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Effects of different forest practices on *Pinus tabulaeformis* population dynamics and species diversity in the Huanglongshan forest region

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Abstract Three *Pinus tabulaeformis* populations which experienced tending, shelterwood cutting, and closed tending were separately investigated to study the effects of these three forest practices on the age structures, static life tables, survivorship curves, and species diversities of *P. tabulaeformis* populations in Huanglongshan Mountain. Time sequence model was adopted to predict the dynamic population numbers of different *P. tabulaeformis* populations with different forest practices. The results revealed that the three populations are essentially identical in population structure, their young and old individuals make up a small proportion and their mid-aged individuals make up a large proportion and consequentially *P. tabulaeformis* populations generally stand stable. In the *P. tabulaeformis* communities with three tending practices, the highest species abundance index appears with tending and shelterwood cutting and the highest evenness index and species diversity appears with closed tending. The *P. tabulaeformis* populations with tending and shelterwood cutting practices belong to one developmental type and the *P. tabulaeformis* populations with closed tending practices belong to a stable type. It indicated that in the future, closed tending as the major practice and tending and shelterwood cutting as the supporting practices should be applied for *P. tabulaeformis* populations in

Huanglongshan Mountain so that the communities will develop continuously.

Keywords age structure, life table, survivorship curve, time sequence, species diversity

1 Introduction

The critical problem of natural forest protection is to fully play the natural recovery potential of natural forest, consider the human cultivation, promote recovery, and the natural recovery potential as a whole in order to make the forestry community more diverse and yet be in harmony. The plant population dynamics is the common result of the individual's living ability and the effect of the environmental condition. Research on age structures, survivorship curves, and life tables has important meaning to discover the future development tendency because it not only reflects the population's reality, but also shows the result of the population's adaptation to the environment (Crawley, 1986; Fuchsa et al., 2000; Manuel and Molles, 2002).

Pinus tabulaeformis is the most widely distributed community in northern China's temperate coniferous forest and one of the main zonal forest trees of the Huanglongshan forest region (Zhou and Luo, 1995). *P. tabulaeformis* has good natural regeneration in southern Loess Plateau, it is very important to improve the local environment and maintain the biodiversity. For many years, a lot of measures such as cutting-ban, tending, and gradual cutting had been practiced in order to promote the recovery of the natural forest and to improve the forest quality. But whether the measures can produce the expected results will influence the policy making of natural forest protection and degraded forest recovery in the future.

The previous research on *P. tabulaeformis* mainly focused on population dynamics, disease and pest control, seed plantation, and growth characteristics (Wang, 1996; Han and Jia, 2001; Yang, 2003; Hou et al., 2005); however, there

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are so far few reports on the influence of different tending measures on the population dynamics and biodiversity. Through analyzing the influence of different tending measures on the population dynamics and biodiversity, this research showed the effects of different measures, provided basis for establishing a stable and harmonious forest management system and meanwhile provide references for natural forest protection and recovery of the same conditions in north and northwest of China.

The Huanglongshan forest region lies in northern Shaanxi province in southeast Loess Plateau, it is adjacent the Yellow River, 60 km long from north to south, 50 km from east to west, the total area is 1,941.74 km². This area is a transition region of warm temperate from semi-humid to semi-arid. The latitude is 1,000–1,300 m, annual average temperature is 8.6°C with the highest 36.7°C and lowest –22.5°C, annual precipitation 611.8 mm, soil is brown soil. Local vegetations are warm-temperate deciduous broad-leaved forest plants, which are mainly *P. tabulaeformis*, *Quercus liaotungensis* Koidz, *Betula platyphylla*, *Populus davidiana*, *Hippophae rhamnoides*, and *Prunus davidiana* (Zhang, 1986).

From 1960s to 1970s, measures such as tending, shelterwood cutting, and closed tending were implemented in the Huanglongshan forest region and there are different effects under various measures. This research chose the natural forests which had similar environmental conditions and had been tended, inter-felt, and closely tended, see Table 1 for the specific contents.

