



Influence of Dike Age on the Distribution Pattern of Pill Bug *Armadillidium vulgare* (Latreille, 1804) (Crustacea: Isopoda) in the Forests at a Reclaimed Coast

Bao-Ming Ge* Dai-Zhen Zhang, Qiu-Ning Liu, Sen-Hao Jiang, Jun Cui, Chun-Lin Zhou and Bo-Ping Tang

Jiangsu Key Laboratory for Bioresources of Saline Soils, Jiangsu Synthetic Innovation Center for Coastal Bio-agriculture, Yancheng Teachers University, Kaifang Avenue 50, Yancheng, 224002, Jiangsu, China

ABSTRACT

The effect of dike age on distribution of pill bug (*Armadillidium vulgare* Latreille, 1804) in the forests was studied at a reclaimed coast in Yancheng, China. The aggregated distribution of *A. vulgare* population was found by Taylor's power law and Iowa's patchiness regression methods in each season ($P < 0.001$). The abundances were markedly affected by habitat type ($F_{5,120} = 49.409, P < 0.001$) and season ($F_{3,120} = 13.577, P < 0.001$), however, there was no significant interaction of habitat type and season ($F_{15,120} = 0.529, P = 0.919$). The abundances distribution was significantly different among habitats in each season as shown by one-way ANOVA, the higher abundance can be found in the warmer seasons. The highest abundance of *A. vulgare* occurred in forests with dike age above 100 years in summer, whereas the lowest occurred in the forests with shortest dike age in spring. Pearson's correlation coefficient analysis of individuals' data indicated that there were significant correlations of abundances distribution among seasons ($P < 0.050$). The distribution of *A. vulgare* varied among different forests, and then the environmental change according to the dike age increasing should be considered as the main factor explaining such variation.

Article Information

Received 25 September 2016

Revised 30 October 2016

Accepted 27 April 2017

Available online 30 June 2017

Authors' Contribution

BMG and BPT conceived and designed the experiments; BMG, DZZ, and JC performed the experiments; QNL, SHJ and BMG analyzed the data; BMG and CLZ wrote the paper.

Key words

Dike history, Distribution pattern, Coastal forest, Diked area, Soil system.

INTRODUCTION

The coastal areas and wetlands are the most important habitats for human (Brown *et al.*, 2006). But few traces of historical ecosystem remain because of human being activities, such as the land use combined with local landscape alterations in estuaries and at coasts (Simenstad and Cordell, 2005). Reclamation is an effective method to obtain land from the coastal wetlands which has been used by human for thousands of years (An *et al.*, 2007; Wang *et al.*, 2012). Reclamation with a long history normally consults in a massive land conversion, for example, the reclamation has been continued for about 2000 years in Yancheng city which located in eastern China, and then the reclaimed land was used for urbanization, rice farms, forests and shrimp ponds (Ge *et al.*, 2014). The land cover has been greatly changed since the wetlands were reclaimed. However, there is a notable mismatch between science and policy in ecosystem management of coast (Paterson *et al.*, 2011), for instance, biodiversity conservation has been discussed (Mora and Sale, 2011).

Under the influences of various land uses, sustainable management of the vast reclaimed lands along shorelines showed different soil dynamics including soil organic matter, phosphorus, and nitrogen concentrations variations (Cui *et al.*, 2012). In biodiversity assessment studies, soil fauna was usually used because of its sensitive response to environmental changes and its functional role on soil ecosystem (Rainio and Niemelä, 2003; Sauberer *et al.*, 2004). Studying soil macrofaunal responses to habitat changes is of considerable interest, even more the influence of dike history on the patterns of soil macrofaunal distribution and community composition has been proved (Ge *et al.*, 2014). However, few studies have addressed how the distribution of indicator of soil macrofaunal would change under long-term dike history, especially at a time scale of centuries.

