INFLUENCE OF POST-FIRE MANAGEMENT ON REGENERATION OF SCOTS PINE (*PINUS SYLVESTRIS* L.) IN NORTH-WESTERN LATVIA

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Abstract
Fire is a frequent disturbance in hemiboreal forests that in Latvia affects mostly Scots pine (*Pinus Sylvestris* L.) stands. Increased forest fire risk is predicted in future as a result of climatic changes. Therefore the aim of our study was to assess Scots pine regeneration after forest fire in different forest types and with different regeneration methods. Tree height was measured and browsing damage assessed seven years after the forest fire in six different forest types, where planting and natural regeneration (in a clearcut and without management) occurred in compartments randomly selected from a list of stands severely affected by forest fire. The height of Scots pine was significantly affected both by forest type and regeneration method. Notable advantages of planting based on tree height were found in wet mineral soils and peat soils. Trees on poor (dry, wet, peat) soils were higher in natural regeneration after clearcut than in natural regeneration without clearcut. The density of Scots pine trees was significantly affected by the forest type but not by regeneration method (planting, natural regeneration, natural regeneration after the clearcut). The most abundant tree species in natural regeneration after clearcut in all forest types was silver birch (*Betula pendula* Roth.). The height of silver birch exceeded that of Scots pine in all analyzed soils in clearcut areas except Vaccinoso-sphagnosa forest type, emphasizing the importance of thinning to ensure a successful development of Scots pine stands.
Key words: natural regeneration, natural succession, salvage logging, browsing.

Introduction

Latvia is located in the northeastern part of Europe in hemiboreal forest zone (Ahti et al., 1968) and 52% of its area is covered by forests. Scots pine (*Pinus sylvestris* L.) is the most common conifer species in northern hemisphere (Nikolov and Helmisaari, 1992) and, according to State Forest Service statistics, dominates in 35% of the forest area in Latvia, mostly on sandy and loamy automorphic soils (*Cladinoso-callunosa, Vacciniosa, Myrtillosa, Hylocomiosa* forest types), on sandy semihydromorphic soils (*Callunoso-sphagnosa, Vaccinoso-sphagnosa* forest types) and on poor peat soils (*Shpagnosa, Caricoso-phragmitosa* forest types). According to data from the State Forest Service, regeneration of Scots pine is mostly done by planting, for example, in 2013 altogether 8507 ha were regenerated by this tree species, from it 79% by planting.

On average, in Latvia forest fire affects 1083 ha of forest stands per year, 90% of it – Scots pine dominated areas. Regeneration in post-fire areas is affected by environmental factors which have been altered by fire severity and intensity (Keeley, 2009) and in most cases differ from those in the clearcut. Post-fire areas are characterized by thinner soil humus layers, higher pH and more available nutrients in soil for plants (Simard et al., 2001). After a high intensity forest fire soils aggregates lose their stability, therefore enhancing soils degradation (Vacchiano et al., 2014). Consequently, natural regeneration after the fire also differs from that after the clearcut: broadleaved tree species still dominate early stages of it, but transition to dominance of coniferous trees takes place later (Ilisson and Chen, 2009), 60-180 years after the forest fire (Gauthier et al., 2010; Chen et al., 2014). In contrast, no significant differences were found in regeneration (diversity and productivity) 25-40 and 70-100 years after fire and harvesting in south-western boreal forests in USA (Reich et al., 2001).

Natural regeneration can be severely impacted by browsing damage, caused by cervids: tree species preferred by these animals (like Scots pine and trembling aspen (*Populus tremula* L.)) can be outcompeted by less-browsed ones (Meža kultūru.., 1984), in this way changing the composition of the stands.

Since the information on post-fire regeneration in hemiboreal forests usually covers short time span and only a single regeneration method, the aim of our study was to assess Scots pine regeneration in different forest types and with different regeneration methods.

Materials and Methods

The study was carried out in north-western part of Latvia, in area that 10 000 years ago was a part of the ancient Baltic Sea. Gradual receding of the sea to its current coastline has created unique complexes of dunes and depressions. Flat terrain hampers water draining thus enhancing formation of wetlands and marshes.

