ECOLOGICAL CONSEQUENCE OF OIL ACCIDENTS IN ECOSYSTEMS OF LOWLAND FOREST

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Abstract

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The paper presents the results of preliminary research into a changed condition of the forest ecosystem in lowland forests of pedunculate oak. Research was carried out in the area of Zagreb Forest Administration, Management Unit Žutica. MU Žutica is an intensively exploited oil and gas area with a very complex exploitation system consisting of as many as 289 oil and gas wells (1 well per 17.67 ha). Based on the largest proportion of the well area in relation to forest vegetation, the following compartments were selected for analysis: compartments 44 and 115 with 15 wells and compartment 127 with 9 wells. Compartments 70 and 101 (no wells) were selected as check compartments. Long increment cores were taken with a Pressler borer from pedunculate oak trees during 1998 and 2004. A quantity of 250 increment cores were taken in 1998 and 40 increment cores were taken in 2004. No samples could be taken in compartment 101 since all the trees had been cut down as a result of an accident in the year 2000 (a burst underground oil pipe). Four and five ten-year time series respectively were determined on the samples. The study of radial increments was combined with pedological research, conducted in six localities chosen in the spring of 2003. Oil and/or oil well fluid contamination in the forest soil was investigated. The analysed radial increments of all the cores taken in 1998 and 2004 show distinct variability in radial increments of all oak trees, which indicates a disturbed condition of these stands. Notably, in both measurements pedunculate oak trees in all the stands, regardless of the stands' age or tree breast diameters, show similar reactions to changes in the stands' ecological condition. The analysis of mineral oil content in the soil revealed severe contamination with oil in the compartments, which renders the soil unsuitable for plant production. With regard to evident tree dieback across the management unit, the conditions and data of snag removal by felling (in the principal and intermediate yield) were taken into account. A GIS map was constructed showing the spatial distribution of snag cutting intensity, as well as the plots in which increment was determined and the soil analysed. According to the cartographic presentation, cutting intensity was concentrated in the centre of the management unit, precisely where there is the largest number of oil wells and oil transport communications. The results point to the need of introducing permanent monitoring of forest condition in this area through an interdisciplinary scientific approach in order to arrive at more exact explanations of the changes.

Key words: pedunculate oak, dieback, radial increment, oil and gas fields, GIS, Croatia

Introduction

Forests along the river Sava in Croatia are one of the most valuable forest ecosystems. However, their natural appearance and natural stability have been drastically changed by long-lasting human impact. As late as the 18th century this area featured almost intact virgin forests growing in an undisturbed rhythm and perfect ecological balance (Baričević, 1998).

The harmonious balance of these biocoenoses was abruptly unsettled by human interventions in the 19th century. The high value of pedunculate oak on the European market in the 19th century led to the almost universal cutting down of old virgin forests and an introduction of a forest management method involving pure stands of pedunculate oak. This management method proved counter-productive, as it failed to achieve biological balance. It finally resulted in defoliation and mildew attacks and the consequent dieback of oak forests along the Sava. This period was marked with planning and regulating the watercourses of the rivers Sava, Lonja and Česma, which affected all the site factors. The current hydro-technical operations involve ameliorations of a part of Lonjsko Polje and Črnec Polje, digging the Lonja-Strug canal, the Deanovec canal, etc. On the one hand, these operations have been beneficial (for agriculture), but on the other they have disrupted the natural flood cycle and changed groundwater courses (Dekanić, 1975; Prpić et al., 1979; Matić, 1996; Mayer, 1995). The discovery of black gold – oil – at the beginning of the century in these areas has aggravated the condition of the already disturbed ecosystem. The construction of forest roads and communications for oil and gas exploitation has rapidly opened forest stands. The roads were built with no regard for the microrelief, while the insufficient number of road outlets caused the terrain to be bogged and swamped (Vorel, 1991). The final consequences were oxygen deficiency in the soil, a lessened microbiological activity in the soil and the degradation of vegetation, which was not adapted to such conditions. Moreover, oil and gas exploitation and transport produces wastewater, mud water and incidental situations, which, despite attempts at rectifying and isolating them, additionally threaten the site (Reintam, 1995; Reintam, Kaar, 1999). Research in the world has also confirmed that pollution with oil and its waste has both immediate and long-term effects. Since oil disintegrates very slowly in the soil, it affects the pedogenesis in the site (Braddock et al., 2003). Forest communities and ecological factors are also highly negatively affected by the contaminated and polluted waters of the river Sava and its tributaries – the receptors of mechanical waste, non-humified faecal waste, large quantities of chemical waste, acids and various other toxic substances (Vujanić, 2004). They all act synergistically on the development of trees and stands and on their growth and increment (Rac, 1998; Vorel, 1991).