The pill bug *Armadillidium vulgare* (Latreille 1804) is a species of isopods (Crustacea: Isopoda), and can be commonly found at the reclaimed coast in eastern China. It has been reported that the terrestrial isopods are soil dwelling arthropods that generally feed on decaying organic matter (Saska, 2008). *A. vulgare* generally consume the organic matter on the soil surface (Refinetti, 1984), populations of *A. vulgare* exposed to decreasing amounts of organic matter tended to increase feeding competition

* Corresponding author: gebaoming@gmail.com
0030-9923/2017/0004-1273 \$ 9.00/0
Copyright 2017 Zoological Society of Pakistan

within populations, although declining in overall isopod numbers (Rushton and Hassall, 1987). As such, content of organic matter in habitats may be influencing *A. vulgare* population densities (Johnson *et al.*, 2012). *A. vulgare* plays an important role in the communities of soil fauna at the diked coastal area (Ge *et al.*, 2014). A better understanding of how the distribution of *A. vulgare* change over time would provide important scientific bases for sustainable land use and biodiversity conservation. Here, we hypothesized that the abundances should be higher in the diked lands with a longer reclamation history in the distribution of *A. vulgare* affected by the dike history in the forests at the reclaimed coast.

MATERIALS AND METHODS

Study areas

Yancheng City is located in Jiangsu Province, China, on the west coast of the Pacific where the transition of subtropical and temperate zones occurs. Its annual rainfall averages from 900 to 1,100 mm. There is the youngest diked dam built in the 1980s at the coast of Yellow Sea,

and then the dam is used as a road now. From the dam to inland, the diked lands correspond to the different historical periods; and then most of the diked lands were used for forest and agriculture. In the study area, the soil was Fluvisols by FAO Taxonomy. Six forest patches with dike age ranging from 30 to approximate 200 years occupied by planted poplar or metasequoia were selected (Fig. 1). The habitats are deciduous forests, and the herbages normally are therophytes. The principal characters habitats were described at the first survey in summer (Table I).

Sampling method

We sampled *A. vulgare* from habitats at August, November 2014 and February, May 2015 according to summer, autumn, winter and spring. A sample plot with the area 20 m × 20 m was settled at each habitat; then five soil blocks of 50 cm × 50 cm with 10 cm depth were collected and sorted in each season. Sampling blocks were located 5 m apart and randomly distributed in the plot. Totally, 120 blocks were removed from the ground and hand-sorted for *A. Vulgare* in this study.

Table I.- The characters of selected habitats in the study in the summer.

Forest code	Vegetation		Trees age (years)	Dike age (years)
	Arbor (coverage)	Herbage (coverage)		
P30	<i>Populus euramericana</i> (90%)	<i>Cynodon dactylon</i> , <i>Chenopodium glaucum</i> (50%)	14	30
M30	<i>Metasequoia glyptostroboides</i> (90%)	<i>Stellaria chinensis</i> , <i>C. glaucum</i> (60%)	14	30
P50	<i>P. euramericana</i> (90%)	<i>C. dactylon</i> , <i>Stellaria oleraceus</i> , <i>C. glaucum</i> (60%)	17	≈50
M50	<i>M. glyptostroboides</i> (90%)	<i>Stellaria media</i> , <i>S.chinensis</i> (80%)	17	≈50
P100	<i>P. euramericana</i> (80%)	<i>C. dactylon</i> , <i>S.oleraceus</i> , <i>C. glaucum</i> (60%)	15	≈100
P200	<i>P. euramericana</i> (80%)	<i>Setaria viridis</i> , <i>C.dactylon</i> , <i>S. oleraceus</i> (50%)	15	≈200

