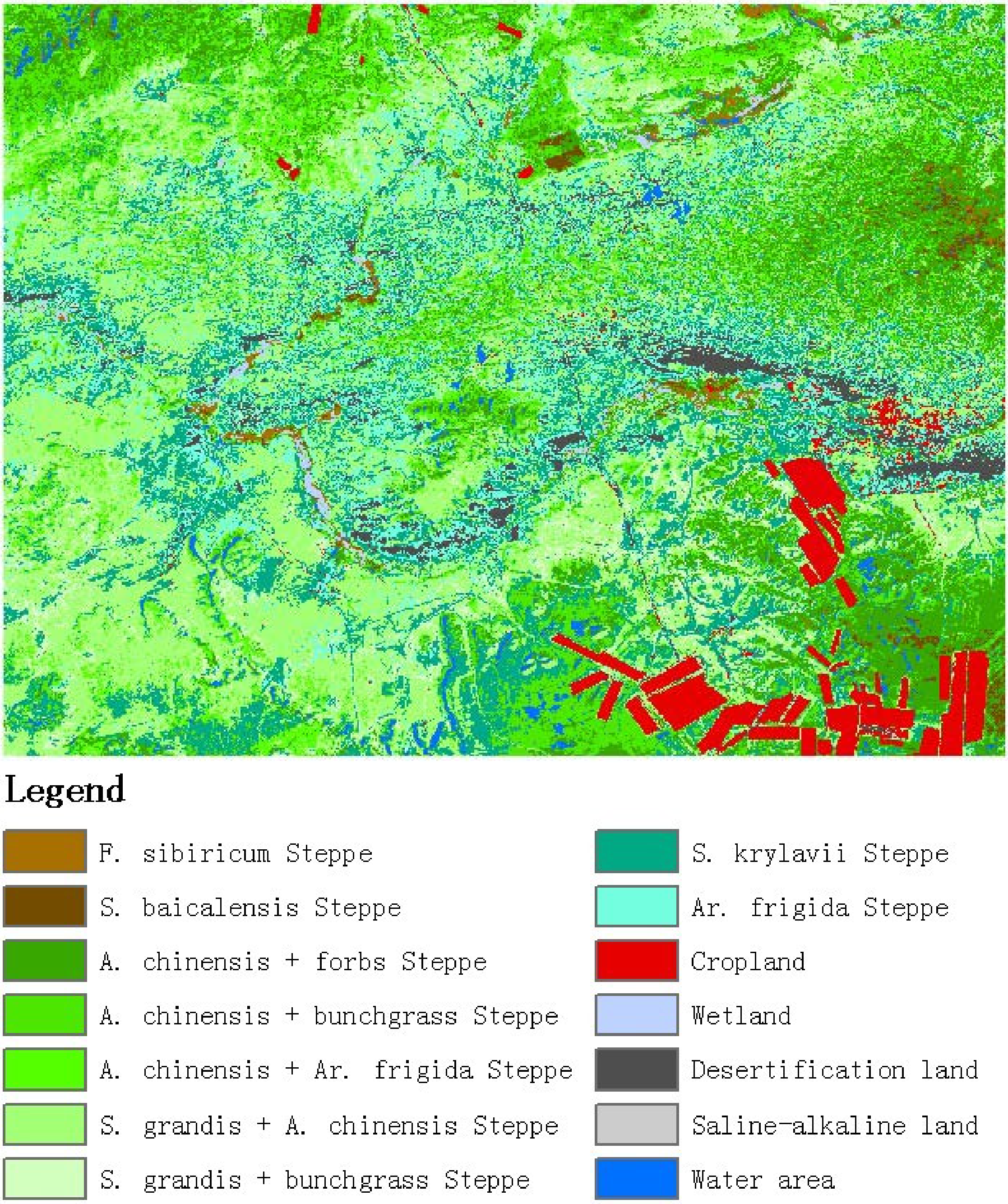

Fig.3 Land Cover in 1997(30m×30m)

