Spatial Distribution Pattern of Longhorn Beetle Assemblages (Coleoptera: Cerambycidae) in Mongolian Oak (*Quercus Mongolica*) Forests in Changbai Mountain, Jilin Province, China

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Keywords: longhorn beetles, topographic condition, vertical height, Mongolian oak forest, Changbai Mountain

Posted Date: August 17th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-795304/v1>

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Abstract

Background: Mongolian oak forest is a deciduous secondary forest with a large distribution area in the Changbai Mountain area. The majority of longhorn beetle species feed on forest resources, The number of some species is also large, which has a potential risk for forest health, and have even caused serious damage to forests. Clarifying the distribution pattern of longhorn beetles in Mongolian oak forests is of great scientific value for the monitoring and control of some pest populations.

Methods: 2018 and 2020, flying interception traps were used to continuously collect longhorn samples from the canopy and bottom of the ridge, southern slope, and northern slope of the oak forest in Changbai Mountain, and the effects of topographic conditions on the spatial distribution pattern of longhorn beetles were analyzed.

Results: A total of 4090 individuals, 56 species, and 6 subfamilies of longhorn beetles were collected in two years. The number of species and individuals of Cerambycinae and Lamiinae were the highest, and the number of *Massicus raddei* (Blessig), *Moechotypa diphysis* (Pascoe), *Mesosa myopsmyops* (Dalman), and *Prionus insularis* Motschulsky was relatively abundant. Topographic conditions did not affect the vertical distribution of richness and abundance of longhorn beetles in the forest, but topographic conditions and vertical height independently affected the composition and quantity of the beetle assemblages. The community composition of longhorn beetles in the forest bottom and canopy was significantly different, and the richness and abundance were higher in the canopy under good light conditions. Cerambycinae and Lamiinae preferred to be active in the canopy, Prioninae preferred to be active in the forest bottom, and Lepturinae did not show any difference in the bottom and the canopy.

Conclusions: The composition of the longhorn beetle community on the ridge was significantly different from that on the southern slope and the northern slope, and the richness and abundance on the ridge and the southern slope were higher than those on the northern slope. Different species had different preferences for topographical conditions and vertical height, which indicated the adaptability of longhorn beetles in the forest.

Introduction

The longhorn beetles (Cerambycidae) are a large group in Coleoptera, with 35,000 known species worldwide (Svacha and Lawrence 2014). Longhorn beetles are widely distributed in the forest and feed on tree branches and trunks. A few species can cause serious harm to trees (Ji et al. 2002). Some species feed on dead and decayed wood and are important decomposers and important ecological factors in the process of tree decay (Linsley 1961; Speight 1989; Alexander 2008). After the trees in the forest die, some longhorn beetles move in quickly and play an important role in accelerating the decomposition of dead and decaying wood (Buse et al. 2008, Ulyshen 2016). They play an important role in promoting forest ecosystem material circulation and forest regeneration (Sirami et al. 2008; Wende et al. 2017; Hammond et al. 2017). Some species have the habit of visiting flowers and are important pollinators and media for the survival and reproduction of plants (Gao et al. 2005; Guo et al. 2012; Meng et al. 2013). At the same time,

some species are sensitive to environmental changes and can be used as biological indicator species (Karpiński et al. 2021).

Longhorn beetles are herbivorous insects, and vegetation type affects the composition and diversity of longhorn assemblages (Noguera et al. 2002; Gao et al. 2014; Wang et al. 2016). Most species of longhorn beetles strongly correlate with forest type (Yotkham et al. 2021). Forests are important habitats for longhorn beetles. Forest composition, forest management, forest fire, environmental change, and spatial heterogeneity all affect the distribution of longhorn beetle diversity (Toledo et al. 2002; Ohsawa 2004; Elliott et al. 2019). Stand type, stand age, composition, sectional area, diameter at breast height (DBH), and dead wood affect the richness and abundance of longhorn beetles (Grove 2002; Saint-Germain et al. 2006; McGeoch et al. 2007; Boucher et al. 2012; Lassauce et al. 2013; Boulanger et al. 2013). The host specificity affected the longhorn beetle community assemblage (Luo et al. 2021). Stands with complex tree species composition and structure and a large variation in diameter class or age structure can provide more diversified food resources for longhorn beetles (Buongiorno 1994), and some species prefer to live in stands with large DBH (Casula et al. 2021). The richness of longhorn beetles is positively correlated with the number of tree species, and the abundance is positively correlated with the number of trees. The richness and abundance of longhorn beetles are relatively high in natural forests (Meng et al. 2013).

With the improvement of survey methods in recent decades, some researchers have begun to realize that the forest canopy is an important habitat for insects, and some in-depth studies have been conducted (Kato et al. 1995; Su et al. 2001; Ulyshen et al. 2007, 2010; Sugimoto and Togashi 2013; Schmeelk et al. 2016). The canopy is an important habitat for the distribution of longhorn beetles due to sufficient light, which can provide different community structures and environmental conditions relative to the lower layer (Weiss et al. 2016; Miller et al. 2020). The diversity and richness of longhorn beetles increased with the increase in vertical height, but the abundance of longhorn beetles did not differ significantly in the area higher than 5 m above the ground in the forest (Ulyshen et al., 2019). Longhorn beetles have a certain distribution pattern in the forest and a high diversity in the canopy (Vance et al. 2003; Engelken and Mccullough 2020). Longhorn beetles are more inclined to the forest bottom of some forests with low plant diversity (Ulyshen 2011). However, this distribution pattern will also change with time and changes in the external and internal environmental conditions (Lee et al. 2014).

