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POST-FIRE SUCCESSION: SELECTED EXAMPLES FROM THE KARST REGION, SOUTHWEST SLOVENIA

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A young shoot at the base of a flowering ash scrub that had been scorched in a wildfire.

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Post-fire succession: Selected examples from the Karst region, southwest Slovenia

ABSTRACT: Forests in Submediterranean Slovenia are threatened by wildfires every year. The article presents the main characteristics of post-fire regeneration in the Karst area. The rate of succession was studied by comparing two burned sites with different periods after the last fire. Field plant sampling was used to determine the plant cover and species composition on each site. Vegetation characteristics were contrasted with nearby unburned sites. We found that the plant species composition of burned areas is similar to that of areas unaffected by wildfire, and that the monitored site has been colonised by specific pioneer plant species five years after the wildfire.

KEY WORDS: biogeography, succession, wildfires, pioneer plant species, Kras plateau, Submediterranean Slovenia

Popožarna sukcesija: Izbrani primeri rastlinske sukcesije na Krasu

POVZETEK: Gozdove obsredozemske Slovenije vsako leto ogrožajo požari. V prispevku predstavljamo glavne značilnosti obnavljanja rastlinskega pokrova po gozdnih požarih na Krasu. Preučevali smo hitrost sukcesije s primerjavo dveh različno starih pogorišč. S terenskim popisom smo določili pokrovnost posameznih rastlinskih plasti in vrstno sestavo. Značilnosti rastja na izbranih pogoriščih smo primerjali tudi z nepogorelimi zemljišči v bližini na enakih rastiščnih pogojih. Ugotavljamo, da je vrstna sestava rastlinstva na pogorišču podobna kot na nepogorelemu zemljišču in da so pet let po požaru na pogorišču naseljene določene pionirske rastlinske vrste.

KLJUČNE BESEDE: biogeografija, sukcesija, gozdni požari, pionirske rastline, Kras, obsredozemska Slovenija

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1 Introduction

The Submediterranean Slovenia is the country's most fire-threatened area due to the climatic, vegetation and anthropogenic factors. Wildfires usually affect the ground and soils, field and shrub layers in a woodland (Jakša 2002). After the event, the vegetation cover regenerates by the process of succession (Lovrenčak 2003).

This paper presents the characteristics of post-fire succession in selected burned areas of the Karst region. Species composition of the various burned areas was examined and typical plant species were determined. Vegetation covers of two burned sites with different periods since the last fire were contrasted. In addition, vegetation characteristics of the burned sites were compared to nearby unburned sites with similar habitat conditions. Changes in plant cover density and species composition through time were noted, as well as the presence of pioneer species.

There has been a limited research on the dynamics of post-fire succession in Slovenia. Kovač (2012) examined three burned areas in Slovenian Istria that were affected by fire in a three-year interval. The vegetation of burned sites consisted mainly of pioneer species. The field layer plant cover density was found to positively correlate with the period since the last fire. Geršič et al. (2014) compiled the characteristics of plant cover regeneration in specific environments – on point bars, rockfall material, screes, construction pits and burned areas. They found a widespread presence of pioneer species. Time was highlighted as the most important factor of succession.

Studies of post-fire succession in Mediterranean ecosystems in France (Capitanio and Carcaillet 2008) and California (Harvey and Holzman 2014) have shown that the highest species diversity on burned sites occurs two years after the wildfire. In Spain it was found that the most common species on burned sites are those that are adapted to wildfires (*Quercus coccifera, Brachypodium retusuin*) (Pausas et al. 1999). In South African Mediterranean-climate ecosystems the field layer cover is greatest one year after the wildfire, while the shrub layer requires more than three years for regeneration (Rutheford et al. 2011). Australian ecosystems recover after longer periods; the shrub and tree layers reach the pre-fire cover after 30 years of succession (Gosper, Yates and Prober 2013).

2 Succession and pioneer species

Ecological succession is the process of vegetation cover regeneration following considerable changes in the environment. The process consists of a time specific sequence of animal and plant species replacing each other in a given area (Lovrenčak 2003; Kladnik, Lovrenčak and Orožen Adamič 2005).

