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Trends of Post-fire Forest Recovery in the South Sikhote-Alin Mountains, Russian Far East

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ABSTRACT

To understand natural regeneration and stand development after fire in mixed broadleaved-coniferous forests of Sikhote-Alin Mountains, ten sample plots of 50m×50m size were established in 1975 and 1983 at the stands burned by wildfires in 1973 and 1982, respectively. And, the number of naturally regenerated seedlings were monitored in two 50m×4m subplots in each plot. The most fire-sensitive conifer species is *Abies nephrolepis*, while *Betula costata* is the most fire-sensitive broadleaved tree species. The most fire-resistant species were *Q. mongolica*, *T. taquetii* and *A. mono*. The results of 20 and 30 years after the fire showed that pioneer tree species, e.g. *Populus*, *Salix*, and *Betula*, were regenerated immediately at the early stage of stand development and grew where there is a mono canopy layer with high density. On the other hand, the densities of successors, e.g. *Pinus koraiensis*, *Picea jezoensis*, *Abies nephrolepis*, *Acer mono* and *Tilia taquetii,* which were present in the study plots before the fire, increased gradually. Naturally regenerated tree species after forest fire by the growth rate were divided into three groups according to their annual height growth. The seral tree species (*Betula costata*, *Betula platyphylla*, *Padus maackii*, *Populus tremula* and *Sarix caprea*) belong to the first group and have the highest growth rate (from 40 to 96 cm per year). The late successional broad-leaved trees (*Tilia taquetii*, *Acer mono* and *Quercus mongolica*) belong to the second group and have intermediate annual height growth (from 3.7 to 13.5 cm per year). The late

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successional coniferous species (*Picea jezoensis*, *Pinus koraiensis* and *Abies nephrolepis*) form the third group and have the least annual height growth (from 1.4 to 3.5 cm per year).

Key Words : *forest fire, Russian Far East, natural regeneration, fire-sensitive species, fire-resistant species, forest succession.*

I. INTRODUCTION

The wildfire is an important source of disturbance in the mixed forests of the South Sikhote-Alin Mountain in the Russian Far East, often resetting the old-growth forest stands to early successional conditions. Forest fire has always been present as a natural component in this forest ecosystem with fire frequency, which has been estimated to be 100-200 years (Mishkov and Starodumov, 1982; Sverlova and Kostyrina, 1985; Sheingauz, 2004). The fires in these forests are characterized by discrete and regular pulses of severe stand-replacing fires, and they essentially create the cyclical pattern of stand development (Kolesnikov, 1956). The stand development proceeds from the immediate post-fire pioneer grass-shrub communities through the intermediate second-growth stands to the native broadleaved forests, which are more susceptible to severe stand-replacing fires than communities of the earlier successional stages. This pattern of fire followed by the relative disturbance-free periods of up to 200 years serves as the essential characteristic of forest dynamics maintaining biodiversity in this region.

The influence of fires on the forest succession has been studied in all forests subjects (Clements, 1928, 1949; Agee, 1993; Pyne, 1995; Shumway *et al.*, 2001; Guyette and Spetich, 2003). This includes a number of studies that have focused on the post-fire development of deciduous broad-leaved-Korean pine forests in the Russian Far East (Solodukhin, 1952, 1956; Mishkov and Starodumov 1982; Komarova, 1992). In spite of many studies on forest fires, few of them explicitly has explored the importance of variation in fire severity on the post-fire stand dynamics. The objective of this study is to understand the dynamics of post-fire stands and subsequent stand development after fire across the range of fire severity and habitat conditions.

II. MATERIALS AND METHODS

1. Study area

1) Abiotic environment

The research was conducted from 1975 to 2004 in the Verkhneussuriskiy Station(VUS), which is located in Pravaya Sokolovka River Basin (tributary of Ussuri River) (Figure 1).

The topographic relief is mainly low to middle-uplands ranging between 500-850m above sea level (a.s.l.) with mountain ridges aligned along general direction northeast-southwest. The climate is influenced by the monsoon air circulation and characterized by cold, snowy and sunny winter, and hot and rainy summer. Mean annual precipitation is 700mm with more 80% falling between June and September. The higher range of temperature covers 37 to 39°C in July-August, and the lower range covers -45 to

