Bangladesh J. Bot. **48**(3): 809-815, 2019 (September) Special

EFFECTS OF SINGLE AND MULTIPLE PLANT SPECIES IN BALANCING TWO KEY ECOSYSTEM FUNCTIONS

ZHIMEI LIU[1,2,3], MAOHUA MA[2,3], SHENGJUN WU*[2,3], ZHEN LIANG[4], YU WANG[2,3], FEI YE[2,3] AND YONGZHI LI[2,3]

Chongqing University, Chongqing, 400044, China

Keywords: Plant species, Balancing, Two key functions, Ecosystem

Abstract

Little is known about the effectiveness of plant species in balancing multiple functions. To reveal the effectiveness of single and multiple species in balancing the two key ecosystem functions, the controlled plant decomposition experiment was conducted by simulating a gradient of water level of fluctuation zone (WLFZ) in the Three Gorges of Reservoir (TGR), China. The results showed that considering single function, *Xanthium sibiricum* and *Hemarthria altissima* performed best for functions of water quality and soil nutrients, respectively. To balance the two functions, a combination of the three species showed better performance in achieving the goals of decreasing nutrients leaking into water in the inundation stage and increasing nutrients in soil in the exposure stage. Although carried out in the controlled condition, the experiment implied that multiple plant species play an important role in optimizing the balance between two ecosystem functions.

Introduction

Plant species play key roles in functioning ecosystems (Byrnes *et al.* 2014). In species-function relationship studies, the methods always considered single function and largely neglected multiple functions and the balance between the functions. Plant litter decomposition directly links with ecosystem functions such as soil C input and water quality of lake and reservoir (Scheibe 2014, Chen *et al.* 2017). Therefore, plant species and ecosystem functions are linked through the litter decomposition process. Many studies examining the relationship between plant species and ecosystem functions just used decomposition rates as a proxy of ecosystem functions (Scherer-Lorenzen 2008, Fujii *et al.* 2016), but rarely examine the full link of species, decomposition process, and ecosystem functions.

The Three Gorges Reservoir (TGR) formed a large riparian zone because of the periodic dam charging and discharging. The vegetation of riparian habitats contains two decomposing processes: firstly, plant fresh tissues decompose during inundation stage when the water level is high, and then the residual litter continues decomposing during the terrestrial stage after the water level goes down. As consequences, the two processes directly influence two key ecosystem functions - water quality and soil nutrients, respectively (Bonanomi *et al.* 2015). The ideal relationship between the two functions would be that not too much nutrients released into water during inundation decomposition of fresh tissue and soil still could gain some nutrients during terrestrial litter decomposition. Under the special environment condition, the increase of one function often leads to low levels of the other function. Revealing the relationship between plant species and ecosystem functions through the decomposition process and how the two functions can be balanced is critically important for restoration and management of riparian ecosystem.

*Author for correspondence: <wsj@cigit.ac.cn>. [1]Chongqing University, Chongqing 400044, China. [2]Chongqing School, University of Chinese Academy of Sciences ,400714, Chongqing, China. [3]Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Science, 400714, Chongqing, China. [4]College of Animal Science, Southwest University, Chongqing, 402460, China.

In order to understand the role of plant species in ecosystem functions with conflict, the controlled experiment was built for answering the following issues: (i) How do various plant species play the different role for ecosystem function? (ii) Can single dominant species play a key role in balancing two ecosystem functions? (iii)Can multiple species be more effective in balancing the two functions?

Materials and Methods

Wuyang Bay (31°11′20″N, 108°27′40″E) with a total area of 2.44 $\times 10^5 m^2$, is situated in the drawdown zone of Pengxi river which is the main branch of Yangtze River in Three Gorges Reservoir of China. The bay has a northern subtropical humid monsoonal climate with an average annual precipitation of 1200 mm, and a mean annual air temperature of 18.2ºC. The study area is deeply affected by the water level fluctuation of TGR. The three primary plant species viz. *Hemarthria altissima*, *Setaria viridis*, *Xanthium sibiricum* were selected for decomposition experiment.

