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Trees reaction after windthrow recorded in tree rings of pristine *Picea abies* forest "Parangalitsa"

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Introduction

Natural disturbances in Norway spruce (*Picea abies* Karst) forests is one of the topics that attract much attention in forest ecology studies in recent years. Among the reasons for this were several big storms in the last decades that caused wide-spread damages in high mountain forests (Lassig and Schonenberger 2000; Fischer et al. 2002; Schelhaas et al. 2003; Zielonka et al. 2009; Heurich 2009). Further more there are expectations, that climate change might increase the severity of storms thus making the topics for natural disturbances, forest resistance and resilience even more important in future (Dale et al. 2001; IPCC 2007). Yet, information about natural dynamics and disturbance regime of Central and South European high mountain Norway spruce-dominated forests is still limited (Korpel 1995; Krauchi et al. 2000; Holeksa and Cybulski 2001; Splechtna et al. 2005; Brang 2005; Svoboda and Pouska 2008; Zielonka et al. 2009). An option to fill-in some of the knowledge gaps on disturbance regimes of spruce-dominated forests in South-Eastern Europe is to conduct studies in the few remaining pristine forests in the Balkan Mountains and in the Carpathians. Yet, such studies often face numerous challenges, and one of the most important is the lack of written records for past disturbances and forest development. Therefore reconstructive methods that allow acquisition of data with yearly or at least decadal resolution are needed. Relatively affordable and popular are those based on the analysis of tree rings. They allow a non-destructive way of data acquisition with yearly resolution, which is a very good proxy for the past growth of single trees (Schweingruber 1996). Therefore tree ring analysis has been one of the main tools to reconstruct past disturbance history and dynamics of forests (Rubino and McCarthy 2004). Another problem that exists in tree-ring studies of disturbances is the definition of trees' reaction after the disturbances. Most studies have used as a clue abrupt increase of tree ring width (i.e. a release), which is considered a consequence from reduced competition and more available growth resources for the survival trees (Lorimer 1985; Veblen et al. 1994; Cherubini et al. 1996; Kulakowski et al. 2003; Black and Abrams 2004; Splechna et al. 2005; Zielonka et al. 2009). Yet, there have been difficulties in defining the criteria to detect which increases of tree-ring width can be considered as releases and many calculation methods have been applied (for a discussion see Rubino and McCarthy 2004). One of the approaches developed to cope with this problem (i.e. the "boundary release criteria", Black and Abrams, 2004) accounts for differences in the possible growth change dependent on the species and social status of a studied tree. Yet, it is mostly applicable for large data sets which often researchers do not have for their region. Furthermore the method has complicated calculation procedure, which hinders the use with smaller datasets derived from spatially-explicit data-collection strategies that provide low number of cores from a small region, but carrying important disturbance signals.

Here we present results from tree-ring study of the disturbance history in Parangalitsa forest reserve in Bulgaria. It has been declared a natural reserve in 1933, but even before that was considered as a protected forest and human activities were limited to hunting of local governors and pasturing on the higher grass-lands above the forest. Timber harvesting on large scale was not allowed and the lack of roads additionally hindered any possible attempts. Therefore the forest presents the chance of studying natural dynamics for at least the age of the dominant cohorts (above 200 years). To perform our study we firstly developed maps of spatially definable forest patches and recent disturbance based on two sets of aerial photographs (in 1966 and 1997) (Panayotov et al. 2010). Then we collected tree ring samples from survival trees on the borders and within disturbance patches with different scales.

The main objective of our research was to study the reaction of trees after disturbances with different scales and severity. We hypothesized that although the general pattern would not be too different from other known examples, species and social-status specific reactions between light-demanding *Pinus* and shade tolerant *Picea* and *Abies* trees can be found. We also asked our selves whether we would be able to find differences dependent on the scale of disturbances (e.g. gaps or medium and large-scale windthrows)?

