UDC 581.524:630.18:556.155(510)

STUDY OF COMMUNITY STRUCTURE AND DISTRIBUTION OF MIXED FOREST NEAR NANWAN LAKE

Yan Tengfei
PhD Student
Sumy National Agrarian University, Sumy, Ukraine
Henan institute of Science and Technology, Xinxiang, Henan
Xinyang agriculture and forest university, Xinyang, Henan
ORCID: 0000-0002-8360-3776
yantengfei@xyafu.edu.cn

Kremenetska Yevheniia
PhD (Agricultural Sciences), Associate Professor
Sumy National Agrarian University, Sumy, Ukraine
ORCID:0000-0001-5581-7868
e.kremenetska@gmail.com

Wan Shibin
Bachelor, Deputy Senior Engineer
Nanwan national forest farm, Xinyang, Henan
ORCID: 0000-0003-1513-9876
wanshibin@163.com

Hu Qiang
Master degree, Teaching-Assistant
Xinyang agriculture and forest university, Xinyang, Henan
ORCID: 0000-0001-9842-866X
371164191@qq.com

He Songlin
Doctorial tutor, Professor
Henan institute of science and technology, Xinxiang, Henan
ORCID: 0000-0001-6196-3626
hsl213@yeah.net

The community structure distribution of a forest that grows in the coastal zone is an important index for the diversity and sustainable development of riparian ecosystem and is also an important basis for the production of forest land management. In order to understand the ecological function of the riparian zone of Nanwan Lake (Xinyang City, Henan Province, China), the growth status of the forest in the downstream of the reservoir was investigated. The results of the study indicate that Pinus massoniana Lamb and Pistacia chinensis Bunge are the predominant species in the coastal zone. There is a gradual decrease in the representation of Pinus massoniana Lamb in this community. Lower story of Quercus dentate Thunb. and Pistacia chinensis Bunge demonstrates significant potential to replace the upper story. The tree structure characteristics (DBH - diameter of a tree trunk at breast high (1,3 m), tree height and crown width) were recorded at each experimental plot. The tree structure characteristics conform the inverted "J" distribution and the linear relationship between the DBH and tree height in the foreststand (can be well described by using Richard model equation), the model equation is $H=1.3+20.095\ (1–e^{-0.090D})^{1.765}$. *In the absence of anthropogenic accidents or natural extremes, the forest lands near Nanwan Lake could effectively use environmental benefits for a long time. In order to improve the level of forest management in mixed forests in these areas, it is suggested to closely monitor the growth status of trees, cut dead or poor growing Pinus massoniana Lamb, and prevent the occurrence of forest fires.*

Key words: *Nanwan Lake riparian zone; mixed forest; community structure characteristics.*

DOI https://doi.org/10.32845/agrobio.2021.3.10

Introduction. Forestland growing in the riparian zone has an important ecological value and functional benefits in water conservation, non-point source pollution interception, litter decomposition, carbon storage, nitrogen deposition and other aspects. It is a momentous ecological buffer area for water area and terrestrial ecosystems (González et al., 2016; Dybala et al., 2019; Ran et al., 2020). Riparian forest land provides a substrate of litter and other organic matter for aquatic organisms, which control water temperature and light through shade, maintain riparian vegetation stability, and reduce soil erosion (Naiman & Decamps, 1997).

The main driving force of vegetation community structure characteristics in riparian zone is the adjacent hydrologic condition. The riparian forest adjacent to the water area is disturbed by the unpredictable and rhythmless reservoir stream which often leads to the decrease of soil dissolved oxygen, the decrease of hydraulic conductivity, the restricted respiration of trees and other factors, which greatly affect the community structure of riparian forest (Kuglerová et al., 2014; Myster, 2018). Besides being directly affected by the flow of the reservoir, riparian forests are also indirectly affected by the microclimate brought by the river (González et al., 2016).

In the riparian zone (typical small climate habitat) the growth strategies of plants and animals, propagation of propagules, migration of groundwater and flow of material and energy have their own unique modes of operation (Naiman & Decamps, 1997).

Compared with the riparian zones formed by large river basins and alluvial plains, reservoir riparian zone shows more obvious ecological vulnerability in spatial heterogeneity, landscape pattern, plant community structure and other aspects, and has more frequent groundwater activities and stronger dependence on stable habitat. However, in practice, the ecological importance of such a small watershed is often ignored by experts and forestry managers (Hagan et al., 2006).

It has been agreed that riparian forests play an important role in buffer. In many European countries, buffer zones are left to protect the ecological environment of rivers when conducting forest management (Oldén et al., 2019). Many researchers have discussed the relationship between the width of buffer zone and the ecological benefit (Ali, 2019; Kuglerová et al., 2014; Ring et al., 2017).

In the management activities of riparian forest, we generally try not to disturb its ecological cycle as much as possible, in order to obtain the maximum ecological benefits (Tolkkinen et al., 2015). Such conservative management measures often lead to problems such as overmaturing of forest land, unreasonable structure of forest canopy and gradually unbalance of tree species in the management of riparian forestland.

Studies have shown that moderate disturbance can improve the functional heterogeneity of forest communities, promote the succession of ecological communities, and improve biodiversity (Kreutzweiser et al., 2012; Kuglerová et al., 2014; Sibley et al., 2012). Proper management measures can promote the ecological benefits of riparian forestland.

Tree species diversity, diameter class diversity and height of tree diversity all affect the attribute of forestland, and further affect the ecological benefit. Thus, stand structural complexity is defined as differences in the diameter and height of individual trees, as well as the heterogeneity of tree size (diameter and/or height) within the stand. In summary, stand structural diversity, complexity, and other related variables (such as average tree size, stand density, and stand basal area) are characterized as stand structural attributes.