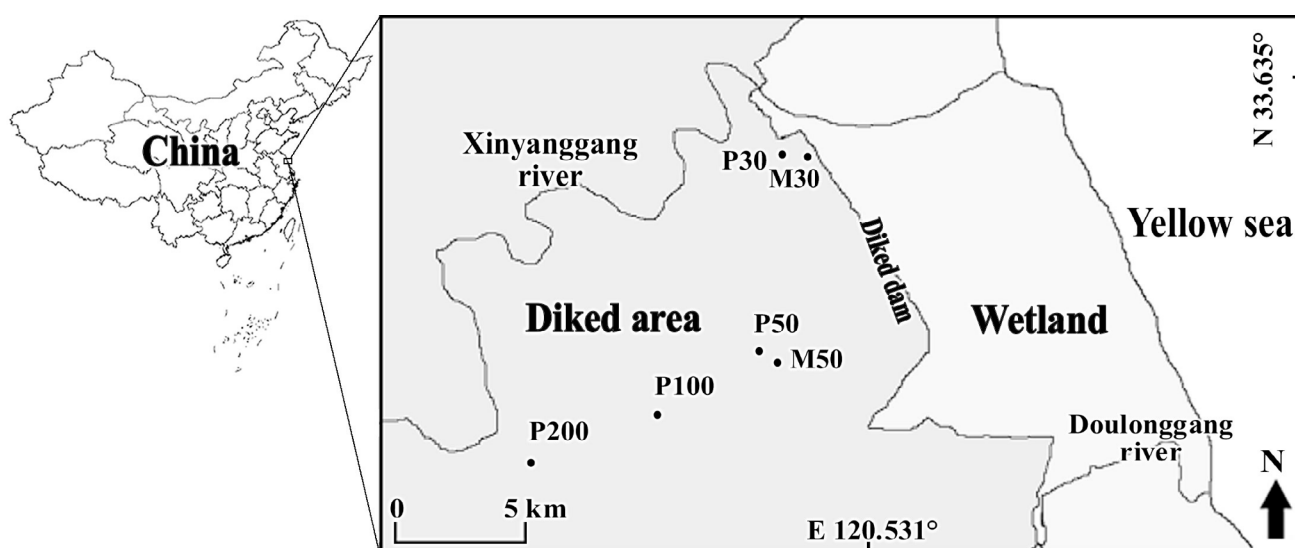


Fig. 1. The distribution of sample sites at the reclaimed coast.

Data analysis

Two-way ANOVA (general linear model, GLM) was employed to detect the differences in abundance of *A. vulgare* by habitat, season, and their interaction; Levene’s test was used before using the GLM (Ge *et al.*, 2013). One-way ANOVA was employed to detect the significance of differences in abundance measured in plots among seasons. Here, Levene’s test was used also before multiple comparisons, then the Student-Newman-Keuls (SNK) test was used if Levene’s test was passed, whereas Dunnett’s T3 test was used. The mean abundances distribution in different habitats was checked by Pearson’s correlation coefficients among seasons (Ge *et al.*, 2015).

For distribution pattern, we used the indices which were the simplest indices based on variance (S^2), mean abundance (x) and mean crowding (m) of abundance per quadrat. The means of slope b and β from Taylor’s power law $\ln S^2 = a + b \ln x$ (Taylor, 1961) and Iowa’s patchiness regression $m = \alpha + \beta x$ (Iwao, 1968) can be used to indicate the level of aggregation. The distribution pattern can be explained as uniform when $b(\beta) < 1$, random when $b(\beta) = 1$, or aggregated when $b(\beta) > 1$ (Arnaldo and Torres, 2005; Vinatier *et al.*, 2011).

RESULTS

The results of two-way ANOVA revealed significant effect of habitat type ($F_{5,120} = 49.409, P < 0.001$) and season ($F_{3,120} = 13.577, P < 0.001$), while there was no significant effect of the interaction between habitat type and season ($F_{15,120} = 0.529, P = 0.919$).

By one-way ANOVA, significant abundance distribution differences of *A. vulgare* from different forests occurred in spring ($F_{5,29} = 13.528, P < 0.001$), summer ($F_{5,29} = 16.238, P < 0.001$), autumn ($F_{5,29} = 10.316, P < 0.001$) and winter ($F_{5,29} = 11.202, P < 0.001$) (Fig. 2). The highest abundances occurred in summer and autumn in the habitats with the dike age older than a century which were coded as P100 and P200, while the lowest abundance occurred in the habitat with shorter dike age coded as P30 (Fig. 2).

Significantly positive correlations on abundance distribution occurred in all comparisons according to Pearson’s correlation test among seasons (Table II). The results showed that the synchronism of abundance distribution in different habitats can be found among seasons, and then significant correlations occurred in the comparisons among seasons.