Material and methods

Study site

Our study site is situated in the upper parts of Bistritsa valley in the Rila Mountains in Southwestern Bulgaria (Fig.1). The study forest (250 ha) is situated between 1450 and 1950 m a.s.l in "Parangalitsa" reserve, which is one of the first strict forest reserves on the Balkan Peninsula. In was declared in 1933 and in 1977 it was included in the "Man and biosphere" list of UNESCO. The forests are dominated by Norway spruce (*Picea abies* Karst). At lower altitudes (e.g. up to about 1650 m a.s.l.) there is participation of up to 70% of Silver fir (*Abies alba* Mill) and up to 40% of European beech (*Fagus sylvatica* L.), while at the treeline belt there is limited participation of up to 20% of the Balkan endemic species Macedonian pine (*Pinus peuce* Griseb.). In many of the forest patches with heterogeneous structure there is participation of Scots pine (*Pinus sylvestris* L.) in the oldest cohort (up to 40 %).

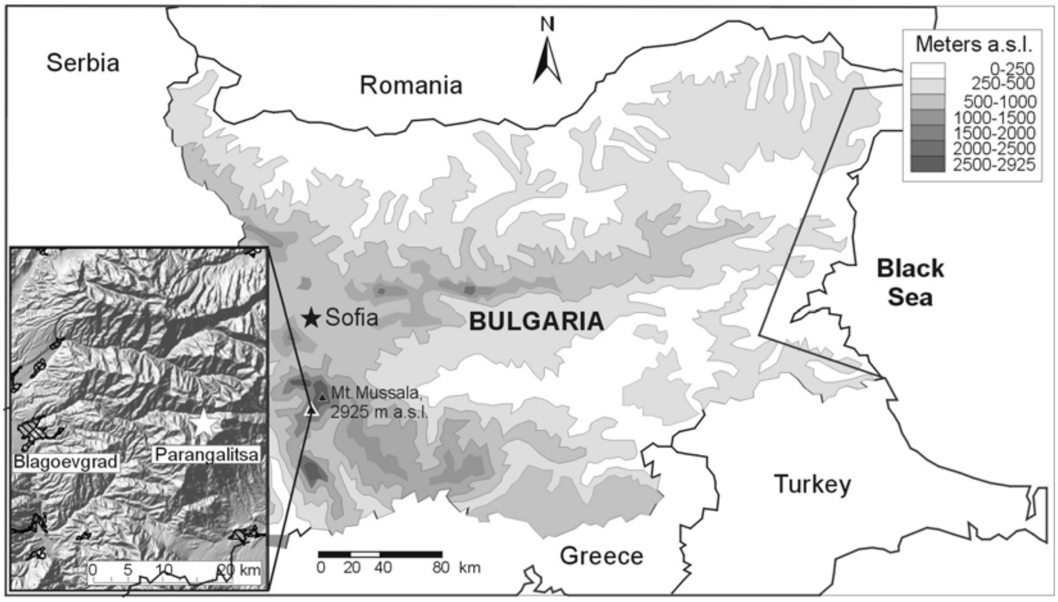

Figure 1: Study site position

The climate in the reserve is mountainous with influence from both Atlantic and Mediterranean cyclones. The average annual temperature at 1400 m a.s.l. is 4.9°C. It ranges from a mean monthly temperature of -3.7°C in January to +14.5°C in July. The annual precipitation amounts to 933 mm, with a maximum in late spring and early summer (Raev et al. 1986). Soils are dominantly brown-forest spoils (Dystric Cambisols) and dark-mountain soils (Umbric Cambisols). The brown soils are found mostly under mixed *Picea-Abies-Fagus* forests from 1500 to 1650 m a.s.l., while the dark mountain soils are found under the pure *Picea* and mixed *Picea-Pinus* forests (Georgiev 1981).

Data collection and analysis

Based on interpretation of aerial photographs from 1966 and 1997 (Panayotov et al. 2010) and historical records we selected several sub-regions with windthrows within the 250 ha forest: A) a border zone of a famous windthrow that happened in 1962 and caused complete blowdown on a territory of more than 20 ha; B) a zone occupied by old forest (150-230 yrs) with active gap processes between 1966 and 1997; and C) even-aged patches, which in unmanaged forests usually originate after canopy-removal disturbances (Oliver 1981). From the border zone of the catastrophic windthrow (study region A) we collected cores at breast height from 66 survival trees. Survival trees on the territory of the blowdown were also sampled. From the edges of the recently formed gaps (study region B) we collected cores from 33 trees. From the borders of the even-aged patches we collected 24 cores from biggest and presumably oldest trees that were expected to be older than the majority of trees within the patches and therefore contain clues for a possible disturbance event.

Sample processing

Tree ring samples were air-dried, mounted on wooden holders, and sanded with successively finer grades of sandpaper. Annual rings were recorded with semi-automatic video equipment at the dendrochronology laboratory of the Institute of Forest Growth (IWW) in Freiburg with precision of up to 0.01 mm. Measurement and cross-dating was performed with the Woodscan software (IWW) following standard procedures (Stokes and Smiley 1968).

To qualify trees' reactions after the disturbance events we calculated the change of tree ring width relative to the average of the previous ten tree rings. We subdivided the trees according to their reactions in 5 release classes (e.g. tree ring width relative to the mean of the previous 10 years from 1)140 to 160%; 2)160-180%; 3)180-200%; 4) 200-220% and 5) >220%) and 5 decrease (suppression) classes (e.g. e.g. tree ring width relative to the mean of the previous 10 years from 1) 0 to 30%; 2) 30 to 40%) 3) 40 to 50%; 4)50 to 60%; and 6) 60 to 70%. To verify if there was a time lag of reactions, the growth changes after the 1962 windthrow were analyzed in two periods – the first 5 years after the event (e.g. 1963-1968) and 5 to 10 years after the event (e.g. 1969-1973). We considered as releases or decreases only cases, when the reaction was sustained for at least 3 to 5 years.

Results and discussion

Almost half (45%) of the sampled 66 trees at the borders and within the 1962 windthrow patches displayed radial growth decreases (i.e. suppression) in the first 5 years after the disturbance (fig. 2). Most of the suppressions were between 70 and 50% relative to the average of the previous ten years. During the first five year period releases were observed in 150% of the trees. This type of reaction was predominant in the period from 5 to 10 years after the disturbance. Then a third of the trees (32%) displayed releases. While the majority of tree-ring width releases were between 160 and 200% (52%), about 25% of the trees increased their tree ring width to more than 200%.

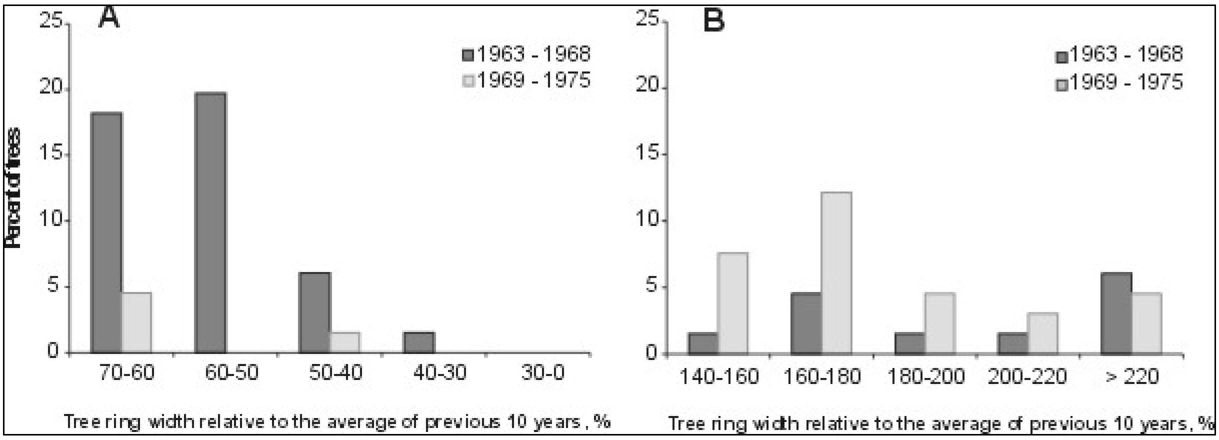

Figure 2: Tree ring width suppressions (A) and releases (B) after the windthrow in 1962.

We could distinguish three main groups of trees according to their pattern of reaction after the 1962 windthrow. The highest number (30%) displayed only a sudden growth decrease and did not release according to our criteria in the following 10-year period (fig. 3A). In most cases such trees recovered steadily, but without sudden tree ring width changes in their growth. Trees that only released (fig. 3B) were slightly more (20%) than those which displayed an abrupt growth suppression followed by a release (12%) (fig. 3C). Strongest reactions were found in tree ring samples from *Abies alba* and *Picea abies* from the lower altitudes of the affected zones. *Pinus* trees (*P. sylvestris* and *P. peuce*) either did not display a growth suppression or release within the specified percentage classes, or reacted by small growth changes.