The DBH diversity describes the degree of difference in tree size within the stand. The greater the difference, the stronger the spatial heterogeneity of the stand is, and the more species it can accommodate. Changes in the size (diameter and/or height) of individual trees, for example, between and within species, are critical to species diversity and the maintenance of forest function (Clark, 2010; Yuan et al., 2018).

The greater capacity to provide ecological niches or food diversity for a variety of animals, plants, and microorganisms in the forest is improved if the variation of stand diameter class and stand structure became more complex (Rolstad et al., 2001). The relationship between tree species structure, species diversity and aboveground productivity in 300,000 sample plots were studied and found that tree structure characteristics were the main driving force of aboveground productivity (Bohn & Huth, 2017). According to the research in the African tropical rain forest region (Poulsen et al., 2017), the availability of forest structure and the availability of large trees, compared with environmental variables and disturbances, are important predictors of abundance and distribution of large liana plants.

Canopy structure is also an important structural feature affecting forest land in riparian zone. Canopy intercepts rainfall to change surface runoff, thus affecting decomposition rate of litter and soil structure, and improving water circulation characteristics of riparian zone (Livesley et al., 2014; Sun et al., 2018).

It was found that the correlation between stand structure and forest species diversity was positive, negative and insignificant, and the determinants of these three relationships mainly lie in the competitive relationship between individual trees, light conditions and selection effect, while the relationship between stand structure characteristics and forest function is more directly determined by the environmental effect in which the stand is located (Ali, 2019).

In recent years, the implementation of China's ecological civilization strategy has played a positive role in the promotion of forestry development. In this context it should be noted that China's forest coverage rate has been continuously increased and the area of artificial forests has been continuously expanded. Undesirable consequences for maintaining the ecological benefits of forests in the coastal zone are observed in the case of abandonment of felling and no other measures for the well-being of all riparian ecosystems.

Nanwan Lake Reservoir is a 4A tourist attraction in Xinyang City, Henan Province, China. It has provided important ecological benefits for the local community in tourism, domestic water, irrigation, regional climate characteristics and other aspects. With the adjustment of forest management measures in recent years, the forest land around the reservoir has obviously degraded in landscape pattern and ecological benefit. In order to find out the growth and development status of the forest land near Nanwan Lake reservoir, the community distribution structure of the forest land in Nanwan Lake reservoir was investigated, so as to provide the production basis for the rational management of the forestland.

Materials and Methods. *Overview of test site.* The test site is located around Nanwan Lake Reservoir in Xinyang City, Henan Province, China (E 114° 08', N 32° 13'). Xinyang city, situated in the south of Henan Province, located at the Qinlingmountain and Huai River boundary, is a transitional region from subtropical zone to warm temperate zone. The terrain is high in the south and low in the north, with an altitude of 75–300 m. Xinyang has plenty of solar radiation, the average annual sunshine hours are 1900–2100 ones. The average annual temperature is 15.3–15.8°C, and the average annual rainfall is 993–1294 mm. The relative humidity averages is 74–78 %. The average annual rainfall is 177–255 mm. There are many rivers in this region, which are part of Yangtze River and Huai River basins. Huai River basin occupies 98.2 % of the city's area and is located in the upper reaches of the Huai River, which traverses the whole city from west to east. Under the influence of special geographical location and climate, the spatial and temporal distribution of rainfall is uneven, and the annual and inter-annual precipitation greatly varies. The precipitation is mainly concentrated in June to August in the main flood season, and the annual difference between high and low rainfall can be up to 2–3 times. The main forest trees species in this area are *Pinus massoniana* Lamb, *Cunninghamia lanceolata* (Lamb.) Hook, *Quercus acutissima* Carruth., *Quercus dentate* Thunb. and *Pistacia chinensis* Bunge etc. These tree species are distributed in pure forest or Mosaic and form the main forest community.

Experiment design. In the downstream of the reservoir, 9 forest land samples close to the water area were selected (Fig. 1), with an area of 20 m × 15 m. We carried out each wood gauging in the samples. The main records included the tree species and growth status of each tree, DBH (≥ 5cm), tree height (H), height under the branches of alive trees, canopy width and other factors.

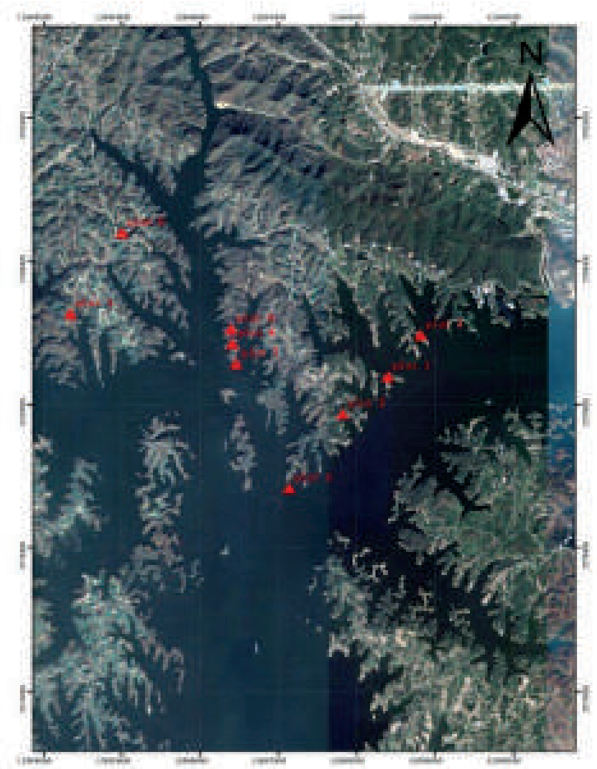

Fig. 1. Test site location

Data analysis. Tree species composition. The composition coefficient of tree species was used to represent the proportion of each tree species in mixed forest, and the proportion of different tree species' basal area in total basal area was used to calculate the composition coefficient of tree species.

Importance value. Importance Value (IV) is an important indicator in the calculation and evaluation of species diversity, which represents the relative importance of plant species in the community with comprehensive values. The more the IV, the more important they are in the stand. The calculation formula as follows (Curtis & McIntosh, 1951):

IV (%) = (relative density + relative frequency + relative significance) × 100/3, where:

– relative density = the number of individuals of a certain species/the number of individuals of all species × 100 %;

– relative frequency = the frequency value of a certain species/the frequency value of all species ×100 %;

– relative significance = basal area of a certain species/ basal area of all species × 100 %.

Diameter distribution. The DBH of trees was taken as the index to measure the size of trees, the trees were graded according to the DBH, and the DBH of trees was statistically analyzed with 2cm as the diameter step length, and the starting DBH was 5 cm.

Forest story division. According to the International Union of Forest Research Organization standard, the vertical stratification of the stand is divided into three vertical stratifications based on the average dominant tree height of the stand. In the upper canopy, the height of the tree is more than or equal to 2/3 of the average height of the dominant tree. In the middle canopy, the height of the trees is more than 1/3 and less than 2/3 of the average height of the dominant tree. Lower canopy, tree height is less or equal to 1/3 of the average height of the dominant trees.

Tree height distribution. The tree height structure was analyzed with 1 m as the height step size.

Tree size diversity index. In order to quantify the distribution characteristics of individual diameter class of trees in a stand, the species diversity evaluation index applied to the ecosystem has been widely used for tree diameter class diversity evaluation, and thus the distance-independent diversity index and the distance-related diversity index have been proposed. The diversity index is independent of the distance, it can be applied easily. DBH data are needed to effectively characterize the diameter class distribution characteristics in the stand (Peder & Ljusk, 2000; Pommerening, 2002; Schulte & Buongiorno, 1998).

Four size diversity indexes independent of distance were selected, Simpson size diversity index (D_N) and Shannon index (H_N) were used to evaluate the diameter class distribution richness of forest land along the riparian zone of Nanwan Lake reservoir. Gini coefficient of basal area (*GC*) and diameter variation coefficient (CV_d) were used to evaluate the DBH size variation degree of forest land along the riparian zone of Nanwan Lake reservoir, with the diameter class of 2 cm.The specific expression is as follows:

Simpson size diversity index (Valbuena et al., 2012)

$$D_N = 1 - \sum_{j=1}^{s} P_j^2$$

Shannon size diversity index [3] (Buongiorno, 2001)

$$H_N = -\sum_{j=1}^{s} P_j \ln(P_j)$$

Gini coefficient index of basal area [6] (Duduman, 2011):

$$GC = \frac{\sum_{i=1}^{n}(2i-n-1)BA_i}{\sum_{i=1}^{n} BA_i(n-1)}$$

Diameter coefficient of variation index is:

$$CV_d = \frac{\sqrt{\frac{\sum_{i=1}^{n}(d_i-\bar{d})^2}{n-1}}}{\bar{d}}$$

S represents number of diameter classes, P_j - proportion of tree numbers in size class *j*, BA_i - basal area for tree with rank *i* (m^2), *n* - total number of trees, *d* - mean diameter (cm).

Relationship between tree height and DBH

Richard model, *Weibull* model, *logistic* model, *Korf* model and *compertz* model were used to simulate the relationship between tree height and diameter at breast height (DBH) and calculate the parameter values of the equations.

To ensure a tree height of 1.3 m at DBH 0; constant 1.3 was added to all models (Tab. 1), where: *a, b, c* - parameters, *a* - total height limit (means upper bound of total height), *b* - related to growing speed, *c* - shape parameter.

SPSS19.0 software was used to simulate each expression parameter.

Table 1

Commonly used tree height, DBH relation expression

No.	model	Expression
1	Richard	$H=1.3+a(1-e^{-bD})^c$
2	Weibull	$H=1.3+a(1-e^{-bD^c})$
3	Logistic	$H=1.3+\frac{a}{1+be^{-cD}}$
4	Korf	$H=1.3+a(e^{\frac{-b}{D^c}})$
5	Compertz	$H=1.3+a(e^{-be^{-cD}})$

Results. *1. Composition of tree species.* By surveying each samples, the stand density is 1220 plants / hm^2, and there are 12 arbor species (Tab. 2).

The top four species in terms of important value are *Q. dentata*, *P. massoniana*, *Q. acutissima*, *P. chinensis.* The coniferous forest species mainly is *P. massoniana*,

Table 2

General situation of tree species in the sample plots

species	Number		Basal area/(m^2)			DBH/cm			H/m			IV
	No.	%	Sum	Average	%	Max	Min	Average	Max	Min	Average	
***Quercus dentata* Thunb.**	156	54.6	1.639	0.008	25.5	31.0	4.6	9.10	21.6	2.1	7.33	33.66
***Quercus dentata* Thunb.(dead)**	4					13.2	5.3		10.2	2.8		
***Pinus massoniana* Lamb**	31	14.4	1.648	0.034	25.6	37.0	13.1	19.96	22.4	10.8	14.41	18.74
***Pinus massoniana* Lamb(dead)**	11					21.0	11.7		15.4	6.5		
***Quercus acutissima* Carruth.**	32	10.9	2.570	0.080	39.9	44.2	6.2	30.66	23.4	4.2	18.28	22.37
***Pistacia chinensis* Bunge**	31	10.6	0.252	0.008	3.9	20.2	5.4	9.32	17.8	3.6	8.64	10.26
***Platycarya strobilacea Sieb. et* Zucc.**	11	3.8	0.095	0.009	1.5	23.0	5.9	9.45	17.8	5.9	8.37	4.84
Symplocos paniculata (*Thunb.*) Miq.	5	1.7	0.034	0.007	0.5	13.1	5.4	8.86	14.7	3.2	9.34	2.30
***Acer ginnala* Maxim.**	4	1.4	0.022	0.006	0.3	9	7.8	8.35	8.4	5.7	7.48	2.12
Broussonetia papyrifera	3	1.0	0.023	0.008	0.4	14.3	6.0	9.23	16.8	7.4	10.80	1.24
***Ulmus parvifolia* Jacq.**	2	0.7	0.141	0.071	2.2	42.0	5.9	23.95	19.3	10.2	14.75	1.73
***Cerasus dielsiana (Schneid.)* Yu et Li**	1	0.3	0.007	0.007	0.1	9.3	9.3	9.30	8.3	8.3	8.3	0.92
***Armeniaca vulgaris* Lam.**	1	0.3	0.003	0.003	0.05	6.4	6.4	6.40	3.8	3.8	3.8	0.91
***Cotinus coggygria* Scop.**	1	0.3	0.004	0.004	0.05	7.0	7.0	7.00	4.6	4.6	4.6	0.91
Total	293	100	6.439	0.022	100							

the relative density of it is 14.4 %, the conifer-broad leaf mixed ratio is 1:6, and the breast-height basal area ratio is 1 : 4. *Q. dentata* accounted for 54.6 % of the total number of plants, followed by *P. massoniana* and *Q. acutissima.*

As for average DBH and tree height, the average DBH of *Q. acutissima* is 30.66 cm, and the average tree height is 18.28 m. Followed by *Ulmus parvifolia* Jacq., which the average DBH was 23.95 cm, the average tree height was 14.75 m, but the number of *U. parvifolia*. The average DBH of *P. massoniana* is 19.96 cm and the average tree height is 14.41 m. Although there were many *Q. dentata*, the average DBH was 9.10 cm and the average tree height was only 7.33 m. The number of *P. chinensis* was close to *Q. acutissima*: with the average DBH of 9.32 cm and average tree height of 8.64 m.

Based on comprehensive analysis, *P. massoniana* and *Q. acutissima* had obvious advantages in the community, which are the constructive species of the arbor community. *P. massoniana* had partial death phenomenon and showed the decline trend, while *Q. dentata* and *P. chinensis* have great potential as regeneration species.

Diameter class distribution. The individual diameter class distribution of all arbor trees in the riparian zone of Nanwan Lake reservoir showed an inverse "J" distribution, among which the number of trees 5 cm ≥ DBH ≤ 14cm accounted for 68.6 % of the total, indicating that the diameter class structure of the forest stand is mainly medium-small diameter class (Fig. 2).

The size of *Q. dentate* was mainly distributed between 5 cm to 29.9 cm. The smaller the size the number of plants was more. The diameter class distribution of *P. massoniana* was mainly from 14 cm to 33.9 cm, and the number of plants in each diameter class distribution was more uniform. The diameter class distribution of *Q. acutissima* was commonly from 18 cm to 45.9 cm, among which the number of plants ≥ 34 cm was more distributed, chiefly with large diameter class. The diameter class distribution of *P. chinensis* mainly ranged from 5 cm to 15.9 cm, and it is dominated by small size. In general, the main tree species in the forest land of Nanwan Lake reservoir are *P. massoniana* and *Q. acutissima*, which are mainly distributed in the large-diameter class, while *Q. dentate* and *P. chinensis* are mostly distributed in the small-medium diameter class in large area. It can be predicted that *P. massoniana* and *Q. acutissima* will be gradually replaced with the growth of *Q. dentata* and *P. chinensis.*

Forest story division. According to the height of dominant trees (Tab. 3), the forest story was divided into three vertical structures: upper, middle and lower. The average height of dominant trees in the forest story was 22.78 m, with 15.19 and 7.59 m as the boundaries of each forest story. The number of trees in the middle canopy was the largest; accounting for 42.4 %.The number of plants in the upper

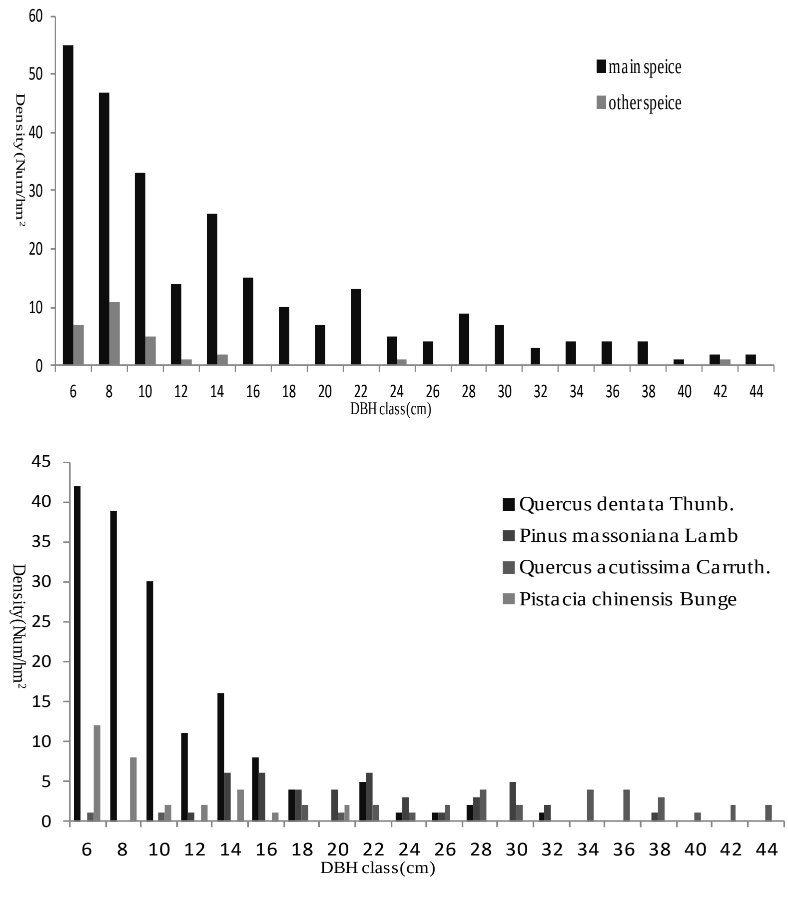

Fig. 2. Size-class distribution of main tree species in the plot

Vertically distribution of the stand

Table 3

Nanwan Lake reservoir forest story stratification

Dominant average height	Forest story	Range	Number
22.78 m	Lower canopy	H≥15.19	100
	Middle canopy	7.59 ＜H＜15.19	124
	Upper canopy	H≤7.59	68