2 Research methods

2.1 Sample plots investigation

After enough investigation of the *P. tabulaeformis* forests under the three different practices, 15 sample plots (5 quadrates in every practice) were chosen in the middle-lower part of the sunny slope with similar conditions. Three 5 m × 5 m shrub quadrates and three 1 m × 1 m herb quadrates were set by the cater-corner line in each plot. The specific contents are as follows: 1) Habitat conditions: topography, landform, human disturbances, soil, meteorology, slope direction, and

position. 2) *P. tabulaeformis* community characters: structure, height, coverage, the methods refers to Dong et al. (1996). 3) Tree species location: taking one border of the plot as *x*-axis, the vertical border as *y*-axis to establish Cartesian coordinates, recording coordinate value, diameter at breast height (DBH) (base diameter for the seedlings), tree height, and crown diameter. 4) Determining the age of *P. tabulaeformis*: using the number of the branch rings as the age for the trees that DBH < 6 cm, for the ones that DBH > 6 cm, six standard trees were chosen to measure the DBH and growth ring then get the age of the other individual trees according to the relation between DBH and age.

2.2 Age distribution

Let 10 years classify one age class, 1–10 year as I age class, 11–20 years as II age class and so on. Record the number of trees in each age class then calculate the total number of every species in the same age class under the same tending practice to get the basic age structure data of every population. Take age class as *x*-axis and the number of trees per hectare as *y*-axis to make the age structure graph (Crawley, 1986; Jiang, 1992).

2.3 Static life table and survivorship curve

Compile static life table according to the age structure data of *P. tabulaeformis* population in the sample plots in which different practices were applied. For detailed methods refer to Crawley (1986), Jiang (1992), Zhou et al. (1992), and Zheng et al. (1997).

2.4 Time sequence prediction model of population dynamics

$$M_t^{(1)} = M_{t-1}^{(1)} + \frac{Xt - X(t-n)}{n}$$

where $M_t^{(1)}$, called the dynamic average of n^{th} cycle, is the average value in t moment of n observations. This paper took the tree numbers of every age class as n value and t is 20, 40, and 60 years to predict the future population development tendency, see Xie (1990) for the principle and method.

Table 1 The tending practices of *Pinus tabulaeformis* forests in Huanglongshan forest region

Type of practices	Methods
Tending	Also called select tending, the purpose is to cut part of the trees in order to create good living condition for the rest of the trees. The main practices are to cut trees in the high-density area and to cut the poor trees so as to make the forest distribute evenly, adjust the forest structure, meanwhile cut the poor objective species when the density is too high. The tending strength normally is 15%–30%. The canopy density of plantation after cutting should not lower than 0.6 and natural forest not lower than 0.5
Shelterwood cutting	Cut all the mature forests in two or more than two times in a longer period (not more than an age class for example 10 to 20 years). The cutting objects are fixed according to the tree species and age, first cut the mature trees, post-mature trees, withered standing trees and leave part of the mature trees which could become in a bigger diameter class and the middle-aged trees. The cutting strength should not lower than 0.5
Closed tending	To the secondary forests in ridges and steep slopes, which have important protection functions but with low productivity, forbidding cutting is the main practice. Cutting, grazing and reclamation are forbidden in the period

2.5 Diversity index

Using the data, calculate the coverage, abundance, frequency, and importance value (IV) of the different species in each sample plot, then calculate the average IV of each species to divide the community to different layers. Calculate α diversity index, richness index S , diversity index (Simpson index D , Shannon-Wiener index H'), evenness index (Pielou index J_sW ; Alatalo index E_a). See (Jiang and Ma, 1997; Shi et al., 1998; Lei, 1999) for the methods.