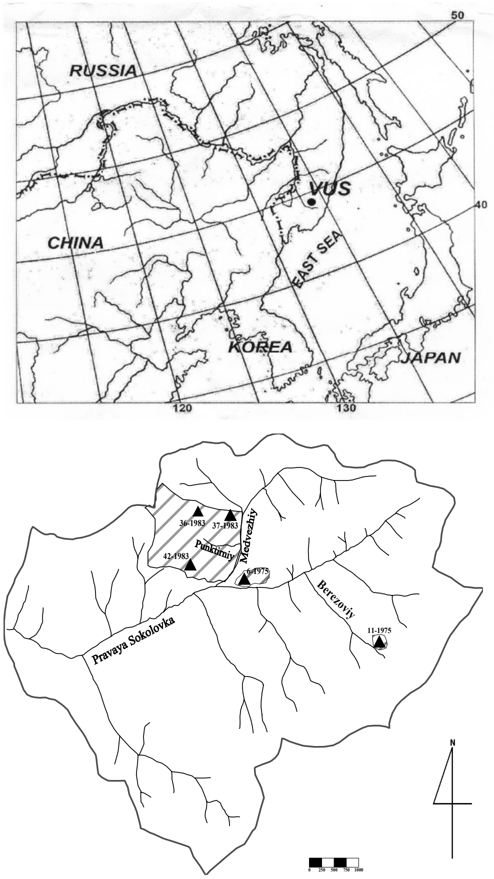

Figure 1. Location map of the study area and sites.

-48°C in January, with an overall mean at 0°C. Approximately 98% of the region is broadleaved-coniferous forest. Korean pine (*Pinus koraiensis*) is the most common tree species at lower elevations sometimes forming single species mono-layer stands, but the broadleaved-coniferous forests is characterized by multi-species and multi-layered stands of Korean pine mixed with several broadleaved species, including *Quercus mongolicae*, *Tilia taquetii*, *Acer mono*, *Acer tegmentosum,* and *Ulmus laciniata* etc. At elevations higher than 800m a.s.l. the broadleaved-Korean pine forests are replaced by dark coniferous fir-spruce forests, primarily consisting of *Picea jezoensi*s and *Abies nephrolepis*. These taiga forests are characterized by a comparatively simple structure and homogeneous composition. The transition zone between the two forest types is a mix of dark coniferous-Korean pine forests formed by *P. koraiensis*, *P. jezoensis* and *A. nephrolepis*.

The major soil type is brown forest soil with well-developed fertile humus horizon. In forest areas in the South of Primorskiy Krai this soil reaches 800-900m a.s.l. The inconsiderable process of podzolization has rather similar characteristic of Korean pine-dark coniferous forests.

2) Post-fire sites

The fire ignition is highly influenced by human activity, weather and forest conditions. The frequency and intensity of fires depend on the type of the fuel sources, which is directly correlated with forest vegetation and site conditions. Sheshukov (1967) classified the fuel sources into 17 types in the Russian Far East and reported that the fuel sources directly depend on the stand density while fire danger is correlated to slope direction. The most dangerous areas are dry insolated slopes with the least being shadowy slopes and valleys.

The xeric and meso-xeric oak-Korean pine forests, which grow on the steep southern slopes, have the greatest fire hazard. The fire season begins just after snow melt in spring and continues through to late autumn. The spring fires are mostly short-term ground fires. However, autumn fires are characterized by long-term ground fires that sometimes transfer to become crown fires. An autumn fire occurred on September and October in 1982 that covered about 15 ha in forests of different types. On the top of the steep slope at the elevation of 650-670m, a steady ground fire turned into intensive crown fire in meso-xeric *Rhododendron mucronulatum*-oak-Korean pine forest, where the sample plot (s.p.) 42-1984 was established. Before the fire, the forest consisted primarily of *P. koraiensis* and *Q. mongolica* with some *T. taquetii*, *Betula platyphylla*, *P. jezoensis* and *A. nephrolepis*. The crown fire caused considerable disturbance to tree crowns combusting almost 100% of pine needles, oak leaves and their smaller branches. Tree trunks were burnt up to 16-18m high and only some individuals of *Q. mongolica* were survived. As the result of this

Table 1. Stand characteristics and fire situation of permanent sample plots (s.p.).