In the study, the results indicated that b and β was greater than 1 totally ($P < 0.001$), and Iowa’s model fitted the data better than Taylor’s power law (Table III). In Iowa’s model, $\alpha < 0$ indicates the tendency to repulsion and then *A. vulgare* was aggregated in each season under the spatial scale of this study.

Table II.- Pearson’s correlation test of *A. vulgare* abundance. Two-tailed test was used and $n = 5$ for each season.

Season	Parameter	Summer	Autumn	Winter
Spring	Pearson correlation	0.981	0.976	0.981
	P	<0.001	<0.001	<0.001
Summer	Pearson correlation		0.997	0.953
	P		<0.001	0.003
Autumn	Pearson correlation			0.958
	P			0.003

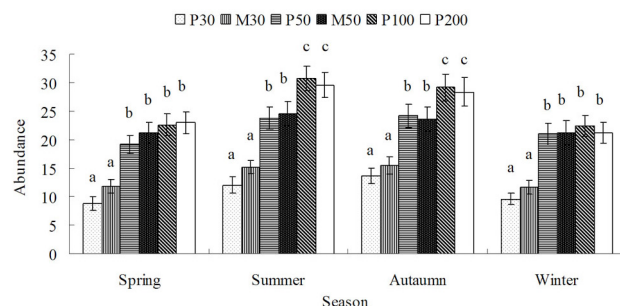


Fig. 2. The abundance (Mean \pm SE) of *A. vulgare*. The means with different scripts are significantly different by SNK test, $\alpha=0.050$.

Table III.- Estimated values of *A. vulgare* dispersion indexes based on Taylor’s power law and Iowa’s patchiness regression.

Season	Taylor's power law				Iowa's patchiness regression			
	α	β	R^2	P	α	β	R^2	P
Spring	-0.532	1.083	0.970	<0.001	-0.342	1.005	0.999	<0.001
Summer	-1004	1.233	0.773	0.021	-0.393	1.007	0.999	<0.001
Autumn	-1.799	1.542	0.980	<0.001	-0.629	1.023	0.999	<0.001
Winter	-1.703	1.500	0.944	0.001	-0.651	1.023	0.999	<0.001
Total	-1.189	1.318	0.893	<0.001	-0.489	1.014	0.999	<0.001

DISCUSSION

Land conversion significantly affected the ecosystem of the coastal zone in the past decades (Etter *et al.*, 2006; An *et al.*, 2007). The history of land use intensely modified the relationship between soil fauna and soil ecosystem (Salamon *et al.*, 2008; Liiri *et al.*, 2012; Ge *et al.*, 2016). In our study, we found that there was the abundance significantly changed among forests with different dike age in each season, which can be proved by the previous researches at the same area (Ge *et al.*, 2014).

Some previous researches have shown that some invertebrate species showed an aggregated spatial distribution pattern in the coastal area (Ge *et al.*, 2013, 2015); in this study a similar result was observed. Significant seasonal differences in abundance of *A. vulgare* were observed; however, it has been reported that the density variation can affect the distribution pattern of species (Hanberry *et al.*, 2011), as spatial disposition can be density dependent (Taylor *et al.*, 1978). However, the variation of abundance *A. vulgare* observed in this study did not significantly impact on the underlying distribution pattern; we can find that the distribution patterns presented the same model in each season.

Different dike histories can lead to alterations in litter production, belowground biomass, soil organic content, and nutrient cycling (Cui *et al.*, 2012; Li *et al.*, 2014), and such features are associated with food availability for soil fauna, while the trophic function and the food web of the diked area is also affected (Lefebvre and Gaudry, 2009). The distribution of soil macrofauna could be affected by the dike age in the reclaimed area (Liiri *et al.*, 2012). The comparisons of spatial distribution across seasons showed that more *A. vulgare* individuals occurred at the forests with longer dike age in each season, whereas the lower abundances occurred in the forests with shorter dike age (Fig. 2). The results indicated that the environments of younger lands should be more similar because they usually have the same land use history; in other forests, the soil characteristics would be varied because of the differences of the dike age and land use practices (Salamon *et al.*, 2008; Zou *et al.*, 2011). The results indicated that the abundance distribution may be caused by the environmental change in the lands with different dike ages (Salamon *et al.*, 2008). The soil organic content in the reclaimed coast normally added following with the increasing of dike age (Li *et al.*, 2014). Then the food supply should be regarded as the main factor based on the previous researches (Rushton and Hassall, 1987; Saska, 2008; Ge *et al.*, 2014). Meanwhile, the life history traits also contribute to the abundance distribution variation among seasons (Refinetti, 1984).