The most common classification of succession types is based on the starting position. Primary succession takes place in areas where there are no soils, plants or animals (Kladnik et al. 2008). Secondary succession is a more common process that takes place in areas which had already been populated. Certain or most of the species in the community have been removed by a specific extraordinary event. However, other species along with the soil remain, so regeneration does not initiate on completely bare soil (Tarman 1992). Among others, secondary succession takes place on burned areas (Tivy 1993).

Succession progresses over a distinctive sequence of stages. Characteristic plant and animal species are present at each successional stage. The early stages are dominated by fast-growing species that are adapted to harsh habitat conditions and rapidly proliferate (Tarman 1992). These pioneer species stabilise the habitat with their extensive root systems and improve soil characteristics by adding organic material. In this way, colonisation of new species is enabled (Lovrenčak 2003).

In the Submediterranean Slovenia, the majority of the most characteristic plant species have pioneer features. The wider study area has specific habitat conditions, species that thrive here require more light and heat, and can withstand limited rainfall as well as dry, shallow, skeletal soils. Hop hornbeam (*Ostrya carpinifolia*), flowering ash (*Fraxinus ornus*) and whitebeam (*Sorbus aria*) are plant species that often grow together on carbonate bedrock. They frequently form associations with autumn moor grass (*Sesleria autumnalis*, Dakskobler, Kutnar and Zupančič 2014). Other pioneer species, which have modest habitat requirements and therefore promptly colonise degraded areas are common juniper (*Juniperus communis*), *Paliurus spina-christi*, blackthorn (*Prunus spinosa*), blackberry (*Rubus spec. div.*) and wild asparagus (*Asparagus acutifolius*) (Figure 1) (Kovač 2012).

3 Wildfires

Wildfires are defined as uncontrolled burning in the forest environment, spreading rapidly and causing damage (Pravilnik o varstvu gozdov 2009). Climate has the largest influence on their emergence and spread. Wildfires are most common in arid, warm, sunny and windy areas (Pečenko 2005).

In Slovenia, wildfires are primarily a disturbance in the environment. They affect social, environmental and economic functions of forests. Aesthetic value of forested land is reduced. Forest animals, especially the micro- and mesofauna in the soil, are threatened. Species composition of the vegetation is changed. Timber resources are lost, which reduces financial profits from forests. Infrastructure located in forests as well as property in nearby settlements is at risk (Jakša 2006).

Wildfires have significant effects on soil characteristics. A large proportion of organic material is burned therefore the organic horizons on burned sites are usually thinner (Urbančič 2002). Immediately after the wildfire nutrient availability increases due to the elements found in ashes and the release of minerals from the soil (Hernández, García and Reinhardt 1997). On the other hand, the removal or reduction of the vegetation cover leads to decreased water retention, faster runoff, soil erosion and nutrient leaching which impedes succession (Gimeno-Garcia, Andreu and Rubio 2000; 2007). To improve soil characteristics and accelerate succession some studies suggest adding compost to burned sites (Cellier et al. 2014).

Slovenian forests are classified into four levels of potential fire risk – very high, high, medium, and low (Jakša 2006). Of the fourteen forest management areas (GGO) Sežana is the most fire endangered (Poročilo … 2014). The high fire risk of the Submediterranean Slovenia stems from physical as well as human geographical factors. The climate, with high temperatures and dry season, plays an important role. The carbonate bedrock with great permeability reduces water retention, thus increasing drought and the probability

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Figure 1: Wild asparagus.

of forest fire occurrence. Strong winds, especially bora, contribute to the rapid spread of fires. Anthropogenic influence on the increased fire risk is manifested in the form of changes in natural vegetation; plantations of Scots pine (*Pinus sylvestris*) and black pine (*Pinus nigra*), both very susceptible to fires. The fire risk of the study area is further increased by transport corridors passing through, most notably the railway (Jakša 2002).