# Sample plot ID/ # Section	Location	Year of fire	Slope aspect	Gradient (degree)	Elevation (m a.s.l.)	Forest type	Degree of disturbance by fire
6-1975/sec.1			SW	20-25	550-570	Xeromesophytic *Schisandra chinensis-Corylus mandshurica* oak-Korean pine stand	strongly destroyed by steady ground fire
6-1975/sec.2			NW	20-25	560-580	Mesophytic broadleaved-Korean pine liana-mixed shrubby stand	strongly destroyed by steady ground fire
6-1975/sec.3			SW	20-25	560-570	Xeromesophytic *Schisandra chinensis-Corylus mandshurica* oak-Korean pine stand	fractionally destroyed by slight ground fire
6-1975/sec.4	44° 02 ′ 04 ″ N 134°11 ′ 06 ″ E	1973	SW	20-25	550-570	Xeromesophytic *Schisandra chinensis-Corylus mandshurica* oak-Korean pine	undisturbed control stand
6-1975/sec.5			S, SW	30-35	600-610	Xeromesophytic *Schisandra chinensis-Corylus mandshurica* oak-Korean pine	strongly destroyed by steady ground fire
6-1975/sec.6			S, SW	30-35	590-600	Xeromesophytic *Schisandra chinensis-Corylus mandshurica* oak-Korean pine stand	fractionally destroyed by slight ground fire
6-1975/sec.7			S, SW	30-35	590-610	Xeromesophytic *Schisandra chinensis-Corylus mandshurica* oak-Korean pine	undisturbed control stand
36-1983	44°03 ′ 05 ″ N 134°10 ′ 51 ″ E	1982	S	20-25	660-680	Xeromesophytic *Schisandra chinensis-Corylus mandshurica* oak-Korean pine stand	strongly destroyed by steady ground fire
37-1983	44° 02 ′ 48 ″ N 134°11 ′ 12 ″ E	1982	NE	10	550-575	Hygromesoptytic broadleaved-dark-coniferous-Korean pine grass-sedge-fern stand	strongly destroyed by steady ground fire
42-1984	44° 03 ′ 05 ″ N 134°11 ′ 08 ″ E		S	36	580-600	Mesoxerophytic *Rhododendron mucronulatum* oak-Korean pine stand	strongly destroyed by crown fire

crown fire, forest litter, herbaceous layer, seedling and saplings were almost completely destroyed. These stands were disturbed by an intensive forest fire about 200 years ago. The characteristic of this site before the crown fire is given in the Table 1.

Xero-mesic oak-Korean pine stands with mixed shrubs on steep and medium slopes are also highly prone to fire. The deep and soft litter layer and thin growing herbaceous cover promote quick fire expansion. We established plot 36-1983 in a stand that suffered an autumn fire in 1982 that spread throughout the xero-mesic *Schisandra chinensis-Corylus mandshurica*-oak-Korean pine forest located at the top of the steep slope. The stable ground fire completely burned out the deep litter layer, seedlings, saplings and most of the herbaceous cover.

Most fires in the mesic broadleaved-Korean pine forest occur in spring and autumn; in summer the dense forest floor vegetation usually prevents the spreading of fire. We established plot 6-1975 in a stand where an intense summer fire occurred in 1973 on the extended slope of the elongated "nose edge" in the watershed between two rivers. Burn stand covered 2 ha and consisted of two different forest types that were completely destroyed by the fire (Table 1).

Mortality varied in the xero-mesic oak-Korean pine stand located on the south-west and southern slopes. We established seven sections in this plot to capture the variation in the effects of fire. Sections 1, 3 and 4 are mid-slope with slope between 20-25 degree and an elevation of 550-570m. Sections 5, 6 and 7 are located on the upper slope with 30-35 degree slope and elevation of 590-610m. Sections 4 and 7 are in the late stage of succession and are considered to be the undisturbed control stands, since the last major fire occurred about 200 years ago.

The mesic broadleaved-Korean pine-liana-mixed shrubby stand (plot 6-1975 section 2) was severely burned with completely disturbed ground layer and intensively damaged tree layer. After the intensive ground fire, the few survivors were all broadleaved trees (e.g., *Q. mongolica* and *T. taquetii*), while all coniferous species were damaged by fire and died. Leaf litter, herbaceous cover, seedlings and saplings were mostly destroyed by fire. There were only some little spots of herbaceous cover left with sedge, fern and herbs. Regeneration primarily came from seed sources in neighboring stands located at higher elevations along the slope.

The higher elevation hygro-mesic broadleaved-dark coniferous-Korean pine forests growing on the gentle slopes and flood plain terrace are characterized by a comparatively low fire hazard (Starodumov, 1966) and by a mosaic of burned litter and herbaceous cover, which results from the uneven distribution of fuel sources in the plots with an abundance of dry pine needles and hardwood leaves. In these stands the litter layer usually burns down to the mineral soil exposing tree roots, to which all coniferous trees are sensitive. In 1982 an autumn ground fire swept through the hygro-mesic broadleaved-dark coniferous-Korean pine grass-sedge-fern stands growing on the shallow slope of the Medvedzhiy river elevated terrace at an elevation of 550-575m, where s.p. 37-1983 was established. The soil was periodically humid and alluvial with a humus horizon of 6-8cm. These stands were harvested using selective cutting mostly of large-sized *P. koraiensis* in 1968-1969. Stand cover was 0.8-0.9 with three layers. In the upper layer (crown cover : 0.5, average height : 23-25m, average diameter :

30-40cm), *P. jezoensis* dominated with an admixture of *P. koraiensis*, *T. taquetii* and *B. costata* ; in the middle layer (crown cover : 0.3-0.4, average height between 16-18m) was formed by *A. nephrolepis* and *A. tegmentosum*. In the lower layer (crown cover : 0.3, height : 12-14m) was dominated by *A. nephrolepis*, *P. jezoensis* and *Acer ukurunduense*.