Materials and methods

Research was conducted in the area of Zagreb Forest Administration, MU "Žutica". Žutica Management Unit is situated about 30 km from Zagreb in a square bordered by the towns of Ivanić-Grad, Popovača, Sisak and Velika Gorica (Lekenik). It is the closest to Ivanić-Grad. For the most part it consists of a polygonal-shaped coherent forest complex shape, which gradually narrows down in the northwest–southeast direction. Its average length is about 12.5 km and the average width is about 6 km (Fig. 1).

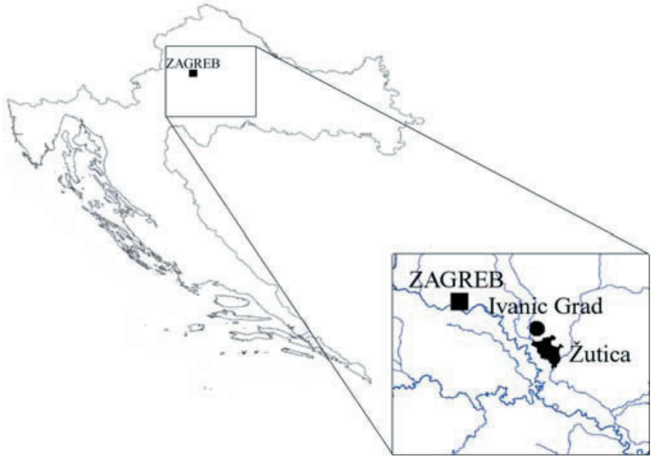

Fig. 1. Research area.

Žutica Management Unit covers an area of 6116.68 ha, of which forest stands account for 5107.41 ha and the remaining 1009.27 ha belong to the category of non-forested and infertile land. The altitude ranges from 93 to 99 m above sea level. The predominant soil is planosol. The management unit is made up of 201 compartments or 930 sub-compartments (stands) averaging 6.27 ha in surface area. This is the most open management unit with 76 km of hard forest roads and other roads used for oil and gas exploitation. The management unit has been very intensively exploited for oil and gas since as early as 1964. The highly complex exploitation system consists of 289 oil and gas wells (1 well per 17.67 ha) in open clearings connected with vehicle roads and widened pathways for underground oil and gas transport. Two large central structures for oil and gas collection, preparation and transport have also been built. In the area of the management unit gas has been drilled since 1964: a quantity of 17 094 ($10^6 m^3$) was produced by 31 December 2001, while gas has been exploited since 1966, with 6984 ($10^6 m$) produced by 31 December 2001 (Aunedi, 2002).

For the purpose of analysing the forest ecosystem condition, compartments 44 (15 wells or 1 oil well per 2.18 ha), 115 (15 wells or 1 oil well per 1.51 ha) and 127 (9 wells or 1 well per 2.89 ha) were selected on the basis of the largest proportion of surface oil wells in relation to forest vegetation, as well as compartment 70 and 101 (no wells) as check compartments. Long increment cores were taken from pedunculate oak trees with a Pressler drill during 1998 and 2004. A quantity of 250 increment cores was taken in 1998. No samples could be taken in compartment 101 in the last measurement in 2004 since all the trees had been cut down as a result of an accident (a burst underground oil pipe in 2000). A total of 40 cores were taken in order to control trends of previous measurements. Four and five 10-year series respectively were determined on the cores (Table 1). Radial increment was analysed in the laboratory of the Department of Forest Management at the Faculty of Forestry, University of Zagreb using the DIGITALPOSITIOMETER Lega Smil3.

Radial increment research was connected with results of pedological research (Pernar et al. 2004), conducted in six localities selected in the spring of 2003. Oil and/or oil well fluid contamination of forest soil in the localities with different kinds of soil pollution was investigated. Investigation also included mud pits or the sites where a pipe had burst within the field itself in compartments 44, 94, 112 and 141 (five plots), and one plot designated as a check plot in compartment 48. Sampling was conducted at three soil depths twice a year (Table 2). The soil samples were analysed in the laboratory of the Department of Silviculture at the Faculty of Forestry, University of Zagreb.