Forest fire occurred in the study area in 1992, affecting mostly (98%) Scots pine dominated forests. After forest fire in a part of the area salvage-logging was carried out, creating a large clearcut. In this

Table 1

Perspective Scots pines per ha in different regeneration methods and forest types

Forest type	Regeneration method		
	planting (P)	natural (N)	natural after clearcut (NC)
Cladinoso-callunosa (Sl)	8320*	3400	2280
Vacciniosa (Mr)	2720	5720	6280
Vaccinoso-sphagnosa (Mrs)	3520	10800	7640
Sphagnosa (Pv)	1800	3000	2520
Caricoso-phragmitosa (Nd)	4480	0	1720
Myrtilloso-sphagnosa (Dms)	-**	1360	4800

*direct seeding; **- – No sampling plots

area Scots pine was planted with the initial stand density of 5000 trees ha^{-1}, except on very poor sandy soil, were direct seeding was used, creating 10000 seed beds per ha. The other part of the burned area remained untouched, but in some parts small clearcuts were created and skidding used to move logs to the roadside. In both of these parts sites were left for natural regeneration.

Study sites were selected only in the compartments affected by stand-replacing fire (according to the inventory after the fire). In each of the three groups with different regeneration – planting (P), natural regeneration after forest fire with no intervention (N) and natural regeneration after clearcut (NC) – compartments for the study were selected randomly within each of the represented forest types.

To assess the regeneration seven years after the fire, in each compartment at least four 25 m^2 sized circular plots were placed systematically on the longest diagonal of the compartment. The total plot area per each compartment was at least 1.5% of its total area. In each plot the height of all growing trees (height > 10 cm) was measured with a metric rule (cm). During the inventory trees were divided in 'perspective' – the highest Scots pines with the distance ≥ 50 cm between them – and 'others'.

Damages caused by cervids were assessed using 4 grade scale:
1 – undamaged;
2 – leading shoot undamaged, lateral branches damaged ≤ 25%;
3 – leading shoot damaged partly, lateral branches damaged ≥ 25%;
4 – leading shoot damaged heavily (two and more times).

Climatic conditions in the study area are strongly influenced by the Baltic Sea: climate is more maritime in comparison to other regions of Latvia, characterized by lower amplitudes of temperature, colder summers and warmer winters. July is the warmest month of the year with the average temperature from +16.4 to +16.7 °C, the coldest month of the year is February with the average temperature from -3.9 to - 4.7 °C. The mean annual precipitation sum is 568 mm, which is one of the lowest in the territory of Latvia according to statistics of the Latvian Environment, Geology and Meteorology Centre.

Shapiro–Wilk test for normality was applied and ANOVA used to estimate the significance of observed differences.

Results and Discussion

The density of perspective Scots pines per ha was used to characterize regeneration in different forest types (Table 1). The highest density of such trees (10800 trees ha^{-1}) was observed in natural regeneration without any human activity in *Vaccinoso-sphagnosa* (Mrs) forest type, second highest – in *Cladinoso-callunosa* (Sl) forest type in post-fire area where the direct seeding was applied: 8320 trees ha^{-1}. In general, density of Scots pine was lower in the forest types on wet poor peat soil (*Sphagnosa* (Pv), *Caricoso-phragmitosa* (Nd)) and the highest (except one case with direct seeding) – on wet poor mineral soil (Mrs) in post-clearcut and post-burned areas which regenerated naturally without human intervention; the influence of forest type on this trait was statistically significant ($p<0.05$). The density of perspective trees in most cases was higher in naturally regenerated than in planted sites, however, the influence of regeneration method was not statistically significant ($p>0.05$).

The height of Scots pine was used to characterize the growth (vitality) of trees (Fig. 1). Both forest type and regeneration method had a significant ($p<0.05$) influence on the height of trees. In natural regeneration the highest pines were found on dry and wet mineral soil (Sl, Mr) and trees in all forest types were higher in natural regeneration after the clearcut than in post-fire area (except Dms). Planting seemed to result in a slightly slower growth than natural regeneration in forest types on dry mineral soil (Sl, Mr) but significantly better on wet mineral soils (Mrs) and on peat soils (Pv, Nd) in post-fire areas.

Criteria of successful forest regeneration, as defined in the legislation, are: at least 3000 trees ha^{-1} (of it at least 80% Scots pine), height ≥ 0.1 m shall be present in Sl, Mr, Mrs and the same density of Scots pines or, alternatively, at least 2000 broadleaved

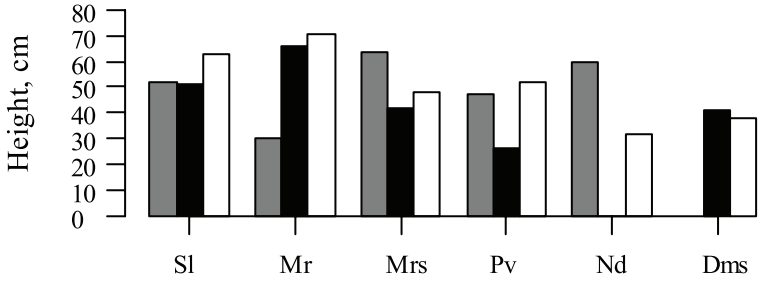

Figure 1. Height (cm) of perspective Scots pines in different forest types and regeneration methods planting, natural, natural after clearcut, Sl - Cladinoso-callunosa, Mr - Vacciniosa, Mrs - Vaccinoso-sphagnosa, Pv - Sphagnosa, Nd - Caricoso-phragmitosa, Dms - Myrtilloso-sphagnosa forest types.

trees ha^{-1} (height ≥ 0.2 m) in Nd, Dms and Pv (Meža atjaunošanas.., 2012). Based on these criteria Scots pine planting was successful (the density of perspective trees exceeds 2400 per ha) in all forest types except Pv; natural regeneration of this tree species – in all forest types except Nd and Dms and natural regeneration after the clearcut – in all except Sl, Nd, Ks. The density and height of broadleaved trees (mainly Silver birch (*Betula Pendula* Roth) fulfilled the requirements for successful natural regeneration in Pv, Nd, Dms, Ks. Supplemental planting of Scots pine is needed in post-clearcut area in natural regeneration in Sl forest type to ensure a successful forest regeneration.

According to our results, the density of Scots pine in planted stands was lower than in naturally regenerated ones (except in Nd), but direct seeding in Sl ensured higher density than natural regeneration. Relatively low density of natural regeneration in stands on peat soils (Nd, Pv) can be the result of combination of scarcity of suitable seedbeds and intense competition by other tree species (that was minimized in planted stands). The competition by other tree species have been noted as an important factor also in other studies, highlighting the importance of early management on the growth of Scots pine (Xenakis et al., 2012). Also, the density of Scots pines in *Cladinoso-callunosa* is relatively low and the result contradicts the common belief, that such conditions (poor sandy soil after forest fire) are most suitable for natural regeneration of this tree species. However, in *Vacciniosa* forest type natural regeneration of Scots pine is notably more successful.

The planted Scots pines were higher than naturally regenerated ones (except in Mr) in post-fire areas. It can be the result of tree breeding, ensuring improved growth rate and a higher disease resistance (Jansons, 2012), combined with a higher vigour of planted trees within the first years after planting due to better root system and nutrient reserves (Mangalis, 2004). The age structure of trees was not analysed in the study, but could also be part of the explanation of the observed tree height differences. Planting happened 1-2 years later than the first natural regeneration, however, the biological age of trees is assumed to be the same. Still, the natural regeneration probably continued for several years, therefore some of the seedlings in natural regeneration could be younger than the planted ones.

A study in Germany has demonstrated an improved regeneration and growth of Scots pine after medium-intensity forest fire in *Oxalio-Myrtillo-Cultopinetum sylvestris* forest type (Hille and den Ouden, 2004). In contrast, after high-intensity forest fire slower growth of trees has been observed (Dzwonko et al., 2015). It might be explained by the effect of fire on soil characteristics (porosity, structure) and significant reduction of nutrient availability, since notable amount of organic carbon (Certini, 2005) in soil and alive or dead biomass (Seedre et al., 2014) is consumed in the fire.