3 Results and analysis

3.1 Influence on *P. tabulaeformis* age structure of different tending practices

Population age structure analysis is one of the main methods to discover the population's living status and update strategy (Zhang, 1991). As we can see from Fig. 1, the age structures under different tending practices were very similar, there were only a few young and old trees but a lot of middle-aged trees. Since *P. tabulaeformis* is a light-demanding species, the young seedlings have great difficulty in growing under heavy shade, but seedlings will develop quickly and enter the main layer when there is a forest gap. Thus, it can be concluded that the *P. tabulaeformis* community is in stable status. The age structures had their own features under different tending practices. The biggest density of *P. tabulaeformis* is in the III and IV age classes after shelterwood cutting, this is because in order to get wood with a big diameter, shelterwood cutting leaves quite a number of middle-aged and pre-mature woods. The biggest density is in the V class with tending practice because tending focuses on the high density young stand, middle-aged stand, and pre-mature stand, while there was no cutting of the mature trees. The tree numbers changed a little in the III, IV, and V class after closed tending, this is because under natural conditions when there is no human disturbance, the community adjusts population density mainly by self-thinning, which is far less than the human's cutting in terms of strength so it does not influence the density of *P. tabulaeformis* significantly. The number of seedlings in the I

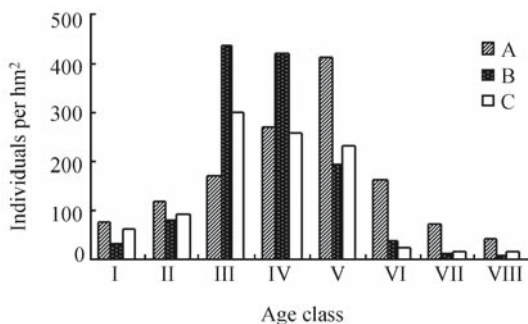


Fig. 1 The age structures of the *P. tabulaeformis* populations with different tending practices
A. Tending; B. Shelterwood cutting; C. Closed tending

and II age classes was quite low especially under inter-feeling. Thus, for future management, besides pursuing economic benefits and cultivating big diameter trees, the population density should be considered as well. In order to improve the population, the coverage stand that has a very high canopy should be adjusted in time to create a beneficial condition for the seedlings to update and grow.

3.2 *P. tabulaeformis* life table and survivorship curve under different cultivation practices

3.2.1 *P. tabulaeformis* life table with different tending practices

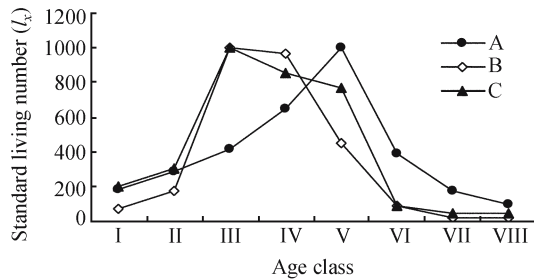
Set 10 years as one age class, calculate the standard number of survivors (l_x), number of deaths (d_x), longevity (T_x), disappearance rate (k_x), and periodical longevity (L_x), to get the *P. tabulaeformis* population's standard life tables with different tending practices (Table 2). As we can see from Table 2, the oldest age for compiling the life table of *P. tabulaeformis* population is 80 years, the age of the highest death rate was different with different tending practices. The death rate in II, IV, and V age classes is higher under closed tending; higher in the IV, V age class under shelterwood cutting, and higher in the IV, V, VI age class under tending. The peaks of expected longevity of different populations all appear in the I and II age classes. The expected longevity (e_x) reflects the individual's average living ability; the average expected longevity reached its highest before the IV age class, which indicated that the living quality of the population is better in this period, when physiological activity is the strongest. The e_x reduced with the increase of the age class, which indicated that the competition among the individuals became stronger but the productivity became lower as the individuals grew and the density increased. The standard life tables of *P. tabulaeformis* with different tending practices is the average value of the three different tending practices; it reflects the basic principles of the *P. tabulaeformis* in the Huanglongshan forest region and it shows that tending and shelterwood cutting are beneficial to the natural regeneration and the individual's growth in the *P. tabulaeformis* population.

