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Changes in the Diversity of Conifer–Broadleaf Forests of Southern Primorye Resulting from Selective Logging and Fires

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Abstract—Species diversity of the overstory, understory, undergrowth, ground vegetation layer, and the taxocene of ground beetles (Coleoptera: Carabidae) was assessed in forest ecosystems of Southern Primorye with different degrees of disturbance. Diversity estimates were obtained in 13 permanent test plots established in nominally primary forests and forests affected by selective logging and fires. The results of ANOVA showed that the corresponding groups of plots significantly differed from each other in the species composition of the overstory, understory, and undergrowth and in Shannon index values for the overstory, understory, and ground beetle taxocene. The Jaccard index of floristic similarity for species of the ground vegetation layer was below 0.1 in comparisons between test plots within the groups of Korean pine and oak forests and ranged from 0.3 to 0.5 in comparisons between these groups, indicating a radical change in the composition of herbaceous plants after pyrogenic forest transformation. The numbers of ground beetles were higher in oak forests, but Shannon index for their taxocene was higher in Korean pine forests. It is concluded that moderate selective logging does not lead to significant changes in the species composition of forests, whereas regular fires in forests are a hazard to their biological diversity.

Keywords: biological diversity, species richness, fires, selection cutting, ecosystem services

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Forests support and regulate the functioning of the biosphere and are used by humans with a certain intensity, which in some regions takes the form of systemic deforestation, e.g., for the purposes of agriculture [1]. Humankind at the current stage of development should inevitably reach a compromise between the use of forest ecosystem services and consumption of forest resources, primarily timber The number of studies on the ecosystem services of forests has increased significantly during the past few decades, providing a basis for a series of political decisions and reduction in the rate of deforestation in the world [2–5].

Forest functions and services are closely interrelated with biological diversity of the communities of living organisms [6, 7]: on the one hand, the components of biodiversity are clearly defined and have quantitative expression; on the other hand, “biodiversity is a complex multidimensional concept that is difficult to measure and monitor, particularly at large scale” [8]. Losses of forest biodiversity present hazards to biological productivity, regional climate, and directly to human life and health [7, 9]. However, modification of methods and technologies of forest management with regard to knowledge of the stability of connections between the components of particular ecosystems may alleviate the adverse consequences of forest exploitation [10, 11].

Depending on environmental conditions and the kind of disturbance impact, fires and logging operations may have divergent consequences for the species composition of ecosystems. For example, fires lead to radical changes in forest ecosystems, but the diversity of ground beetles may either increase or decrease against this background [12–15]. In the review by Thom and Seidl [16], an increase in the biological diversity of forests after logging was observed in 38 out of 145 cases, and a “disturbance paradox” was revealed: increasing disturbances to forests under conditions of climate change can put ecosystem services at risk while simultaneously facilitating biodiversity.

Our study deals with analysis of biodiversity in some components of conifer–broadleaf forests of Southern Primorye exposed to regular fires and selective logging. Forest fires in this region are a powerful factor of landscape transformation. Published data are available on pyrogenic transformation of Korean pine forests in Primorye over an area of more than 1.5×10^6 ha [18]. To date, large territories south of Vladivostok and west of Ussuriysk have been completely deforested due to regular fires resulting from human activities, and primary conifer–broadleaf forests in many areas have transformed into Mongolian oak forests [19]. The consequences of these processes have not been described with respect to the loss of ecosystem functions and biological diversity. Relevant published data usually concern the consequences of a single disturbance of known intensity, while we consider systemic impact of forest fires over decades.

The purpose of this study was to reveal the character of changes in species diversity of forest biocenoses under the impact of fires and selective logging. Analysis of diversity was performed for the overstory, understory, undergrowth, ground vegetation layer, and also for the taxocene of *Carabus* ground beetles (Coleoptera: Carabidae). These beetles were included in analysis because such studies on them have not been performed in the region, although specialists acknowledge their significance as indicator species.

MATERIAL AND METHODS

Study region and test plots. Studies were performed in the forest plot of Primorye State Agricultural Academy (PSAA), which occupies an area of 28 000 ha in the Ussuri forest district. This area lies 30 km east of Ussuriysk and borders on the west to the Ussuri Nature Reserve (Fig. 1). Its natural features are favorable for the purposes of our research. They include dissected topography (the Przewalski Mountains); dense river network; high natural diversity of forest types, which is characteristic for the region as a whole; location at the junction of the Manchurian and Okhotsk floras; the presence of cutover areas of different ages resulting from logging operations differing in method and intensity; and close location to the Prikhankayskaya Plain, an open, unforested area subject to agricultural burning, which may spread and cause forest fires. The climate is characterized by a long growing season (over 150 days), annual average temperature of 3.5–5.5°C, and annual average precipitation of 600–950 mm, which accounts for relatively high productivity of forests [20].