With regard to the evident tree dieback across the entire management unit, the condition and data of snag cutting in the management unit (in the principal and intermediate yield) in the last ten years (1988–1998) were analysed. A GIS map was constructed showing the spatial distribution of snag cutting intensity, as well as the plots in which increment was determined and the soil analysed (Figs 2, 3).

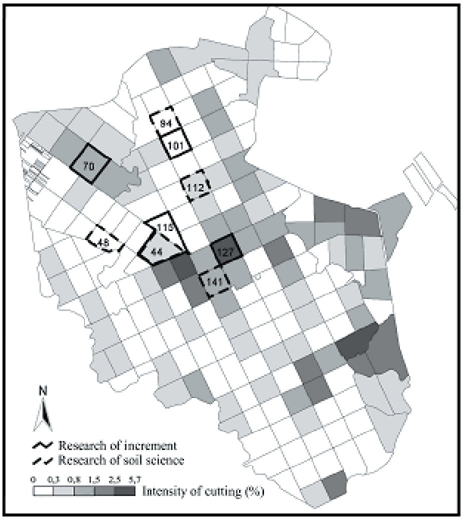

Fig. 2. Spatial distribution of snag cuttings intensity (%) – intermediate yield.

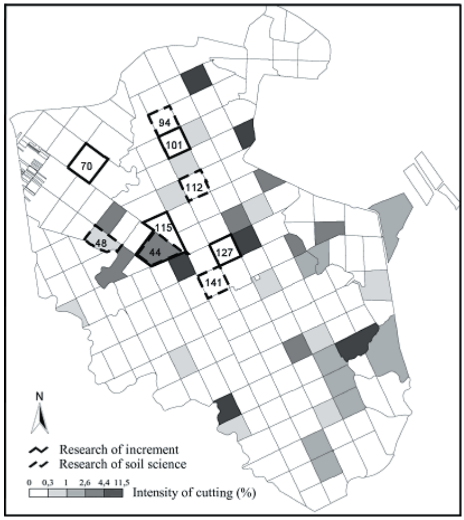

Fig. 3. Spatial distribution of snag cuttings intensity (%) – main yield.

Results and discussion

The analysed radial increment of all increment cores taken in 1998 and 2004 indicates distinct variability in radial increments in all oak trees, which points to the disturbed condition of these stands. It can be noted that pedunculate oak trees in all stands in both measurements, regardless of the stands' age or the tree breast diameters, react similarly to changed ecological conditions in the stands. For further analyses of time series of two measurements, the arithmetic means of radial increment (annual ring width) for each year were presented as functions of time in Figs 4 and 5. The parameters of linear trends (b_0, b_1) of radial increments for the 10-year period were shown in Table 1. The data in Figs 4 and 5, involving distinct variability of radial increment and its continual decrease, are an indication of a disturbed ecological balance not only in these stands but also in the entire management unit. A more severe decrease in the increment in the stands situated in compartments 44, 115 and 127 began around 1962 and culminated in 1968. The change in the increment coincides with the beginnings of more intensive oil and gas exploitation in the management unit of Žutica. In the control stands (compartments 70 and 101), a change in the increment was noted in 1984 and 1987, which coincides with the introduction of a new waterflood method intended to increase oil and gas production, which was gradually applied over the whole area of the management unit in 1976. An identical decrease in tree increments is also noted in compartments 44, 115 and 127. Apart from these, there have also been other stress years which may, directly or indirectly, be linked to oil and gas exploitation, depending on the time of oil drilling (Aunedi, 2002).

T a b l e 1. Linear parameters of pedunculate oak time series.