According to the rising time of the water level of the study area, the above ground fresh plant tissues of each species were collected in the late of September, 2014, immediately transported to the laboratory, washed the sludge, and sorted by species. The leaf and stems were separated alone and the stems were cut into 1 cm of length for each species. Finally, the leaf and stems were uniformly mixed as the plant samples. Ninety seven g of the plant fresh tissues was placed in the 30 cm of diameter nylon gauze litterbags with a 1 × 1 mm mesh size. The soil was collected from the place where the grass species grow and sieved (2 mm mesh) to remove stones and root fragments, then was filled into the experiment container based on the 1.2 $g.cm^{-3}$ of average soil bulk density obtained from the measured value of the study area. Soil initial chemical properties were as follows: total organic carbon (TOC) 8.97 ± 0.41 g/kg, total nitrogen (TN) 0.99 ± 0.085 g/kg, ammonium nitrogen (NH_4-N) 6.24 ± 0.42 mg/kg, nitrate nitrogen (NO_3-N) 2.99 ± 0.31 mg/kg and pH 6.58 ± 0.34.

The plant decomposition experiment was carried out in the container with 30 cm of diameter and 1 m in length. The bottom of the container was filled with the soil (30 cm of height). The litterbags were placed near the soil. The water was gradually trickled into the container until the water level reached 60 cm in order to create an anaerobic environment at the litterbag decomposition layer, since the actual process of plant decomposition was under the anaerobic environment during the inundation period. The water used in the experiment meets Grade III (Environmental Quality Standard for Surface Water GB3838-2002, China).

Five treatments were designed : (1) Control (no plant species), (soil + water), (2) *H. altissima* only, (soil + water + *H. altissima*), (3) *S. viridis* only, (soil + water + *S. Viridis*), (4) *X. sibiricum* only, (soil + water + *X. sibiricum*), (5) mutiple species: *H. altissima* (33% in weight)+ *S. viridis* (33% in weight) + *X. sibiricum* (34% in weight), (soil + water + mixture). For all plant treatments, 97g of the plant fresh tissues was placed in the nylon gauze litterbags (mesh size: 1 mm × 1 mm). The total of 192 litterbags (4 plant treatments × 6 repetitions × 8 samping dates) was placed near the soil. All the litterbags were flooded from October 22, 2014 to March 25, 2015, and exposured from March 25, 2015 to August 20, 2015. During the inundation period, litterbags, surface soil and overlying water of each treatment were extracted after 28, 55, 90, and 159 days, respectively. During the exposure period, litterbags and soil of each treatment were extracted after 189, 229, 255 and 276 days, respectively.

Seven measures of two key ecosystem functions data were included: soil nutrients (TOC, TN, NH_4-N and NO_3-N) and water quality (TOC, TN, and TP). Percentage of each function in each sampling time was calculated. The measured maximum of each function as maximum level of the function (100%) across the plant species in each sampling time was defined. The ratio of other values to the maximum value was considered as percentage of the function that other species could achieve. Water quality function was expressed by 100% minus calculated percentage of each function, because the higher the contents of TOC, TN and TP in the water were, the worse water quality was.

Results and Discussion

TC and TN contents of four plant species showed significant differences ($P_{TC} < 0.05$, $P_{TN} < 0.05$) (Table 1). *H. altissima* contained the highest carbon content at 42.05% and the lowest nitrogen content at 0.915%, and had the maximum C: N ratio (C/N) (Table 1). During the inundation period, initial fast decrease for mass remaining was observed at the 55th days of decomposition (55.2% for *H. altissima*, 64.3% for *S. viridis*, 65.9% for *X. sibiricum*, 63.6% for multiple species), then a slowly decrease in the exposure period (Fig. 1). The mass remaining of plants including the two decomposition processes were all fitted by the Olson exponential model (Olson 1963) in Table 2 ($p < 0.05$). k values ranked in the following order *H. altissima* > Multiple species > *S. viridis*＞*X. sibiricum* and Multiple species＞ *S. viridis*＞ *H. altissima*＞*X. sibiricum* in the inundation and exposure stage, respectively (Table 2). The results of the present study correspond with the general decomposition mechanisms which were controlled by two different stages: a quick elution process of soluble substances in the early stage and a slow refractory litter decomposition in the later stage (Moore *et al.* 2006). The decomposition rate of inundation plants rose up with the increase of C/N ratio (below 50) (Tables 1, 2). This finding is supported by Xiao (Xiao *et al.* 2017), who found that soaking plant decomposition rates were positively related to initial C/N ratios of 25 to 50, negatively related to initial C/N ratios of 50 to 100 in the WLFZ of TGR. *X. sibiricum* with undershrub showed the lowest decomposition rates because of the inhibition of further decomposition by the organic-chemical composition (Xie *et al.* 2004). k value of the multiple species represented different ranking in the inundation and exposure stages. The different responses resulted from substrate quality, morphological traits, and the environment condition of each species (Bastianoni *et al.* 2015).