The network of roads and village in the western part of the PSAA forest plot also contributed to the occurrence of fires and pyrogenic transformation of primary forests dominated by Korean pine (*Pinus koraiensis* Siebold & Zucc.) and Manchurian fir (*Abies holophylla* Maxim.) into secondary oak forests [21, 22]. The Ussuri reserve and the adjacent part territory of the plot are covered by relatively undisturbed primary conifer–broadleaf forests. Thus, the territory of the plot is crossed by the natural boundary between pyrogenic and primary forests, which passes from the southwest to the northeast. This was taken into account when choosing the locations of permanent test plots (TPs).

A total of 13 TPs (50 × 50 m) were established in the territory of PSAA forest plot: four in its southwestern part, in oak forests, and nine in the southwestern part, in Korean pine–fir forests, including four TPs in cutover areas of resulting from selective logging operations in the 2000s. Mensurational description of forest stand was performed in each TP [23].

Description of understory, undergrowth, and ground vegetation layer. Three 10 × 10-m test squares were laid out in the corners of each TP and used to identify and record plant species comprising the understory (young trees of forest-forming species), undergrowth (shrubs and trees not contributing to the overstory), and ground vegetation layer (herbaceous plants), indicating the total number of constituent species (N) and their total projective coverage (TPC). Descriptions in Korean pine forests were made in late June 2019; in oak forests, in late June 2020.

Collection of ground beetles. Barber traps were installed in Korean pine forests in 2017 and in oak forests in 2020. In each TP, 15 vessels 250 mL in volume were buried in the ground, the upper edge flush with the surface, along a straight line transect at intervals of 2–3 m and baited with 6% apple vinegar. The traps exposed for two months (June and July) were examined every week. Thus, nine samples of insects were collected from each TP. According to data from the nearby Timiryazevsky weather station, no anomalies in the distribution of heat and precipitation occurred in sampling years, and sampling frequency was sufficient for leveling out the local seasonal dynamics of insect occurrence. Only species of the genus *Carabus* were recorded, with the number of beetles trapped on a particular data being indicated for each species.

Data analysis. Biological diversity was evaluated using the Shannon index (H), expressing variables in natural logarithmic form [24, 25]. The practical significance of this index for biodiversity research has been confirmed in a number of studies [14, 25–27]. the Jaccard index (J) was calculated to characterize floristic similarity between TPs, The significance of differences between average parameter values was estimated by ANOVA.

RESULTS

Overstory. Discrimination between disturbed and undisturbed TPs in conifer–broadleaf forests was based on the relative extent of timber stock removal and external signs such as the number of stumps and uneven distribution of trees. Table 1 shows data on the composition and main mensurational parameters of stands in TPs. Disturbance impacts alter the species composition of the overstory accompanied by reduction of timber stock and, hence, of phytomass carbon stock.

The overstory of relatively undisturbed and post-logging forests is composed by 8–14 species, compared to 2–4 species in oak forests. The average tree age does not exceed 120 years, which is characteristic