2. Methods

We established ten sample plots of 0.25 ha (50m×50m) in different stands disturbed by forest fires in 1982 and 1973, respectively. All individual trees greater than 2cm in DBH were numbered and mapped. Seedlings were divided into 10-50cm size classes and counted in two 50m × 4m subplots in each plot. Trees were classified into three fire effect categories : 1) undamaged, 2) damaged, and 3) dead. For trees classified as damaged, the fire scar height on the stem and the degree of damage to the root system were determined using the procedure developed by Starodumov and Tsibukov (1969) and Sheshukov *et al.* (1978). The fire scars height on the stems were divided into 5 classes by the size : 0.1-0.5; 0.6-1.0; 1.1-2.5; 2.6-5.0; and more than 5.0m. Depending on the damage degree of a cambium in the basis of trunks, 3 groups have been allocated : 1) weak damaged by the violation of not more than 25% of the trunk circumference; 2) medium damaged : 26-50%; and 3) strongly damaged : more than 50%. Dynamics of tree mortality has been assessed by the annual revisions on the total percentage of drying trees from original number of each species at the first 10 years after the fire, and then at intervals of 2-5 years.

Scientific names of all the species are referenced from the "Vascular Plants of Soviet Far East" (Volumes. 1-8 1985-1996).

III. RESULTS AND DISCUSSION

1. Impact of fire on standing trees

The early stage of succession after fire depends in large part on the composition of the survivors of the pre-fire timber stand. Not all of the trees die because of the fire. Some trees get damaged or even undamaged trees die soon after the fire due to strong winds, fungal infection and insect damages that occur soon after a fire.

One year after fire in the xero-mesic oak - Korean pine stand (s.p. 36-1983) about 50% of

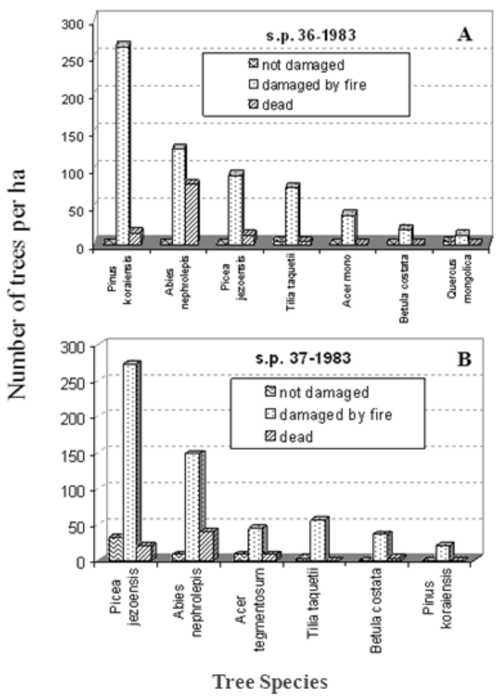

Figure 2. The effect of fire on woody species in the burned stands in the xero-mesic oak-Korean pine forest (A) and hygro-mesic broadleaved-dark coniferous-Korean pine forest (B)

trees had root damage, the stem and roots were damaged in 20% of trees, 15% of trees had stem damage, and only two species (*Q. mongolica* and *T. taquetii*) were survived (1 each) that were undamaged by the fire (Figure 2).

In broadleaved-dark coniferous-Korean pine stands (s.p. 37-1983), 7% of trees were undamaged, 62% had damaged root systems, about 8% of trees had fire scars on the stem, and almost 10% of trees had fire damage to both stems and roots. The year following the fire approximately 15% of the trees of oak-Korean pine stands and 13% in broadleaved-dark coniferous-Korean pine forests had died. These primarily consisted of *A. nephrolepis* and *P. jezoensis*. Stem scars reached to 5-6m on *A. nephrolepis* and *P. jezoensis* in both plots, while *P. koraiensis* were scarred only below 1m. Because they have finer branches and thin bark most young trees (less than 12cm DBH) of both broad-leaved and coniferous species have suffered from fire. The drying of large trees occurred most frequently as a result of the thermal damage of cambium at the base of the stem and root system.