3.2.2 Survivorship curves of *P. tabulaeformis* populations with different tending practices

Take the living number (l_x) in the life tables of *P. tabulaeformis* populations with different tending practices as the y-axis and age class as the x-axis. Make the *P. tabulaeformis* population survivorship curves (Fig. 2). As we can see from Fig. 2, if we take the biggest standard living number as the starting point, different survivorship curves of *P. tabulaeformis* populations with different tending practices were close to Deevy III type (Zhang and Shangguan, 1992). Meanwhile, it showed that the *P. tabulaeformis* populations were divided at the point where the death rate was at its peak. But basically

Table 2 The life table of the *P. tabulaeformis* populations with different tending practices

Management type	Age stage	a_x	l_x	d_x	q_x	L_x	T_x	e_x	$\ln a_x$	$\ln l_x$	K_x
Tending	I	75.10	180.26	-103.87	-576.23	232.19	3040.92	16.87	4.32	5.19	-0.46
	II	118.38	284.13	-127.51	-448.79	347.88	2855.54	10.05	4.77	5.65	-0.37
	III	171.50	411.64	-233.72	-567.78	528.50	2507.65	6.09	5.14	6.02	-0.45
	IV	268.88	645.36	-354.64	-549.51	822.68	1979.15	3.07	5.59	6.47	-0.44
	V	416.63	1000.0	611.16	611.16	694.42	1156.47	1.16	6.03	6.91	0.94
	VI	162.0	388.84	214.82	552.47	281.43	462.05	1.19	5.09	5.96	0.80
	VII	72.50	174.02	80.41	462.07	133.81	180.62	1.04	4.28	5.16	0.62
	VIII	39.0	93.61	0	0	46.80	46.8	0.50	3.66	5.54	0
Shelterwood cutting	I	29.70	68.37	-108.61	-1588.59	122.67	2725.53	39.87	3.39	4.22	-0.95
	II	76.88	176.98	-823.02	-4650.47	588.49	2623.12	14.82	3.85	5.18	-1.73
	III	434.38	1000.00	28.79	28.79	985.61	2044.10	2.04	6.07	6.91	0.03
	IV	421.88	971.22	525.17	540.74	708.63	1058.49	1.09	6.04	6.88	0.78
	V	193.75	446.04	359.71	806.45	266.18	349.87	0.78	5.27	6.10	1.64
	VI	37.50	86.33	64.75	750.00	53.96	83.68	0.97	3.62	4.46	1.39
	VII	9.38	21.58	2.65	122.67	20.26	29.73	1.38	2.24	3.07	0.13
	VIII	8.23	18.94	0	0	9.47	9.47	0.50	2.11	2.94	0
Closed tending	I	59.40	198.0	-104.08	-525.67	250.04	3130.25	15.81	4.08	5.29	-0.42
	II	90.63	302.08	-697.92	-2310.34	651.04	2921.88	9.67	4.51	5.71	-1.20
	III	300.0	1000.0	145.83	145.83	927.08	2291.67	2.29	5.70	6.91	0.16
	IV	256.25	854.17	83.33	97.56	812.50	1364.58	1.60	5.55	6.75	0.10
	V	231.25	770.83	678.50	891.89	427.08	552.08	0.72	5.44	6.65	2.22
	VI	25.00	83.33	41.67	500.0	62.50	125.0	1.50	3.22	4.42	0.69
	VII	12.50	41.67	0	0	41.67	62.50	1.50	2.53	3.73	0
	VIII	12.50	41.67	0	0	20.83	20.83	0.50	2.53	3.73	0

**Fig. 2** Survivorship curves of the *P. tabulaeformis* populations with different tending practices

A. Tending; B. Shelterwood cutting; C. Closed tending

with the same tendency, the lack of young trees was the characteristic of inferior regeneration. There were individuals in the VIII age class, which indicated that the *P. tabulaeformis* populations had a long reproduction period. If these biological characteristics can be fully used, the recovery of the *P. tabulaeformis* populations will have large potential.

3.3 Time sequence prediction of quantity dynamics of *P. tabulaeformis* populations with different tending practices

Based on the data of the number of trees in every age class of *P. tabulaeformis* populations with different tending practices in the Huanglongshan forest area, predict the tree numbers in every age class in the next 20, 40, and 60 years and make the relationship figure of age and tree numbers (Fig. 3). From Fig. 3, the peak of the number of trees in each age class differs with the time sequence in the forecast of all the three tending

practices. The number of individuals continued to reduce in the middle-aged classes, while the number of individuals increased first and reduced gradually in the old-aged classes with time. It showed that the tree numbers in the young-aged classes are less than enough to maintain the long-term stability of the population, but tree density was too high in the middle-aged classes. So there should be cutting activities in those areas to reduce the stand density and coverage and create beneficial conditions for the young seedlings, giving a stable increase in the number of young trees for long-term stable development.