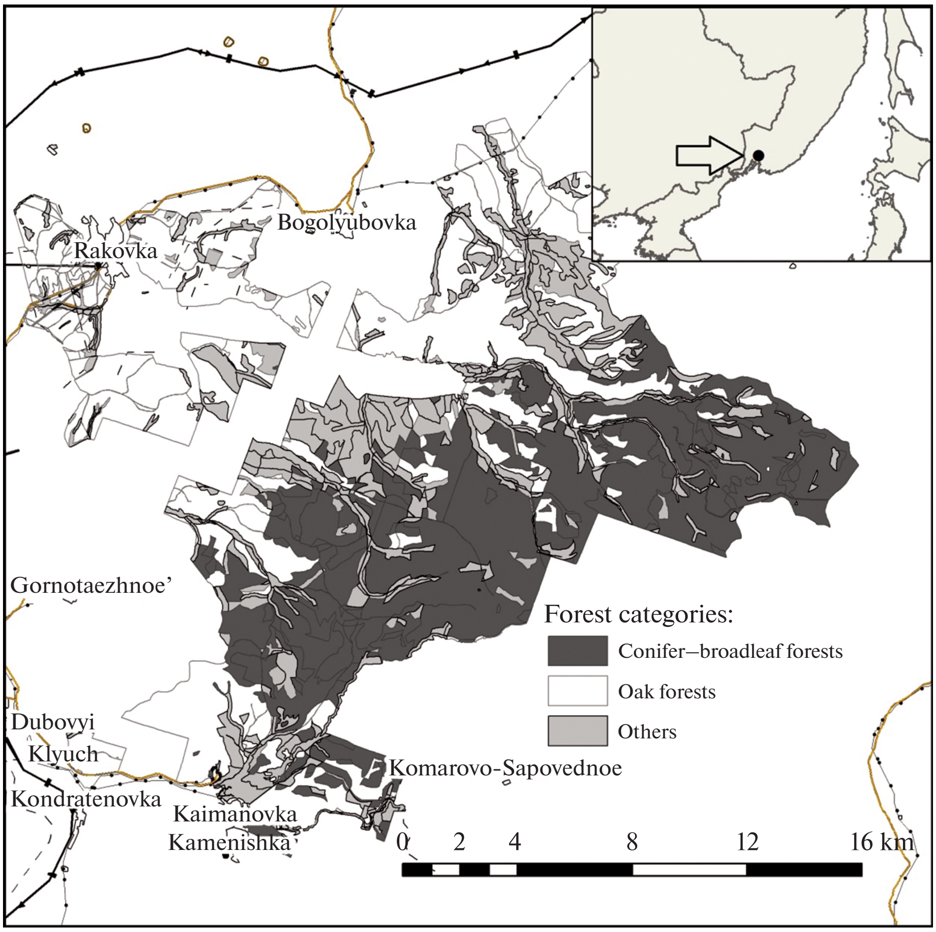

Fig. 1. Forest categories in the PSAA experimental plot.

of middle-aged Korean pine forests. The overstory of postfire forests is composed almost completely by Mongolian oak, which is tolerant of surface fires. The average timber stocks in relatively undisturbed, postlogging, and postfire forests are 388 ± 40, 216 ± 41, and 204 ± 37 m^3/ha, respectively. Selective logging with the removal of no more than 50% of local timber stock has been conducted in the PSAA forest plot during the past 15–40 years, but the environment characteristic of Korean pine and dark fir forests has been preserved (see below). The average diameter of oak trees by the age of 90 years reaches 14–18 cm; i.e., the biomass increment is small. There are severalfold differences in Shannon index values between the groups of stands. The H values for relatively undisturbed, postlogging, and postfire forests averaged 1.77, 1.91, and 0.50, respectively. The results of ANOVA revealed significant differences between the groups of forests in the number of species ($F = 24.1$; $p < 0.001$), timber stock ($F = 7.0$; $p < 0.05$), and Shannon index ($F = 27.2$; $p < 0.001$).

Understory, undergrowth, and ground vegetation layer. Parameters characterizing the state of understory, undergrowth, and ground vegetation layer varied as follows: ground vegetation layer: N = 19–42 ind., TPC = 11.5–49.9%, $H = 0.66–2.50$; understory and undergrowth: N = 7–27 ind., TPC = 14.8–79.2%, $H = 0.66–2.66$.; Shannon index values for the understory and undergrowth in postfire oak forests were significantly lower than in Korean pine forests ($F = 5.9$; $p < 0.05$). The shrub layer in oak forests is sparse, and projective cover is formed mainly by young Mongolian oak trees 1–3 m high with an umbrella-shaped crowns. The total number of species in the understory and undergrowth of postfire oak forests is approximately twice lower than in relatively undisturbed and postlogging forests ($F = 32.4$; $p < 0.001$).