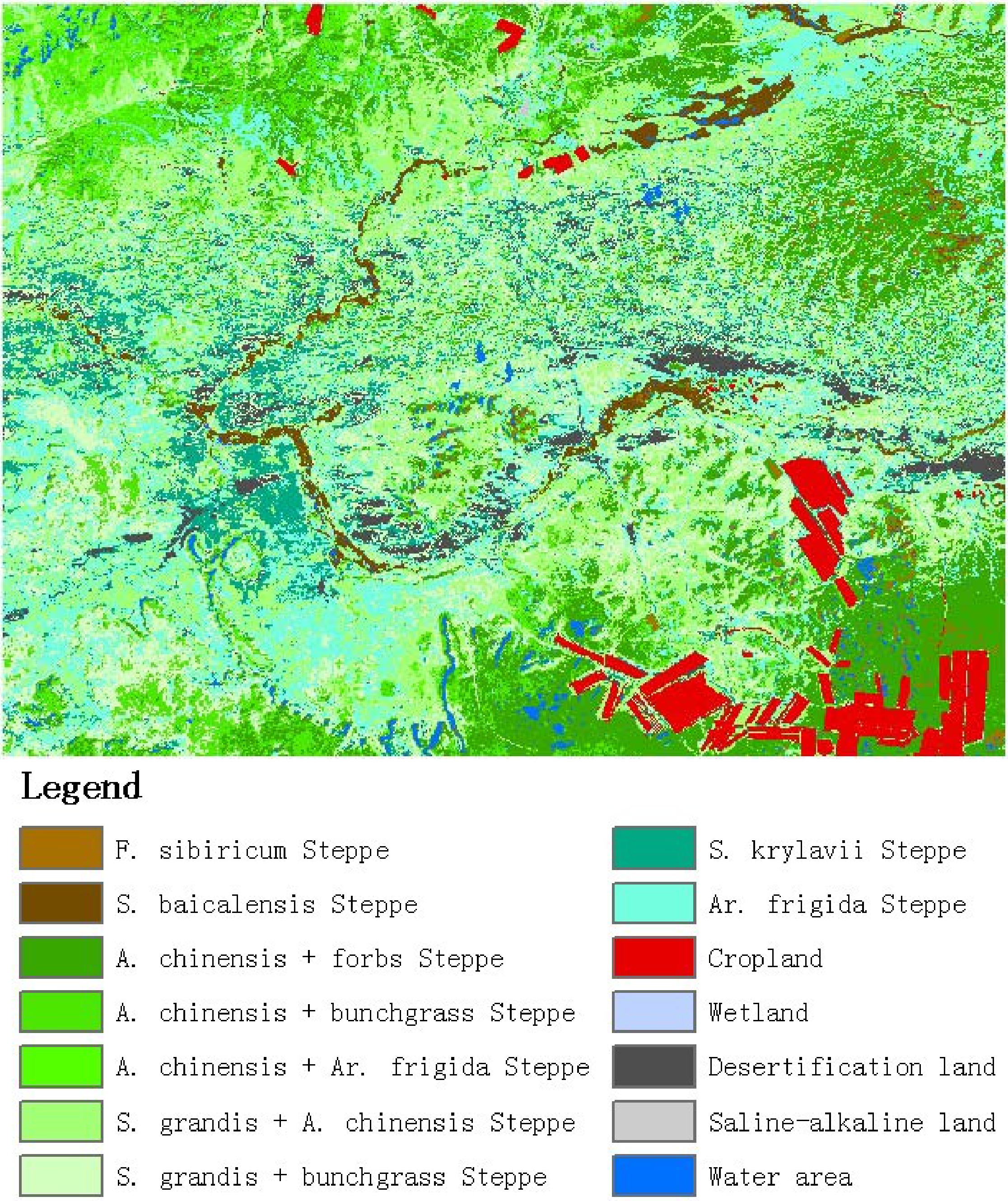

Fig.4 Land Cover in 2000 (30m×30m)

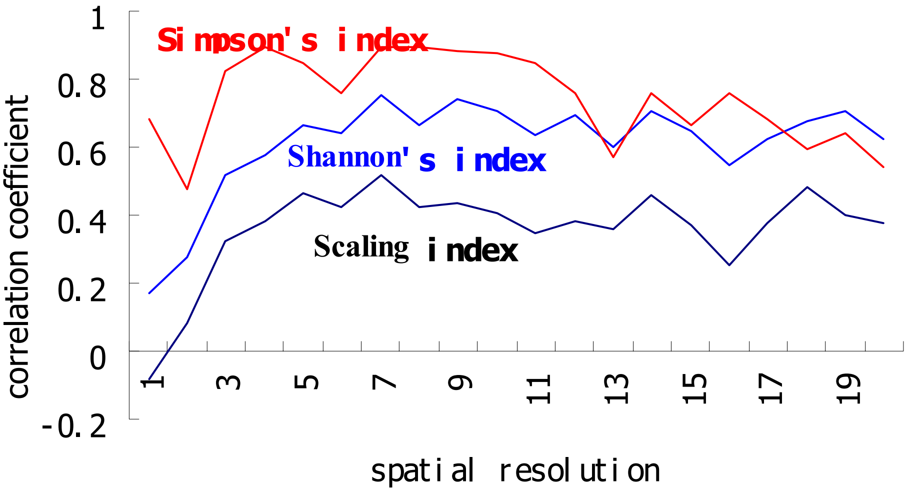

Fig.5 Effects of spatial resolution on correlation coefficient between diversity and productivity

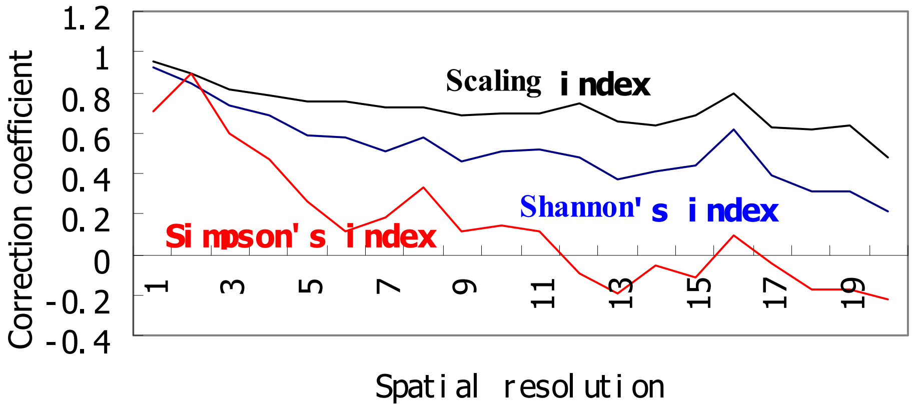

Fig.6 Effects of spatial resolution on correlation coefficient between diversity and desertification area