The application of flying interception traps can collect specimens throughout the day during the whole active period of longhorn beetles, greatly improving the collection efficiency and promoting the in-depth study of longhorn beetle communities in the forest (Hanks 2012; Lamarre et al. 2012; Rassati et al. 2020). Although more research results have been obtained on the distribution pattern of longhorn beetles in stands, there are still a few studies on the effect of topographic factors on the spatial distribution of longhorn beetles. *Quercus mongolica* forest is a natural secondary forest with the largest distribution area and growing stock volume in Jilin Province. However, the species composition, the vertical distribution pattern of longhorn beetles in the forest, and the effects of topographic factors such as ridges and different slope aspects on the distribution pattern of longhorn beetles are still unclear, which restricts the monitoring of longhorn beetle assemblages and major pests. In this study, longhorn beetles were collected

continuously throughout the active adult period to reveal the species distribution pattern and influential factors of longhorn beetle in a Mongolian oak forest. This study also provided a basis for the conservation of insect diversity, monitoring and control of the outbreak of dangerous longhorn beetles, exploration of the response of longhorn beetles to forest environmental changes, and the conservation and utilization of diversity of environmentally sensitive species. The main aims included: (1) determination of the species composition of longhorn beetles in the oak forest and (2) determination of the vertical distribution pattern of longhorn beetles in the oak forest and the effect of topographic condition on the vertical distribution of longhorn beetle assemblages.

Study area

The study area was located in Dashi Village, Jilin city, Jilin Province, with a geographical location of 126°51'34" E, 43°33'45" N. The vegetation belongs to the flora of Changbai Mountain, and the main stand type is natural secondary forest, i.e., Mongolian oak forest. The main tree groups taxa *Quercus mongolica* Fischer ex Ledebour, *Fraxinus rhynchophylla* Hance, *Acer mono* Maxim, *Tilia amurensis* Rupr. *Tilia mandshurica* Rup et Maxim., and *Armeniaca sibirica* L. The region has the following characteristics: a temperate continental monsoon climate, four distinct seasons, little rain, dry and windy in spring, warm and rainy in summer, cool in autumn, and cold and snowy in winter. The annual average temperature is 3–5°C; the lowest temperature can reach -35°C, and the highest is 38°C. The annual sunshine duration is 2400–2600 h, and the average annual precipitation is 700–800 mm, mostly concentrated from June to August. The first frost usually occurs in late September.

Materials And Methods

Sample setting

We selected one Mongolian oak forest stand of about 4 ha as the study stand. The average height of the stand was about 17 m, and the slope of the southern and northern slopes was about 22°. *Quercus mongolica* was the main tree species with a canopy density of about 0.7. We used RTK (GNSS I80) to locate the position and elevation of each tree and determined the tree species and DBH of each tree in the sample (Table 1).

Table 1 The tree species composition of plots on the ridge, southern slope, and northern slope

Positions	Tree species	DBH	Tree number		Stand basal area	
			Number	%	Area (cm ²)	%
On the ridge	<i>Quercus mongolica</i>	21.4	440	60.60	169744.9	72.17
	<i>Tilia amurensis</i>	15.8	93	12.81	20985	8.92
	<i>Acer mono</i>	11.0	76	10.47	8567.9	3.64
	<i>Fraxinus rhynchophylla</i>	14.5	47	6.47	8589.2	3.65
	<i>Pinus tabulaeformis</i>	28.6	22	3.03	16090.4	6.84
	<i>Betula dahurica</i>	20.0	19	2.62	6427.7	2.73
	<i>Sorbus alnifolia</i>	13.4	12	1.65	1810.6	0.77
	<i>Larix kaempferi</i>	14.0	6	0.83	1016.4	0.43
	Other trees	12.0	11	1.52	2010.7	0.85
	Total	16.7	726	100	235242.8	100
On the southern slope	<i>Quercus mongolica</i>	20.6	419	58.6	165975.9	79.94
	<i>Acer mono</i>	10.2	116	16.22	10254	4.94
	<i>Tilia amurensis</i>	12.3	72	10.07	10664.3	5.14
	<i>Fraxinus rhynchophylla</i>	10.9	52	7.27	6797.5	3.27
	<i>Tilia mandshurica</i>	13.2	15	2.1	2454	1.18
	<i>Pinus tabulaeformis</i>	24.9	14	1.96	8761	4.22
	<i>Ulmus davidiana</i>	8.6	13	1.82	820.9	0.40
	Other trees	15.7	14	1.96	1890	0.91
	Total	14.6	715	100	207617.6	100
On the northern slope	<i>Quercus mongolica</i>	22	144	27.70	58499.4	37.52
	<i>Tilia amurensis</i>	17.7	110	21.15	27022.3	17.34
	<i>Fraxinus rhynchophylla</i>	16.1	89	17.12	22592.8	14.50
	<i>Acer mono</i>	13.2	80	15.38	13817.1	8.87
	<i>Tilia mandshurica</i>	14.6	26	5	4971.5	3.19
	<i>Betula dahurica</i>	29.8	26	5	15090.1	9.68
	<i>Armeniaca sibirica</i>	15.6	9	1.73	2401.4	1.54
	<i>Sorbus alnifolia</i>	11.4	8	1.54	923.5	0.59

<i>Pinus tabulaeformis</i>	25.8	5	0.96	2708.2	1.74
<i>Betula platyphylla</i>	31.5	5	0.96	4097.1	2.63
Other trees	16.3	18	3.46	3734.3	2.40
Total	19.5	520	100	155857.7	100

Specimen collection

In the forest, 48 sample plots were set according to topographic conditions, and the distance between each plot was greater than 30 m. Flying interception traps were set in each canopy and bottom to collect longhorn beetle specimens, and no lure was placed in the trap. We use a rope to hang the traps on the branches of the canopy 13–15 m above the ground. The bottom traps were suspended between two trees by iron wire at a distance of more than 1 m from the trunk. The collection cups of the trap were about 30 cm from the ground. The cup was filled with saturated saline to prevent the specimen from decaying. A low amount of odorless detergent was added to reduce the surface tension of the water and facilitate the sinking of the specimen to the bottom of the cup. A total of 96 traps were set in the sample plot, i.e., 48 in the canopy (H), 48 in the bottom (L). Of the 96 traps, 32 were located on ridges (A), 32 were located on the southern slope (B), and 32 were located on the northern slope (C) in the forest (Table 2).