Table 4

Vertical distribution table of Forestland in Nanwan Lake reservoir

Species	Lower canopy	Middle canopy	Upper canopy
Q. dentata	68	78	10
Q. dentate **(dead)**	3	1	
P. massoniana	0	6	25
P. massoniana **(dead)**	3	7	1
Q. acutissima	1	4	27
P. chinensis	15	14	2
P. strobilace	4	6	1
S. paniculata	2	3	-
A. ginnala	2	2	-
B. papyrifera	1	1	1
U. parvifolia	-	1	1
C. coggygria	1	-	-
C. dielsiana	-	1	-
A. vulgaris	1	-	-

canopy was less, accounting for 23.2 %. This indicates that in the whole forest story, the trees in the middle and lower layers occupy the main distribution.

The main tree species in the upper story of forest near Nanwan Lake are *P.massoniana* and *Q. acutissima*, among them a small amount of *Q. dentata* and *P. chinensis* distributed (Tab. 3). The middle story is mainly dominated by *Q. dentata*, and a small amount of *P. massoniana* and *P. chinensis* distributed, about a half among them (*P. massoniana)* are dead and their growth condition is limited. The lower story is dominated by *Q. dentate* with a small amount of *P. chinensis* and *P. strobilacea.*

Tree height distribution. The distribution curve of tree height is asymmetrical shape of mountain and continuous (Fig. 3).

Tree height ranges from 6 m to 8 m has a large distribution. Maximum tree height is 23 m. The height distribution of *Q. dentata* is mainly concentrated in the range of 3 m to 14 m. The height of *P. massoniana* is mainly distributed in the range of 12 m to 21 m, the height of *Q. acutissima* – in the range of 16 m to 22 m, the height of *P. chinensis* – in the range of 4 m to 8 m. From the perspective of tree height distribution, the tree height distribution of different tree species is clearly stratified. *Q. acutissima* and *P. massoniana* are growing in the middle and upper canopies, while *Q. dentate* and *P. chinensis* are concentrated in the lower and middle canopies. From the perspective of DBH distribution, the tree height distribution and diameter class distribution of each tree species have the same trend.

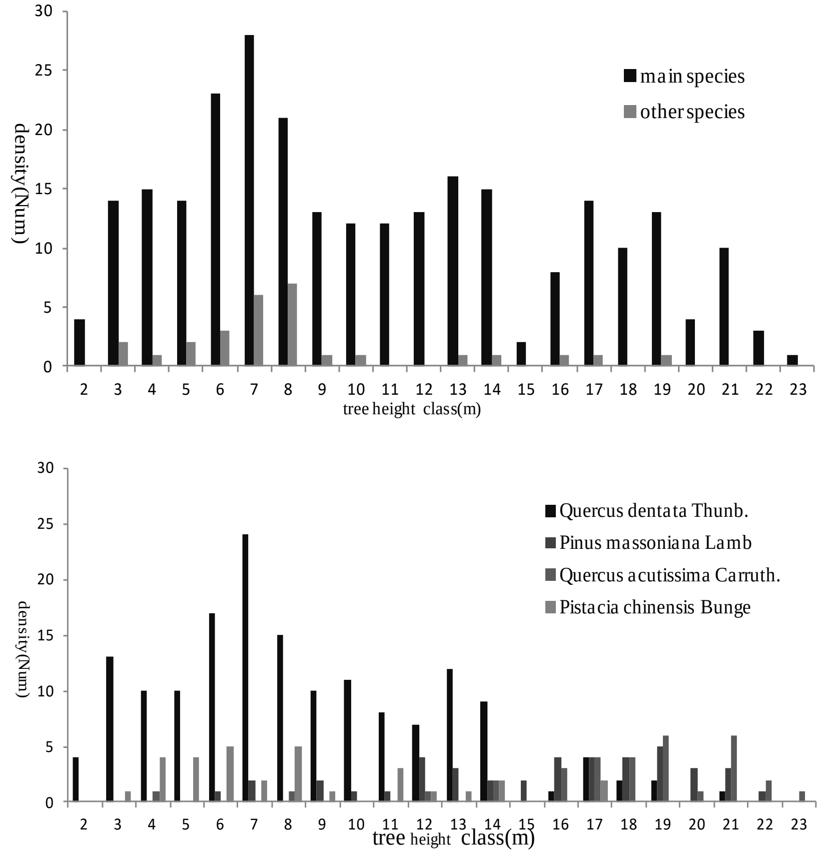

Fig. 3. The height distribution of main tree species in the plot

Diversity index of tree diameter class distribution

Table 5

Index table of diameter class distribution diversity of arbor forest in Nanwan Lake reservoir riparian zone

Index	Value	Theoretical index value range
Simpson size diversity index	0.878	[0,1]
Shannon size diversity index	2.441	[0,ln(*S*)]
Gini coefficient index of basal area	0.600	[0,1]
diameter coefficient of variation index	0.656	[0,1]

The Simpson size diversity index of diameter class distribution of arbor forest in Nanwan Lake reservoir riparian zone is 0.878. Shannon size diversity index is 2.441. Gini coefficient index of basal area is 0.600. Diameter coefficient of variation index is 0.656 (Tab. 5).This indicates that the distribution richness of diameter class structure in Nanwan Lake reservoir riparian zone is more abundant, the difference of tree diameter class is obvious, and the forest stand diameter class structure is in a relatively good condition.

