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DYNAMICS AND DISTRIBUTION OF PEAT WATER MACRO NUTRIENTS (N, P, K, Ca, Mg AND S) IN OIL PALM PLANTATION BASED ON SEASON, PEAT THICKNESS, CHANEL DISTANCE AND PLANT AGE

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SUMMARY

Peatland that has been converted to other land uses such as oil palm plantation has to be well managed. Fertility of peatland will influence oil palm productivity. Macro nutrients such as nitrogen, phosphorus, potasium, magnesium and sulfur is required by oil palm for optimal growth and production. Naturally, oil palm requirement of the nutrients could not be supplied sufficiently from the soil so that fertilization is needed. Fertilizing has to be well carried out in order to increase nutrient absorbtion efficiency. The objective of the research is to study peat water macro nutrients (N, P, K, Ca, Mg and S) distribution in oil palm plantation based on season, peat thickness, channel distance and plant age. Result of the research showed that content of dissolved P, K, Ca, Mg and S were higher in dry season whereas N was higher in rainy season. In shallow peat, content of dissolved N, P, K, Ca and Mg were higher than that in deep peat however S was lower. