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FACTORS OF NATURAL REGENERATION OF *Platycladus orientalis* (L.) FRANCO IN GUILIN, CHINA

ČIMBENIK PRIRODNE OBNOVE VRSTE *Platycladus orientalis* (L.) FRANCO U GUILINU, KINA

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SUMMARY

Cypress (*Platycladus orientalis* (L.) Franco) is one of the important evergreen trees for afforestation in barren mountains, soil consolidation, and water conservation, but natural regeneration of cypress is complex and slow. An understanding of the influence mechanism of the natural regeneration of cypresses is essential for elevating survival and regeneration. This study aimed to clarify the relationship between stand factors, environmental factors, and regeneration of cypress plantations. A total of 42 cypress sample plots in Guilin, China, were selected to evaluate the impact of various stand factors and environmental factors on the regeneration of cypresses using survey statistics and Pearson and Spearmanrank correlation analysis. In this study, cypress has the highest frequency and density of regeneration among all the seedlings in the 18 surveyed forests, but the height structure of cypress seedlings distributes in uneven mode and mainly Grade I (height < 30 cm) seedlings. Low-density herbs and high-density moss mulching had a directly positive effect on the number of cypress regeneration seedlings. Larger soil stone content and gap area can promote cypress regeneration, which is appropriate for cypresses in the seedling stage. In conclusion, timely weeding, proper soil loosening, and improving light transmittance contribute to promoting the regeneration of cypresses.

KEY WORDS: Cypress; Stand factors; Environmental factors; Natural regeneration.

INTRODUCTION
UVOD

Natural regeneration (NR) refers to the process where forests are reformed entirely relying on natural forces (Chazdon and Guariguata 2016; Khaine et al.2018 ;Ribeiro et al. 2022). As an important and complex ecological process, the NR of forests is always one of the main fields of research of forest management and ecosystem, which has an important impact on vegetation development and ecosystem. In recent years, to clarify the influential factors of NR of plants, scholars have made great efforts in terms of environmental factors such as seed characteristics, stand factors, soil factors, habitat factors, and interference factors. For instance, seedling establishment is not only the initial stage of controlling forest dynamic development but also an important stage. Microhabitat greatly affects seedling establishment

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(Efimenko and Aleinikov 2019; Noguchi et al. 2011). Madsen reported that under the open canopy (13% light) or closed canopy (5% light), fertilized and irrigated in a mineral soil seedbed have different effects on seedling growth of beech (*Fagus sylvatica*), and weed competition did not significantly reduce seedling growth (Madsen 1995). These implicated that light intensity, soil water content and nutrient supply effect on natural regeneration of beech. In turn, NR also improves soil fertility, microbial biomass carbon and enzyme activity more than artificial afforestation (Hu et al. 2020; Pang et al. 2018) and also alters compositional and functional shifts in soil seed banks(Medeiros-Sarmento et al. 2021). Additionally, the characteristics of forest gaps have an important impact on light environment, temperature and humidity and micro terrain, and play an important role in forest regeneration, for example, number of beech increased with gap size and light availability; and herbaceous species abundance also significantly effected by gap size (Naaf and Wulf 2007; Qin et al. 2011). These studies have shown that the efficiency of NR is affected by environmental factors.

Additionally, the stand factor is another regulatory factor that affects the frequency of NR. For example, in forests, gaps of different sizes and ages have different effects on tree density, dominance, the conversion rate from seedlings to young trees, and spatial pattern of seedlings and young trees (Ugarković et al. 2018; Zhu et al. 2014), which significantly affects the growth of regeneration seedlings (Beckage and Clark 2003). Different shade-tolerant tree species also have certain segmentation in the utility of forest gap ecological resources (Ugarković et al. 2018). In addition, natural forest regeneration is also affected by some special habitats, such as karst scar habitat (Gholami et al. 2018). Studied found that the special habitat of karst scar (except the dissolution corridor) in the karst area can preserve some plant residues and provide a source of propagules for plant regeneration (Hu et al. 2020; Pang et al. 2018). Bryophyte communities affect seed dispersal, seed germination, and seedlings establishment, and also exert a role of the allelopathy on vascular plants (Fukasawa et al. 2019).

Platycladus orientalis (L.) Franco (cypress) is an evergreen tree species of the cypress family. Cypress likeswarm and humid climate conditions and has wide adaptability to soil including neutral, slightly acidic and calcareous soil, and particularly prefers the shallow calcareous purple soil and lime soil in the upper layer. Cypress needs sufficient upper light to grow, but they also have a certain resistance to shadein the seedling stage. Cypress can play an important role in the ecological construction of arid and barren forests in mountainous areas. However, the natural NR of cypress plantations used for ecological construction is very difficult, which greatly reduces the efficiency of ecological improvement (Kimambo and Naughton-Treves 2019). Importantly, in cases where cypress dominated forest is aimed/auchtonus forest type, the weakness of NR ability of cypress plantation significantly affects the stability of the ecosystem, which is not conducive to sustainable management. At present, it is known that the NR of cypress plantations is the result of a comprehensive restrictions of many factors. For example, the regeneration of Arizona cypress affected by wildfire (Dos Santos et al. 2019). Cypress seedlings can grow in large numbers due to the release of seeds from serous cones, the exposure of mineral soil, and the increase of solar radiation (Barton and Poulos 2018). Proper thinning intensity can achieve a better regeneration effect of cypress (Olson et al. 2014). Different stand densities, soil water content, and litter cover thickness significantly impact on seed germination and early seedling growth (Islam et al. 2016). However, there is no research on the environmental factors and stand factors limiting cypress regeneration, thus,the strategies for managing and promoting the natural regeneration of cypress plantations are not yet fully understood.