3.4 Biodiversity index with different tending practices

Species diversity is an important index to show the ecological function and stability of the community. See the changing tendency of the biodiversity index (Table 3) and analysis of significance (Table 4) of the *P. tabulaeformis* populations with different tending practices. The influence of different tending practices on species diversity can be seen from Table 3: 1) The richness index was significantly different among the three tending practices: tending > shelterwood cutting > closed tending. Since the shrubs had been cut and cleaned during the tending and shelterwood cutting, the bare land in the forest and the forest gaps provide proper environmental conditions for the growth of plants. In the limited space, all kinds of plants continue to grow and have competition for sunlight, water, soil nutrition, and living space, the species increased and the population is in the progressive period. Since there was no strong extra disturbance of the closed

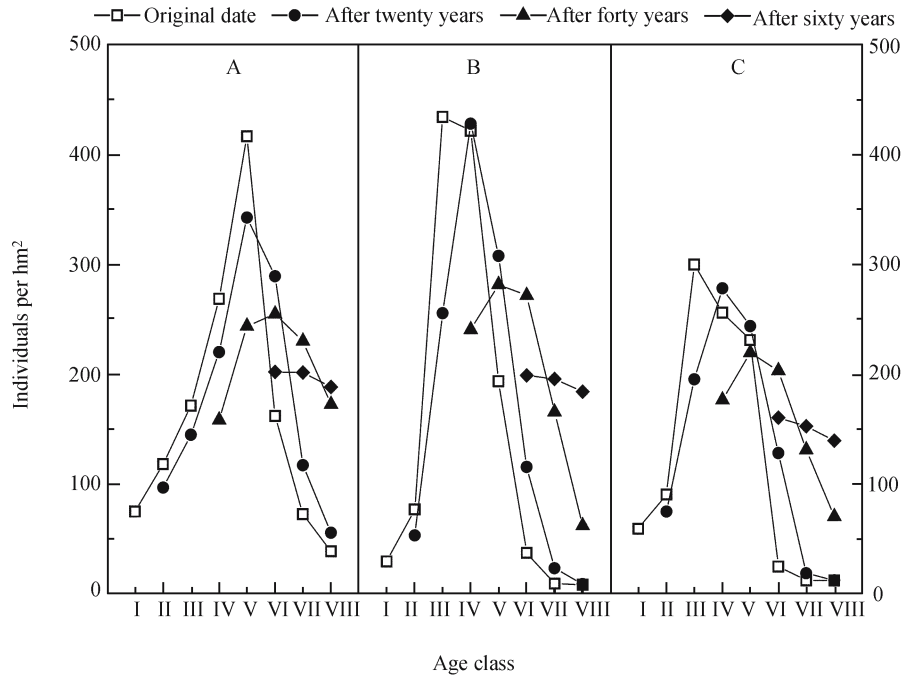


Fig. 3 Predicted number of the *P. tabulaeformis* populations with different tending practices
 A. Tending; B. Shelterwood cutting; C. Closed tending

Table 3 The diversity index of *P. tabulaeformis* communities with different tending practices

Forest layer	Diversity index	Closed tending	Shelterwood cutting	Tending
Herb layer	Richness (<i>S</i>)	20	23	25
	Simpson (<i>D</i>)	0.42	0.64	0.94
	Shannon-winner (<i>H'</i>)	0.98	1.63	3.21
	Pielou (<i>J_sW</i>)	0.33	0.50	0.84
	Alatalo (<i>E_a</i>)	0.43	0.44	0.64
Shrub layer	Richness (<i>S</i>)	32	36	46
	Simpson (<i>D</i>)	0.91	0.90	0.56
	Shannon-winner (<i>H'</i>)	2.81	2.79	1.35
	Pielou (<i>J_sW</i>)	0.81	0.74	0.42
	Alatalo (<i>E_a</i>)	0.64	0.60	0.43
Arbor layer	Richness (<i>S</i>)	7	8	9
	Simpson (<i>D</i>)	0.52	0.18	0.43
	Shannon-winner (<i>H'</i>)	1.01	0.44	0.95
	Pielou (<i>J_sW</i>)	0.52	0.24	0.43
	Alatalo (<i>E_a</i>)	0.61	0.41	0.47

