Postprint: Species-Area Relationships of Plant Communities in Riparian Zones of Beijing' s Mountainous Areas

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Abstract

The species-area relationship is one of the fundamental issues in community ecology and an important approach to understanding plant community structure. To determine the minimum quadrat area for investigating plant communities in the riparian zones of mountainous rivers in Beijing, 50 plots of 80 m length were established along the Huaijiu River riparian zone in Huairou District, Beijing, using a method of gradually expanding plot area based on site conditions of the riparian zone, and the minimum plot area required for different types of riparian zones was surveyed, calculated, and fitted. The research results indicate that the Huaijiu River riparian zone in Huairou District, Beijing, contains 255 plant species, belonging to 70 families and 185 genera. Through cluster analysis, the Huaijiu River riparian zone was classified into six types: natural riparian zone, near-natural riparian zone, artificial slope arbor-shrub-grass riparian zone, artificial slope ornamental arbor-shrub-grass riparian zone, artificial slope sparse arbor-shrub-grass dry-stone riparian zone, and artificial slope mortared-stone riparian zone. According to the Akaike Information Criterion (AIC), the model S=c-ae-bA was preferentially selected for natural riparian zones, near-natural riparian zones, artificial slope arbor-shrub-grass riparian zones, and artificial slope sparse arbor-shrub-grass dry-stone riparian zones; the model S=aA/(1+bA) was preferentially selected for artificial slope ornamental arbor-shrub-grass riparian zones; and the model S=c/ (1+ae-bA) was preferentially selected for artificial slope mortared-stone riparian zones. To satisfy the same proportion of plant species survey, the minimum plot area required for different types of riparian zones shows significant differences. When 80% of plant species in the riparian zone plant survey is satisfied, artificial slope mortared-stone riparian zones (84 m^2) and natural riparian zones (217 m^2) require smaller plot areas, followed by artificial slope sparse arbor-shrub-grass dry-stone riparian zones (362 m^2); near-natural riparian zones (450 m^2) and artificial slope arbor-shrub-grass riparian zones (460 m^2) require similar plot areas, while artificial slope ornamental

arbor-shrub-grass riparian zones require the largest plot area of 571 m^2. The derived minimum plot area for riparian zone plant surveys is of great significance for riparian zone biodiversity conservation and guiding riparian zone ecological restoration.

Full Text

Species-Area Relationship of Riparian Plant Communities in the Mountainous Areas of Beijing

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Abstract

The species-area relationship is a fundamental concept in community ecology and an important approach for understanding plant community structure. Different sampling methods significantly affect the species-area relationship. To determine the minimum sampling area required to assess species richness in riparian communities of Beijing' s mountainous regions, we employed a method of gradually expanding plot sizes along the Huaijiu River riparian zone in Huairou District, Beijing. Surveys were conducted to calculate and fit the minimum plot area required for different riparian habitat types. The results show that the Huaijiu River riparian zone contains 255 plant species belonging to 185 genera across 70 families. Through cluster analysis, the riparian zone was classified into six typical types: natural riparian, near-natural riparian, artificial bank plant riparian, artificial bank ornamental plant riparian, artificial bank sparse plant dry-stone riparian, and artificial bank masonry riparian. According to the Akaike Information Criterion (AIC), the optimal estimation models are: S = c - ae^(-bA) for natural riparian, near-natural riparian, artificial bank plant riparian, and artificial bank sparse plant dry-stone riparian; S = aA/(1 + bA) for artificial bank ornamental plant riparian; and S = a(1 - e^(-bA)) for artificial bank masonry riparian, where A is plot area, S is the number of species in area A, a, b, c are parameters to be estimated, and e is the base of natural logarithm. To meet the criterion of surveying the same proportion of plant species, significant differences exist among different riparian habitat types. For surveying 80% of plant species in a riparian habitat, artificial bank masonry riparian required the smallest sampling area of 84 m^2, followed by natural riparian (217 m^2), artificial bank sparse plant dry-stone riparian (362 m^2), near-natural riparian (450 m^2), and artificial bank plant riparian (460 m^2). The largest area of 571 m^2 was required for artificial bank ornamental plant riparian. These results are important for riparian plant diversity conservation and provide guidance for minimum area requirements in protection and ecological restoration.

Keywords: mountainous area; species-area relationship; plant community; riparian types; minimum sampling area

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Introduction

The minimum area of a plant community, also known as the critical sampling area, is defined as the smallest area that can provide sufficient environmental and biological characteristics of a specific community type, or can ensure the revelation of true features of species composition and structure. Minimum area effectively reflects the inherent characteristics of plants and relative uniformity at a certain scale. Since minimum area is largely determined by spatial heterogeneity, determining the minimum area for different plant community types is essential in community ecology research. The species-area curve method is most commonly used to determine minimum area, which can predict species extinction rates based on habitat reduction and loss, design optimal reserve sizes, and assess human impacts on diversity—making it significant for biodiversity conservation.

Riparian zones are transitional areas between terrestrial and aquatic ecosystems, typically defined as the area between high and low water levels and the zone where extreme floods and soil water-holding capacity no longer affect plants. These zones exhibit strong edge effects and high plant diversity. Mountain river riparian zones form different plant community types along upstream-downstream and riverbed-to-floodplain gradients, with varying soil physicochemical properties and moisture characteristics. They play crucial roles in maintaining riverbank stability, reducing non-point source pollution, providing habitats for flora and fauna, and offering tourism resources. However, inappropriate development and utilization have fragmented riparian zones and reduced plant diversity, severely affecting their functions. Therefore, ecological restoration and protection of riparian resources have become urgent issues.

Most plant diversity surveys determine plot area based on empirical values (e.g., 40 m × 40 m for tropical forests, 20 m × 20 m for subtropical forests, 10 m × 10 m for temperate forests, 2 m × 2 m or 1 m × 1 m for herbaceous plants). Inappropriate use of empirical values wastes resources and may lead to inaccurate results. While minimum area studies have increased, most focus on forest communities, with limited research on riparian zones due to resource constraints. Applying species-area relationships to determine minimum plot area in riparian zones can expand the regional types studied and promote the development of species-area theory.

This study examines the Huaijiu River riparian zone in Beijing's mountainous areas. Based on comprehensive surveys of the entire river section, we used cluster analysis to classify riparian types and studied minimum areas for different community types. We reveal variation patterns in minimum area among different riparian plant communities and evaluate the applicability of four species-area curve models. This ensures scientific rigor in riparian plant community surveys and provides reference for mountain river riparian zone research, promoting conservation and restoration efforts.

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1. Study Area

The Huaijiu River (40°21 -40°30 N, 116°16 -116°21 E) is a typical mountain stream in Beijing with high representativeness in economic and social aspects. Originating from Donggong Village, Huanghua Town, Huairou District, it flows 68.9 km before entering Huairou Reservoir at Qianxinzhuang. The watershed area is 347.2 km². The region has a continental monsoon climate with large seasonal temperature variations. Mean annual precipitation is 667.2 mm, with July mean temperature of 25.3°C and January mean temperature of -5°C. Annual maximum temperature reaches 38°C. Soils are primarily common cinnamon soil, brown soil, and coarse skeletal brown soil. Dominant vegetation includes arbor species such as *Populus canadensis*, *Salix matsudana*, *Carya cathayensis*, and *Castanea mollissima*, with Asteraceae, Poaceae, and Fabaceae as dominant herb families including *Bidens pilosa*, *Artemisia dubia*, *Setaria viridis*, and *Glycine soja*.

[Figure 1: see original paper] Spatial position and basin map of the Huaijiu River riparian zone in Beijing

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2. Plot Setup and Survey Content

Along the Huaijiu River riparian zone in Huairou District, we established plots approximately every 5 km, skipping or adding plots for special sites. Plots were labeled sequentially from upstream to downstream as Plot 1, 2, ···, n. Each plot was divided into 1 m × 1 m quadrats, which were merged based on site conditions into continuous plots with lengths of 10, 20, 30, 40, 50, 60, 70, and 80 m, and width determined by riparian zone width (average 5.81 ± 3.55 m). This created eight area gradients per plot.

We recorded latitude/longitude, bank slope type, and human disturbance intensity (scored higher with greater bank modification). Gravel coverage and hardened area proportion were recorded as ratios to total plot area. All arbor and shrub species names, DBH (1.0 cm), crown density, and crown width were documented. In each 1 m × 1 m quadrat, herb species names, quantities, total coverage, and average height were recorded.