Table 2 Flying interception trap location information

Trap position	Ridge (A)	Southern slope (B)	Northern slope (C)
Canopy (H)	AH	BH	CH
Bottom (L)	AL	BL	CL

Specimen collection and preservation

In 2018 and 2020, traps were set up in the survey stands from May 15 to September 15 each year. The longhorn beetle specimens were collected every 2 weeks. In the case of rainy days, the collection time was extended. The collected specimen was put into the sample bag and transported to the laboratory. After each collection, the collection cup was filled with salt, water, and detergent. The specimens were made by needle insertion to facilitate long-term preservation in the laboratory. All of the insect specimens were preserved in the Insect Laboratory of the College of Forestry, Beihua University.

Data analysis

MANOVA was used to analyze the effect of topographic conditions on the vertical height distribution of the longhorn beetle's richness and abundance. The Friedman test was used to determine the difference in richness and abundance with respect to the topographic condition and vertical height. Estimates 9.1 software was used to calculate the rarefaction curve of the species distribution pattern under different topographic conditions and vertical heights (Solow and Roberts 2006; Colwell 2013). Finally, we performed non-metric multidimensional scaling to show differences in the composition of longhorn beetle

assemblages at the two vertical heights and along the three slopes by using PC-ORD (McCune and Mefford 2011). The autopilot mode of PC-ORD was used to conduct this analysis using the Bray–Curtis distance measure. This was followed by PerMANOVA to compare the community composition among the two vertical heights and along the ridge, southern slope, and northern slope.

Results

Longhorn beetle assemblage composition

A total of 4090 individuals, 56 species, and 6 subfamilies of longhorn beetles were collected in the natural Mongolian oak forest. There were 2199 individuals belonging to 22 species of Cerambycinae, 1154 individuals belonging to 20 species of Lamiinae, 41 individuals belonging to 11 species of Lepturinae, only one species belonging to Aseminae, Prioninae, and Disteniinae, and 689 individuals belonging to Prioninae. Of the 56 species of longhorn beetles, only *Massicus raddei* (Blessig), *Plagionotus pulcherpulcher* (Blessig), *Rhaphuma gracilipes* (Faldermann), *Mesosa myopsmyops* (Dalman), *Moechotypa diphysis* (Pascoe), and *Prionus insularis* Motschulsky accounted for more than 1% of the total. There were 43 species and 2119 individuals in the canopy (H) and 40 species and 1914 individuals in the bottom (L). There were 39 species and 1782 individuals on the ridge (A), 34 species and 1370 individuals on the southern slope (B), and 29 species and 938 individuals on the northern slope (C) (Table 3).

Table 3 Longhorn beetles assemblage composition

Subfamilies/Species	Canopy (H)	Bottom (L)	Ridge (A)	Southern slope(B)	Northern slope(C)	Total	%
Cerambycinae							
<i>Amarysius sanguinipennis</i> (Blessig)	1	0	0	0	1	1	0.02
<i>Anaglyptus colobotbeoides</i> (Bates)	9	4	1	7	5	13	0.33
<i>Chlorophorus motschulskyi</i> (Ganglbauer)	1	0	0	1	0	1	0.02
<i>Chlorophorus sexmaculatus</i> (Motschulsky)	1	0	0	0	1	1	0.02
<i>Chlorophorus sulcaticeps</i> Pic	2	2	2	2	0	4	0.10
<i>Chlorophorus tohokensis</i> Hayash	1	0	0	1	0	1	0.02
<i>Cyrtoclytus capracapa</i> (Germar)	8	18	7	10	9	26	0.65
<i>Massicus raddei</i> (Blessig)	990	643	785	549	299	1633	39.93
<i>Obrium obscuripenne</i> Pic	0	1	0	0	1	1	0.02
<i>Oupyrrhidium cinnabarium cinnabarium</i> (Blessig)	0	1	0	1	0	1	0.02
<i>Plagionotus pulcherpulcher</i> (Blessig)	154	91	106	105	34	245	5.99
<i>Purpuricenius sideriger</i> Fairmaire	1	0	1	0	0	1	0.02
<i>Rhaphuma acutivittis</i> (Kraatz)	1	3	2	0	2	4	0.10
<i>Rhaphuma gracilipes</i> (Faldermann)	85	103	52	77	59	188	4.60
<i>Rhopalopus speciosus</i> Plavilstshikov	1	0	1	0	0	1	0.02
<i>Trichoferus campestris</i> (Faldermann)	7	4	2	8	1	11	0.28
<i>Trichoferus guerrii</i> (Pic)	5	1	2	4	0	6	0.15
<i>Xylotrechus clarinus</i> Bates	4	3	3	0	4	7	0.18
<i>Xylotrechus cuneipennis cuneipennis</i> (Kraatz)	27	13	11	13	16	40	0.98
<i>Xylotrechus pyrrhoderus</i> Bates	0	2	2	0	0	2	0.05