As far as we know, the effect of environmental factors and stand factors on cypress regeneration is studied for the first time. In this study, we aimed to explore (1) whether cypress can regenerate naturally; (2) which factors affect NR of cypresses; and (3) how these factors affected NR of cypresses. This study provides an empirical basis for the management and the promotion of NR for cypress plantations.

METHODS
METODE

Overview of the study area – *Pregled područja istraživanja*

This study was conducted in Guilin city, located in the Southwest of Guangxi, China (latitude 24° 55' – 25° 18', longitude 110 ° 18' – 110 ° 45', altitude 115–421 m) (Figure 1). Cypress is one of the major species of artificial vegetation in this area and is mostly distributed in the middle and lower part of the mountains. The climate of the survey region is the subtropical monsoon climate with the characteristic of a mild climate, abundant rainfall, long frost-free period, sufficient light, abundant heat, long summer and short winter, four distinct seasons, and the same season of rain and heat. The climatic condition of survey region is superior with less snow in three winters and frequent flowers in four seasons. The annual average temperature is around 19.4 °C, July and August are the hottest months of the year with an average temperature of about 28.5 °C; January and February are the coldest months of the year with an average temperature of about 8.3 °C. The annual average frost-free period is 309 days, the annual average rainfall is 1974 mm, and the annual average relative humidity is

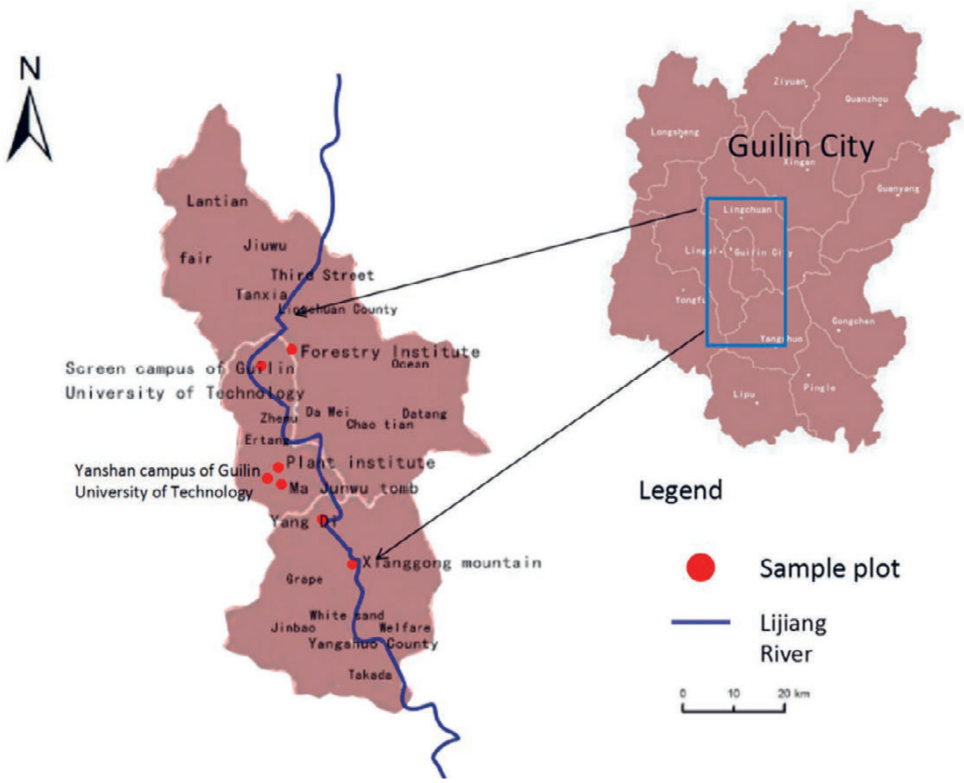

Figure 1. Area map of 42 sample plots in 7 area in China.
Slika 1. Karta područja prikazuje 42 uzorka uzetih s ploha sa 7 područja u Kini.

73–79%. The annual wind direction is mainly northerly with an average wind speed of 2.2–2.7 m/s. The annual average sunshine time is 1670 h and the average air pressure is 994.9 hPa. The soil of the selected survey area is mainly calcareous.

The desired position of Figure 1.

Introduction of influencing factors – *Uvod u čimbenike utjecaja*

This study was conducted from July to October 2020 and from May to June 2021 within 7 regions, and each region set up 6 duplicate sites thus a total of 42 study plots of cypress forests, and each plot is a square with 10 m × 10 m.