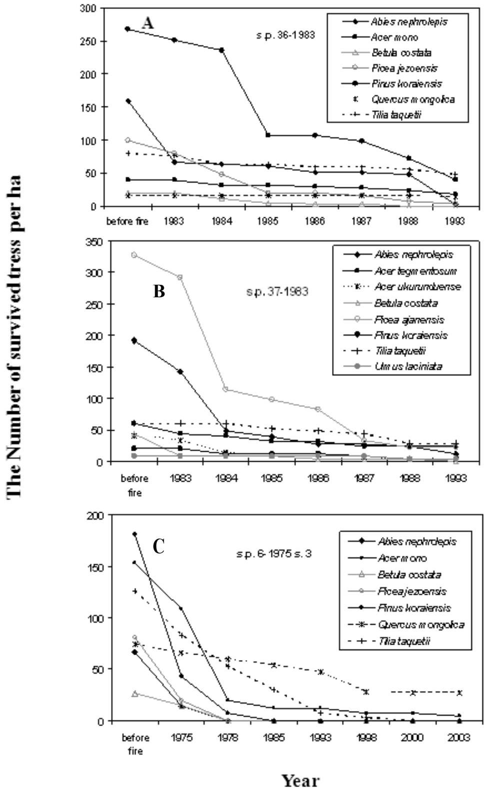

Figure 3. Changes in the survival rate of canopy woody species after fire from 1982 to 1993 in the burned xero-mesic oak-Korean pine forest (A), hygro-mesic broadleaved-dark coniferous-Korean pine forest (B) and from 1975 to 2003 in the sparse-burned of xero-mesic oak-Korean pine forest (C)

Post-fire mortality characteristics among woody species in the burned oak-Korean pine stand (s.p. 36-1983) and broadleaved-dark coniferous-Korean pine stand (s.p. 37-1983) for 11 years after steady ground fire of 1982, and for 30 years after a low intensity ground fire of 1973 in the oak-Korean pine stand (s.p. 6-1975, section 3) reflects the number of the surviving trees of separate species to their pre-fire quantity (Figure 3).

Overall survival rate after six years on s.p. 36-1983 and s.p. 37-1983 was 25.7% and 14.6% respectively. The crown density was 0.2-0.3 in both stands. A few trees of coniferous and broad-leaved species survived only in low intensity burned microtopes in the both stands. In the damaged *P. koraiensis* and *P. jezoensis* bark fell from the larger part of the stem, and the crown consisted of only smaller branches of the 1st and 2nd order. Dead *P. koraiensis* more than six years after the fire had either lost their apices or were entirely broken stems without crown. On some stems only the bases of the branches of the first order existed, bark became dark and cracked, the process of mortality had begun. At 11 years after the fire 19.6% of all the original trees in s.p. 36-1983 remained viable, while 9.9% in s.p. 37-1983.

In the severely burned stand where few trees survived (s.p. 6-1975 section 3), crown density decreased from 0.3-0.4 to 0.2 by the 20th year after fire (Figure-3C). The *P. koraiensis* mixed with *T. taquetii* and *Q. mongolica*, which made up the upper tree layer before fire, was absent. The survival *Q. mongolica* and *T. taquetii* had dead tops and were less than 20m in height. Few *A. mono*, which had dominated in the lower tree layer before fire, were found. In the 30th year after the fire, section 3 of s.p. 6-1975 consisted mostly of *Q. mongolica* and had crown density of less than 0.1m. On section 5 of s.p. 6-1975 tree population decline continued longer than other sections and 30 years following fire canopy closure remained lower (0.3) than pre-fire (0.5) and consisted primarily of three species (*Q. mongolica*, *T. taquetii* and *A. mono*).

Studies in stands with different fire severity show that tree mortality after intensive ground fires continues for 3-5 years in the stands consisting primarily from *P. jezoensis* and *A. nephrolepis* stands (s.p. 37-1983) and for 6-7 years in broadleaved-Korean pine stands (s.p. 6-1975 sec. 1, 2, and 6, 36-1982). Post-fire mortality continues longer if the initial fire effects were less severe : for 15-20 years after a low intensity ground fire if survived trees have crown density between 0.3-0.4 (s.p. 6-1975, sec. 3) and for 25-30 years after slight ground fires if survived trees have crown density about 0.5 (s.p. 6-1975 sec. 5). The same pattern of post-fire mortality in fir-spruce and broadleaved-Korean pine stands has been observed in other studies (Starodumov and Tsibukov, 1969; Sheshukov *et al.*, 1978). Our study also reveals that the post-fire mortality rate of trees is higher in the first year after crown fire compared to areas exposed to ground fires. For example the crown fire of 1982 in mesoxerophytic oak-Korean pine-rhododendron stands (s.p. 42-1984) caused within one year the death of 99.6% of *P. koraiensis*, 80% of *B. platyphylla* and 77% of *Q. mongolica*.