<i>Xylotrechus rufilius</i> Bates	8	3	3	6	2	11	0.28
<i>Chloridolum sieversi</i> (Ganglbauer)	1	0	1	0	0	1	0.02
Lamiinae							
<i>Acalolepta fraudatrix</i> (Bates)	0	1	0	0	1	1	0.02
<i>Acanthocinus griseus</i> (Fabricius)	1	0	1	0	0	1	0.02
<i>Anoplophora glabripennis</i> Breuning	0	1	0	1	0	1	0.02
<i>Eumecocera impustulata</i> (Motschulsky)	1	3	2	1	1	4	0.10
<i>Eutetrappa metallescens</i> (Motschulsky)	0	5	4	0	1	5	0.12
<i>Exocentrus fisheri</i> Gressitt	6	0	1	4	1	6	0.15
<i>Lamiomimus gottschei</i> Kolbe	3	10	7	6	0	13	0.33
<i>Leiopus stillatus</i> (Bates)	2	1	3	0	0	3	0.07
<i>Menesia sulphuratasulphurata</i> (Gebler)	1	0	0	0	1	1	0.02
<i>Mesosa hirsute</i> Bates	4	0	0	4	0	4	0.10
<i>Mesosa myopsmyops</i> (Dalman)	264	110	135	173	66	374	9.14
<i>Moechotypa diphysis</i> (Pascoe)	456	241	258	323	116	697	17.04
<i>Monochamus guttulatus</i> (Gressitt)	5	1	5	0	1	6	0.15
<i>Neacanista tuberculipennis</i> Gressitt	31	1	16	11	5	32	0.79
<i>Oplosia suvorovi</i> (Pic)	1	0	0	0	1	1	0.02
<i>Pterolophia angusta</i> (Bates)	1	0	0	1	0	1	0.02
<i>Pterolophia rigida</i> (Bates)	0	1	1	0	0	1	0.02
<i>Rhopa loscelisunifasciatus</i> Blessig	0	1	1	0	0	1	0.02
<i>Ropica dorsalis</i> Schwarzer	1	0	1	0	0	1	0.02
<i>Egesina bifasciana</i> Matsushita	1	0	0	1	0	1	0.02

Lepturinae

<i>Anastrangalia sequensi</i> (Reitter)	2	8	7	3	0	10	0.24
<i>Anoplodera cyanea</i> (Gebler)	3	2	4	0	1	5	0.12
<i>Gaurotes ussuriensis</i> Blessig	1	2	1	2	0	3	0.07
<i>Leptura arcuata</i> Panzer	2	7	3	2	4	9	0.23
<i>Macroleptura thoracica</i> (Creutzer)	1	3	1	2	1	4	0.10
<i>Macropidonia ruficollis</i> (Pic)	0	1	0	1	0	1	0.02
<i>Pedostrangalia femoralis</i> (Motschulsky)	2	0	1	1	0	2	0.05
<i>Pidonia gibbicollis</i> (Blessig)	2	2	0	2	2	4	0.10
<i>Rhagium inquisitor japonicum</i> (Bates)	0	1	0	1	0	1	0.02
<i>Stictoleptura succedanea</i> (Lewis)	0	1	0	1	0	1	0.02
<i>Stictoleptura variicomis</i> (Dalman)	0	1	1	0	0	1	0.02
Aseminae							
<i>Arhopalus rusticus</i> (Linnaeus)	0	2	2	0	0	2	0.05
Prioninae							
<i>Prionus insularis</i> Motschulsky	75	614	344	44	301	689	16.85
Disteniinae							
<i>Distenia gracilis</i> (Blessig)	3	2	2	2	1	5	0.12
Total	2176	1914	1782	1370	938	4090	100

Among the 56 species, 16 species were distributed only in the canopy (H), 13 species were distributed only in the bottom (L), and 27 species were distributed in both positions, as shown in Figure 1a. Among the 17 species distributed on the ridge, the southern slope, and the northern slope, 11 species were distributed only on the ridge, 10 species were distributed only on the southern slope, and 6 species were distributed only on the northern slope, as shown in Figure 1b.

Species-abundance distribution with different vertical heights and slope directions

When the number of traps was low, there was no significant difference in the number of species between the canopy and the bottom. When the number of traps exceeded 10, the number of species in the canopy (H) was higher than that in the bottom (L). Under different topographic conditions, longhorn beetles

collected by the same number of traps had higher number of species on the ridge (A), followed by the southern slope (B) and the northern slope (C), as shown in Figure 2 (a, b).

The richness and abundance in the canopy and bottom

Two-factor ANOVA was carried out for species number and individual number of longhorn beetles between topographic conditions (A, B, C) and vertical heights (H, L). The results showed that the interaction between topographic conditions and vertical height had no significant influence on the richness and abundance of the longhorn beetles, but the topographic conditions had a significant influence on the richness and abundance, while vertical height had a significant influence on the number of species (Table 4).