Abundance of other tree species was assessed in the study area to characterize the stand structure. Data were collected only in naturally regenerated stands where no thinning had been carried out (Fig. 2). Besides Scots pine in these stands 8 other tree and shrub species were growing: silver birch, trembling aspen (*Populus tremula* L.), common alder (*Alnus glutinosa* Gaerth.), goat willow (*Salix caprea*), other willow (*Salix*) species, Norway spruce (*Picea abies* L.), mountain ash (*Sorbus aucuparia* L.) and glossy buckthorn (*Frangula alnus* Mill.). Natural regeneration of tree species other than Scots pine were notably and significantly denser after the clearcut than in sites with no human intervention in post-fire area. The highest density of other tree species was found in forest types on wet (or drained) peat soil and wet fertile mineral soil (Nd, Pv, Ks, Dms). In this group of forest types the density of naturally regenerated Scots pine after the clearcut was lowest, presumably due to high competition. Only in Pv and Sl (poorest soils) density of other tree species was similar in areas with or without clearcutting. The lowest density of other tree species was observed in Sl, Mr, Mrs where the density of Scots pine was the highest (Table 1) in

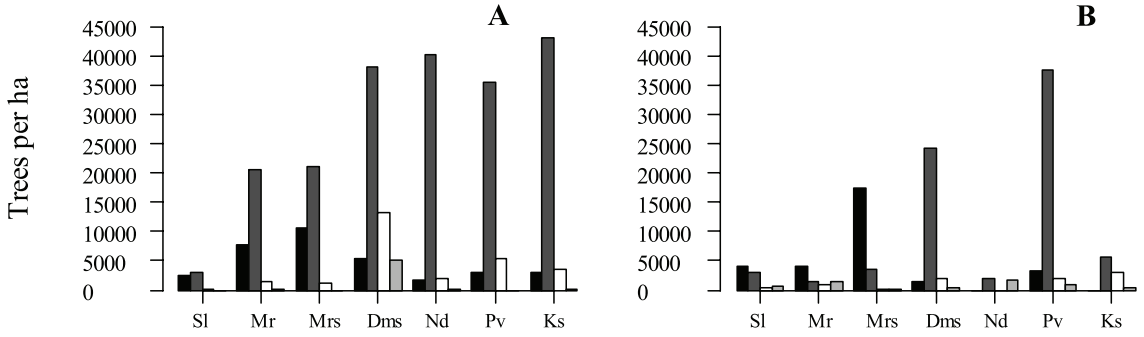

Figure 2. Total density trees ha^{-1}, depending on regeneration methods: **A**– natural regeneration after clearcut, **B**- natural regeneration. Scots pine, silver birch trembling aspen and willows other tree species Sl - *Cladinoso-callunosa*, Mr - *Vacciniosa*, Mrs - *Vaccinoso-sphagnosa*, Dms - *Myrtilloso-sphagnosa*, Nd - *Caricoso-phragmitosa*, Pv - *Sphagnosa*, Ks – *Myrtillosa turf.mel.* forest types.

natural regeneration without clearcutting in Sl, Mr and Mrs density of Scots pine exceeded that of other tree species.

Silver birch was the most abundant tree species in natural regeneration in post-clearcut areas: its share of the total number of trees was from 54.9% in Sl to 91.0% in Nd. Moreover, in all forest types with this regeneration method silver birch was more abundant than Scots pine (Fig. 2, A). Only in Sl forest type the mean density of Scots pine was similar to that of silver birch: 2280 and 3120 trees ha^{-1}, respectively. Moreover, Silver birch was higher than Scots pine in all forest types (except in Mrs); height differences were smaller in forest types on poor dry and wet mineral soil, where differences in abundance between pine and other tree species also were smallest: Sl, Mr, Mrs (Fig. 3). The mean height of birch in Ks, Nd, Pv, Dms exceeded that of Scots pine by 52, 43, 28, 24 cm, respectively, i.e. on average 0.5 times.

Similar to our results, the high density of broadleaves, especially silver birch, after clearcutting or natural disturbances has been found in numerous studies (Sarma, 1954; Ilisson and Chen, 2009; Gauthier et al., 2010; Chen et al., 2014; Dzwonko et al., 2015). Also, in areas not affected by forest fire natural regeneration after clearcutting had a higher density of other tree species in forest types on wet soils, but density of Scots pine was higher in forest types on poor (and) sandy soils (Saliņš, 2002). Regeneration of Scots pine on more fertile soils can be difficult due to rich vascular plant layer and more intense competition with other tree species, mainly silver birch (Elksnis, 1974). Other factors, like availability of seeds, can also affect the success of regeneration and stand composition. In Central Europe the main limiting factors for Scots pine regeneration in post-fire areas is the amount of produced seeds and the distance from the seed trees: if it exceeds 50-100 m, availability of seeds can be insufficient (Dzwonko et al., 2015). In our study the distance or direction to the nearest surviving tree (a possible seed source) was not measured, since there was no simple way to determine, which trees survived a few years after fire (to the first seed crop) and which died instantly in the fire (Donis