On the basis of long-term monitoring of damage rate and destruction of trees growing on the sample plots, the sequence of the tree species along a fire-resistance scale has been elaborated (Komarova *et al.*, 2005). The most fire sensitive conifer species is *A. nephrolepis*. This is probably due to its thin bark, higher resin content of needles, branches and stem, and shallow root system. *P. jezoensis* has similar, but less pronounced characteristics and is slightly less susceptible to fire. Species with thicker bark such as *P. koraiensis* are better able to survive at running ground fires. However, a thick dry layer of needles that covers surface roots burns easily, making this species prone to root damage in ground fires as well as other coniferous species. This often results in tree death due to the damage to the cambium layer of the roots and the base of tree. *B. costata* is the most fire sensitive deciduous tree species, followed in increasing order of fire resistance *A. ukurunduense*, *A. tegmentosum*, *B. platyphylla*, *Padus maackii*, *Fraxinus mandshurica*, *Ulmus laciniata*, *A. mono*, *T. taquetii*, *Q. mongolica*. The most fire resistant species, *Q. mongolica*, has comparatively thick bark capable of protecting the cambium layer from the overheating in all except the most severe fires. Mortality after ground fires is comparatively small. Our results are strikingly similar to the fire resistance scale reported in other studies for these forests (Solodukhin 1954, Starodumov, 1966).

2. Establishment and growth of the post-fire regeneration of the tree species

Post-fire stand development is mostly generated within the 4 groups of plants : 1) survivors from the pre-fire stand; 2) those destroyed during fire, but regenerating due to dispersal of diaspores from neighboring stands; 3) those regenerating from sprouts or from dormant seeds preserved in soil; and 4) plants absent in original community but establishing from dispersal of diaspores delivered from outside the burned area. The determination on which species dominates at different times during succession after an intense fire is associated with the lifespan of the species : the shorter lived species dominate at the early stage, while the longer lived ones do at the later stage. Clements (1928) defined three major groups of species : initial, seral and climax species. Initial species (e.g., *Aralia elata* and *Sambucus racemosa*) have the shortest life cycle and are found only the first few years after fire. The second group (i.e. the seral species) have longer life duration and occur at the later stages of succession reaching their greatest number of individuals and maximum productivity in the first and middle stages of post-fire recovery. Seral species usually form the new stands of second-growth forests. Climax species have a capacity for a long life and stable self-regeneration in the established second growth forests. The late stages of post-fire succession are generally formed by climax species, which make up the climax community.

The establishment and the growth of a new generation of trees depends on fire intensity and degree of damage on plant cover and litter. Burned sites usually have small-scale heterogeneity of microsites with various degrees of burning out of vegetation, litter and soil (with weak, moderate, strong and very strong disturbance to vegetation and litter), which matches with the four types of post-fire microtopes : 1) with a comparatively well preserved plant cover and litter layer or disturbed less than 50%; 2) with partially preserved plant cover and litter layer or disturbed more than 50%; 3) with plant cover and litter layer destroyed, but with an undisturbed humus horizon; and 4) with plant cover and litter layer destroyed and a highly damaged humus horizon.

Spatial variation within post-fire communities has a significant influence on tree regeneration and the establishment of herbs and shrubs. Deciduous tree species dominated the extremely high and high intensively burned microtopes of s.p. 37-1983. The two-year growth was fastest for *Populus tremula*, *Populus koreana*, *Salix caprea*, *Salix taraikensis*, which reached the height of 80-100cm, whereas the two-year-old *B. costata* did not exceed the height of 20-30cm. Orthotropic shrubs; *S. racemosa*, regenerated dense thickets here did not concede on height to fast-growing young plants of aspens and willows in the first 5 years after fire. Even-age plants of birches, getting behind in growth from them, were severely suppressed their dense crown at this time and their 5-years saplings did not exceed 1.0m of height.

In the microsites with moderate and weak fire intensity, various herbaceous species, which regenerated vegetatively, formed dense herbaceous layers dominated by ferns (e.g., *Leptorumohra*