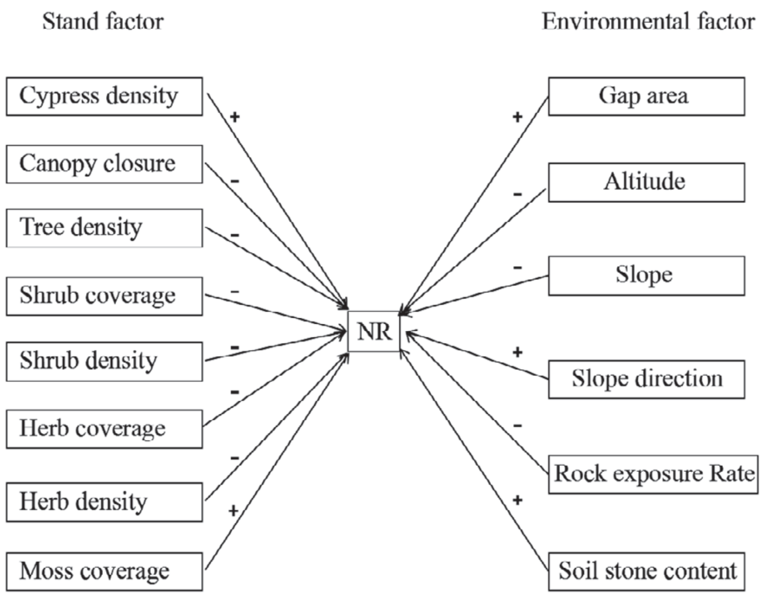

Figure 2. Hypothesis on influencing factors of NR of cypress plantation. Note: + represents positive correlation; - represents negative correlation.
Slika 2. Hipoteza o utjecaju čimbenika prirodne obnove nasada obične azijske tuje Napomena: + predstavlja pozitivnu korelaciju; - predstavlja negativnu korelaciju.

Each plot is at least 50 m apart so that they have different ecological conditions. Therefore, plots could be served as single observations.In each plot of cypress forests, the team investigated the regeneration characteristics, stand factors (biological factors) and environmental factors (abiotic factors). The recorded characteristics of natural regeneration mainly included species, quantities, and tree heights of regeneration plants; stand factors of records mainly include adult cypress density, tree canopy density, tree density, shrub coverage, shrub density, herb coverage, herb density, and moss coverage; environmental factors of records mainly include long and short axis length of forest gap, altitude, geographical coordinates, slope, slope direction, rock exposure rate, and soil stone content.

Establishment of a model for influence factor of NR of cypress plantation – *Utvrđivanje modela za utjecaj čimbenika prirodne obnove (NR) na plantaži obične azijske tuje*

According to the principles of objectivity, representativeness, systematicness, and measurability, and based on the investigation analysis, our study constructed an influence factor model of NR of cypress plantation, which was composed of stand factors and environmental factors, as shown in Figure 2.

The desired position of Figure 2.

Division standard of regeneration seedlings – *Distribucija pomlatka prema visinskim klasama*

An age structure is an important characteristic of population dynamics. The height level of seedlings can be used to replace an age structure in seedling research. In this study, cypress seedlings were divided into four grades based on plant height level (Table 1).

The desired position of Table 1.

Data analysis – *Analiza podataka*

The data of characteristics stand factors and environmental factors of regeneration seedling in the sample plots were pre-processed. Slope direction management: In each plot of cypress forest, the fixed slope direction is 0° to the north and the slope direction gradually increases clockwise, thereby 0 ~ 45° and 315° ~ 360° are shady slopes; 45° ~ 135° is semi shady slope; 135° ~ 225° is sunny slope; 225° ~ 315° is semi sunny slope.

Gap measurement: In each plot of cypress forest, gap area was calculated by the elliptic area formula: $S = \pi AB / 4$ (where S was the forest gap area, A was the long axis length and B was the short axis length).

Statistical analysis: All data analysis was completed by GraphPad Prism v9 software. Data were subjected to a nonparametric test using Kruskal-Wallis.Pearson and Spearmanrank correlation test was used for correlation analysis. Multiple stepwise regression analysis was used to explore which stand factors and environmental factors had an impact on regeneration. $P < 0.05$ was considered statistically significant.

RESULTS
REZULTATI

Density structure of regeneration seedlings – *Gustoća sklopa pomlatka*

he study plots were located in pure cypress forest or mixed forest, with the characteristics of altitude of 149 – 348 m. The community structure of survey area was complete with arbor, shrub and grass, and plant species was abundant. See Table 2 for the main types of trees and shrubs and all types of regeneration seedlings in the survey area.

The desired position of Table 2.

In 42 investigated plots, the distribution of cypress regeneration seedlings and plants was extremely uneven. The regeneration density of one plot (No.8 plot) was up to 48000 ~ 49000 individuals / hm^2, and we also found that the moss coverage of this sample plot was very high and the forest gap area was large. The density of regeneration seedlings in other sample plots was concentrated at 1–8000 individuals / hm^2, as shown in Table 2. However, plant density of regenerated seedlings in 20 sample plots was 0 individuals / hm^2, meaning no regeneration phenomenon. Additionally, the average regeneration density of 22 sample plots with cypress seedlings was calculated, as 5018 individuals / hm^2. In general, the number of regenerations of cypress in some sample plots was large and small in some sample plots, and the density and regeneration frequency of cypress plantation in the survey plots still have room for improvement.

The desired position of Table 3.

Table 1. Classification criteria of seedlings and young trees
Tablica 1. Kriteriji klasiranja sadnica i mladih stabala

Grade *Sadnica*	Grade I Seedling *Sadnica I klase*	Grade II Seedling *Sadnica II klase*	Grade III young tree Mlado stablo *III klase*	Grade IV young tree *Mlado stablo IV klase*
Standard *Standard*	H<30 cm	30 cm≤H<60 cm	60 cm≤H<100 cm	H≥100 cm and DBH<5 cm

Table 2. Table of main tree and shrub species and all regeneration seedling species in the survey area