Tree height – DBH relationship

Table 6

The tree height – DBH curve was used to fit the parameters

Model	Fitting results			
	a	b	c	R^2
Richard	20.095	0.090	1.765	0.818
Weibull	19.537	0.020	1.406	0.817
Logistic	18.527	8.621	0.179	0.810
Korf	28.488	9.195	0.867	0.818
Compertz	19.243	3.058	0.122	0816

Using the main tree species as samples, the parameters *a, b* and *c* of several commonly used tree height-DBH model equations were fitted to obtain the parameters of each model. Among them, Richard equation and Korf equation have the best fitting effect, with the determination coefficient (R^2) both reaching 0.818.Comparing the residual results obtained by the two methods, Richard's equation is better, which is applicable to describe the relationship between tree height and DBH in the forestland of the Nanwan Lake reservoir riparian zone. The model equation is $H = 1.3 + 20.095\ (1–e^{-0.090D})^{1.765}$.

Discussion. The forest land along the riverbank of the reservoir plays an important role in the change and formation of the reservoir microclimate, and is also an important habitat for various vegetation, birds and microorganisms. The health status and management measures of riparian forest land play a positive role in the maintenance of the whole reservoir environment as well as the development of biodiversity and forest land productivity (Naiman & Decamps, 1997; Zhang et al., 2012).

In this study, the growth status of forestland in the downstream of the Nanwan Lake reservoir riparian zone was investigated. We found that *P. massoniana* and *Q. acutissima* are the constructive species of the riparian zone, among which *P. massoniana* is gradually declining in the whole community, and *Q. dentata* and *P.chinensis* mainly distributed in the lower canopy showed strong replacement potential, which is consistent with the planting history of the riparian forest of the Nanwan Lake reservoir.

In the 1960s, after the reservoir was built, the local management developed a large area of plantation using *P. massoniana* and *Q. acutissima.* For a long time, this kind of mixed model has achieved good results. With the succession of forest community structure, local suitable species *Q. dentata* and *P. chinensis* showed strong competitive advantage.

In the investigation process, we also found that many large-diameter *P.massoniana* appeared dry death phenomenon, which may be due to the rapid growth of newer species in the lower canopy; *P. massoniana* gradually weakened in the whole niche competition, the root system could not get enough nutrients, and gradually died.

The condition of *Q. acutissima.* is better than *P. massoniana* in the large size class. The main competitive pressure on *P. massoniana.* is likely to come from *Q. acutissima*. The update status of *Q. acutissima* in small size class is not ideal, and the distribution range is small. It can be predicted that with the growth of the lower canopy species, *P. massoniana* and *Q. acutissima* will be gradually replaced. In the future, the stand will be dominated by the *Q. dentata*, among which the main accompanying species is *P. chinensis.* This is also consistent with the characteristics of the transition region from subtropical zone to warm temperate zone in Xinyang region.

The hierarchical structure of different canopy story in mixed forests affects the primary productivity of forestlands through the distribution of light energy inner forest canopy and the distribution of species communities under the canopy, further affecting the structural characteristics of ecosystem communities (Marks et al., 2020). The relationship between ecosystem diversity and ecosystem function usually has two mechanisms, niche complementary effect and selection effect. The diversity of ecosystem also directly affects the diversity of stand diameter class structure (Naeem, 2002; Tinya et al., 2018). Therefore, the distribution characteristics of individual diameter class structure in stand are also important parameters to evaluate the stability and diversity of the system. From the current status, the forest structure characteristics in the riparian forest land of Nanwan Lake reservoir accord with the inverted "J" pattern distribution, Richard equation can well describe the linear relationship between DBH and tree height in the stand. Indexes such as the diameter class richness and tree size diversity indicate that the DBH distribution of each diameter class is appropriate and within a reasonable range.

In the absence of anthropogenic accidents or natural extremes, the forest lands near Nanwan Lake could effectively use environmental benefits for a long time.

Conclusions. Forestland is an important part of riparian ecosystem and the stability of forest land structure is also a prerequisite for the maintenance of biodiversity (Gregory et al., 1991). It is almost impossible to restore the ecological function of riparian zone communities once they are destroyed. Riparian forests play a disproportionate role in maintaining ecosystem diversity and climate stability considered its area (González et al., 2016; Tolkkinen et al., 2020). The restoration and reconstruction of riparian forest can effectively improve the efficiency of carbon storage and is an important measure for ecological restoration (Dybala et al., 2019). By investigating the spatial structure characteristics and species in the riparian zone of Nanwan Lake Reservoir forest land, this study evaluated the functional structure characteristics and ecosystem stability, and predicted the management measures of the forest land in the future. From a global perspective, conifer species are gradually declining due to drought, fire, invasion of pests and diseases caused by climate change, and the trend towards broadleaf forest is similar to the results of this research (Kominoski et al., 2013; Mantgem et al., 2009). In order to improve the level of forest management in mixed forests near Nanwan Lake reservoir, it is suggested to closely monitor the growth status of trees, cut dead or poor growing *P. massoniana*, and prevent the occurrence of forest fires.

Acknowledgments

Funding has been provided by Xinyang Agricultural and Forestry University Science and Technology Innovation Team project.