Table 4 Repeated-measures MANOVA for topographic conditions and vertical height, and the interactive effects of number of species and number of individuals

Factors	<i>d.f.</i>	Individuals (N)		Species (S)	
		F	<i>P</i>	F	<i>P</i>
HL	1,94	0.46	0.499	5.069	0.027*
ABC	2,45	4.486	0.014*	3.962	0.022*
HL×ABC	2,45	0.865	0.424	0.246	0.782

With respect to the spatial vertical distribution, the richness and abundance of longhorn beetles in the canopy (H) were significantly higher than those in the bottom (L) ($Q_{1,94} = 6.737$; $p = 0.009$; $Q_{1,94} = 7.681$; $p = 0.006$). Among all the subfamilies, the numbers of species and individuals of Cerambycinae were the highest, and the richness and abundance in the canopy (H) were significantly higher than those in the bottom (L) ($Q_{1,94} = 11.308$; $p = 0.001$; $Q_{1,94} = 8.696$; $p = 0.003$). The numbers of species and individuals of Lamiinae were the highest, and the richness and abundance in the canopy (H) were significantly higher than those in the bottom (L) ($Q_{1,94} = 11.765$; $p = 0.01$; $Q_{1,94} = 16.200$; $p = 0.000$). There was no significant difference in the richness and abundance of Lepturinae in the canopy (H) and the bottom (L) ($Q_{1,94} = 1.800$; $p = 0.180$; $Q_{1,94} = 1.800$; $p = 0.180$) (Figure 3).

The richness and abundance of longhorn beetles on the ridge, southern slope, and northern slope

The richness of longhorn beetles on the ridge (A) and southern slope (B) was significantly higher than that on the northern slope (C) ($Q_{2,93} = 9.453$, $p = 0.009$), and the abundance on the ridge (A) was significantly higher than that on the northern slope (C) ($Q_{2,93} = 12.438$, $p = 0.002$) (Figure 2a). Among the major subfamilies, there was no significant difference in the richness of Cerambycinae on the ridge (A), southern slope (B), and northern slope (C) ($Q_{2,93} = 1.528$, $p = 0.446$), but the abundance was significantly higher on the ridge (A) and southern slope (B) than on the northern slope (C) ($Q_{2,93} = 9.276$, $p = 0.01$) (Figure 2b). The richness and abundance of Lamiinae on the ridge (A) and southern slope (B) were significantly higher than those on the northern slope (C) ($Q_{2,93} = 14.000$, $p = 0.001$; $Q_{2,93} = 6.397$, $p = 0.041$) (Figure 2c). The richness

and abundance of Lepturinae were not significantly different among the ridge (A), southern slope (B), and northern slope (C) ($Q_{2,93}=1.104, p=0.576$; $Q_{2,93}=1.114, p=0.564$) (Figure 2d).

Indicator species

With respect to vertical height, three longhorn beetles were significantly associated with traps placed in the canopy (H), and one species was significantly associated with the bottom (L). Among the three directions, *Massicus raddei* (Blessig) was significantly associated with the ridge (A), and *Mesosa myopsmyops* (Dalman) was significantly associated with the ridge and the southern slope (B). On the ridge (A), *Mesosa myopsmyops* (Dalman), *Moechotypa diphysis* (Pascoe), and *Neacanista tuberculipennis* Gressitt were significantly associated with the ridge canopy (AH), and *Prionus insularis* Motschulsky and *Lamiomimus gottschei* Kolbe were significantly associated with the ridge bottom (AL). On the southern slope (B), *Mesosa myopsmyops* (Dalman) and *Neacanista tuberculipennis* Gressitt were significantly associated with the southern canopy (BH), and *Prionus insularis* Motschulsky was significantly associated with the southern bottom (BL). Only *Mesosa myopsmyops* (Dalman) was significantly associated with the northern canopy (CH) on the northern slope (Table 5).

Table 5 Significant trap height associations based on indicator species analysis

Location combination	Spatial position	Species	IV	<i>p</i>	Number of individuals
H×L	H	<i>Mesosa myopsmyops</i> (Dalman)	66.2	0.0001	374
	H	<i>Neacanista tuberculipennis</i> Gressitt	32.3	0.0001	32
	H	<i>Plagionotus pulcherpulcher</i> (Blessig)	48.5	0.0187	245
	L	<i>Prionus insularis</i> Motschulsky	70.5	0.0002	689
A×B×C	A	<i>Massicus raddei</i> (Blessig)	48.1	0.0038	1633
	B	<i>Mesosa myopsmyops</i> (Dalman)	41.9	0.0265	374
A	AH	<i>Mesosa myopsmyops</i> (Dalman)	75.6	0.0002	374
	AH	<i>Moechotypa diphysis</i> (Pascoe)	77.5	0.0152	697
	AH	<i>Neacanista tuberculipennis</i> Gressitt	41.0	0.0170	32
	AL	<i>Prionus insularis</i> Motschulsky	76.3	0.0068	689
	AL	<i>Lamiomimus gottschei</i> Kolbe	37.5	0.0184	13
	AL				
B	BH	<i>Mesosa myopsmyops</i> (Dalman)	66.5	0.0398	374
	BH	<i>Neacanista tuberculipennis</i> Gressitt	37.5	0.0193	32
	BL	<i>Prionus insularis</i> Motschulsky	55.4	0.0497	689
C	CH	<i>Mesosa myopsmyops</i> (Dalman)	57.9	0.0485	374

Community composition

Non-metric multidimensional scaling yielded a two-dimensional solution with a final stress of 22.88. The R^2 values were 0.45 (axis 1) and 0.31 (axis 2). It was clear from the two-dimensional depiction of these results (based on axes 1 and 2) that the longhorn beetle assemblage sampled in the canopy (H) was compositionally distinct from that sampled at the bottom (L), and the beetle assemblage in the canopy (H) and at the bottom (L) of the three positions (A, B, C) differed (Figure 5).