Common Name	Scientific Name
Main plant species in the survey area	
Cypress	
Melia azedarach	Melia Azedarach
Choerospondias axillaris	Choerospondias axillaris (Roxb.) Burtt et Hill.
Berry neem	Cipadessa baccifera (Roth.) Miq.
Jade leaf golden flower	Mussaenda pubescens W. T. Aiton
Alchornea trewioides	Alchornea trewioides (Benth.) Muell. Arg.
Paper mulberry	Broussonetia Papyrifera (Linn.) L'Hér. ex Vent.
Cuiyun grass	(Selaginella uncinata (Desv.) Spring
Sedge	Carex brunnea Thunb.
Southern brocade moss	Brotherella henonii (Duby) Fleisch
Setaria plicata	Setaria plicata (Lam.) T. Cooke
Seedling species recorded in the sample plot	
Cypress	
Berry neem	
Jade leaf golden flower	
Broussonetia papyrifera and Camphor	Cinnamomum camphora (L.) J. Presl
Pepper tree	Zanthoxylum bungeanum Maxim.
Purple brocade	Euphorbia cotinifolia Miq.
Rhamnus	Rhamnus davurica Pall.
Rhus chinensis	Rhus chinensis var. Roxburghii (DC.) Rehder
Wild pepper	Lindera glauca var. Nitidula Lecomte
Maclura tricuspidata	Maclura tricuspidata Carrière
White catalpa	Mallotus paniculatus (Lam.) Müll. Arg.
Eucalyptus	Eucalyptus robusta Sm.
Star anise maple	Alangium chinense (Lour.) Harms
Yellow cow wood	Cratoxylum cochinchinense (Lour.) Blume
Cassia tree	Cinnamomum japonicum Siebold
Toona sinensis	Toona sinensis (Juss.) Roem.
Sweet-scented osmanthus	(Osmanthus fragrans (Thunb.) Lour.
Eurya	Eurya japonica Thunberg
Mulberry	(Morus alba L

Table 3. Distribution of NR seedling density of cypress
Tablica 3. Distribucija NR gustoće sadnica obične azijske tuje.

Renewal density (individuals / hm^2) *Broj pomlatka po (pojedinačno / hm^2)*	Number of sample plots *Broj uzorkovanih ploha*
0	20
1-1000	5
1001-2000	6
2001-3000	2
3001-4000	2
4001-5000	2
5001-6000	1
6001-7000	1
7001-8000	2
48000-49000	1

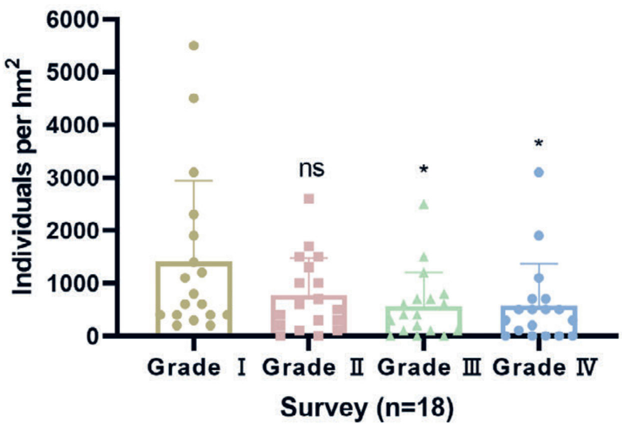

Figure 3. Height class structure of cypress regeneration seedlings. * represents P < 0.05, ns represents P > 0.05.
Slika 3. Visinska struktura pomlatka obične azijske tuje. * predstavlja P < 0,05, ns predstavlja P > 0,05.

Height structure of regeneration seedlings – *Visinska struktura prirodnog pomlatka*

In the investigated plots, cypress seedlings were only observed in 22 sample plots, of which sample plot No.8was very specialin that the number of renewed seedlings was much higher than that in other sample plots. To reduce the experimental error, sample plot No.8 with maximum value was removed when analyzing the height structure of seedlings at all levels. Although cypress seedlings appeared in plot 23, plot 26, and plot 28, grade I seedlings were lacking, that is, cypress seedlings in these three plots were planted manually. To reduce the experimental error, these three plots were also not involved in the analysis. Therefore, only remaining 18 sample plots were involved in the analysis of the height distribution of cypress seedlings.

As shown in Figure 3, the results showed that there were significant differences in the number of seedlings between grade I and grade III or IV young trees. The height structure of cypress regeneration seedlings showed a skewed distribution, and the numbers of cypress regeneration seedlings decreased with grades. The number of Grade I seedlings was the largest, suggesting that the seeds successfully germinated to form seedlings, and cypresses have no germination obstacles. The number of Grade I, Grade II, Grade III, and Grade IV showed a decreasing trend.

The desired position of Figure 3.

Cypress regeneration effected by stand factors especially herb coverage and moss coverage – *Na prirodnu obnovu obične azijske tuje utječu sastojinski čimbenici, posebice pokrovnost biljem i mahovinom*

To explore the impact of stand factors on the NR of cypress, the correlation analysis between stand factors and cypress regeneration seedlings was carried out (Table 4). The results showed that there was a significant negative correlation between herb density and regeneration density. In addition, a significant positive correlation between moss coverage and seedlings of all grades and renewal density was observed (Table 4). However, no significant correlation between other parameters and cypress regeneration seedlings could be observed (Table 4, Figure 4). For example, although cypress density is a reason for affecting the number of seeds under the forest, cypress regeneration seedlings showed no direct or significant correlation with the number and density, indicating that there are sufficient provenances in the sample plot, and provenance is not the main factor affecting cypress regeneration.

The desired position of Table 4.

The desired position of Figure 4.