Table 1. Initial chemistry for each plant treatments used in the decomposition bag study.

Litter quality	*H. altissima*	*S. viridis*	*X. sibiricum*	Mutiple plants
C (%)	42.05 ± 0.03^{A}	40.77 ± 0.47^{A}	38.59 ± 0.81^{B}	41.01 ± 1.15^{A}
N (%)	0.915 ± 0.25^{B}	1.03 ± 0.21^{B}	1.61 ± 0.05^{A}	0.96 ± 0.07^{B}
C/N	48.47 ± 9.21^{A}	40.53 ± 7.07^{A}	24.00 ± 1.41^{B}	45.05 ± 2.68^{A}

Values are average ± SE. Different letters of the same row indicate significant difference among the plant types.

There was significant negative relationship between the functions of water quality and soil nutrients (Fig. 2). The higher soil nutrients increased for one species, the higher the risk of deteriorating water quality was and vice versa. Considering the average percentages of the functions of water quality and soil nutrients, *X. sibiricum* could arrive maximum level (26.67%) for water quality, *H. altissima* could arrive maximum level (98.23%) for soil nutrients (Table 3). From the perspective of single function, the present study suggested that *X. sibiricum* for water quality and *H. altissima* for soil nutrients were the best choices for plant restoration, respectively. Findings suggested that the percentages of the maximum function of water quality and soil nutrients could not be achieved simultaneously by any single species (Table 3). The present results concur with others' findings that single species only could maintain one function' maximum level

(Grime 1974, Díaz *et al.* 2004). However, there were some cases of study that single species such as keynote species could maintain multiple functions (Barcikowski *et al.* 2005, College 2008). In the study there was no similar result reported earlier, probably because these dominant plant species were not keynote species. The WFLZ of the TGR was a fragile ecosystem due to the shift

Table 2. Correction factor (a), decomposition rate (k) and determination coefficient (R^2) based on Olson model for mass remaining during the two periods.

Plant species	Different period	a	k	R^2	P
H. altissima	Inundation period	93.22	0.00604 ± 0.000405 a	0.72	0.0197
	Exposure period	60.64	0.00153 ± 0.0000709 A	0.84	0.00027
S. viridis	Inundation period	94.12	0.00456 ± 0.000739 b	0.76	0.01018
	Exposure period	69.77	0.00165 ± 0.000431 A	0.90	0.00022
X. sibiricum	Inundation period	93.50	0.00394 ± 0.000563b	0.69	0.0108
	Exposure period	70.37	0.000902 ± 0.0000524 B	0.84	0.00013
Multiple plants	Inundation period	94.13	0.00472 ± 0.00019 b	0.77	0.0106
	Exposure period	72.51	0.00179 ± 0.000406 A	0.95	0.00013

The different lowercase and capital letters represent significant difference during the inundation and exposure period among plant species, respectively ($p < 0.05$).