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3. Research Methods

Species-area relationship studies commonly use saturated curve fitting to estimate total community species richness, eliminating the need to know total species count beforehand when calculating critical sampling area and reducing field workload. We used four common saturation curve models to fit species-area relationships:

1. S = aA/(1 + bA)
2. S = c - ae^(-bA)
3. S = a(1 - e^(-bA))
4. S = c(1 - $e^{(-aA))}$b

where A is area, S is species number in area A, a, b, c are parameters, and e is the natural logarithm base.

Model fit was evaluated using Akaike Information Criterion (AIC = -2L + 2K, where L is log-likelihood and K is parameter count). Smaller AIC indicates better fit and more accurate predictions. Curve fitting used SPSS 18.0, PCA and cluster analysis used SPSS 18.0 and R 3.2.2, and figures/tables used Excel 2003.

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4. Results

4.1 Riparian Vegetation Community Composition Survey results from 50 plots showed 255 species belonging to 185 genera across 70 families in the Huaijiu River riparian zone. Asteraceae had the most species (19.61%), followed by Poaceae (9.41%) and Fabaceae (9.02%). Based on life forms from *Flora of Beijing* and *Flora of China*, arbor species accounted for 11.76% (mainly *Populus canadensis*, *Salix matsudana*, *Morus alba*), shrubs 9.41% (mainly *Lespedeza bicolor*, *Ziziphus jujuba*, *Grewia biloba*), lianas 2.35% (mainly *Metaplexis japonica*, *Menispermum dauricum*, *Ampelopsis humulifolia*, *Parthenocissus quinquefolia*), annual herbs 32.55% (mainly *Bidens pilosa*, *Digitaria sanguinalis*), and perennial herbs 35.69% (mainly *Artemisia dubia*, *Artemisia capillaries*, *Rubia cordifolia*, *Viola prionantha*).

Upstream riparian zones had (47.11 ± 2.68) species with (914.88 ± 133.31) individuals, while midstream and downstream zones showed significant changes in species and quantities due to tourism and agriculture, with (32.29 ± 5.13, 31.94 ± 3.58) species and (640.89 ± 126.06, 527.20 ± 71.80) individuals respectively.

[Figure 2: see original paper] Change in species number of dominant families
[Figure 3: see original paper] Change in species number of plant life forms
[Figure 4: see original paper] Riparian community plant species statistics
[Figure 5: see original paper] Riparian community plant number statistics

4.2 Classification of Huaijiu River Riparian Zone Types We performed principal component analysis on 12 environmental factors from 50 plots. After varimax rotation, four principal components explained 28.49%, 26.86%, 11.70%, and 8.89% of variance respectively. PC1 reflected bank slope type and hardened area proportion (loadings: 0.912, 0.868). PC2 reflected soil bulk density and organic carbon (loadings: 0.752, 0.863, 0.851). PC3 reflected distance to reservoir inlet and elevation (loadings: 0.895, 0.902). PC4 reflected bank width (loading: 0.870).

Based on these results, we selected four representative factors (bank slope type, hardened area proportion, soil bulk density, soil organic carbon) for cluster analysis, which divided 50 plots into six types: natural riparian, near-natural riparian, artificial bank plant riparian, artificial bank ornamental plant riparian, artificial bank sparse plant dry-stone riparian, and artificial bank masonry riparian.

Factor loadings of the four principal components

[Figure 6: see original paper] Cluster analysis of 50 riparian sampling plots

4.3 Species-Area Curve Fitting for Different Riparian Types Species number increased with plot area in all riparian types. Maximum plot areas were: natural riparian 316.30 m^2, near-natural riparian 494.12 m^2, artificial bank plant riparian 757.76 m^2, artificial bank ornamental plant riparian 423.21 m^2, artificial bank sparse plant dry-stone riparian 456.41 m^2, and artificial bank masonry riparian 289.36 m^2. Maximum species numbers in these plots were 41, 35, 46, 32, 37, and 7 respectively.