1st inventory										
Time series	Investigation area						Control area			
	Department 44		Department 115		Department 127		Department 70		Department 101	
	b_0	b_1	b_0	b_1	b_0	b_1	b_0	b_1	b_0	b_1
1959–1968	1.690	0.033	2.076	0.997	1.789	0.043	2.042	0.046	0.991	0.019
1969–1978	2.192	-0.012	3.211	0.061	2.750	-0.040	3.130	-0.039	3.379	-0.117
1979–1988	2.271	-0.034	3.436	0.031	2.554	-0.012	4.288	-0.079	2.707	0.008
1989–1998	2.127	-0.008	2.320	0.038	2.294	-0.006	2.313	0.116	2.055	0.036
2nd inventory										
Time series	Investigation area						Control area			
	Department 44		Department 115		Department 127		Department 70		Department 101	
	b_0	b_1	b_0	b_1	b_0	b_1	b_0	b_1	b_0	b_1
1955–1964	1.376	0.045	4.360	-0.287	1.779	0.086	2.572	0.025	Accident of oil in the year 2000	
1965–1974	2.264	1.000	3.447	-0.159	2.342	-0.047	4.202	-0.218		
1975–1984	2.488	-0.014	3.032	-0.011	2.462	-0.028	3.132	0.028		
1985–1994	1.919	0.072	2.012	0.078	1.652	0.074	2.677	0.090		
1995–2004	2.293	-0.046	2.258	0.001	1.413	0.052	2.081	0.085		

Sampling and general soil characterisation was followed by analysing the composite samples for total and mineral oil content (oil carbohydrates) in the soil and in the water eluate, electrical conductivity and heavy metal content. Since the plots were established in the sites of recorded soil pollution with oil well fluids, they were clearly exposed to significantly different impacts, whether those of time, (carbohydrate biodegradation), quantity of oil liquid dropping or its distribution in space, and consequently to differing rates of concentration changes (due to microrelief, soil humidity or surface waters).

Preliminary research results show that in the site of the water mud pit (compartment 112) the entire soil profile shows an increased oil carbohydrate content. The soil surface in the microdepression containing an oil spill site is the most severely contaminated with hydrocarbons. In other localities initial measurements do not indicate soil contamination with hydrocarbons. Based on the analysis for mineral oil content in the soil (Table 2), it can be concluded that the soil in plot P2 in compartment 112 shows a high degree of oil contamination and is thus unsuitable for plant production (Pernar et al., 2004).

With regard to the issue of tree dieback, the spatial distribution of snag felling intensity in the intermediate yield (0–5.7%), presented with the grey colour gradation using GIS, is given in Fig. 2, while the snag felling intensity in the principal yield (0–11.5%) is shown in Fig. 3. The localities of preliminary increment and soil research were also included. According to the cartographic maps, the intensity of snag felling is concentrated in the centre

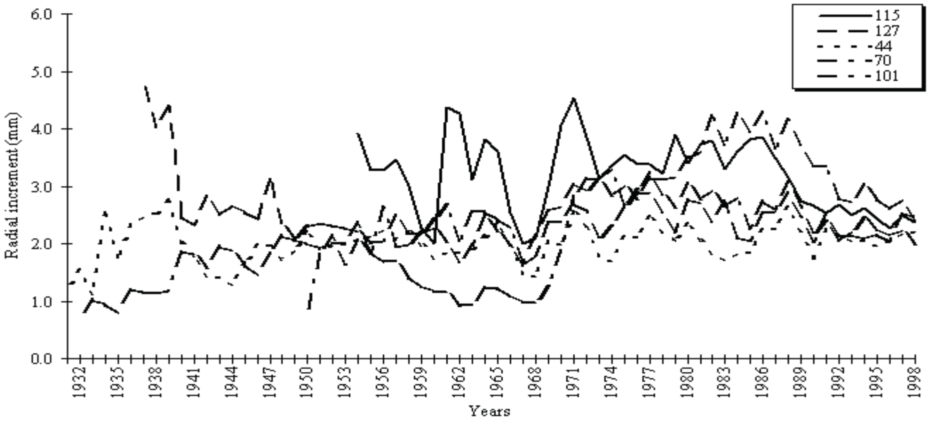

Fig. 4. Time series of pedunculate oak in Žutica for period 1933–1998.