4 Methodology

The rate of vegetation regeneration is influenced by several factors including soil, climate, slope, aspect, elevation, wind exposure, and various anthropogenic impacts such as afforestation (Geršič et al. 2014). This paper deals exclusively with the role of time; the study sites were chosen accordingly. The time period between wildfires and field observations was chosen according to similar research on ecological succession in the Mediterranean (Lloret 1998; Meira-Neto 2011). The Slovenian Forest Service provided the fire inventory, from which Kamarija, burned in 2009, and Podgovec, burned in 2013, were selected (Figure 2). The location of the older burned site was compared against locations of fires in later years to ensure that the selected site was not subsequently affected by fire. It was verified that the same forest association was present at both locations, suggesting similar habitat conditions and thus allowing a comparison of plant cover primarily with respect to time. No post-fire reconstruction was carried out at any of the selected locations. Direct influence of anthropogenic factors on succession was therefore minimised.

In June 2014 four plant samplings were carried out – one on each selected burned site and one on an unburned site close to each study site (Figure 3; Figure 4). Vegetation characteristics of the unburned sites are assumed to be indicative of those of the burned study sites prior to the fire. The assumption is based on the comparable level and circumference of trees on sampling plots, indicating similar habitat conditions (Tivy 1993). Comparing the results of plant monitoring on burned sites with those on unburned sites allows an insight into the changes in land cover and species composition. The Braun-Blanquet method of plant sampling (Braun-Blanquet 1932) was used to determine abundance, cover and unity of each plant species

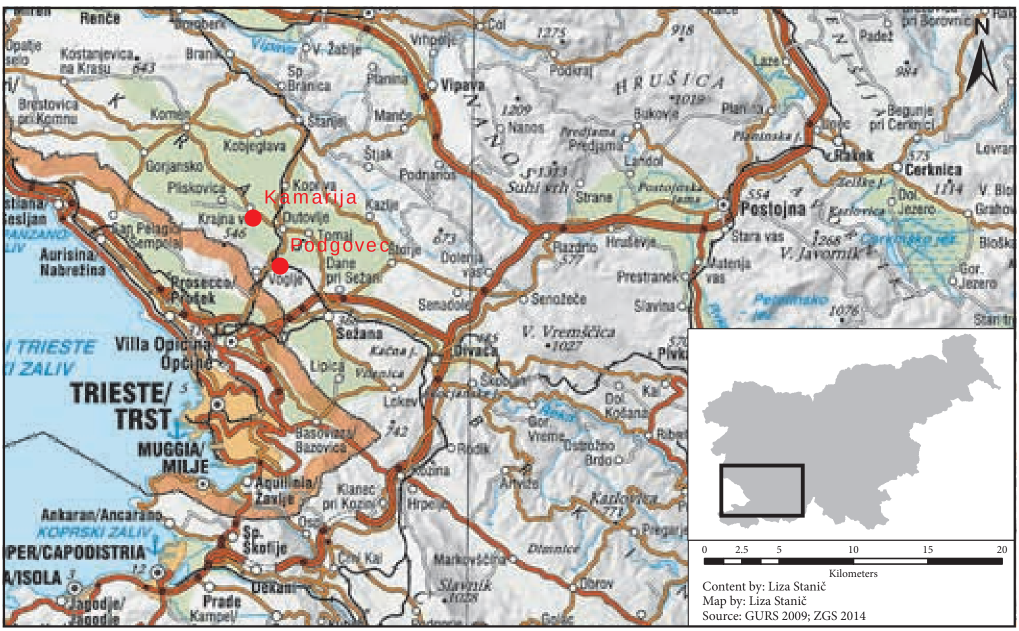

Figure 2: Location of study sites.

present (Lovrenčak 2003). The method is enables quick and accurate vegetation sampling as well as an analysis of species-habitat relationships (Wikum and Shanholtzer 1978). Species were identified using botanical identification keys (Pintar and Wraber 1990; Lippert 2000; Fletcher 2007; Schauer 2008; Lang 2013).

Figure 3: Locations of sampling plots at Kamarija.

Figure 4: Location of sampling plots at Podgovec.