Plant species numbers in different riparian zone types in Huaijiu River

All six riparian types showed logarithmic relationships between plot area and species number, with $R^2 > 0.989$ for all except artificial bank masonry riparian ($R^2 = 0.805$). Artificial bank masonry riparian required the smallest plot area. Natural riparian showed rapid species increase with area, reaching saturation at 212 m^2. Artificial bank ornamental plant riparian, near-natural riparian, and artificial bank sparse plant dry-stone riparian also showed rapid increases, saturating at 300 m^2, 285 m^2, and 362 m^2 respectively. Artificial bank plant riparian required the largest area, saturating at 460 m^2.

According to AIC, natural riparian, near-natural riparian, artificial bank plant riparian, and artificial bank sparse plant dry-stone riparian best fit $S = c - ae^{(-bA)}$. Artificial bank ornamental plant riparian best fit $S = aA/(1 + bA)$. Artificial bank masonry riparian best fit $S = a(1 - e^{(-bA)})$.

4.4 Minimum Plot Area for Different Riparian Types Substituting fitted parameters into formulas with proportion factors P = 0.7, 0.8, 0.9 yielded minimum sampling areas:

Species-area curve fitting results
Minimum sampling area calculated by species-area curve

Minimum areas varied significantly among riparian types and increased with precision level. For surveying 70%, 80%, and 90% of species: artificial bank masonry riparian required 67, 84, and 108 m^2; natural riparian required 261, 362, and 535 m^2; near-natural riparian required 217, 450, and 732 m^2; artificial bank plant riparian required 460, 571, and 732 m^2; artificial bank ornamental plant riparian required 362, 571, and 732 m^2; and artificial bank sparse plant dry-stone riparian required 217, 362, and 535 m^2.

For the 80% species criterion, artificial bank masonry riparian required the smallest area (84 m^2), followed by natural riparian (217 m^2), artificial bank sparse plant dry-stone riparian (362 m^2), near-natural riparian (450 m^2), and artificial bank plant riparian (460 m^2). Artificial bank ornamental plant riparian required the largest area (571 m^2).

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5. Discussion

5.1 Plot Layout Method for Species-Area Curves Riparian zones are unique transitional ecosystems between terrestrial and aquatic systems, showing much greater heterogeneity than forest or grassland communities. Bank width is determined by adjacent land use, and vegetation can alter microtopography. Our method of gradually expanding plot area based on site conditions effectively addresses difficulties in plot layout caused by riparian heterogeneity. Different sampling methods significantly affect species-area relationships. While random sampling may provide better fit in some cases, our approach systematically captures the continuous, variable nature of riparian zones across entire river sections rather than isolated cross-sections.

5.2 Riparian Zone Classification Previous studies focused on limited cross-sections or specific river reaches. We used PCA to extract key environmental factors and cluster analysis to classify 50 plots into six functional types based on bank slope type, vegetation layers, and restoration measures. This comprehensive classification reveals that different riparian types require different minimum areas, highlighting the importance of type-specific sampling strategies.

5.3 Applicability of Species-Area Curve Models Our results show that model applicability varies by riparian type. Natural, near-natural, artificial bank plant, and artificial bank sparse plant dry-stone riparian zones best fit the negative exponential model (S = c - ae^(-bA)), while artificial bank ornamental plant riparian fits the rational function model (S = aA/(1 + bA)) and artificial bank masonry riparian fits the exponential saturation model (S = a(1 - e^(-bA))). This variation likely reflects differences in plant diversity and spatial distribution patterns. The fitted minimum areas were generally larger than actual survey areas, consistent with findings from other forest community studies.

5.4 Minimum Area Requirements for Different Riparian Types Our results demonstrate substantial variation in minimum area requirements. Artificial bank masonry riparian requires the smallest area because this restoration method destroys original site conditions, with sparse vegetation growing only in masonry gaps. Natural riparian, despite having no restoration measures and maintaining natural habitats, requires relatively small areas due to protection from human disturbance. Artificial bank ornamental plant riparian requires the largest area because human-planted ornamental species are spatially dispersed. Artificial bank sparse plant dry-stone riparian shows moderate requirements as dry-stone structures protect vegetation while allowing growth.