Stepwise multiple regression analysis was carried out on 8 stand factors,including cypress density, canopy density, tree density, shrub coverage, shrub density, herb coverage, herb density, and moss coverage, to analyze the factors that may affect NR of cypress (Table 5). As a result, the model eliminated 6 variables, while the herb coverage and moss coverage were retained. The optimal regression equation was composed of herb coverage and moss coverage, as follows: RD = –6467.345 + 194.074 * MC + 101.769 * HC. (RD represents renewal density; MC represents moss coverage; HC indicates herb coverage)

The results showed that the regeneration density of cypress was mainly affected by two factors: herb coverage and moss coverage. Adjusting the determination coefficient R^2 to 0.37 showed that these two variables could partially determine the regeneration density of cypress. In short, high-density of herb was unfavorable to cypress regeneration while high moss coverage was contrary.

The desired position of Table 5.

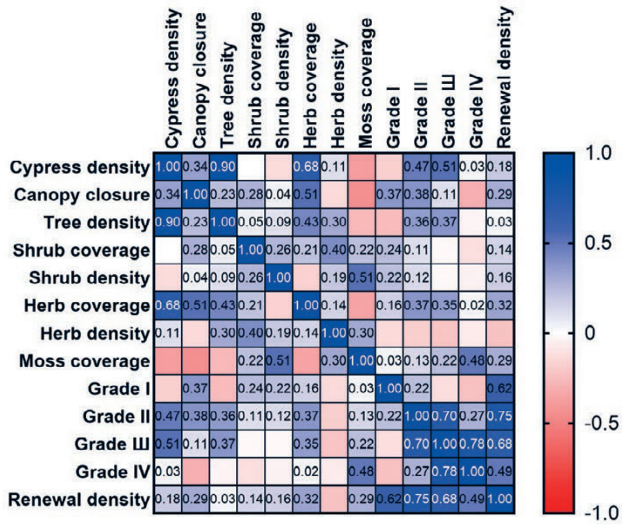

Figure 4. Pearson's correlation coefficient heatmap between stand factors and the number of cypress regeneration seedlings.
Slika 4. Toplinska karta Pearsonovog koeficijenta korelacije između sastojinskih čimbenika i pomlatka obične azijske tuje.

Table 4. Spearman correlation between stand factors and the number of cypress regeneration seedlings
Tablica 4. Spearmanova korelacija između čimbenika sastojine i broja regeneracijskih sadnica obične azijske tuje

Stand factor *Sastojinski čimbenici*	Grade I *Klasa I*	Grade II *Klasa II*	Grade III *Klasa III*	Grade IV *Klasa IV*	Renewal density *Gustoća pomlatka*
Cypress density *Gustoća obična azijska tuja*	0.086	0.004	-0.056	-0.119	0.034
Canopy closure *Sastojinski sklop*	-0.071	-0.104	-0.102	-0.209	-0.034
Tree density *Gustoća stabala*	-0.034	0.031	0.096	-0.075	0.002
Shrub coverage *Pokrovnost grmlja*	0.017	-0.114	0.003	-0.004	0.01
Shrub density *Gustoća grmlja*	0.138	0.133	0.044	0.061	0.084
Herb coverage *Pokrovnost bilja*	-0.276	-0.198	-0.231	-0.283	-0.267
Herb density *Gustoća bilja*	-0.222	-0.276	-0.292	-0.283	-.310*
Moss coverage *Pokrovnost mahovinom*	.647**	.666**	.662**	.718**	.708**

Note: * and ** denote significance level at $P < 0.05$ and $P < 0.01$, respectively.
*Napomena: * i ** označavaju razinu značajnosti pri $P < 0,05$ i $P < 0,01$.*

Table 5. Multiple regression model of cypress regeneration density and stand factors

Tablica 5. Višestruki regresijski model za gustoću prirodnog pomlatka i stanišnih čimbenika

	B	β	t	P
Constant term *Stalno*	-6467.345		-2.72	0.01
Moss coverage *Pokrovnost mahovinom*	194.074	0.63	4.867	0
Herb coverage *Pokrovnost biljem*	101.769	0.374	2.887	0.006

Cypress regeneration effected by environmental factors especially soil stone content, slope direction, and forest gap area – *Na prirodnu obnovu obične azijske tuje utječu ekološki čimbenici, posebice sadržaj kamena u tlu, ekspozicija i površina otvora (gapova)*

We next explore the effect of environmental factors on cypress regeneration. The correlation analysis between various components of environmental factors and the number of cypress regeneration seedlings showed that the number of cypress regeneration seedlings was significantly positively correlated with soil stone content, slope direction, and forest gap area, but not with other environmental factors (Table 6; Figure 5). The number of cypress regeneration seedlings for level I-III and renewal density were significantly positively correlated with soil stone content. Cypress renewal density and the height of cypress seedlings at all levels were positively correlated with slope direction (Table 6; Figure 5). We also observed a significantly positive correlation between the number of cypress seedlings of all grades and renewal density and forest gap area (Table 6; Figure 5).

The desired position of Table 6.

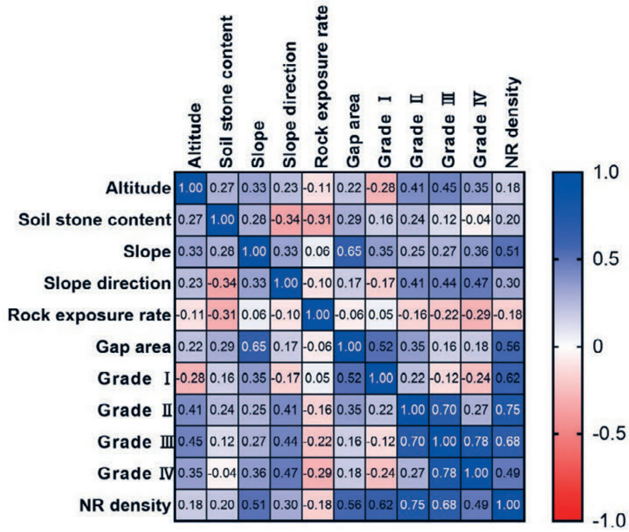

Figure 5. Pearson's correlation coefficient heatmap between environmental factors and the number of cypress regeneration seedlings.