High values of Jaccard index (with a maximum of 0.76) were obtained in pairwise comparisons of herbaceous species lists between TPs within the groups of relatively undisturbed, postlogging, and postfire forests, providing evidence for high similarity in the species composition of ground vegetation layer. When comparing the composition of herbaceous species between conifer–broadleaf forests and oak forests, the values of this index were close to zero. Differences in the TPC of herbaceous species between the three groups of forests lack statistical significance, while the

Table 1. Forest mensuration characteristics of test plots

Plot	Stand composition	*M*, m^3/ha	*G*, m^3/ha	*A*, years	*D*, cm	*H*
	Relatively undisturbed forests (group 1)					
1	6Ah2Qm1Pk1Til + Bc, Cc, Amo, Ks, Fm, Pa, Tp	506	42.4	83	42.7	1.53
2	6Ah2Pk1Bc1Amo + Til, Cc, Fm, Bp	466	37.1	102	45.6	1.48
3	4Qm3Til2Ah1Fm + Amo, Ah, Bd, Bp, Uj, Яб, Ma	333	33.7	118	31.4	1.65
4	3Til2Qm2Fm1Pk1Ah1Bp + Amo, Uj, Bd, Ma, Bc, Ks, Ama, Jm	324	34.0	102	33	2.04
5	3Ah2Pk2Bc1Til1Amo1Cc + Jm, Qm, Uj, Ks, Ma, Fm, Pa, Tp	312	32.0	80	24.2	2.15
	Forests after selective logging (group 2)					
1	4Pk2Til1Ah1Amo1Bc1Cc + Uj, Pa, Fm, Tp, Pm	273	26.8	110	40	1.87
2	3Til2Amo2Qm1Ah1Ks1Cc + Pk, Bc, Ma, Ap, Bp, Fm, Uj, Bc	207	23.1	105	34.6	2.20
3	3Ah2Pk2Til1Bc1Amo1Cc + Fm, Uj, Tp, Jm	283	29.1	110	37.8	1.85
4	3Pk2Ah2Uj2Amo1Гр + Til, Tp, Bc, Ma, Jm	105	10.3	94	31.1	1.70
	Secondary pyrogenic forests, oak forests (group 3)					
1	6Pk2Qm2Bd	305.2	37.6	80–90	18.5	0.99
2	10Qm + Pt, Bd, Pk	128.2	17.4	80–90	14.1	0.27
3	9Qm1Pk + Bd, Pt	182.4	25.7	80–90	16.1	0.56
4	10Qm + Bd	200.4	26.3	80–90	16.3	0.17

Designations: *M,* standing timber stock; *G,* basal area (the total cross-sectional area of trees at breast height); *A,* average tree age; *D,* average trunk diameter in dominant tree species; *H,* Shannon index. Tree species: Pk, *Pinus koraiensis*; Ah, *Abies holophylla*; Qm, *Quercus mongolica*; Til, *Tilia amurensis* and *T. mandshurica*; Bc, *Betula costata*; Fm, *Fraxinus mandshurica*; Uj, *Ulmus japonica*; Pa, *Phellodendron amurense*; Ks, *Kalopanax septemlobus*; Cc, *Carpinus cordata*; Jm, *Juglans mandshurica*; Bd, *Betula dahurica*; Bp, *Betula platyphylla*; Pt, *Populus tremula*; Amo, *Acer mono*; Ama, *Acer mandshuricum*; Ap, *Acer pseudosieboldianum*; Ma, *Maackia amurensis*; Pm, *Prunus maackii*. Species listed after the plus sign contribute no more than 5% to the total timber stock.

average values of Shannon index differ significantly between these groups ($F = 4.9$; $p < 0.05$), which is explained by the spread of adventive species in oak forests.

Diversity of *Carabus* species. A total of 2397 beetles of nine *Carabus* species were trapped (Table 2). *Carabus macleayi, C. maakii, C. schrenkii,* and *C. smaragdinus* were rare, while the remaining five species were common in all TPs. plots. The number of species recorded in TPs was maximum in undisturbed forests and minimum in secondary forests. The number of beetles trapped in oak forests was significantly greater: the group average values for TPs 1, 2, 3 were 160, 101, and 298 ind., respectively. However, some species widespread in Korean pine forests occurred only as single individuals in oak forests. The average Shannon index values in relatively undisturbed, postlogging, and postfire forests were 1.35, 1.09, and 0.77, respectively, with differences between these groups being statistically significant ($F = 16.0$; $p < 0.001$).

DISCUSSION

Forest stands examined after selective logging are characterized by higher values of Shannon index than undisturbed stands. An explanation to this fact is that areas under canopy gaps resulting from logging are occupied by both light-loving tree species (Japanese white birch *Betula platyphylla* Sukaczev and European aspen *Populus tremula* L.) and broadleaf species. Their establishment makes the composition of tree stand more even. In contrast, tree stand in undisturbed forest is strongly dominated by large (up to 40 m high) Korean pine and fir trees, with broadleaf trees growing as subordinate species under their canopy. Such an effect was also observed after selective felling operations in oak and pine forests in Spain [28].