The PerMANOVA results indicated that the longhorn beetle assemblage sampled in the canopy (H) was compositionally distinct from that at the lower level (L) ($t = 2.54$, $p = 0.0018$). There was a significant

difference in the assemblage composition on the three positions ($t = 2.47$, $p = 0.0014$); the ridge (A) was compositionally distinct from the southern slope B ($t = 1.810$, $p = 0.003$) and the northern slope (C) ($t = 1.723$, $p = 0.004$). There was a significant difference between the assemblage composition of traps placed in the ridge canopy (AH) and on the southern slope canopy (BH) ($t = 1.902$, $p = 0.003$), and on the southern slope canopy (BH) and on the northern slope canopy (CH) ($t = 1.426$, $p = 0.048$). Only on the ridge (A), beetle assemblages composition were different on the canopy (AH) from those on the bottom (AL) ($t = 2.157$, $p = 0.0006$) (Table 6).

Table 6 The PerMANOVA results of the beetle assemblage sampled at different positions

Sampling position	<i>df</i>	<i>t</i>	<i>p</i>
HL	1, 94	3.538	0.0018*
ABC	2, 93	2.468	0.0014*
A-B		1.810	0.003*
B-C		0.937	0.516
A-C		1.723	0.004*
ABCHL	5, 90	2.173	0.001*
AH-BH		1.902	0.003*
AH-CH		0.911	0.531
BH-CH		1.426	0.048*
AL-BL		1.031	0.378
AL-CL		0.938	0.836
BL-CL		1.291	0.091
AH-AL		2.157	0.0006*
BH-BL		0.906	0.602
CH-CL		1.178	0.203

Correspondence analysis of longhorn beetles and different positions

The individual number of 56 species of longhorn beetles from 6 subfamilies was square root transformed. Correspondence analysis was conducted between the canopy (H) and bottom (L) and the ridge (A), southern slope (B), and northern slope (C) for 6 subfamilies and 56 species of longhorn beetles, and the results are shown in Figure 6(a, b). In Figure 6 (a), the contribution rate of the first axis was 60.07%, and that of the second axis was 39.93%. The cumulative contribution rate was 100%, and the eigenvalue = 0.18. In Figure 6 (b), the contribution rate of the first axis was 39.08%, and that of the second axis was 17.36%. The cumulative contribution rate was 56.44%, and the eigenvalue = 0.36.

Among the six subfamilies, Lamiinae (*n*1), Lepturinae (*n*2), Disteniinae (*n*4), and Cerambycinae (*n*5) had a strong correlation with the slope direction of the ridge (A) and southern slope (B). Prioninae (*n*3) had a strong correlation with the ridge (A) and northern slope (C), while Aseminae (*n*6) had only one species collected from the ridge (A). In the bottom and canopy under different topographic conditions, only one species of Aseminae (*N*6) was collected from the bottom of the ridge (A), and only one species of Prioninae (*N*3) was closely related to the ridge bottom (AL) and northern slope bottom (CL). Lepturinae (*n*2) was closely related to the ridge bottom (AL), while Lamiinae (*n*1) and Cerambycinae (*n*5) were closely related to the ridge canopy (AH), southern slope canopy (BH), and northern slope (CH).

The majority of the 56 species of longhorn beetles were closely related to the ridge canopy (AH), southern slope canopy (BH), and northern slope (CH). Among the species with more individuals, *Mesosa myopsmyops* (Dalman) (11), *Moechotypa diphysis* (Pascoe) (12), *Massicus raddei* (Blessig) (41), and *Plagionotus pulcherpulcher* (Blessig) (44) were closely related to the ridge canopy (AH), southern slope canopy (BH), and northern slope (CH), while *Rhaphuma gracilipes* (Faldemann) (47) was closely related to the southern slope bottom (BL) and northern slope bottom (CL). *Prionus insularis* Motschulsky (32) was closely related to the ridge bottom (AL) and northern slope bottom (CL).

Discussion

Longhorn beetle community composition

In this study, 96 traps were used to continuously collect longhorn beetle specimens during the whole active period, and a large number of individuals were collected, totaling 4090, which exceeded the number of longhorn beetles collected in a broad-leaved Korean pine forest by Liu et al. (1525) and Li et al. (1303) (Liu et al. 2015; Li et al. 2016). Although no lure was used in the whole collection process, the number of species and individuals collected was relatively high, which indicated that the collection efficiency of longhorn beetles can be improved by setting traps in the canopy and the bottom simultaneously.

The stand composition is a comprehensive reflection of the forest succession process. In a forest with high spatial heterogeneity, more species requiring special habitats can survive (Buongiorno 1994; Utterra et al. 1996). The composition and diversity of stands affected the diversity and richness of longhorn beetles, and the richness of longhorn beetles in this study was lower than that in a broad-leaved Korean pine forest (Liu et al. 2015; Li et al. 2016). This was related to the relatively simple composition and structure of the Mongolian oak forest (Huang and Zhou 2003; Yang et al. 2015).

Among the 56 species of longhorn beetles, there were 50 species with individuals accounting for less than 1% of the total, accounting for 89.29% of the total species, which is consistent with the research of Hanks et al., in which the species with fewer individuals accounted for the majority (Hanks et al. 2012, 2013, 2014; Liu et al. 2015). *Massicus raddei* (Blessig), *Moechotypa diphysis* (Pascoe), *Prionus insularis* Motschulsky, *Mesosa myopsmyops* (Dalman), and *Plagionotus pulcherpulcher* (Blessig) were highly abundant, which are important saproxylic beetles and mainly feed on the decaying, dying, or dead wood of Mongolian oak. In particular, *Massicus raddei* (Blessig), which accounted for 39.93% of the total quantity,

has caused serious damage in the study area, and much of the larger-diameter *Quercus mongolica* has been invaded by *Massicus raddei* (Blessig). In this study, the species richness of Cerambycinae, Lamiinae, and Lepturinae was high, but the abundance of Lepturinae was low, which was related to the simple stand composition and few flowering plants in the oak forest (Gao et al. 2005).