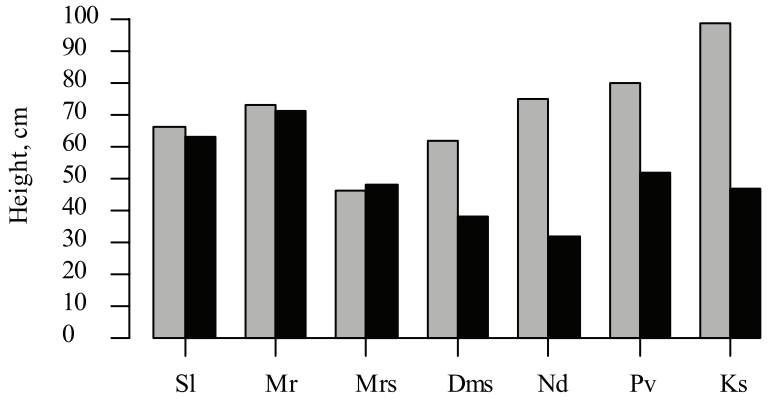

Figure 3. Mean density and height of naturally regenerated Scots pine and silver birch in clearcuts Scots pine, Silver birch, Sl - *Cladinoso-callunosa*, Mr - *Vacciniosa*, Mrs - *Vaccinoso-sphagnosa*, Dms - *Myrtilloso-sphagnosa*, Nd - *Caricoso-phragmitosa*, Pv - *Sphagnosa*, Ks-*Myrtillosa turf.mel* forest types.

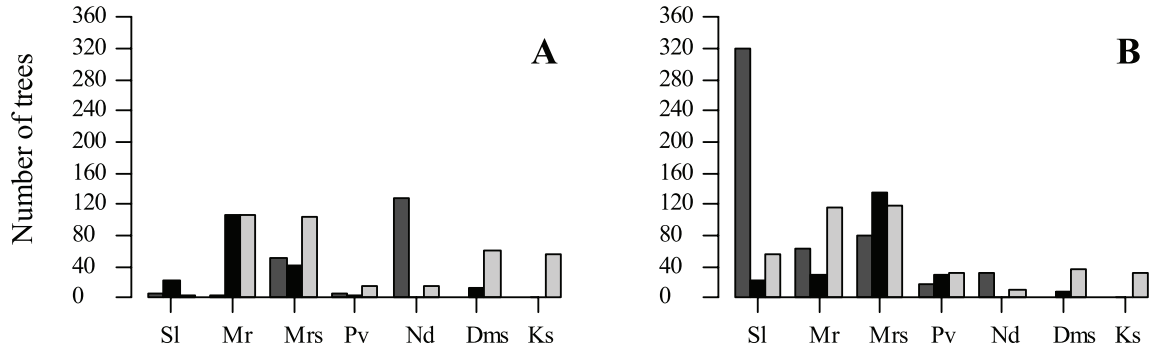

Figure 4. Number of Scots pines with (A) and without (B) browsing damage
Planting Natural regeneration Natural regeneration after clearcut, Sl - *Cladinoso-callunosa*, Mr - *Vacciniosa*, Mrs - *Vaccinoso-sphagnosa*, Pv - *Sphagnosa*, Nd - *Caricoso-phragmitosa*, Dms - *Myrtilloso-sphagnosa*, Ks- *Myrtillosa turf.mel* forest types.

et al., 2010). Also, the timing of the fire might have played a crucial role in the determination of species composition in young stands: it occurred just before birch seeds were ripening, preparing the perfect seed bed (mineralized soil surface, no plant competition) for far-flying seeds of this tree species.