Slika 5. Toplinska karta Pearsonovog koeficijenta korelacije između ekoloških čimbenika i pomlatka obične azijske tuje.

The desired position of Figure 5.

Multiple stepwise regression analysis was carried out between cypress regeneration density and six environmental factors, such as altitude, soil stone content, slope, slope direction, rock exposure rate, and forest gap area,to analyze the factors that may affect NR of cypress (Table 6). The results showed that the model excluded four variables including altitude, slope, slope direction, and rock exposure rate, and established a model based on soil stone content and gap area. The optimal regression equation was composed of two variables as follows:

$RD = -2030.644 + GA * 295.61 + 223.517 * SSC$. (RD represents renewal density; GA represents forest gap area; SSC is the soil stone content)

Table 6. Spearman correlation between environmental factors and the number of cypress regeneration seedlings

Tablica 6. Spearmanova korelacija između ekoloških čimbenika broja prirodnog pomlatka obične azijske tuje

Environmental factor *Ekološki čimbenici*	Grade I *Klasa I*	Grade II *Klasa II*	Grade III *Klasa III*	Grade IV *Klasa IV*	Renewal density *Gustoća pomlatka*
Altitude *Nadmorska visina*	0.054	0.259	0.248	0.288	0.17
Soil stone content *Sadržaj kamena u tlu*	.477**	.339*	.310*	0.25	.384*
Slope *Nagib*	0.122	0.239	0.288	0.304	0.22
Slope direction *Ekspozicija*	.384*	.551**	.574**	.514**	.530**
Rock exposure rate *Stupanj kamenitosti*	-0.067	-0.022	0.034	0.047	-0.011
Gap area *Površina otvora*	.742**	.695**	.646**	.662**	.755**

Note: * and ** denote significant difference at $P < 0.05$ and $P < 0.01$, respectively.

*Napomena: * i ** označavaju značajnu razliku pri P < 0,05 i P < 0,01.*

Table 7. Multiple regression model between cypress regeneration density and environmental factors

Tablica 7. Model višestruke regresije između gustoće prirodnog pomlatka obične azijske tuje i ekoloških čimbenika

	B	b	t	P
Constant term *Stalno*	-2030.644		-2.642	0.012
Soil stone content *Sadržaj kamena u tlu*	295.61	0.621	5.459	0
Gap area *Površina otvora*	223.517	0.307	2.697	0.01

The results showed that the regeneration density of cypress was mainly affected by soil stone content and forest gap area. Adjusting the determination coefficient R^2 to 0.739 showed that these two variables could determine the regeneration density of cypress to a higher extent. Taken together, soil stone content, slope direction, and forest gap area were important environmental factors for promoting cypress regeneration.

The desired position of Table 7.

Subsequently, to further explore the effects of soil stone content, slope direction, and forest gap area on cypress regeneration, we respectively analyzed the correlation between their and the number of cypress seedlings. As shown in Table 7, the number of cypress regeneration seedlings showed an upward trend with the increase of soil stone content. The soil of the sample plot contains a lot of gravel, and the gravel is evenly distributed in the soil (Table 7).

The desired position of Table 8.

We also analyzed the effect of slope direction on cypress regeneration seedlings in 18 sample plots with cypress regeneration (Figure 6). The regeneration capacity of regenerated cypress seedlings with different slope directions was ranked as follows: shady slope > semi shady slope > sunny slope > semi sunny slope. There was no significant difference in the number of grade I seedlings on the four slopes, but significantly different between the grade II seedlings on the shady slope and the sunny and semi sunny slope were observed. The number of grade III seedlings on shady slope was significantly different from the other three slope directions. The difference results of the grade IV seedlings were the same as those of the grade II seedlings (Figure 6).

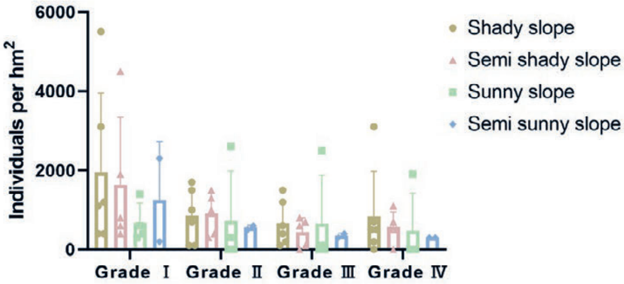

Figure 6. Number of renewal seedlings in different slope directions.

Slika 6. Broj sadnica iz prirodne obnove na različitim ekspozicijama.

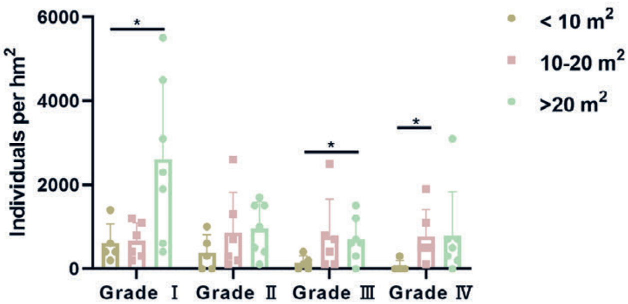

Figure 7. Number of regeneration seedlings in different gap areas. * represents P < 0.05.