The predominance of suppression reactions in the first five years after the 1962 storm could be explained in several ways. Many of the trees suffered crown damages, which still can be observed on site. In such cases the tree suddenly looses a substantial part of the photosynthetic green mass system and thus accumulation of the necessary for wood production carbohydrates is seriously decreased (Schweingruber 1996). This causes production of either incomplete tree rings, which may appear as locally missing tree rings, or production of very narrow tree rings (Panayotov 2005). Even if the crown is not injured the shaking of the stem during a very strong storm can cause damages to the root system and especially to the fine roots (Stokes 1999) which are responsible for the major part of the intake functions of the roots (Marchand et al. 1986). On its side this can also cause growth stress and result in production of narrower tree rings.

In contrast to the reaction of trees after the 1962 windthrow, the 33 trees at the edges of recently formed gaps displayed mostly radial growth increases (i.e. releases). This was found in 88% of the cores (Fig. 4). The percentage of trees with radial increase of more than 200% (48%) was also higher than that of the survival trees from the 1962 windthrow. Abrupt growth suppressions were found in smaller number of trees (24 %).

Probably the storms that caused uprooting of one or several trees and thus the formation of gaps were less severe than those causing complete blowdown over larger territories. Thus the trees at the border of the newly formed gaps might have not suffered crown, root or other damages. In opposite, they acquired access to more space for crown growth and more light after the disappearance of some of the direct competitors. More over that some of the survival trees on the borders of the gaps were co-dominants at the time of the gap formation and thus received the chance to become dominant trees. Such changes in the social status and resource availability of the trees could explain the release reactions in the tree ring cores.