Our results demonstrate that regeneration in post-clearcut areas not only abundance, but also height of silver birch on more fertile wet or drained soils notably exceeds that of Scots pine. A number of studies have suggested that the shift from broadleaved tree dominated forests to Scots pine dominated ones in boreal zone occurs 60-180 years after forest fire (Gauthier et al., 2010; Chen et al., 2014). In nemoral zone broadleaved trees dominated the regeneration for at least 15 years after severe forest fire on mesic soils (Dzwonko et al., 2015). These results suggest that long-term studies are necessary to increase the knowledge on the role of forest fires in survival of Scots pine in hemiboreal forests. It might be that other factors besides forest fire have played an important role in keeping the Scots pine dominated forests in high proportion e.g. human activity or browsing pressure by cervids.

To assess the factors affecting browsing damage in post-fire regeneration, a mixture of Scots pine, trembling aspen and willows – the species most preferred by cervids – were analyzed in naturally regenerated stands with or without clearcutting. Trembling aspen was present in natural regeneration in all forest types, including those on poor sandy soil (Sl, Mr), except one (Nd in sites without clearcuting). The highest density of trembling aspen in natural regeneration (both with and without clearcutting) was in Dms; this was also the only forest type where density of it was higher than that of Scots pine (Fig. 2). In former clearcuts willows were present in all, except the poorest soils (Sl), in contrast to natural regeneration without human intervention, where willows were found only in two forest types (Pv and Ks). Besides, the density of young trembling aspen and willows were higher in stands after clearcutting than in areas without human intervention, suggesting, that additional soil scarification due to skidding has played an important role in the success of their regeneration.

The number of damaged Scots pines exceed undamaged trees mostly in forest types on wet (Dms, Nd) or drained (Ks) soils (Fig. 4). The proportion of trees with browsing damage was similar in planted and naturally regenerated stands (30% and 31%, respectively), but notably higher in natural regeneration after the clearcuts (46%).

Differences in amount of browsing damage on Scots pines (both between regeneration methods and forest types) might at least partly be explained by preference of cervids to feed in the areas with higher availability of diverse feed stock. In Switzerland the quantity feed stock was found to be an insufficient indicator to determine roe deer feeding spots; also structural components of forests played an important role (Moser et al., 2008). It is in line with results from another study in Central Europe, where intensity of browsing damages in large post-fire area was dependent on availability of security cover (hiding places) for the animals, but not regeneration method (Borkowski and Ukalski, 2012). In our study, notably more hiding places for animals could be found close to areas with natural regeneration rather than in planted stands, located in large clearcut with trees notably lower than the height of the cervids. Other studies (Jaunzeme, 1980) in Latvia also have found more damage in small (0.4 – 1.0 ha) than in large (>3.1 ha) young stands, suggesting that it is the combined effect from availability of feed stock and hiding places. The design of our study did not permit the analysis of browsing damage depending on the distance from the edge of clearcut in planted stands, however, in areas of the same regeneration method (and availability of

hiding places) stands (and sample plots) with a higher admixture of broadleaved trees had more damages also on Scots pine.

Conclusions

1. Seven years after forest fire the density of Scots pine trees was significantly affected by the forest type but not by regeneration method (planting, natural regeneration, natural regeneration after clearcut).
2. The height of Scots pine was significantly affected both by the forest type and regeneration method. Notable advantages of planting based on tree height were found in wet mineral soils and peat soils (*Vaccinoso-sphagnosa, Caricoso-phragmitosa* forest type). Trees in all forest types were higher in natural regeneration after clearcut than in natural regeneration in post-fire area (except *Myrtilloso-sphagnosa* and forest type).
3. The most abundant tree species in natural regeneration (after clearcut) in all forest types was silver birch. Also, its height in clearcut areas exceeded that of Scots pine in all forest types, except in *Vaccinoso-sphagnosa* forest type.
4. The density of Scots pine exceed that of other species in *Vaccinoso-sphagnosa* forest type in post-burned areas without human intervention; Scots pine dominates in tree species composition in *Cladinoso-callunosa* and *Vaccinosa* forest types.
5. A higher amount of browsing damage on Scots pines were observed in the forest types with the highest admixture of broadleaved trees and shrubs (trembling aspen, willows).

Acknowledgments

The study was supported by Forest Competence Centre (ERAF, L-KC-11-0004) project 'Ecological risk in management of forest capital value – methods of assessment and recommendations of their minimization'. Authors express the gratitude to prof. Dr.hab.biol. Imants Liepa for his comments and suggestions on the methods of the study.

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