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6. Conclusion

This study used a site-condition-based gradual plot expansion method to investigate species-area relationships in Beijing' s mountainous riparian zones. The Huaijiu River riparian zone contains 255 species from 70 families. Six riparian types were identified through cluster analysis: natural, near-natural, artificial bank plant, artificial bank ornamental plant, artificial bank sparse plant dry-stone, and artificial bank masonry.

According to AIC criteria, different models optimally fit different riparian types: S = c - ae^(-bA) for natural, near-natural, artificial bank plant, and artificial bank sparse plant dry-stone riparian; S = aA/(1 + bA) for artificial bank ornamental plant riparian; and S = a(1 - e^(-bA)) for artificial bank masonry riparian.

For 80% species coverage, minimum areas are: artificial bank masonry riparian (84 m^2), natural riparian (217 m^2), artificial bank sparse plant dry-stone riparian (362 m^2), near-natural riparian (450 m^2), artificial bank plant riparian (460 m^2), and artificial bank ornamental plant riparian (571 m^2). These results provide scientific guidance for riparian biodiversity conservation and restoration planning.

References

[1] Cain S A. The species-area curve. The American Midland Naturalist, 1938, 19(3): 573-581.
[2] Niu J Y, Chen Y N, Li W H. Minimum sampling area of desert riparian forest communities in the lower reaches of the Tarim River. Chinese Journal of Ecology, 2009, 28(6): 1182-1187.
[3] Désiets P, Houle G. Effects of resource availability and heterogeneity on the

slope of the species-area curve along a floodplain-upland gradient. Journal of Vegetation Science, 2005, 16(5): 487-496.
[4] Báldi A. Habitat heterogeneity overrides the species-area relationship. Journal of Biogeography, 2008, 35(4): 675-681.
[5] Barkman J J. A critical evaluation of minimum area concepts. Vegetatio, 1989, 85(1/2): 89-104.
[6] Dai L M, Wang Q L, Su D K. Minimum area and species richness of plant communities in the riparian zone of the Erdaobai River. Chinese Journal of Applied Ecology, 2002, 13(6): 641-645.
[7] Mashayekhi M, MacPherson B, Gras R. Species-area relationship and a tentative interpretation of the function coefficients in an ecosystem simulation. Ecological Complexity, 2014, 19: 84-95.
[8] Kong W J, Xia H J, Zhang Y. Minimum sampling area for monitoring herb diversity in riparian zones of temperate rivers, China. Ecological Research, 2016, 31(4): 547-555.
[9] Zhou N, Wu J S, Shen Z X, Zhang X Z, Yang P W. Species-area relationship within and across functional groups at alpine grasslands on the northern Tibetan Plateau, China. Journal of Mountain Science, 2016, 13(2): 265-275.
[10] Sreekar R, Huang G H L, Zhao J B, et al. The use of species-area relationships to partition the effects of hunting and deforestation on bird extirpations in a fragmented landscape. Diversity and Distributions, 2015, 21(4): 441-450.
[11] Novaglio C, Ferretti F, Smith A D M, et al. Species-area relationships as indicators of human impacts on demersal fish communities. Diversity and Distributions, 2016, 22(11): 1186-1198.
[12] Naiman R J, Decamps H. The ecology of interfaces: riparian zones. Annual Review of Ecology and Systematics, 1997, 28: 621-658.
[13] Nilsson C, Berggren K. Alterations of riparian ecosystems caused by river regulation. BioScience, 2000, 50(9): 783-792.
[14] Xiao D N, Li X Z. Landscape Ecology. China Forestry Publishing House, 1996.
[15] Swanson F J, Fredriksen R L, McCorison F M. Material transfer in a western Oregon forested watershed // Edmonds R L, ed. Analysis of Coniferous Forest Ecosystems in the Western United States. Stroudsburg, Pennsylvania, USA: Hutchinson Ross Publishing Company, 1982.
[16] Sunil C, Somashekar R K, Nagaraja B C. Riparian vegetation assessment of Cauvery river basin of South India. Environmental Monitoring and Assessment, 2010, 170(1/4): 545-553.
[17] Zhang Y X, Wang R Q. Riparian function and management. Journal of Soil and Water Conservation, 2001, 15(6): 143-146.
[18] Bennett P. Guidelines for Assessing and Monitoring Riverbank Health. NSW: Hawkesbury-Nepean Catchment Management Trust, 2000: 3-4.
[19] Sweeney B W, Bott T L, Jackson J K, et al. Riparian deforestation, stream narrowing, and loss of stream ecosystem services. Proceedings of the National Academy of Sciences of the United States of America, 2004, 101(39): 14132-14137.
[20] Bedison J E, Scatena F N, Mead J V. Influences on the spatial pattern