References:

1. Ali, A. (2019). Forest stand structure and functioning: Current knowledge and future challenges. Ecological Indicators, 98, 665–677. doi:10.1016/j.ecolind.2018.11.017

2. Bohn, F. J. & Huth, A. (2017). The importance of forest structure to biodiversity–productivity relationships. Royal Society Open Science, 4(1), 160521. doi: 10.1098/rsos.160521

3. Buongiorno, J. (2001). Quantifying the implications of transformation from even to uneven-aged forest stands. Forest Ecology and Management, 151(1–3), 121–132. doi: 10.1016/S0378-1127(00)00702-7

4. Clark, J. S. (2010). Individuals and the Variation Needed for High Species Diversity in Forest Trees. Science, 327(29), 1129–1132. doi: 10.1126/science.1183506

5. Curtis, J. T. & McIntosh, R. P. (1951). An Upland Forest Continuum in the Prairie-Forest Border Region of Wisconsin. Ecology, 32(3), 476–496. doi: 10.2307/1931725

6. Duduman, G. (2011). A forest management planning tool to create highly diverse uneven-aged stands. Forestry, 84(3), 301-314. doi:10.1093/forestry/cpr014

7. Dybala, K. E., Matzek, V., Gardali T. & Seavy, N. E. (2019). Carbon sequestration in riparian forests: A global synthesis and meta-analysis. Global Change Biology, 25, 57–67. doi:10.1111/gcb.14475

8. González, E., Felipe-Lucia, M. R., Bourgeois, B., Boz, B., Nilsson, C., Palmer, G. & Sher, A. A. (2016). Integrative conservation of riparian zones. Biological Conservation, S0006320716306887. doi: 10.1016/j.biocon.2016.10.035

9. Gregory, S. V., Swanson, F. J., Arthur, M. K. W. & Cummins, K. W. (1991). An ecosystem perspective of riparian zones. Bioence, 41(8), 540–551.

10. Hagan, J. M, Pealer, S. & Whitman, A. A. (2006). Do small headwater streams have a riparian zone defined by plant communities? Canadian Journal of Forest Research, 36(36), 2131–2140. doi: 10.1139/X06-114

11. Kominoski, J. S., Shah, J. J. F., Canhoto, C., Fischer, D. G., Giling, D. P., González, E., Griffiths N. A., Larrañaga A., LeRoy, C. J., Mineau, M. M., McElarney, Y. R., Shirley, S. M., Swan, C. M. & Tiegs, S. D. (2013). Forecasting functional implications of global changes in riparian plant communities. Frontiers in Ecology & the Environment, 11(8), 423–432. doi: 10.1890/120056

12. Kreutzweiser, D. P., Sibley, P. K., Richardson, J. S. & Gordon, A. M. (2012). Introduction and a theoretical basis for using disturbance by forest management activities to sustain aquatic ecosystems. Freshwater Science, 31(1), 224–231. doi: 10.1899/11-114.1

13. Kuglerová, L., Jansson, R., Ågren, A., Laudon, H. & Malm-Renöfält, B. (2014a). Groundwater discharge creates hotspots of riparian plant species richness in a boreal forest stream network. Ecology, 95(3), 715–725. doi: 10.1890/13-0363.1

14. Kuglerová, L., Ågren, A., Jansson, R. & Laudon, H. (2014b). Towards optimizing riparian buffer zones: Ecological and biogeochemical implications for forest management. Forest Ecology and Management, 334, 74–84. doi: 10.1016/j.foreco.2014.08.033

15. Livesley, S. J., Baudinette, B. & Glover, D. (2014). Rainfall interception and stem flow by eucalypt street trees – the impacts of canopy density and bark type. Urban Forestry & Urban Greening, 13(1), 192–197. doi: 10.1016/j.ufug.2013.09.001

16. Mantgem, P. J. V., Stephenson, N. L., Byrne, J. C. Daniels, L. D., Franklin, J. F., Fulé, P. Z., Harmon, M. E., Larson, A. J., Smith J. M., Taylor A. H. & Veblen, T. T. (2009). Widespread increase of tree mortality rates in the western United States. Science (New York, N.Y.), 323, 521–524. doi: 10.1126/science.1165000

17. Marks, C. O., Yellen, B. C., Wood, S. A., Martin, E. H. & Nislow, K. H. (2020). Variation in tree growth along soil formation and microtopographic gradients in riparian forests. Wetlands, 08, 1–14. doi: 10.1007/s13157-020-01363-9

18. Myster, R. W. (2018). What we know about the composition and structure of igapó forests in the Amazon basin. Botanical Review, (84), 394–410. doi: 10.1007/s12229-018-9204-y

19. Naeem, S. (2002). Ecosystem consequences of biodiversity loss:the evolution of a paradigm. Ecology, 83(6), 1537-1552. doi: 10.2307/3071972

20. Naiman, R. J. & Decamps, H. (1997). The ecology of interfaces:Riparian zone. Annual Review of Ecology & Systematics, 28, 621–658. doi: 10.1146/annurev.ecolsys.28.1.621

21. Oldén, A., Peura, M., Saine, S., Kotiaho, J. S. (2019). The effect of buffer strip width and selective logging on riparian forest microclimate. Forest Ecology and Management, 453, 117623. doi: 10.1016/j.foreco.2019.117623

22. Peder, W., & Ljusk, O. E. (2000). Solving the stand management problem under biodiversity-related considerations. Forest Ecology & Management, 126, 361–376. doi: 10.1016/S0378-1127(99)00107-3

23. Pommerening, A. (2002). Approaches to quantifying forest structures. Forestry, 75(3), 305–324. doi: 10.1093/forestry/75.3.305

24. Poulsen, J. R., Koerner, S. E., Miao, Z., Medjibe, V. P., Banak, L. N. & White, L. J. T. (2017). Forest structure determines the abundance and distribution of large lianas in Gabon. Global Ecology & Biogeography, 26(4), 472-485. doi: 10.1111/geb.12554

25. Ran, Y., Ma, M., Liu, Y., Zhou, Y., Sun X., Wu S. & Huang, P. (2020). Hydrological stress regimes regulate effects of binding agents on soil aggregate stability in the riparian zones. Catena, 196, 104815. doi: 10.1016/j.catena.2020.104815