Spatial distribution of the longhorn beetle community

Most longhorn beetles are herbivorous insects, and their diversity and richness are closely related to the diversity of plants (Wang et al. 2005; Noguera et al. 2017). In natural forests, the tree composition is a comprehensive reflection of the forest succession process. Topographic factors, such as slope aspect, affect the distribution pattern of longhorn beetles by influencing the composition and diversity of trees, light, temperature, humidity, and other microenvironments in the habitat (Peris-Felipo et al. 2011). In this study, topography and vertical height affected the distribution pattern of the richness, abundance, and community composition of longhorn beetles, but there was no interaction between topography and vertical distribution. The community composition of longhorn beetles on the ridge was significantly different from that on the southern slope and the northern slope. The richness and abundance of longhorn beetles were higher on the ridge and southern slope, which was related to the better light conditions on the ridge and southern slope and the larger DBH of the trees. The richness and abundance of longhorn beetles were higher in the stands with trees with a greater diameter (Haavik and Stephen 2010; Liu et al. 2015). This distribution pattern of longhorn beetles is also related to the fact that different plants at different locations in the forest can release different volatiles and attract different species of longhorn beetles (Dodds et al. 2010).

The spatial distribution pattern of insects in the forest is also the result of long-term adaptation of species to the environment (Matheron 1967; Graham et al. 2012). Light has an obvious effect on the activity of longhorn beetles. Many longhorn species are phototropic or prefer to move in the environment with sufficient light (Ji et al. 1991). In this study, the vertical distribution of longhorn beetles was not affected by topographic factors in the Mongolian oak forest, and the community composition of longhorn beetles was significantly different in the bottom and canopy of the oak forest, which is consistent with the results of Ulyshen's study (Ulyshen and Sheehan 2019). The richness and abundance of longhorn beetles in the forest canopy were higher than those at the bottom; the number in the canopy accounted for 76.79% of the total. This is mainly because the light and temperature of the canopy were more variable than those of the bottom, which can provide different community structures and environmental conditions from those of the bottom, and some dead branches in the canopy can provide an ideal habitat for some wood-eating longhorn beetles to feed and lay eggs, which can result in the survival of more beetles (Weiss et al. 2016, 2019; Ramos-Robles et al. 2020; Miller et al. 2020). A total of 11 species were collected only in the canopy, which is consistent with the distribution of some longhorn beetles only in the canopy (Engelken and Mccullough 2020). A total of 27 longhorn beetle species were distributed in both the canopy and the bottom, which is consistent with the study by Miller et al. in which most species were distributed at the bottom and in the canopy of the forest (Miller et al. 2020).

The species and subfamilies with different habits showed different distribution patterns in the canopy and bottom (Ulyshen et al. 2019), and different species were distributed in different parts of the forest (Li et al. 2017; Flaherty et al. 2019; Foit et al. 2019). In this study, *Massicus raddei* (Blessig), *Moechotypa diphysis* (Pascoe), and *Mesosa myopsmyops* (Dalman) preferred to be active in the canopy. The results for some indicator species support this view, which is related to the vertical distribution of larvae in the trunk (Yang et al. 2012). The richness and abundance of Cerambycinae and Lamiinae were higher in the canopy, and the indicator species of these subfamilies in the canopy also supported this view, which is similar to the distribution of these groups in previous studies (Rassati et al. 2019; Engelken and Mccullough 2020).

Although the canopy plays an important role in protecting the diversity of longhorn beetles, the bottom is also an important habitat for longhorn beetles, and some longhorn beetles have higher richness in the bottom of the forest (Vance et al. 2003). Some wood-eating longhorn beetle larvae prefer to live in specific locations in the trunk, while some species decrease with the height of the trunk, which is related to the habitat conditions such as different bark thicknesses that these locations can provide for longhorn beetles (Cadorette-Breton et al. 2016). In this study, *Prionus insularis* Motschulsky preferred to move at the bottom, and the emergence holes were more distributed on trunks with larger DBH near some bottom traps, and the spatial distribution showed a state of aggregation, indicating that the health status and DBH of trees affect the choice of a host of longhorn beetles (Li et al. 2016, 2018; Chen et al. 2018). Some studies have shown that the number of Lepturinae with the habit of visiting flowers is higher at the bottom (Rassati et al. 2019), but the same result was not found in this study, which may be due to the lack of flowering plants in the bottom layer of the Mongolian oak forest.

Conclusion

In the Mongolian oak forest of Changbai Mountain, the richness and abundance of longhorn beetles were significantly affected by topographic conditions. The richness and abundance of longhorn beetles were higher on the ridge and southern slope with higher light conditions, and the community composition on the ridges was significantly different from that on other slopes. There was a certain vertical distribution pattern of longhorn beetles in the forest, the species composition was different in the canopy and at the bottom, and the richness of longhorn beetles was higher in the canopy with better light conditions. The vertical distribution of different subfamilies differed in the stand. Cerambycinae and Lamiinae tended to be active in the canopy, and Prioninae tended to be active in the bottom of the stand. The topographic conditions and vertical height of the stand affect the richness, abundance, and community composition of longhorn beetles. Therefore, in the future monitoring of longhorn beetle populations, alien invasive species, and pests, it is necessary to fully consider the monitoring sites to cover as many diverse terrains and vertical positions as possible.