of soil carbon and nitrogen in forested and non-forested riparian zones in the Atlantic Coastal Plain of the Delaware River Basin. Forest Ecology and Management, 2013, 302: 200-209.
[21] Capon S J, Chambers L E, Nally R M, et al. Riparian ecosystems in the 21st century: hotspots for climate change adaptation? Ecosystems, 2013, 16(3): 359-381.
[22] Kuglerová L, Ågren A, Jansson R, Laudon H. Towards optimizing riparian buffer zones: ecological and biogeochemical implications for forest management. Forest Ecology and Management, 2014, 334: 74-84.
[23] Thomas S M, Griffiths S W, Ormerod S J. Beyond cool: adapting upland streams for climate change using riparian woodlands. Global Change Biology, 2016, 22(1): 310-324.
[24] Jiang Z C, Zhang J T. Fitting of species-area curves and determination of minimum area for shrub communities in the arid valley of the upper Minjiang River. Acta Ecologica Sinica, 2007, 27(5): 1818-1825.
[25] Stella J C, Rodríguez-González P M, Dufour S, Bendix J. Riparian vegetation research in Mediterranean-climate regions: common patterns, ecological processes, and considerations for management. Hydrobiologia, 2013, 719(1): 291-315.
[26] Liu Y H, He W M, Zhang H Y, Dong L. Plant species diversity and its response to environment in typical riparian zones of the middle and lower Yellow River. Chinese Journal of Ecology, 2015, 34(5): 1325-1331.
[27] Zhang J T, Li Y. Determination of optimal quadrat size for *Artemisia ordosica* communities in the Ordos Plateau. Research of Soil and Water Conservation, 2013, 20(3): 185-189, 195.
[28] Zhang J T. Studies on plant community diversity in the Dongling Mountain area of Beijing: fitting and evaluation of species-area curves. Acta Phytoecologica Sinica, 1999, 23(6): 490-500.
[29] Zhang J T. Determination of minimum area and method comparison for natural mixed oak forests. Acta Ecologica Sinica, 1999, 19(4): 499-503.
[30] Yue M, Zhang J T, Zhang W H. Minimum sampling area for shrubs and herbs in several plant communities of Taibai Mountain. Acta Botanica Boreali-Occidentalia Sinica, 2005, 25(4): 715-720.
[31] Zhang J T, Li Y. Relationship between species-area curve and species diversity of plant communities in Huoshan, Shanxi. Chinese Journal of Ecology, 2013, 32(1): 39-44.
[32] Zhang J T, Li Y. Relationship between plant species number and sampling area in subalpine meadow communities. Chinese Journal of Ecology, 2013, 32(4): 929-934.
[33] Wang R Z, Guo Q X. Species-area relationship of woody plants in broadleaved-Korean pine forests in Xiaoxing' an Mountains. Acta Ecologica Sinica, 2016, 36(13): 4091-4098.
[34] Kong W J, Xia H J, Zhang Y. Analysis of minimum sampling area for plant surveys in the lower Tarim River. Acta Ecologica Sinica, 2011, 31(5): 1221-1225.
[35] Dong Z R, Sun D Y. River Near-natural Assessment: Methods and