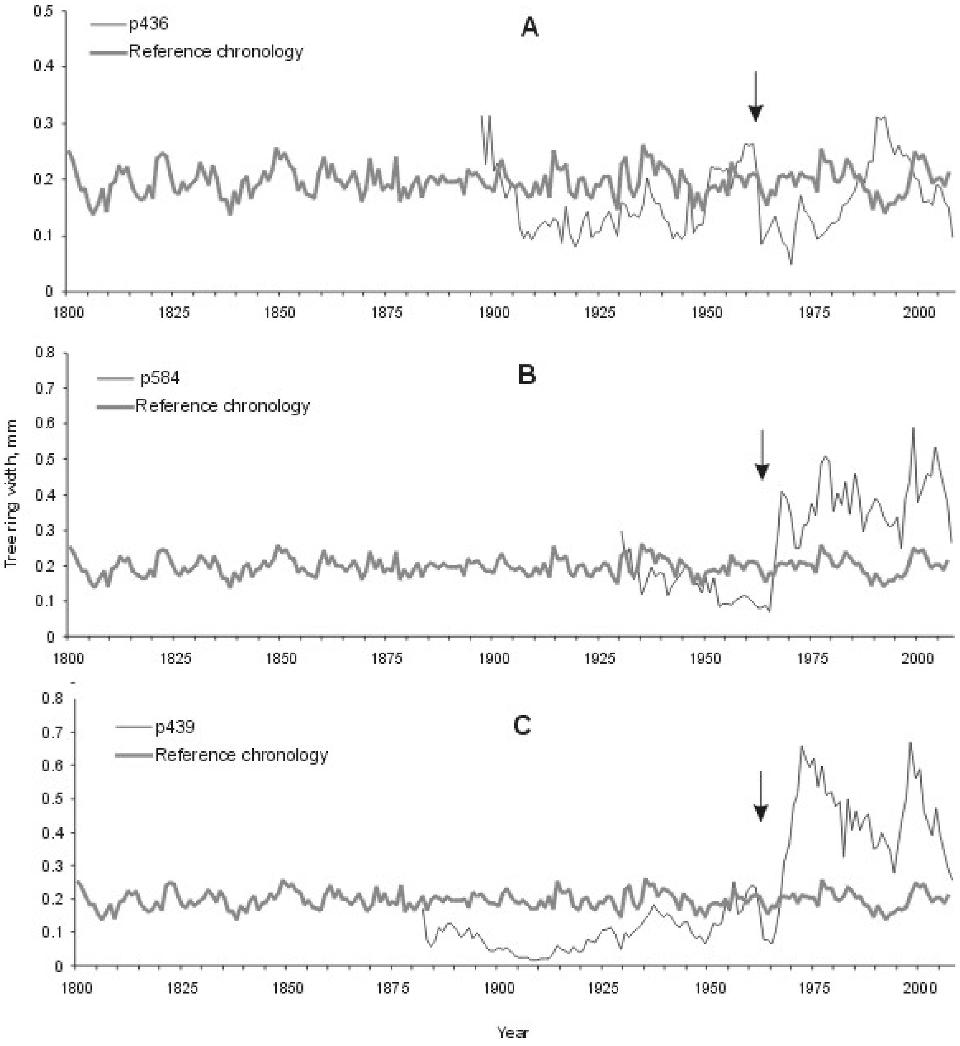

Figure 3: Pattern of tree ring width change after the 1962 windthrow: A: abrupt suppression; B: abrupt release; C: abrupt suppression followed by a release. Arrows indicate the year of disturbance.

The shade tolerant *Abies* and *Picea* trees reacted by higher changes in the tree ring width than the light demanding *Pinus* trees both in the cases of catastrophic windthrow and gap formation (fig. 3). We consider that the reasons are related to the social status trees and genetic features of the trees. In our case the *Pinus* trees were dominant trees within the canopy. Thus their crowns were accustomed to more light and could not benefit much from the sudden reduction of competition for light. Additionally both *Pinus sylvestris* and *Pinus peuce* form small crowns situated at the top of the canopy when there is higher competition. Thus their crowns could not benefit from the sudden occurrence of more light at the lower and middle layers of the canopy and this explains the smaller changes of ring width. In opposite *Picea abies* and *Abies alba* trees generally from long crowns covering a large part of the stem. Their lower crown parts remain in shadow and contribute less for the general carbohydrates production. In cases of gap opening the lower parts of the crowns receive more light and may increase the photosynthesis rates and carbohydrates production. Thus these species benefit much more from the increased side light. Additionally *Picea* and *Abies* survive for long periods under the shadow of canopy and then can benefit from the death of dominant trees. Thus if the trees were suppressed or even co-dominant at the moment of gap formation they could suddenly increase their growth both in length and radius, which is detectable as growth release.

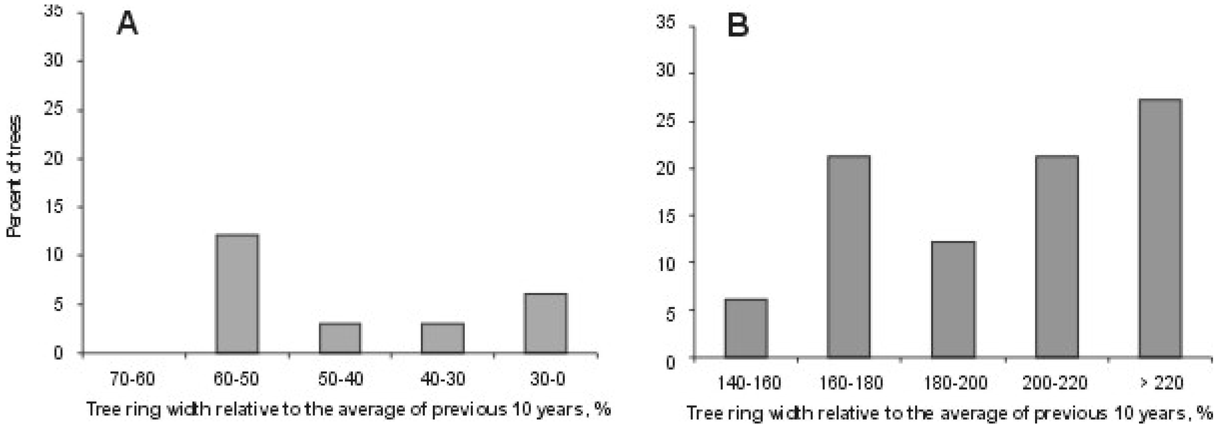

Figure 4: Tree ring width suppressions (A) and releases (B) at the border of gaps formed in the period 1966-1997.