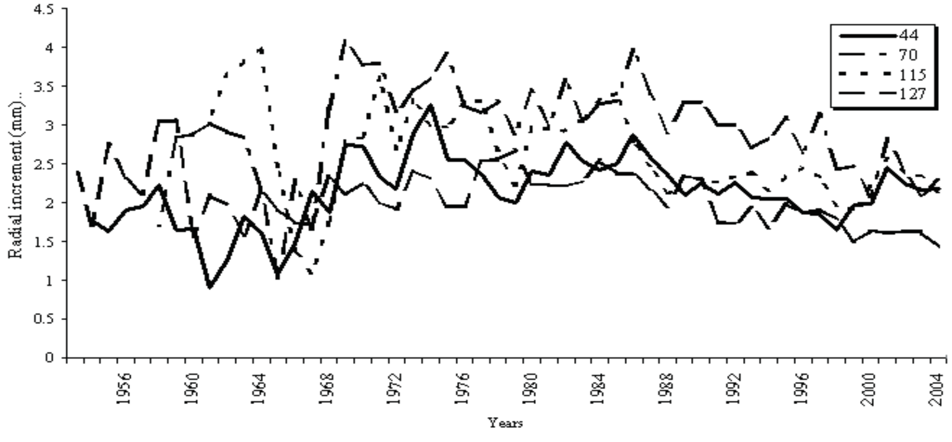

Fig. 5. Time series of pedunculate oak in Žutica for period 1953–2004.

and towards the northeast of the management unit. The reason for the former is that this area contains the largest number of oil wells and oil transport communications, while the latter is related to a changed groundwater regime resulting from the construction of the Lonja-Strug relief canal running along the north and northwest boundary of the management unit.

T a b l e 2. Lipoid matters and petrol hydrocarbons in soil.

Forest compartment, soil sample plot and depth of sampling	Lipoid matters				Total petrol hydrocarbons (mineral oil)			
	April, 2003	October, 2003	May, 2004	November, 2004	April, 2003	October, 2003	May, 2004	November, 2004
	mg kg^{-1}							
94 (P1) 0-10	90.802	125.769	129.662	224.347	7.347	15.813	15.960	34.545
94 (P1) 30-50	28.308	32.494	27.287	118.040	4.202	3.906	5.852	28.700
94 (P1) 70-100	25.395	20.911	22.867	96.915	4.220	2.387	4.018	14.770
112 (P2) 0-10	797.121	1341.895	884.715	748.832	233.597	269.675	318.728	204.190
112 (P2) 30-50	666.586	2422.520	1178.905	1313.520	347.297	794.255	461.615	482.965
112 (P2) 70-100	692.367	374.212	1487.750	1517.360	300.353	157.167	738.745	546.805
112 (P3) 0-10	1916.140	2481.375	2385.350	2912.800	364.469	156.275	304.500	154.500
112 (P3) 30-50	90.176	77.936	39.715	115.375	21.083	21.693	9.891	22.365
112 (P3) 70-100	40.070	38.349	63.499	68.672	13.898	15.106	18.648	32.935
141 (P4) 0-10	561.817	540.040	149.247	210.112	82.680	88.781	19.978	16.695
141 (P4) 30-50	33.847	43.310	13.689	99.905	10.323	15.526	4.935	17.780
141 (P4) 70-100	43.982	65.319	18.454	266.402	18.833	26.432	5.698	99.575
44 (P5) 0-10	108.064	78.338	62.751	172.412	12.442	35.602	8.582	25.025
44 (P5) 30-50	27.559	22.958	19.923	64.057	5.447	5.418	7.182	16.450
44 (P5) 70-100	16.407	19.835	20.215	81.705	8.153	7.350	5.817	10.115
48 (P6) 0-10	149.614	95.635	70.051	222.137	10.487	7.830	4.767	62.160
48 (P6) 30-50	17.070	17.186	14.073	85.117	9.165	6.069	2.919	33.530
48 (P6) 70-100	14.118	20.761	13.377	82.842	11.152	9.968	3.850	16.870

Conclusion

Based on the maps and the analysed data, the following conclusions may be drawn:

Preliminary research into radial increment and soil indicates a threatened condition of the forest ecosystem in the management unit of Žutica. Radial or diameter increment of pedunculate oak also manifests a continually decreasing trend (Figs 4, 5).

A decrease in the increment has been particularly distinct in the last 40–50 years, when interventions in the surface and underground area have taken place (the building of forest roads, ameliorative treatments, the construction of oil and gas exploitation and transport infrastructure). These treatments have acted synergistically on the forest ecosystem and have been reflected on the increment and production of timber volume of pedunculate oak and other species. As a consequence, there has been an increase in the number of snags. It should be pointed out that the same phenomenon has occurred in all the stands regardless of age (Figs 2, 3).

The results of pedological research in compartments 44 and 141 support radial research in compartments 44 and 127 (Figs 2, 3).

The above results point to the need of organising permanent monitoring of the forest condition in the period to come. To secure a more precise explanation of the recorded changes it is necessary to apply an interdisciplinary scientific approach.

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