Abbreviations

DBH: Diameter at breast height; H: Canopy layer, L: Bottom layer, A: Ridge, B: Southern slope; C: northern slope; AH: Ridge canopy layer; AL: Ridge bottom layer; BH: Souther slope canopy layer; BL: Souther slope

bottom layer; CH: Northern slope canopy layer; CL: Northern slope bottom layer.

Declarations

Acknowledgments

We would like to thank Prof. Gao Wentao (Beihua University) for helping to identify longhorn beetles specimens.

Authors' contributions

Shengdong Liu, Qingfan Meng and Yinghua Jin designed this research. Shengdong Liu, Xin Meng, Qingfan Meng, Yan Li and Hongri Zhao carried out the fieldwork and made specimens. Shengdong Liu analyzed the results, and wrote the paper. Yinghua Jin facilitated in the data analysis. The author(s) read and approved the final manuscript.

Funding

This research was supported by grants from the National Natural Science Foundation of China (31600517), the Science and Technology Development Project of Jilin Province (20180201059NY), Open Project of Key Laboratory of Geographical Processes and Ecological Security of Changbai Mountains, Ministry of Education (GPES202003).

Availability of data and materials

The data are available upon a reasonable request to the Authors.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

Figure 1

Richness in the canopy (H) and bottom layer (L) (a) and on the ridge (A), southern slope (B), and northern slope (C) (b)

Figure 2

Sample-based rarefaction curves for the canopy (H) and bottom layer (L) (a), ridge (A), southern slope (B), and northern slope (C) (b)

Figure 3

The richness and abundance of Cerambycidae (a), Cerambycinae (b), Lamiinae (c), and Lepturinae (d) in the canopy and the bottom

Figure 4

The richness and abundance of Cerambycidae (a), Cerambycinae (b), Lamiinae (c), and Lepturinae (d) on the ridge, southern slope, and northern slope

Figure 5

Non-metric multidimensional scaling ordination of longhorn beetles at two vertical heights (H, L) and three positions (A, B, C) represented by different symbols and colors

Figure 6

Correspondence analysis of 6 subfamilies and 56 species of longhorn beetles with the ridge (A), southern slope (B), and northern slope (C) (a), ridge canopy (AH), southern slope canopy (BH), northern slope (CH), ridge bottom (AL), southern slope bottom (BL), and northern slope bottom (CL) (b). (Notes: 1 *Acalolepta fraudatrix* (Bates), 2 *Acanthocinus griseus* (Fabricius), 3 *Anoplophora glabripennis* Breuning, 4 *Eumecocera impustulata* (Motschulsky), 5 *Eutetrappa metallescens* (Motschulsky), 6 *Exocentrus fisheri* Gressitt, 7 *Lamiomimus gottschei* Kolbe, 8 *Leiopus stillatus* (Bates), 9 *Menesia sulphuratasulphurata*

(Gebler), 10 *Mesosa hirsute* Bates, 11 *Mesosa myopsmyops* (Dalman), 12 *Moechotypa diphysis* (Pascoe), 13 *Monochamus guttulatus* (Gressitt), 14 *Neacanista tuberculipennis* Gressitt, 15 *Oplosia suvorovi* (Pic), 16 *Pterolophia angusta* (Bates), 17 *Pterolophia rigida* (Bates), 18 *Rhopa loscelisunifasciatus* Blessig, 19 *Ropica dorsalis* Schwarzer, 20 *Egesina bifasciana* Matsushita, 21 *Anastrangalia sequensi* (Reitter), 22 *Gaurotes ussuriensis* Blessig, 23 *Leptura arcuata* Panzer, 24 *Macroleptura thoracica* (Creutzer), 25 *Macropidonia ruficollis* (Pic), 26 *Pedostrangalia femoralis* (Motschulsky), 27 *Pidonia gibbicollis* (Blessig), 28 *Rhagium inquisitor japonicum* (Bates), 29 *Stictoleptura succedanea* (Lewis), 30 *Stictoleptura variicomis* (Dalman), 31 *Anoplodera cyanea* (Gebler), 32 *Prionus insularis* Motschulsky, 33 *Distenia gracilis* (Blessig), 34 *Amarysius sanguinipennis* (Blessig), 35 *Anaglyptus colobotbeoides* (Bates), 36 *Chlorophorus motschulskyi* (Ganglbauer), 37 *Chlorophorus sexmaculatus* (Motschulsky), 38 *Chlorophorus sulcaticeps* Pic, 39 *Chlorophorus tohokensis* Hayash, 40 *Cyrtoclytus capracapra* (Germar), 41 *Massicus raddei* (Blessig), 42 *Obrium obscuripenne* Pic, 43 *Oupyrhridium cinnabarium cinnabarium* (Blessig), 44 *Plagionotus pulcherpulcher* (Blessig), 45 *Purpuricenius sideriger* Fairmaire, 46 *Rhaphuma acutivittis* (Kraatz), 47 *Rhaphuma gracilipes* (Faldermann), 48 *Rhopalopus speciosus* Plavilstshikov, 49 *Trichoferus campestris* (Faldermann), 50 *Trichoferus guerrii* (Pic), 51 *Xylotrechus clarinus* Bates, 52 *Xylotrechus cuneipenniscuneipennis* (Kraatz), 53 *Xylotrechus pyrrhoderus* Bates, 54 *Xylotrechus rufilius* Bates, 55 *Chloridolum sieversi* (Ganglbauer), 56 *Arhopalus rusticus* (Linnaeus), n1 Lamiinae, n2 Lepturinae, n3 Prioninae, n4 Disteniinae, n5 Cerambycinae, n6 Aseminae.)