Slika 7. Broj sadnica iz prirodne obnove u različitim površinama otvora. * predstavlja P < 0,05.

The desired position of Figure 6.

In addition, the number of grade I seedlings in forest gap of > 20 m^2 and number of grade IV seedlings in forest gap of < 10 m^2 were respectively significantly different from that in other levels of forest gap. We also found that the number of regeneration seedlings was the highest in the group of gap area > 20 m^2 in all four height Grade (Figure 7), which was consistent with our previous results that the larger gap area was favorable for cypress regeneration.

The desired position of Figure 7.

DISCUSSION
RASPRAVA

NR of cypress plantations is considered challenging, and evaluating the regeneration potential of cypress plantations is of great significance for scaling up the natural regenera-

Table 8. Number of cypress regeneration seedlings in different soil stone content

Tablica 8. Broj prirodnog pomlatka obične azijske tuje u tlu različite kamenitosti

Soil stone content *Kamenito tlo*	Grade I *Klasa I*	Grade II *Klasa II*	Grade III *Klasa III*	Grade IV *Klasa IV*	Renewal density individuals / hm² Gustoća obnavljanjapojedinačno / hm²
> 50%	146	128	109	103	48600
30% - 50%	31	17	12	7	6700
10% - 30%	10	6	2	2	2000
< 10%	11	7	5	6	2900

tion of cypress. In this study, plant density of regenerated seedlings in 20 sample plots was 0 individuals / hm^2, meaning no regeneration phenomenon. The reason for this phenomenon may be that these 20 plots are from the three sample survey areas where human activities were intensive. The frequent occurrence of concentrated human trampling incidents hindered the occurrence of seedlings. Morover, we revealed that NR through seed reproduction under appropriate environmental conditions could be achieved despite the rare NR of cypress plantation. The NR of cypress is closely related to the environment and stand factors. The suitable condition for NR of cypress is wet, high light intensity, soft soil, and low understory vegetation coverage.

We found that the number of Grade I, Grade II, Grade III, and Grade IV showed a decreasing trend, indicating that the number of young plant regeneration decreased with the increase of age; as well as implicating that the competition for regeneration plants from a young age to old age was fierce with high mortality. Competition becomes increasingly fierce when the supply of resources such as light and space cannot meet the needs of individual growth of the population. Thus, as young cypress individuals grow, the external environment requires that cypress seedlings be more resistant and adaptable to survive. As a result, the upper height level seedlings cannot stably enter the next stage, leading to a decline in the number of renewal seedlings.

The influence mechanism of herb coverage effect on cypress regeneration – *Utjecaj mehanizma pokrovnosti bilja na prirodnu obnovu obične azijske tuje*

This study found that there was a significant negative correlation between understory herb density and the number of cypress seedlings (Table 3; Figure 4), which was similar to the previous research results (Dyderski et al. 2018). The reason may be that cypress regeneration seedlings need nutrients and light during growth and development, which will produce fierce competition with herbs (Colmanetti et al. 2021). A competitive relationship between herbs and seedlings is driven by two reasons: They compete for photosynthetic nutrient space on the ground and nutrient and water resources underground; Herbaceous plants influence the behavior of herbivores and attract them to the area where the cypress is also located, increasing the risk destruction (Duclos et al. 2013). So, the regeneration of cypress seedlings will be suppressed due to the continuous increase of herb density (Montti et al. 2011). Therefore, for the investigated forest, the goal of promoting NR of cypress can be achieved by moderately thinning understory plants.

The influence mechanism of moss coverage effect on cypress regeneration – *Utjecaj mehanizma pokrovnosti mahovinom na prirodnu obnovu obične azijske tuje*

The number of cypress seedlings increased with increasing moss coverage (Table 3; Figure 4), suggesting that the density of cypress seedlings and moss coverage are beneficial to grow of each other. Mosses grow basically close to the ground and their high coverage rates contribute to improving soil moisture and reducing soil surface temperature. Studies reported that mossy mulch is associated with high mortality of small seed herbaceous plants (Fukasawa et al. 2019), which may be reduced the herbaceous plants competing for nutrients with cypress seedlings. Thus, a high moss coverage rate is conducive to cypress regeneration. On the one hand, different stand densities cause the heterogeneity of light and heat conditions in the forest, which impacted the growth and development of understory moss. On the other hand, the strong water and soil retention abilities of mosses provide a moist soil surface microclimate and inhibit herbaceous plant growth (Mallik and Kayes 2018). Last but not least, most of the water source needed by bryophytes is derived from atmosphere, thereby bryophytes do not compete with cypress regeneration seedlings for a large amount of water in the soil. Moreover, cypress is a sun-loving tree species but tolerates slightly shade rather than drought when young. To some extent, the growth habit of cypress in young stage resembles that of mosses. Therefore, for this study, the moss layer can not only provide a relatively humid growth environment for cypress seedlings and young trees but also act as a protective pad (Fukasawa,et al. 2018) . Conclusively, the higher moss coverage, the more suitable for NR of cypress.

The influence mechanism of soil stone content effect on cypress regeneration – *Utjecaj mehanizma kamenitosti tla na prirodnu obnovu obične azijske tuje*

In the present study, the number of cypress regeneration seedlings showed an upward trend with the increase of soil stone content. We speculated that increasing soil gravel content maybe elevate soil porosity thereby the roots of cypress seedlings are easier to take root. The soil with different stone content creates a completely different space for the root system of cypress seedlings from the pure soil, in which the factors have changed, such as water, fertility, gas, and temperature. In such an environment, cypress roots could actively regulate the accumulation of biomass by adjusting the physical distribution and changing the root metabolic rate, thus, the purpose of improving the growth level of cypress seedlings was achieved.