Although dike age affects the abundance of *A.*

vulgare, no significant change of the distribution pattern (aggregated) among habitats with different dike ages was found in each season (Table III). This phenomenon indicated that the distribution pattern should be determined by the biological characters of species (Ge *et al.*, 2013). While the abundances changed significantly with the factor of dike age and season (Table III, Fig. 2). The lowest *A. vulgare* abundance occurred in winter, temperature stress should be a driving force for the seasonal variation of distribution (Ge *et al.*, 2015).

The effect of temporal and spatial organization on interspecific associations should be considered when applying to ecosystem management practices of coastal areas. For the biodiversity conservation activities in the coastal area, the reclaimed coasts should be seriously treated because of the vast change of land use and land coverage after dike (Cui *et al.*, 2012; Li *et al.*, 2014). Normally, the bio-indicator species in these areas play a very important role in the soil ecological procession, such as soil macrofauna (Ge *et al.*, 2016; Wang *et al.*, 2016). Then the environmental changes can trigger the species to make response to the changes of food, water and other habitat needs which can directly or indirectly affect the species distribution (Refinetti, 2000; Briones, 2014). The species distribution pattern may the key for dealing with the scientific and technological problem at the developing area, such as at the coastal area in eastern China and the similar areas.

CONCLUSION

The land conversion caused by the reclamation can change the ecosystem of coastal area. The distribution of the species in similar habitats can also be affected by the history of reclamation. The significant effect of the dike age was found in the study on the abundance distribution of *A. vulgare* in the forests at the reclaimed coastal area. Such variation indicates the response of the species to environmental change according to the dike age increasing. There was no change of the spatial distribution pattern of *A. vulgare* and the aggregated pattern can be considered as a species-specific trait of *A. vulgare* in this study.

ACKNOWLEDGEMENTS

This research was supported by the National Natural Science Foundation of China (31301871, 31300443); the Natural Science Foundation of Jiangsu Province (BK20130422); the Foundation of Yancheng Agricultural Science and Technology (YKN2013013) and the Natural Science Foundation of the Jiangsu Higher Education Institutions of China (16KJA180008).

Statement of conflict of interest

Authors have declared no conflict of interest.