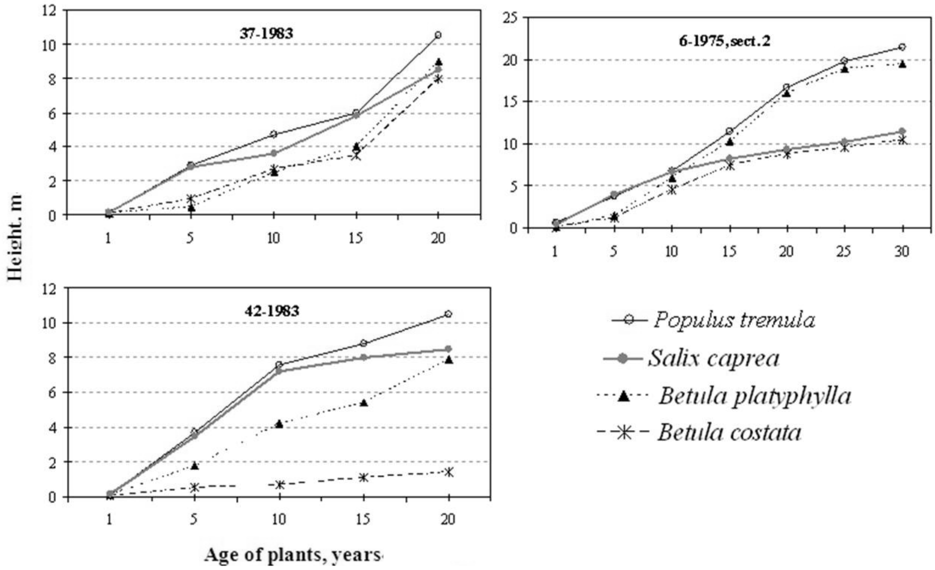

Figure 4. The effect of environments on the height-age relations of some seral species after forest fire.

amurensis, *Diplasium sibiricum*) and sedges (e.g., *Carex xyphium* and *Carex Campylorhina*). Few individuals of seral species grew where the main roots of coniferous trees burned. In these less severely damaged microtopes the average height of *P. tremula*, *P. korean*a, and *S. caprea* was 40-60 cm and *B. costata* was 5-10cm. In the following years growth of seral species was very high in the microtopes with high disturbance and the heights of *P. tremula*, *P. koreana*, *S. capre*a, *S. taraikensis* reached at total of 4.5-5.0 m by the 7^{th} year after fire.

The rate of tree growth depends much on environmental conditions. Seral species are more plastic to different environments than climax species, however they also changed in response to environments. The height-age relations were revealed for young plants of some seral species growing on three permanent sample plots representing a wide variety of environmental conditions (Figure 4).

The height-age curves are differ for well-developed and suppressed saplings. In order to avoid considerable variations in the shape of the height-growth curves, we estimated only the well-developed young trees. *P. tremula* has lower sensibility to different environments, and its growth is faster than other seral species. *B. costata* is the most sensitive species to environment, and the rate of its growth considerably changes in different sites. The plants of this kind species usually prefer humid habitats and avoid very dry places. In 20 years growing after fire in meso-xeric oak-Korean pine forest (s.p. 42-1984) *B. costata* was not exceeded more than 2m in height and most part of these trees were died out.

The growth rate is one of the most important characters of seral and climax species. Based on the tables of the annual height increment coming out of our investigation on different burned sites, it becomes possible to make comparative calculations of mean annual height increment of young trees of different seral and climax species (Figure 5).

These woody species can be subdivided into three groups according to their annual height growth. All seral species (*B. costata*, *B. platyphylla*, *P. maackii*, *P. tremula* and *S. caprea*) belong to the first group and have the highest growth rate (from 40 to 96 cm per year). The climax broad-leaved trees (*T. taquetii*, *A. mono* and *Q. mongolica*) belong to the second group and have intermediate annual height growth (from 3.7 to 13.5 cm per year). The climax coniferous species (*P. jezoensis*, *P. koraiensis* and *A. nephrolepis*) form the third group and have the least annual height growth (from 1.4 to 3.5 cm per year).

As crown closure gets more dense, the competition for space, light, moisture, nutrients and minerals increases between young trees. The post-fire regeneration of even-aged individuals of

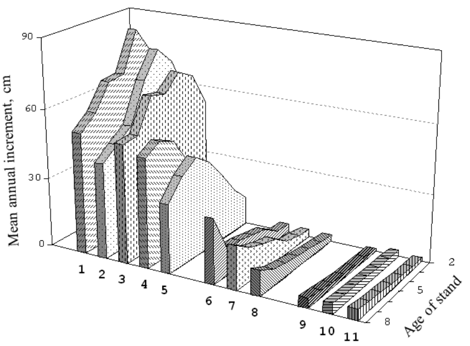

Figure 5. Mean annual height increment of natural regenerated seedlings at different stand ages along post-fire succession in the xero-mesic oak-Korean pine stand.
1 – *Populus tremula*, 2 – *Padus maackii*, 3 – *Salix caprea*, 4 – *Betula platyphylla*, 5 – *Betula costata*, 6 – *Acer mono*, 7 – *Tilia taquetii*, 8 – *Quercus mongolicae*, 9 – *Picea jezoensis*, 10 – *Pinus koraiensis*, 11 – *Abies nephrolepis*

seral species develops a hierarchy of size with a few well-developed big saplings and large clump of suppressed individuals. The weak trees suppressed by stronger ones have diminished in the process of self-thinning. Natural thinning is the most clearly seen for the first 10 years after fire among seral species. We investigated the dynamics of post-fire regeneration for woody species during 22 years in the broadleaved-dark coniferous-Korean pine stand (Figure 6).