The influence mechanism of slope direction effect on cypress regeneration – *Utjecaj mehanizma ekspozicije na prirodnu obnovu obične azijske tuje*

Regeneration capacity of regenerated cypress seedlings was significantly affected by slope direction,this may be because that the intensity and hours of sunshine vary with slope directions, thus resulting in great differences in water, heat, physical and chemical properties of soil (Sewerniak 2016). According to our investigation results, the sunshine time was short and the light intensity was only 112.76 lum/ft^2 on shady slope, and the evaporation of soil water was small, with natural water content reaching up to 33.07%. Unlike shady slope, the sunshine time was long and the light intensity was 184.08 lum/ft^2 on sunny slope, of course, that the evaporation of the soil water was large and the natural water content of soil was low, with only 28.83%. Cypress seedlings are mostly distributed on the shady slope and semi shady slope due to the different illumination conditions. The illumination on shady slope is less than that on sunny slope, and the soil is relatively wet, which is conducive to cypress renewal (Yu et al. 2013). Therefore, in the investigated forest, slope direction has become the dominant factor of NR of cypress in semi-arid areas.

The influence mechanism of gap area effect on cypress regeneration – *Utjecaj mehanizma površine otvora na prirodnu obnovu obične azijske tuje*

In addition, the number of regeneration seedlings was also affected by gap area (Figure7), and the larger gap area was favorable for cypress regeneration. This phenomenon is not difficult to understand for sun-loving cypress seedlings, where the forest gap areas create more abundant light conditions. Next, when they grow up gradually, the influence of gap area becomes smaller due to entering the stable growth period. Therefore, the correlation between the number of cypress seedlings and gap area decreased with the height (grade). Generally, the factor of light was first changed by the formation of forest gap. the relatively large density of plantation results in insufficient light in the forest and a slow NR process. Therefore, with the increase of the gap area, the understory plants get more illumination time, more comprehensive light quality, and more physiologically effective radiation (Chen et al. 2018). Also, the distribution pattern of ambient temperature, humidity, and water resources around the understory plants (including cypress seedlings) also changed. Finally, the purpose of promoting cypress renewal was achieved. In short, in the investigated forest,the larger area of the forest gap, the better lighting conditions in the forest gap, more conducive to the regeneration of cypress seedlings.

Conclusion and prospective – *Zaključak i perspektiva*

In the investigated forest, compared with other tree species, the density and frequency of cypress regeneration seedlings are larger. The height distribution of cypress regeneration seedlings is mainly grade I seedlings, and there are few grade II, III, and IV regeneration seedlings. Thus, in future research, how to improve the survival rate of Grades II, III, and IV cypress regeneration seedlings could be studied.

In this study, the progress of cypress seedlings regeneration naturally was affected by stand factors and environmental factors. Especially, in stand factors, high density of herb was unfavorable to cypress regeneration while high moss coverage was contrary; in environmental factors, soil stone content, slope direction, and forest gap area were important environmental factors for promoting cypress regeneration. In the future management of cypress plantations, stand factors and environmental factors should be paid more attention to improve the regeneration of seedlings. For example, in the cypress seedling stage to properly loosen the soil, mix gravel particles or coarse materials into the soil to increase soil porosity, water permeability, and air permeability, timely watering and combing the grass to improve the light transmittance. In addition, the indexes of ground diameter and growth height of cypress regeneration seedlings are also related to the quality of regeneration status. Therefore, in the future research, the research on the ground diameter and growth index of cypress regeneration seedlings should be supplemented.

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Conflict of interest – *Sukob interesa*

The authors declare that they have no competing interests.

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SAŽETAK

Obična azijska tuja (*Platycladus orientalis* (L.) Franco) je jedno od važnih zimzelenih stabala za pošumljavanje u neplodnim planinama, za konsolidaciju tla i očuvanje vode, ali prirodna regeneracija obične azijske tuje je složena i spora. Razumijevanje mehanizma utjecaja na prirodnu regeneraciju obične azijske tuje bitno je za poticanje preživljavanja i regeneraciju. Cilj ovog istraživanja je objasniti odnos između šumskih sastojina, okolišnih čimbenika i regeneracije nasada obične azijske tuje. Ukupno 42 uzorka čempresa u Guilinu, Kina, odabrane su za procjenu utjecaja različitih čimbenika sastojine i okolišnih čimbenika na regeneraciju čempresa korištenjem statistike ankete i korelacijske analize Pearson i Spearmanrank. U ovoj studiji, obična azijska tuja ima najveću učestalost i gustoću regeneracije među svim sadnicama (18) u istraživanoj šumi, ali je visinska struktura sadnica obične azijske tuje raspoređena neravnomjerno, a radi se uglavnom o sadnicama I klase (visina < 30 cm). Bilje niske gustoće i malčiranje mahovine velike gustoće, imali su izravan pozitivan učinak na broj sadnica za regeneraciju obične azijske tuje. Veći sadržaj kamena u tlu i opustošenih površina mogu potaknuti regeneraciju obične azijske tuje, ali je to prikladnije za obične azijske tuje u fazi sadnice. Zaključno, pravodobno plijevljenje korova, pravilno rahljenje tla i poboljšanje propusnosti svjetla mogli bi potaknuti regeneraciju obične azijske tuje.

KLJUČNE RIJEČI: obična azijska tuja; čimbenik sastojina; čimbenik okoliša; prirodna regeneracija.