Rather small number of trees on the borders of the two analyzed even-aged forest patches reacted after the disturbances. Although most of them produced much wider tree rings (i.e. releases) some also displayed growth suppressions (fig. 5). Yet, the small number of reacting trees does not allow a clear distinction of the predominant response type after the disturbance event that destroyed most of the trees in these regions. A possible problem in defining the response of trees is the rather long time lag (more than 100 years) after the events and the high chances that some of the surviving at that time trees have already died. Yet, about 15% of the found old trees displayed sharp releases (e.g. above 200% of tree ring width increase).

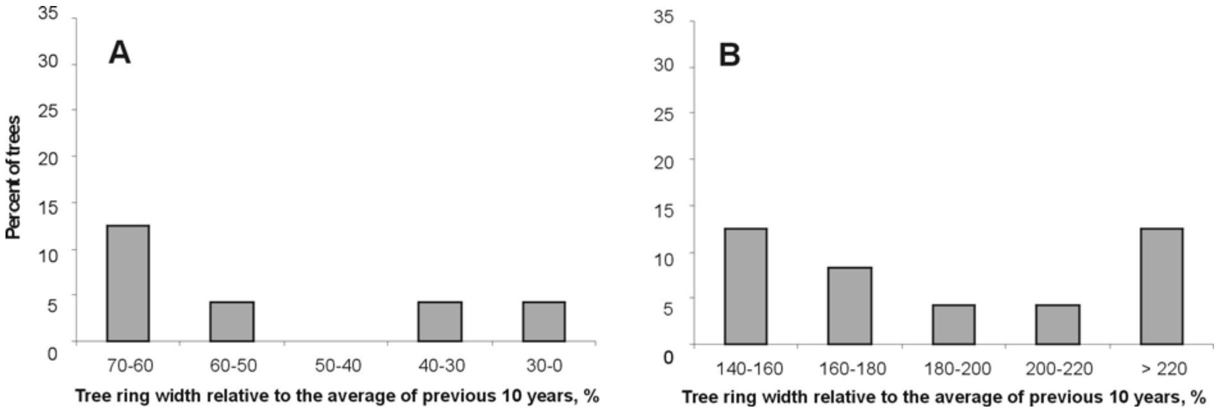

Figure 4: Tree ring width suppressions (A) and releases (B) at the border of forest patches with uniform structure formed after disturbances approx. 100 years ago.

Our findings confirm the conclusions of other studies that sudden changes of tree ring width are common after wind disturbances in coniferous forests (Lorimer 1985; Veblen et al. 1994; Cherubini et al. 1996; Kulakowski et al. 2003; Black and Abrams 2004; Splechna et al. 2005; Zielonka et al. 2009). Yet, our data demonstrates that abrupt suppressions may be the predominant type of trees' reactions immediately after severe storms and thus should not be disregarded in disturbance studies. In opposite, the decrease signals may help estimate more precisely the year of storm event when they are simultaneous and situated within a specific region. From the point of view of applying the release criteria for dating disturbances this means that a wrong estimate can be made. In many cases this would not be a problem because researchers often look for decades in which there was a disturbance. Yet, if higher precision is aimed suppression signs could also be used as a clue. One other point of interest is that if we had applied to our dataset approach, that does not take into account the exact position of trees, but detects only highly-repeated release patterns, we would miss to detect the disturbances in older periods. Because the number of surviving trees is rather small their reactions would diminish if the percentage of all reacting trees within the study forest is considered as clue for a stand replacing disturbance.

Conclusion

We found that the majority of survival trees at the border of a severe windstorm in Parangalitsa reserve experienced growth suppressions in the first 5 years after the event. Growth releases were delayed and predominant in the period from 5 to 10 years after the disturbance. In opposite survival trees at the borders of recently formed gaps displayed mostly sharp releases. Growth suppressions were high, but in low number of trees. Few survival trees at the borders of stand replacing disturbances that happened approximately 100 yrs. ago displayed clear release or suppression pattern. Yet, they could be used to date successfully the events in combination with other clues such as aerial photographs and age of clearly definable cohorts formed after the disturbances. Our results demonstrate that in retrospective disturbances studies in coniferous forests growth suppressions should not be neglected but used in combination with growth releases.

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