5 Characteristics of selected burned sites

The study burned sites are located in the GGO Sežana in the south-western Slovenia. They lie on the Karst Plateau, where the bedrock is made of permeable Cretaceous limestone (Jurkovšek 2014). The terrain is levelled and no surface watercourses are present (Natek and Natek 2008). The climate is Submediterranean with high summer daytime temperatures and droughts due to the permeable bedrock. Owing to its location on the border between Mediterranean and continental influences, the region is characterised by strong winds, most notably the north-eastern bora wind (Senegačnik 2012). The most common soil types are redzinas, chromic cambisols and the region's typical red soil (*terra rossa*). Natural vegetation has been almost completely removed by intensive logging in the past. Systematic attempts to afforest the barren surface with black pine (*Pinus nigra*) began in the 19th century (Urbančič, Ferlin and Kutnar 1999; Zupančič and Žagar 2008). Efforts have been successful and today anthropogenic black pine plantations are one of the most common forest associations in the Karst region (Senegačnik 2012).

The forest association on both study sites was found to be hop hornbeam with *Sesleria autumnalis* (*Seslerio-Ostryetum*) which was at the oldest development stage prior to the fire (ZGS 2009–2013; 2014). This forest association is typical for karst as it thrives on dry, sunny and warm sites with shallow soils on carbonate bedrock (Dakskobler, Kutnar and Zupančič 2014). The older burned study site is Kamarija. It is located north of the town of Sežana, approximately 500 m south of the village Krajna vas along the Dutovlje–Pliskovica road. The second burned study site is Podgovec, which is located northeast of Sežana, 1 km southwest of the village Kreplje along the Sežana–Dutovlje railway line. Selected characteristics of the burned areas are presented in Table 1.

Table 1: Selected characteristics of burned study sites (ZGS 2009–2013; 2014).

Burned area	Kamarija	Podgovec
Location	45° 45' 50.48'' N 13° 48' 24.01'' E	45° 44' 5.9'' N 13° 49' 55.11'' E
Altitude (m)	265	260
Exposition	NW	N
Slope (°)	5	6
Date of fire event	14/04/2009	22/07/2013
Extent of burned area (ha)	2.25	2
Cause of fire	Unknown	Communications (train)
Type of fire	Surface	Surface
Post-fire reconstruction	No	No

6 Vegetation characteristics of studied burned sites

The results of the vegetation monitoring on burned sites were compared with the results from unburned sites nearby. Plant cover characteristics were examined by determining the species composition, abundance, cover and unity according to the Braun-Blanquet method.

6.1 The Kamarija burned site

The Kamarija burned site is separated from the comparative unburned site by a firebreak and a distance of 245 m. From this it can be assumed that the comparative unburned site was not affected by the fire that burned the study site (Figure 5).

The stoniness amounts to 5% on both sampling plots. The comparison of tree height and breast height circumference returns no significant differences between the burned and unburned site (Table 2). Similar tree heights and circumferences on both sites suggest analogous habitat conditions (Tivy 1993), justifying the comparison between the two sites. The differences in vegetation characteristics can be largely attributable to effects of the fire.

Figure 5: Kamarija burned site (left) and unburned comparative site (right).

Table 2: Comparison of the breast height circumferences and the heights of trees on the Kamarija burned site and unburned comparative site.

	Burned site	Unburned site
Mean tree circumference (cm)	up to 50	50–100
Mean tree height (m)	10–20	10–20
Greatest tree circumference (cm)	155	97
Greatest tree height (m)	24	20

The comparison of vertical vegetation layers covers reveals differences between sampling plots (Table 3). The biggest discrepancies between the burned and unburned sites are in the shrub layer covers – 5% on the burned site compared to 30% on the unburned site. Small differences were recorded in the tree layer covers.

Table 3: Comparison of vertical vegetation layer covers on the Kamarija burned site and comparative unburned site.

		Burned site	Unburned site
Cover of specific vertical vegetation layers on sampling plots (%)	Tree layer	50	60
	Shrub layer	5	30
	Field layer	95	95
	Total	150	185

The burned site tree layer is dominated by flowering ash (*Fraxinus ornus*) and sessile oak (*Quercus petraea*). Both species are also present on the unburned site, but black pine (*Pinus nigra*) has the greatest cover, abundance and unity. The shrub layer consists of similar species as the tree layer with the addition of common juniper (*Juniperus communis*). On the burned site, blackberry (*Rubus spec. div.*) and common privet (*Ligustrum vulgare*) were also recorded in the shrub layer.