REFERENCES

- An, S., Li, H., Guan, B., Zhou, C., Wang, Z., Deng, Z., Zhi, Y., Liu, Y., Xu, C., Fang, S., Jiang, J. and Li, H., 2007. China's natural wetlands: Past problems, current status, and future challenges. *Ambio*, **36**: 335–342. [https://doi.org/10.1579/0044-7447\(2007\)36\[335:CNWPPC\]2.0.CO;2](https://doi.org/10.1579/0044-7447(2007)36[335:CNWPPC]2.0.CO;2)
- Arnaldo, P.S. and Torres, L.M., 2005. Spatial distribution and sampling of *Thaumetopoea pityocampa* (Den and Schiff) (Lep. Thaumetopoeidae) populations on *Pinus pinaster* Ait. in Montesinho, N. Portugal. *Forest Ecol. Manage.*, **210**: 1–7. <https://doi.org/10.1016/j.foreco.2005.02.041>
- Briones, M.J.I., 2014. Soil fauna and soil functions: a jigsaw puzzle. *Front. environ. Sci.*, **2**: 7. <https://doi.org/10.3389/fenvs.2014.00007>
- Brown, C., Corcoran, E., Herkenrath, P. and Thonell, J., 2006. *Marine and coastal ecosystems and human well-being: a synthesis report based on the findings of the millennium ecosystem assessment*. United Nations Environment Programme, Nairobi, Kenya.
- Cui, J., Liu, C., Li, Z., Wang, L., Chen, X., Ye, Z. and Fang, C., 2012. Long-term changes in topsoil chemical properties under centuries of cultivation after reclamation of coastal wetlands in the Yangtze Estuary, China. *Soil Till. Res.*, **123**: 50–60. <https://doi.org/10.1016/j.still.2012.03.009>
- Etter, A., Mcalpine, C., Pullar, D. and Possingham, H., 2006. Modelling the conversion of Colombian lowland ecosystems since 1940: Drivers, patterns and rates. *J. environ. Manage.*, **79**: 74–87. <https://doi.org/10.1016/j.jenvman.2005.05.017>
- Ge, B., Zhang, D., Cui, J., Jiang, S., Tong, X., Zhou, C. and Tang, B., 2016. Impact of dike age on biodiversity and functional composition of soil macrofaunal communities in poplar forests in a reclaimed coastal area. *Turk. J. Zool.*, **40**: 241–247. <https://doi.org/10.3906/zoo-1506-15>
- Ge, B.M., Bao, Y.X., Cheng, H.Y., Zhang, D.Z. and Tang, B.P., 2013. Temporal and spatial distribution pattern of *Bullaeta exarata* in a tidal flat at south shore of Hangzhou Bay, China. *Iran. J. Fish. Sci.*, **12**: 96–104.
- Ge, B.M., Zhang, D.Z., Bao, Y.X., Cui, J., Tang, B.P. and Hu, Z.Y., 2015. Effect of saltmarsh cordgrass, *Spartina alterniflora*, invasion stage on *Cerithidea cingulata* (Caenogastropoda: Potamididae) distribution: a case study from a tidal flat of Western Pacific Ocean, China. *Pakistan J. Zool.*, **47**: 141–146.
- Ge, B.M., Zhang, D.Z., Cui, J., Zhang, H.B., Zhou, C.L. and Tang, B.P., 2014. Biodiversity variations of soil macrofauna communities in forests in a reclaimed coast with different diked history. *Pakistan J. Zool.*, **46**: 1053–1059.
- Hanberry, B.B., Fraver, S., He, H., Yang, S.J., Dey, D.C. and Palik, B.J., 2011. Spatial pattern corrections and sample sizes for forest density estimates of historical surveys. *Landsc. Ecol.*, **26**: 59–68. <https://doi.org/10.1007/s10980-010-9533-7>
- Johnson, W.A., Alfaress, S., Whitworth, R.J. and McCormack, B.P., 2012. Crop residue and residue management effects on *Armadillidium vulgare* (Isopoda: Armadillidiidae) populations and soybean stand densities. *J. econ. Ent.*, **105**: 1629–1639. <https://doi.org/10.1603/ec12040>
- Iwao, S., 1968. A new regression method for analyzing the aggregation pattern of animal populations. *Res. Popul. Ecol.*, **10**: 1–20.
- Lefebvre, F. and Gaudry, E., 2009. Forensic entomology: a new hypothesis for the chronological succession pattern of necrophagous insect on human corpses. *Annls. Soc. Ent. Fr.*, **45**: 377–392.
- Li, J., Pu, L., Zhu, M., Zhang, J., Li, P., Dai, X., Xu, Y. and Liu, L., 2014. Evolution of soil properties following reclamation in coastal areas: a review. *Geoderma*, **226/227**: 130–139. <https://doi.org/10.1016/j.geoderma.2014.02.003>
- Liiri, M., Häsä, M., Haimi, J. and Setälä, H., 2012. History of land-use intensity can modify the relationship between functional complexity of the soil fauna and soil ecosystem services—A microcosm study. *Appl. Soil Ecol.*, **55**: 53–61. <https://doi.org/10.1016/j.apsoil.2011.12.009>
- Mora, C. and Sale, P.E., 2011. Ongoing global biodiversity loss and the need to move beyond protected areas: a review of the technical and practical shortcomings of protected areas on land and sea. *Mar. Ecol. Prog. Ser.*, **434**: 251–266. <https://doi.org/10.3354/meps09214>
- Paterson, D.M., Hanley, M., Black, K., Defew, E.C. and Solan, M., 2011. Science and policy mismatch in coastal zone ecosystem management. *Mar. Ecol. Prog. Ser.*, **434**: 201–202. <https://doi.org/10.3354/meps0279>
- Rainio, J. and Niemelä, J., 2003. Ground beetles (Coleoptera: Carabidae) as bioindicators. *Biodiv. Conserv.*, **12**: 487–506. <https://doi.org/10.1023/A:1022412617568>
- Refinetti, R., 1984. Behavioral temperature