Table 4 Significance test of diversity in *P. tabulaeformis* community with different tending practices

Tending practices	<i>t</i> value				
	<i>S</i>	<i>D</i>	<i>H'</i>	<i>J_w</i>	<i>E_a</i>
Tending-Shelterwood cutting	1.522	0.314	0.245	2.504	1.781
Tending-Closed tending	1.941	3.406*	2.210	3.378*	-3.592*
Shelterwood cutting-Closed tending	3.024*	-2.866*	5.670**	-4.615**	-9.105**

Note: The degree of freedom *df* = 4; $T_{0.05} = 2.776$, $T_{0.01} = 4.604$; * means that the difference is significant, ** means that the difference is extremely significant.

tending populations, the succession tendency of the species was relatively mild and in a more stable status. With the death of the transitional species, the species richness became reduced and the dominant species started to dominate the community. 2) The species diversity indexes and evenness index were significantly different among the three tending practices: closed tending > tending > shelterwood cutting. Tending and shelterwood cutting had strong disturbance on the community leading to the community being distributed unevenly, in forest gap showing clumped distribution, and in the high coverage area showing discrete distribution. The dominant species in closed tending areas were in the top period of the succession. When there was no human disturbance, the community is relatively stable so the species showed random distribution and the evenness index was high.

Different tending practices all had influences on species composition, structure and function, so the species diversity including richness, evenness, and diversity were also different. As we can see from Table 4, there was no difference in species diversity index between tending and shelterwood cutting practices; the differences were mostly significant between tending, shelterwood cutting, and the closed tending population. It showed that tending and shelterwood cutting had great influence on species diversity in *P. tabulaeformis* communities, species stability reduced, species succession and regeneration speed increased and the community was in an unstable status; the *P. tabulaeformis* populations with closed tending were stable and their species diversity had no significant change.

4 Discussion

The survivorship curves of *P. tabulaeformis* in Huanglongshan were close to the Deevey III type but were not fully consistent to the Deevey III type if the I and II age classes were included. The reason is because there were only a few young individuals and a lot of old individuals. It indicated the lack of young seedlings in the area (Zhang, 1998; Zhang et al., 2004). The Time order prediction of *P. tabulaeformis* populations indicated that the number of old individuals increased first and reduced gradually in three *P. tabulaeformis* populations, and the lack of young trees to fulfill the population was the common characteristic. For the natural *P. tabulaeformis* population in which the reproduction depends on seed, the regeneration is not a problem if there is enough seed production. In fact, the natural regeneration of *P. tabulaeformis* is very good, if there is a forest gap, the young seedlings will grow, so the long-term stability and maintenance should not be a problem. Not only the age distribution and the characteristics of the life table, but also the population's biological characteristics and the site conditions should be considered when analyzing one population, otherwise the conclusion will be far from reality.

P. tabulaeformis is a sunlight-loving species, it can tolerate drought and infertility, and an acidic soil. Only a very small number of *P. tabulaeformis* need shading in the early growth period, it needs enough sunlight, water, and soil nutrition. The soil and climate condition in the Huanglongshan area can satisfy *P. tabulaeformis* growth. In future forest management, we should focus on adjusting the relationship among different ecological factors and have a sustainable development for the population. We could adopt the "close-to-natural forest" management theory, through cultivating the object trees in order to improve the forest quality and economic value; through shelterwood cutting to create small forest gaps to create better conditions for the young seedlings to grow; through cutting disturbance trees to provide more sunlight thus inducing the mature trees to have more seeds; in the abundant harvest year, harvest seeds in the most proper time, establish plantations, and expand artificial populations.

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