The herb layer species composition is similar on both sampling plots. The most common species on both sites is tor-grass (*Brachypodium pinnatum*). *Cirsium pannonicum* is also present in an equal extent on both sampling plots. Other abundant plant species on the burned site are common tormentil (*Potentilla erecta*) and orchard grass (*Dactylis glomerata*). In contrast, the abundant species on the unburned sites are yellow salsify (*Tragopogon dubius*), *Leucanthemum ircutianum*, meadow clary (*Salvia pratensis*), purple-globe clover (*Trifolium alpestre*) and hedge bedstraw (*Galium mollugo*).

6.2 The Podgovec burned site

The fire on the Podgovec burned area occurred 11 months prior to the vegetation monitoring. The plot chosen to provide the comparative vegetation characteristics is located 280 m away from the study site and

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Figure 6: Podgovec burned site (left) and unburned comparative site (right).

separated by a railway line. Due to these characteristics it can be assumed that the comparative site was not affected by the fire (Figure 6). Traces of fire are clearly visible on the burned site – tree trunks are scorched to a height of 3.5 m, the forest floor is covered with remains of charred twigs and cones.

The stoniness on the burned site is 15% compared to 10% on the unburned site. There are no notable differences in tree height and circumference between the two sampling plots (Table 4). This suggests similarity of habitat conditions, allowing for a meaningful comparison of vegetation characteristics.

Table 4: Comparison of the breast height circumferences and the heights of trees on Podgovec burned site and unburned comparative site.

	Burned site	Unburned site
Mean tree circumference (cm)	over 100	50–100
Mean tree height (m)	over 20	over 20
Greatest tree circumference (cm)	142	128
Greatest tree height (m)	30	26

The analysis of differences in tree height and circumference was followed by the comparison of specific vertical vegetation layers covers (Table 5). The difference in tree layer cover between the burned and unburned site is minor. As result of the fire, the shrub layer is considerably sparser. On the burned site its cover amounts to only 5%, while on the unburned site it is 30%. Field layer cover is also noticeably lower on the burned than on the unburned site. From the comparison with the unburned site it can be assumed that prior to the fire the field layer covered almost the entire sampling plot, while following the fire its cover is reduced to less than one third. The moss layer covers 5% of the unburned site but is not present on the burned site.

Table 5: Comparison of vertical vegetation layer covers on the Podgovec burned site and comparative unburned site.

		Burned site	Unburned site
Cover of specific vertical vegetation layers on sampling plots (%)	Tree layer	50	60
	Shrub layer	5	30
	Field layer	30	95
	Moss layer	0	5
	Total	85	190

The analysis of species composition revealed that black pine (*Pinus nigra*) dominates the tree layer on both sampling plots. The species has a lower cover on the burned site (50%) compared to the unburned site (65%) due to fire damage to lower branches. The burned site shrub layer consists mainly of blackthorn (*Prunus spinosa*) and flowering ash (*Fraxinus ornus*). All scrubs have bare scorched branches with no leaves.

Some flowering ash scrubs have young shoots at the base. The shrub layer is more diverse on the unburned site. In addition to the blackthorn and flowering ash, there are common juniper (*Juniperus communis*), blackberry (*Rubus spec. div.*) and sessile oak (*Quercus petraea*). The burned site field layer is patchy, comprising tor-grass (*Brachypodium pinnatum*), blackberry (*Rubus spec. div.*) and wild asparagus (*Asparagus acutifolius*). On the comparative sampling plot the field layer is more uniform. Besides the species present on the burned site, it is made up of *Melittis melissophyllum*, *Helleborus odorus* and ivy (*Hedera helix*).