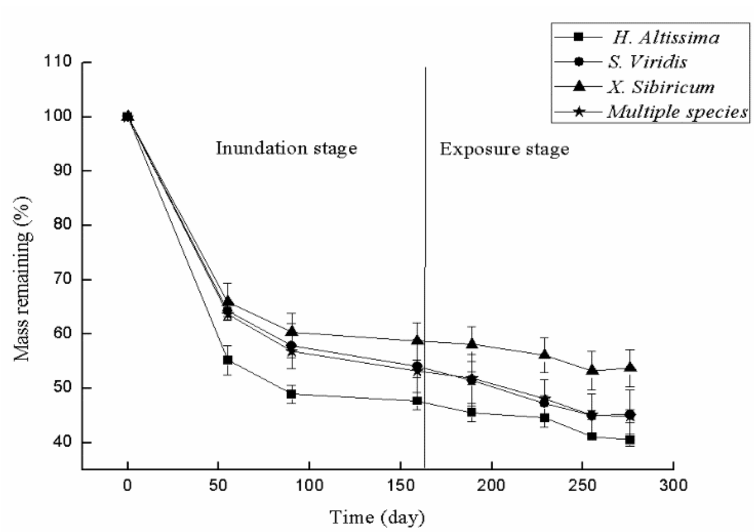

Fig. 1. Mass remaining of *H. altissima, S. viridis, X. sibiricum* and multiple species during the two decomposition processes.

from the original flood controlled irregular hydrology to the artificial regular hydrology (Bao *et al.* 2015). Only a few herbaceous plants have adapted to the new conditions of habitats (Zhang *et al.* 2012). The ecosystem is still in the initial stage of succession and may not yet show up the keynote species. In the future, a keynote species with the slower decomposition rate in the inundation period and fast exposure decomposition may play an important role over time in the WFLZ, meeting the balance of two functions.

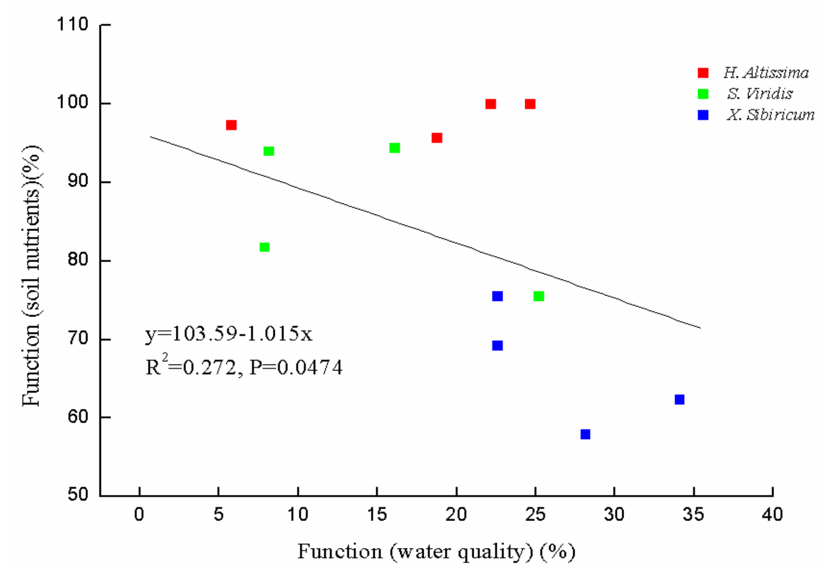

Fig. 2. Relationship between two functions. All data are the percentage of the function that is achieved for each time of each plant species.

Table 3. The percentage of the function that is achieved for each function and each single species (assessed across two ecosystem functions).

Function		Function of each species (mean values of four sampling times) for each function (%)		
		H. altissima	*S. viridis*	*X. sibiricum*
Water quality	TOC	11.51	11.28	15.71
(Innundation stage)	TN	22.26	11.53	6.01
	TP	16.85	15.55	58.29
	Average	**16.87**	**12.79**	**26.67**
Soil nutrients	TOC	100.00	93.29	80.69
(Exposure stage)	NH_4-N	96.46	79.47	51.72
	Average	**98.23**	**86.38**	**66.21**