The species richness of the ground vegetation layer in oak forests is higher than in Korean pine forests and fir forests. Due to frequent surface fires in oak forests, there appear adventive species that are not characteristic of Korean pine forests In the Appalachian Mountains (North America), fires have also accounted for an increase in the species diversity of local plant communities [38]. However, when the impact of fires is systemic and increases due to climate change, it creates the risk of complete loss of forest ecosystem, as it may occur in Southeast Asia [29].

Fires in oak forests of Southern Primorye occur at intervals of no more than 10 years and do not give enough time for the for the formation of shrub layer. Therefore, the most widespread species in the understory and undergrowth are those commonly occurring in burned-out areas: shrubby bushclover (*Lespedeza bicolor* Turcz.), Mongolian oak (*Quercus mongolica* Fisch. ex Ledeb.), aspen (*Populus tremula* L.), and Dahurian birch (*Betula dahurica* Pall.). The under-

Table 2. Occurrence of *Carabus* ground beetles in test plots 1–5

Carabus species	Relatively undisturbed forests					Forests after selective logging				Pyrogenic oak forests			
	1	2	3	4	5	1	2	3	4	1	2	3	4
C. macleayi Blackburn	5				1								
C. billbergi Mannerheim	7	32	49	32	26	5	98	11	11	364	157	182	144
C. careniger Chaudoir	5	12	20	22	33	16	16	25	29	37	36	48	48
C. granulatus L.	7	13	38	45	7	3	6	19	31		1		1
C. maackii Mor.	1		1										
C. schrenkii Motsch.	1		3	3	4	2	1		2	1	3	6	7
C. smaragdinus Fischer			5	9	10	4	3	3	8			2	2
C. venustus Mor.	11	21	18	18	87	15	25	46	10	2	1	1	4
C. vietinghoffi Adams	42	11	33	163	7	1	11		2	35	74	11	25
Total	79	89	167	292	175	46	160	104	93	439	272	250	231
Number of species	8	5	8	7	8	7	7	5	7	5	6	6	7

growth in oak forests is poorly developed, and this is another factor accounting for the high species richness of herbaceous plants, because the ground vegetation layer in these communities receives more light.

Differences in parameters of diversity of the ground vegetation layer, understory, and undergrowth between TPs in relatively undisturbed and postlogging forests are lower. This indicates that these groups have higher potential for recovering their initial habitus without passing through intermediate stages of succession. Low-intensity selective logging does not lead to sharp changes in the diversity of Korean pine and dark fir forest formation. For example, logging with 50% removal of timber stock in forests of central Finland caused no drastic change in their species composition [30], and moderate intensity logging in in forests of northern Mexico had no significant effect on the diversity of tree species [10].

The average values of Jaccard index in pairwise comparisons of herbaceous species lists within the three groups of TPs and between the groups of undisturbed and postlogging forests are within the range of 0.3–0.5 (Fig. 2). This indicates that all TPs in these forest groups belong to the same formation. Similarity in the composition of herbaceous species between postfire oak forests and other groups is several times lower. Therefore, the ground vegetation layer in oak forests and Korean pine–fir forests is mainly composed by different species. In the study on floristic similarity of forest communities in the Altai Mountains, the threshold value of Jaccard index for a high similarity level was estimated at 0.5 [31]. This threshold value is apparently lower in more southern areas, where the number of species increases. In our study, a value of 3 or lower may be regarded as indicative of close similarity.

The species identified as characteristic mainly of conifer–broadleaf forests are as follows: *Onoclea sensibilis* L., *Oxalis acetosella* L., *Asarum sieboldi* Miq., *Osmundastrum asiaticum* Tagawa, *Trillium komarovii* H. Nakai et Ko. Ito., *Thalictrum filamentosum* Maxim., *Carex siderosticha* Hance, *Athyrium filix-femina* (L.) Roth ex Mert., *Galium dahuricum* Turcz. ex Ledeb., and *Adiantum pedatum* L. Some species are mainly characteristic of oak forests. They include *Pyrola incarnata* Freyn, *Trifolium lupinaster* L., *Ranunculus japonicus* Thunb., *Taraxacum officinale* Webb ex F.H.Wigg., *Sonchus arvensis* L., *Sedum aizoon* L., *Artemisia stolonifera* Kom., and *Dictamnus dasycarpus* Turcz.