7 Findings about post-fire vegetation regeneration

The results of vegetation monitoring demonstrate that ecological succession of burned areas occurs rapidly. The fire-affected Podgovec site can be clearly distinguished from unburned surrounding areas. The extent of the fire is clearly demarcated by a sparse field layer, scorched tree trunks and charred plant remains on forest floor. Three years after a wildfire Kovač (2013) found advancing vegetation recovery, however the burned site could still be clearly distinguished from unburned sites. The Kamarija site, which had been burned five years before the monitoring, can hardly be differentiated from adjacent unburned areas. The differences become apparent only after analysing the results of vegetation monitoring. Five years of ecological succession are therefore sufficient for plant cover regeneration to such an extent that burned sites are visually indistinguishable from the surrounding area. A possible explanation for the quick recovery is the wildfire type that occurred on study sites because the surface fire damaged only the field and shrub layers. Studies in Spain showed that if all vegetation layers are removed the colonisation of tree individuals takes at minimum 25 years (Röder et al. 2008). In Mediterranean-climate ecosystems the field layer regenerates after two years (Pausas et al. 1999; Rutheford et al. 2011), and the shrub layer after 10–15 years (Capitanio and Carcaillet 2008).

Analysis of vertical vegetation layers suggests that the cover is greater on older burned areas. The total vegetation cover is 85% at the Podgovec site compared to 150% at the Kamarija site. These differences arise mainly due to the covers of field layer. Both of the burned area plot sites have similar tree and shrub layer covers – 50% and 5% respectively. The field layer, on the other hand, covers 30% of the plot site at Podgovec and 95% at Kamarija. This points to the conclusion that the field layer cannot regenerate to the pre-fire state in one year. However, in five years the field layer returns to its original extent, while the shrub and tree layer covers remain constant. The comparison of vertical vegetation layers covers at the Kamarija site with unburned nearby areas suggests that five years are not sufficient for the regeneration of tree and shrub layers.

In addition to vegetation layers covers, this paper examines burned area species composition, focusing on the presence of pioneer plant species. Vegetation sampling found similar species on burned sites and nearby unburned sites. This is in line with studies showing demonstrating that species composition of burned sites is affected by adjacent sites (Keeley, Fotheringham and Baer-Keeley 2005). Typical species of burned sites in Slovenian Istria are aspen (*Populus tremula*), flowering ash (*Fraxinus ornus*) and downy oak (*Quercus pubescens*) (Geršič et al. 2014). Our monitoring found a different species composition. On the Podgovec burned site the following pioneer species were detected: flowering ash (*Fraxinus ornus*), blackthorn (*Prunus spinosa*), wild asparagus (*Asparagus acutifolius*) and blackberry (*Rubus spec. div.*). The same species were also present on the comparative plot. Well-known pioneers flowering ash (*Fraxinus ornus*) and common juniper (*Juniperus communis*) were found both on the Kamarija burned site and the nearby unaffected area. Hop hornbeam (*Ostrya carpinifolia*), blackberry (*Rubus spec. div.*) and common privet (*Ligustrum vulgare*) are exceptions because they were recorded only on the Kamarija burned site but are not present on the comparative unburned site.

8 Conclusion

Wildfires frequently threaten specific areas particularly in Submediterranean Slovenia. Nevertheless, few geographic studies of post-fire plant succession have been conducted. This paper presents the main findings derived from field plant sampling on two selected burned areas in the Karst region. The sampling was carried out using the Braun-Blanquet method. To assess the changes in vegetation characteristics on burned areas compared to the state before the wildfire, plants were sampled on comparable unburned areas nearby. Species composition and plant cover densities of individual vertical vegetation layers were recorded.

The surface fire affected the selected areas. This type of wildfire damaged the ground, field and shrub vegetation layers. The tree layer remained largely intact except for the lowest branches. The time span between burned areas discussed is five years. In this time, the field layer regenerated to the extent comparable to the unburned area. The plant cover density of the shrub layer remains more modest than before the wildfire even after five years.

The plant species composition of burned areas is similar to that of areas unaffected by wildfire. Five years after the wildfire the monitored site has been colonised by specific pioneer plant species such as hop hornbeam (*Ostrya carpinifolia*), blackberry (*Rubus spec. div.*) and wild privet (*Ligustrum vulgare*). Due to specific habitat conditions with dry, warm and sunny climate, and shallow, rocky soils, many common Submediterranean plant species are classified as pioneers. It is therefore typical for both burned and unburned areas to contain pioneer plant species. Furthermore, surface fires have little effect on higher vertical vegetation layers so there is little change in the insolation of the site. Consequently, there is no mass colonisation of pioneer species, only individual plants are present.

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