- regulation in the pill bug, *Armadillidium vulgare* (Isopoda). *Crustaceana*, **47**: 29–43. <https://doi.org/10.1163/156854084X00298>
- Refinetti, R., 2000. Circadian rhythm of locomotor activity in the pill bug, *Armadillidium vulgare* (Isopoda). *Crustaceana*, **73**: 575–583. <https://doi.org/10.1163/156854000504679>
- Rushton, S.P. and Hassall, M., 1987. Effects of food quality on isopod population dynamics. *Funct. Ecol.*, **1**: 359–367. <https://doi.org/10.2307/2389792>
- Salamon, J.A., Zaitsev, A., Gärtner, S. and Wolters, V., 2008. Soil macrofaunal response to forest conversion from pure coniferous stands into semi-natural montane forests. *Appl. Soil Ecol.*, **40**: 491–498. <https://doi.org/10.1016/j.apsoil.2008.07.004>
- Saska, P., 2008. Granivory in terrestrial isopods. *Ecol. Ent.*, **33**: 742–747. <https://doi.org/10.1111/j.1365-2311.2008.01026.x>
- Sauberer, N., Zulka, K.P., Abensperg–Traun, M., Berg, H.M., Bieringer, G., Milasowszky, N., Moser, D., Plutzer, C., Pollheimer, M., Storch, C., Tröstl, R., Zechmeister, H. and Grabherr, G., 2004. Surrogate taxa for biodiversity in agricultural landscapes of eastern Austria. *Biol. Conserv.*, **117**: 181–190. [https://doi.org/10.1016/S0006-3207\(03\)00291-X](https://doi.org/10.1016/S0006-3207(03)00291-X)
- Simenstad, C. and Cordell, J., 2005. Challenges of habitat restoration in a heavily urbanized estuary: evaluating the investment. *J. Coast. Res.*, **67**: 6–23.
- Taylor, L.R., 1961. Aggregation, variance and the mean. *Nature*, **189**: 732–735. <https://doi.org/10.1038/189732a0>
- Taylor, L.R., Woiwod, I.P. and Perry, J.N., 1978. The density–dependence of spatial behavior and the rarity of randomness. *J. Anim. Ecol.*, **47**: 383–406. <https://doi.org/10.2307/3790>
- Vinatier, F., Ticier, P., Duyck, P.F. and Lescourret, F., 2011. Factors and mechanisms explaining spatial heterogeneity: A review of methods for insect populations. *Methods Ecol. Evol.*, **2**: 11–22. <https://doi.org/10.1111/j.2041-210X.2010.00059.x>
- Wang, J., Chen, Y., Shao, X., Zhang, Y. and Cao, Y., 2012. Land–use changes and policy dimension driving forces in China: Present, trend and future. *Land Use Policy*, **29**: 737–749. <https://doi.org/10.1016/j.landusepol.2011.11.010>
- Wang, S., Chen, H.Y.H., Tan, Y., Fan, H. and Ruan, H., 2016. Fertilizer regime impacts on abundance and diversity of soil fauna across a poplar plantation chronosequence in coastal Eastern China. *Sci. Rep.*, **6**: 20816. <https://doi.org/10.1038/srep20816>
- Zou, P., Fu, J. and Cao, Z., 2011. Chronosequence of paddy soils and phosphorus sorption–desorption properties. *J. Soil Sediment.*, **11**: 249–259. <https://doi.org/10.1007/s11368-010-0301-8>