For the function of soil nutrients, *H. altissima*, *S. viridis* and *X. sibiricum* had significant differences and multiple species and *S. viridis* had the same level (no significant difference). According to the significant analysis, there are three levels in the following order *H. altissima*, *S. Viridis* = Multiple species, *X. sibiricum*. For water quality, Multiple species could reach maximum 36.99% in all plant species and had the same level with *X. sibiricum* (26.67%). Only considering water quality, Multiple species and *X. Sibiricum* were fitting choice. If combined with soil nutrients, Multiple species was better than *X. sibiricum* because Multiple species was in the intermediate level (83.65%) and *X. sibiricum* was at the low level (66.21%). It is suggested that the multiple plants were an optimal choice from the perspective of considering tradeoffs between the goals of reducing water environment risk and achieving the high level of soil nutrients. It was speculated that the different plant traits and mixture ratio may be main factors for the balance of two functions. The mixed plants contain two different function traits, such as species (*H. altissima*) with the fast decomposition rates and species (*S. viridis* and *X. sibiricum*) with the slow decomposition rates in the inundation stage. The plant species with different function traits showed the consequence of the counter balancing of the positive and negative effects of each species in the multiple plants (Bastianoni *et al.* 2015). In addition, the loading ratio in which the single species is represented in the mixture, is crucial for the decomposition rate of the multiple plants (Setiawan *et al.* 2016), since a higher or lower proportion of nutrient-rich litter in the mixture could lead to the detection of non-additive responses. In the study, mixture containing 66% of low decomposition rate litter (*S. viridis* and *X. sibiricum*) led to a lower decomposition rate for multiple species in the inundation stage, while mixture containing 66% of high decomposition rate litter (*H. altissima* and *S. viridis*) led to a fast decomposition rate for multiple species in the exposure satge. The slow decomposition rate in the inundation stage and fast decomposition rate in the exposure stage for multiple plants reduced water environment potential risk, also increased the soil nutrients.

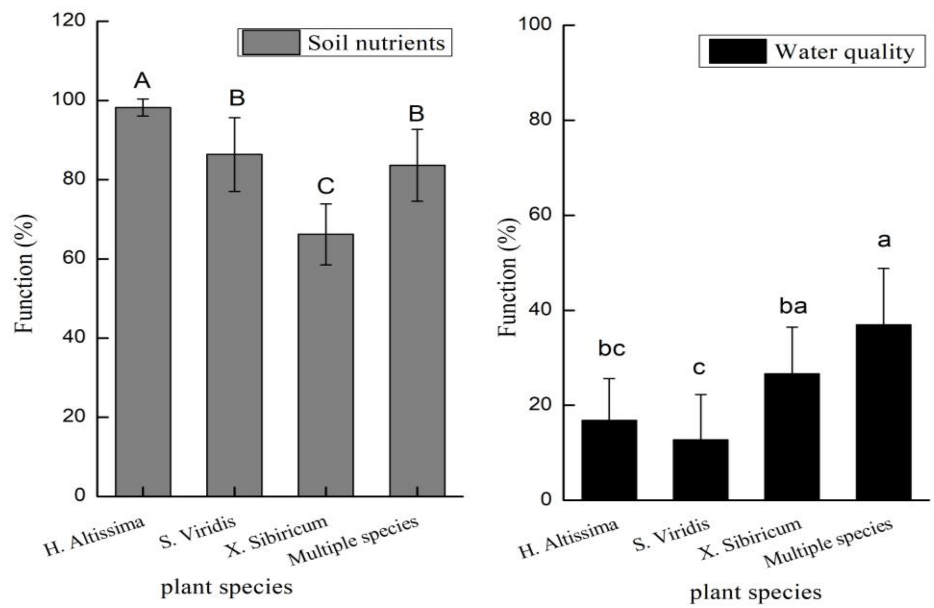

Fig. 3. The average percentages of the functions (water quality and soil nutrients) across the single species and multiple species. The percentage of water quality function was from average value of TOC, TN and TP, and soil nutrients was from average value of TOC and NH_4-N.

This study reports on the effectiveness of single and multiple species on balancing ecosystem functions (water quality and soil nutrients) by a controlled experiment in the WLFZ in the TGR - a typical of the riparian zone, China. From the perspective of the single function, single species played an important role. The multiple species showed better performance in achieving the goals of decreasing nutrients leaking into water in the inundation stage and increasing nutrients in soil in the exposure stage. It implied the effectiveness of multiple plant species in balancing ecosystem functions. Further research is needed to determine whether and how species and function diversity play an important role in balancing ecosystem functions.