The seasonal dynamics of occurrence of ground beetles in the PSAA forest plot is described in our previous studies [32, 33]. It is shown that their occurrence depends primarily by phenological features of beetle species and the amount of precipitation moistening the forest litter and soil. Almost pure Mongolian oak stands are vulnerable to leaf-gnawing pests. In the course of phytopathological monitoring of forest stands in the PSAA plot we repeatedly recorded population outbreaks of gypsy moth *Lymantria dispar* L. and winter moth *Operophtera brumata* L., whose larvae are a basic food resource for *Carabus* beetles. It appears that a high abundance of ground beetles in oak forests is an indirect consequence of disturbances in the forest structure, with their diversity in oak forests being half lower than in conifer–broadleaf forests according to Shannon index values. Studies performed in other regions show that fires have an adverse effect on the diversity of soil entomofauna, which is explained in particular by change in the diversity of conditions on the soil surface after the removal (burning) of dead wood fragments and forest litter [16, 34–36]. On the other hand, studies performed in larch forests of the Great Lakes region [15] and Texas [14] reported a positive effect of fires on ground beetle communities. Such contradictory results appear to be explained by differences in environmental conditions

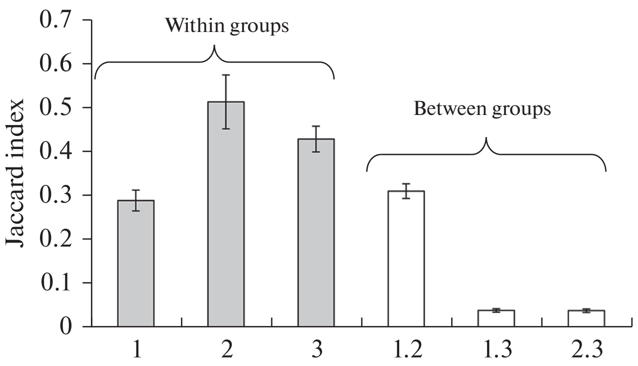

Fig. 2. Mean values of Jaccard index in comparisons of species lists within and between the groups of test plots (1) relatively undisturbed forests, (2) postlogging forests, (3) postfire forests.

of the study regions, primarily in the amount of woody debris and precipitation regime.

In general, selective logging with an intensity of up to 40% in the southern Sikhote-Alin do not change the biological diversity of four elements of forests considered in this study. The effect of systemic fires on these elements is not equal. The diversity of the overstory, understory, and undergrowth in postfire forests has decreased, while that of the ground vegetation layer has increased as a consequence of radical change of plant associations, which is confirmed by Jaccard index values. The numbers of ground beetles proved to be higher in oak forests, with the Shannon index for their taxocene being significantly lower than in Korean pine–broadleaf forests.

Biological diversity in modern research is usually estimated not by itself but is relation to ecosystem functions of forests [6, 10, 16]. A series of studies demonstrate a relationship between carbon stock in forest ecosystems and their biodiversity [6, 7, 37]. Only one parameter of forest productivity—timber stock—was used in this study. Changes in species richness upon transformation of Korean pine–fir forests into oak forests were associated with twofold reduction in timber stock (see Table 1). Forest fires in Southern Primorye during the past two decades have bot contributed to the maintenance of biodiversity. In this region there are distinct gradients of expansion of pyrogenic forests to primary forest areas, with complete deforestation of some areas in the Khasan and Khankay districts.

CONCLUSIONS

Changes in the diversity of forest ecosystem of Southern Primorye under the effect of selective logging and fires are not identical. Разнообразие лесных экосистем на юге Приморья под действием выборочных рубок и лесных пожаров изменяется неодинаково. Selective logging operation of moderate intensity in conifer–broadleaf forests pose no serious hazard to their diversity, and biomass stocks will be recovered without changes in the initial species composition of tree stand. Pyrogenic secondary forests replacing primary forests dominated by Korean pine and Manchurian fir are characterized by different species composition of the overstory, understory, undergrowth, and ground vegetation layer. The species composition of ground beetles differs slightly, but their total numbers are higher in secondary forests while Shannon index values are higher in primary forests. The long-term impact of fires on conifer–broadleaf forests leads also to reduction in timber stock by an average of 50%.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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