Applications. China Water & Power Press, 2010.
[36] Zhang J T. Studies on plant community diversity in the Dongling Mountain area of Beijing: determination of critical sampling areas for several community types. Acta Ecologica Sinica, 1998, 18(1): 15-23.
[37] Scheiner S M. Six types of species-area curves. Global Ecology and Biogeography, 2003, 12(6): 441-447.
[38] Anderson D R, Burnham K P, White G C. AIC model selection in overdispersed capture-recapture data. Ecology, 1994, 75(6): 1780-1793.
[39] Editorial Committee of Flora of Beijing. *Flora of Beijing*. Beijing Press, 1992.
[40] Editorial Committee of Flora of China, Chinese Academy of Sciences. *Flora of China*. Science Press, 2004.
[41] Paine L K, Ribic C A. Comparison of riparian plant communities under four land management systems in southwestern Wisconsin. Agriculture, Ecosystems & Environment, 2002, 92(1): 93-105.
[42] Suzuki W, Osumi K, Masaki T, et al. Disturbance regimes and community structures of a riparian and an adjacent terrace stand in the Kanumazawa Riparian Research Forest, northern Japan. Forest Ecology and Management, 2002, 157(1/3): 285-301.
[43] Nagy R C, Porder S, Neill C, et al. Structure and composition of altered riparian forests in an agricultural Amazonian landscape. Ecological Applications, 2015, 25(6): 1725-1738.
[44] Zhang J T, Li Y. Relationship between plant species diversity and soil factors in the Huihe River wetland riparian zone. Acta Ecologica Sinica, 2014, 34(6): 1535-1547.
[45] Zhang J T, Li Y. Floristic analysis of riparian plants in the Yongding-Haihe mainstream in Beijing. Wetland Science, 2016, 14(3): 396-402.
[46] Dosskey M G, Vidon P, Gurwick N P, et al. The role of riparian vegetation in protecting and improving chemical water quality in streams. Journal of the American Water Resources Association, 2010, 46(2): 261-277.
[47] Bullinger-Weber G, Le Bayon R C, Thébault A, et al. Carbon storage and soil organic matter stabilisation in near-natural, restored and embanked Swiss floodplains. Geoderma, 2014, 228-229: 122-131.
[48] Bätz N, Verrecchia E P, Lane S N. Organic matter processing and soil evolution in a braided river system. CATENA, 2015, 126: 86-97.
[49] Zhang J T. Comparison of ecological information between random and systematic sampling. Acta Phytoecologica Sinica, 1998, 22(5): 473-480.
[50] Tjørve E. Shapes and functions of species-area curves: a review of possible models. Journal of Biogeography, 2003, 30(6): 827-835.
[51] Ulrich W, Buszko J. Sampling design and the shape of species-area curves on the regional scale. Acta Oecologica, 2007, 31(1): 54-59.
[52] Zhang J T, Li Y. Species-area relationship of 42 hm^2 coniferous-broadleaved mixed forest plots. Acta Phytoecologica Sinica, 2012, 36(1): 30-38.
[53] Zhang J T, Li Y. Species-area relationship of broadleaved-Korean pine forest plots in Jiaohe, Jilin. Acta Ecologica Sinica, 2017, 37(14): 4770-4777.
[54] Zhang J T. Qualitative and quantitative study on functional zoning of

ecological riparian zones. Research of Soil and Water Conservation, 2007, 38(S1): 542-546.
[55] Yin X W, Yang Z F. Preliminary study on river ecological function zoning oriented toward ecological restoration targets. Acta Scientiae Circumstantiae, 2011, 31(9): 1843-1850.
[56] Zhao X F, Yang Z F, Zuo Q T. Methods and case studies of river function zoning. Advances in Water Science, 2011, 22(6): 741-749.
[57] Aguiar F C, Cerdeira J O, Martins M J, Ferreira M T. Riparian forests of Southwest Europe: are functional trait and species composition assemblages constrained by environment? Journal of Vegetation Science, 2013, 24(4): 628-638.
[58] Naiman R J, Décamps H, McClain M E. Riparia: Ecology, Conservation, and Management of Streamside Communities. Elsevier Academic Press, 2005.
[59] Wang J J, Zhang J T, Li Y. Plant richness and diversity of small coastal islands in Wenzhou and their influencing factors. Acta Ecologica Sinica, 2017, 37(2): 523-540.
[60] Bonet A. Secondary succession of semi-arid Mediterranean old-fields in South-Eastern Spain: insights for conservation and restoration of degraded lands. Journal of Arid Environments, 2004, 56(2): 213-233.
[61] Yu F H, Krüsi B, Schütz M, et al. Plant communities affect the species-area relationship on *Carex sempervirens* tussocks. Flora-Morphology, Distribution, Functional Ecology of Plants, 2008, 203(3): 197-203.

Note: Figure translations are in progress. See original paper for figures.