Acknowledgements

This work was financially supported by Chongqing Science & Technology Commission (No. cstc2015jcyjA00006), Pilot Science and Technology Project, Chinese Academy of Sciences (No. XDA23040303), Doctoral Science of Southwest Fund (No. SWU113093), Fundamental Research Funds for Central University (No. XDJK2015C033) and National Natural Science Foundation of China (NO. 41501096).

References

Bao Y, Gao P and He X 2015 The water-level fluctuation zone of Three Gorges Reservoir - A unique geomorphological unit. Earth-Science Reviews **150**: 14-24.

Bastianoni A, Chacón N, Méndez CL and Flores S 2015. Decomposition dynamics of mixed litter in a seasonally flooded forest near the Orinoco river. Acta Oecologica **64**: 21-28.

Bonanomi G, Senatore M, Migliozzi A, Marco AD, Pintimalli A, Lanzotti V and Mazzoleni S 2015. Decomposition of submerged plant litter in a Mediterranean reservoir: A microcosm study. Aquatic Botany **120**: 169-177.

Byrnes JEK, Gamfeldt L, Isbell F, Lefcheck JS, Griffin JN, Hector A, Cardinale BJ, Hooper DU, Dee LE, Duffy JE 2014 Investigating the relationship between biodiversity and ecosystem multifunctionality: challenges and solutions. Methods in Ecology & Evolution **5**: 111-124.

Chen H, Mommer L, Ruijven J, Kroon H, Fischer C, Gessler A, Hildebrandt A, Scherer-Lorenzen M, Wirth C and Weigelt A 2017. Plant species richness negatively affects root decomposition in grasslands. J. Ecol. **105**.

College M 2008. Keystone species: Species that are critical to their ecosystems. Marietta College.

Díaz S, Hodgson JG, Thompson K, Cabido M, Cornelissen JHC, Jalili A, Montserrat-Martí G, Grime JP, Zarrinkamar F and Asri Y 2004. The plant traits that drive ecosystems: Evidence from three continents. Journal of Vegetation Science **15**: 295-304.

Fujii S, Mori AS, Koide D, Makoto K, Matsuoka S, Osono T and Isbell F 2016. Disentangling relationships between plant diversity and decomposition processes under forest restoration. J. Appl. Ecol. **54**.

Grime JP 1974 Vegetation classification by reference to strategies. Nature **250**: 26-31.

Moore, R.T., Trofymow, A.J., Prescott, E.C., Fyles, J. and Titus, D.B., 2006. Patterns of carbon, nitrogen and phosphorus dynamics in decomposing foliar litter in Canadian forests. Ecosystems **9**: 46-62.

Olson JS 1963. Energy storage and the balance of producers and decomposers in ecological systems. Ecology **44**: 322-331.

Scheibe A and Gleixner G 2014. Influence of litter diversity on dissolved organic matter release and soil carbon formation in a Mixed Beech Forest. PLoS One **9**: e114040.

Scherer-Lorenzen M 2008. Functional diversity affects decomposition processes in experimental grasslands. Functional Ecol. **22**: 547-555.

Setiawan NN, Vanhellemont M, An DS, Schelfhout S, Baeten L and Verheyen K 2016. Mixing effects on litter decomposition rates in a young tree diversity experiment. Acta Oecologica **70**: 79-86.

Xiao L, Zhu B, Nsenga KM and Jiang S 2017. Plant soaking decomposition as well as nitrogen and phosphorous release in the water-level fluctuation zone of the Three Gorges Reservoir. Sci. Total Environ. **592**.

Xie, YH, Qin H Y and Yu D 2004. Nutrient limitation to the decomposition of water hyacinth (*Eichhornia crassipes*). Hydrobiologia **529**: 105-112.

Zhang CH, Song TT, Liu J, Xia HJ and Wang JZ 2012. Restoration of natural herbaceous vegetation of xiangxi river’s water-level fluctuation zone after the flooding in Three Gorges Reservoir area. Advanced Mater. Res. **599**: 739-743.

(Manuscript received on 3 June, 2019; revised on 19 September, 2019)