26. Ring, E., Widenfalk, O., Jansson, G. Holmström, H., Högbom, L. & Sonesson, J. (2017). Riparian forests along small streams on managed forest land in Sweden. Scandinavian Journal of Forest Research, 33(2), 133–146. doi: 10.1080/02827581.2017.1338750

27. Rolstad, J., Gjerde, I., Storaunet, K., O. & Rolstad, E. (2001). Epiphytic lichens in Norwegian coastal spruce forest: Historic logging and present forest structure. Ecological Applications, 11(2), 421–436. doi: 10.2307/3060899

28. Schulte, B. J. & Buongiorno, J. (1998). Effects of uneven-aged silviculture on the stand structure, species composition, and economic returns of loblolly pine stands. Forest Ecology & Management, 111(1), 83–101. doi: 10.1016/S0378-1127(98)00312-0

29. Sibley, P. K., Kreutzweiser, D. P., Naylor, B. J., Richardson, J. S. & Gordon, A. M. (2012). Emulation of natural disturbance (END) for riparian forest management: synthesis and recommendations. Freshwater Science, 31(1), 258–264. doi: 10.1899/11-094.1

30. Sun, J., Yu, X., Wang, H., Jia, G., Zhao, Y. Tu, Z., Deng, W., Jia, J. & Chen, J. (2018). Effects of forest structure on hydrological processes in China. Journal of Hydrology, 561, 187–199. doi: 10.1016/j.jhydrol.2018.04.003

31. Tinya, F., Márialigeti, S., Bidló, A., & Ódor, P. (2018). Environmental drivers of the forest regeneration in temperate mixed forests. Forest Ecology and Management, 433, 720–728. doi: 10.1016/j.foreco.2018.11.051

32. Tolkkinen, M., Mykrä, H., Annala, M., Markkola, A. M., Vuori, K. M. & Muotka, T. (2015). Multi-stressor impacts on fungal diversity and ecosystem functions in streams: natural vs. anthropogenic stress. Ecology, 96(3), 672–683. doi: 10.1890/14-0743.1

33. Tolkkinen, M. J., Heino, J., Ahonen, S. H. K., Lehosmaa, K. & Mykra, H. (2020). Streams and riparian forests depend on each other: A review with a special focus on microbes. Forest Ecology and Management, 462, 117962. doi: 10.1016/j.foreco.2020.117962

34. Valbuena, R., Packalén, P., Martin-Fernández, S. & Matti, M. (2012). Diversity and equitability ordering profiles applied to study forest structure. Forest Ecology and Management, 276, 185–195. doi: 10.1016/j.foreco.2012.03.036

35. Yuan, Z., Wang, S., Ali, A., Gazol, A., Ruiz-Benito, P., Wang, X., Lin, F., Ye, J., Hao Z. & Loreau M. (2018). Aboveground carbon storage is driven by functional trait composition and stand structural attributes rather than biodiversity in temperate mixed forests recovering from disturbances. Annals of Forest Science, 75(3), 67. doi: 10.1007/s13595-018-0745-3

36. Zhang, Y., Chen, H. Y. H. & Reich, P. B. (2012). Forest productivity increases with evenness, species richness and trait variation: a global meta-analysis. Journal of Ecology, 100(3), 742–749. doi: 10.1111/j.1365-2745.2011.01944.

Янь Тенфей, а*спірант, Хенанський інститут науки та техніки, м. Сіньсян, Хенань, КНР; Сіньянський університет сільського господарства та лісу, м. Сіньян, Хенань, КНР; Сумський національний аграрний університет, м. Суми, Україна*

Кременецька Євгенія Олексіївна, *кандидат сільськогосподарських наук, доцент, Сумський національний аграрний університет, м. Суми, Україна*

Ван Шибін, *заступник старшого інженера, Національна лісова ферма Наньван, м. Сіньян, Хенань, КНР*

Ху Цян, *асистент, Сіньянський університет сільського господарства та лісу, м. Сіньян, Хенань, КНР*

Він Сонглін, *викладач докторантури, професор, Хенанський інститут науки та техніки, м. Сіньсян, Хенань, КНР*

Дослідження структури угруповань та поширення змішаних лісів поруч із озером Наньван

Розподіл структури угруповання у лісі, що зростає у зоні узбережжя, є важливим показником різноманітності та сталого розвитку прибережної екосистеми, а також важливою основою для управління лісовими землями. Для того, щоб зрозуміти екологічну функцію прибережної зони озера Наньван (місто Сіньян, провінція Хенань, Китай), досліджено стан зростання лісу у нижній течії водойми. Результати дослідження свідчать про те, що Pinus massoniana Lamb і Pistacia chinensis Bunge є переважаючими видами у складі насаджень прибережної зони. Відбувається поступове зменшення представництва Pinus massoniana Lamb у даному угрупованні. Нижній ярус із Quercus dentate Thunb. і Pistacia chinensis Bunge демонструє значний потенціал для заміни верхнього ярусу. Характеристики структури дерев (діаметр стовбура дерева на висоті грудей (1,3 м), висота дерева та ширина крони) були встановлені на кожній експериментальній ділянці. Характеристики структури дерев підтверджують перевернутий розподіл «J» і лінійний зв'язок між діаметром на висоті грудей і висотою дерев у насадженні (можна добре описати за допомогою рівняння моделі Річарда), рівняння моделі $H=1.3+20.095(1-e^{-0.090D})^{1.765}$*. За умови відсутності антропогенних аварій або природних екстремальних явищ, лісові землі навколо озера Наньван ще довго могли б ефективно використовувати екологічні переваги. З метою покращення рівня ведення лісового господарства у мішаних лісах на даних територіях, пропонується уважно стежити за станом росту дерев, видаляти загиблі або погано зростаючі дерева Pinus massoniana Lamb, а також запобігати виникненню лісових пожеж.*

Key words: *прибережна зона озера Наньван; мішаний ліс; характеристики структури дерев.*