In the first year after fire there were 41.9 thousand seedlings per hectare of 18 woody species, dominated by *P. tremula* (45.4%) and *S. caprea* (24.5%). The germination of birch and coniferous seeds is facilitated by the high ash

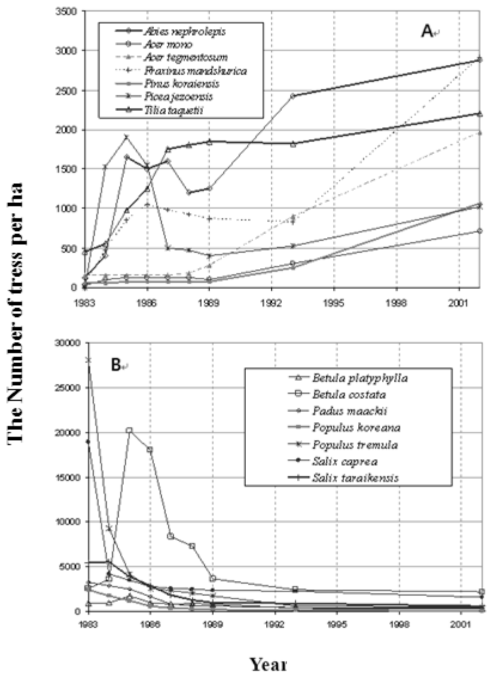

Figure 6. Changes in the quantity of naturally regenerated tree stems less than 2cm diameter after fire (A-seral, B-climax species) for 22 years in the broadleaved-dark coniferous-Korean pine forest (s.p. 37-1983).

content in burned soil. The total number of birch, fir and spruce seedlings increased considerably on the 2-year burn site to 253.8 thousands woody seedlings per hectare, and consisted primarily of *B. costata* and *B. platyphylla* (93.2%), and *P. jezoensis* and *A. nephrolepis* (4.3%). By the 22nd year after fire, only 1.7% of young *P. tremula*, 6.3% of *S. taraikensis*, 6.9% of *S. caprea* and 11.3% of *P. maackii* survived compared to the number of plants in the first year. By the 30th year after fire in the broadleaved-Korean pine stands (s.p.6-1975, sect. 2), only 12.2%, 2.9%, 2.6% and 2.6% of the original seedlings of *P. tremula*, *S. taraikensis*, *B. costata* and *S. caprea*, respectively, survived.

By 22 years after fire in the broadleaved-dark coniferous-Korean pine stand, seral species formed a simple tree layer due to intensive natural thinning. As a result, the number of young seedlings of climax species began to increase. In s.p. 37-1983 the number of *T. taquetii* increased by 5.2 times, *P. koraiensis* by 21.9, *A. nephrolepis* by 24.5 and *A. mono* by 29.2 compared to the number of naturally regenerated young trees in the first year. In s.p. 6-1975 section 2, the development of young climax species was considerably inhibited by dense layer of herbaceous plants and shrubs. Only after a dense seral species layer subsequently formed that inhibited growth of light sensitive herbaceous plants and shrubs, climax species can be regenerated with less competition in the ground layer. In the 30th year after fire *T. taquetii* increased by 64.7%; *P. jezoensis* by 66.8%; *A. nephrolepis* by 70.4%; *P. koraiensis* by 78.4%; and *A. mono* by 89.7% compared to the 2nd year after fire.

IV. CONCLUSION

As a result of long-term monitoring on the stand dynamics, in broadleaved-Korean pine forests and in broadleaved-dark coniferous-Korean pine forest in the South Sikhote-Alin, Primorsky Krai, Russian Far East tree population decrease that had already existed before fire was continued for several years after fire. Furthermore, it was also convinced that the development of new generation of trees depends on the fire intensity, characteristics of tree species, number of survived trees, the initial post-fire abundance of herbaceous plants and shrubs, and the general forest-growing conditions as well. Tree mortality continued for 4-7 years after high intensity fires, while did for 20-30 years after slight fires if crown density of survived trees is 0.4-0.5. When crown density is more than 0.5, subsequent forest species composition was not changed by fire. The most fire-sensitive species was *A. nephrolepsis* among conifers and *B. costata* among deciduous species. The most fire-resistant species were *Q. mongolica*, *T. taquetii* and *A. mono*. The high growth rate of several species after intensive fires provided good conditions for the development of their first generation. The young generations of climax species have more comfortable conditions to grow at the burned stands where survived trees have crown density 0.4-0.5.

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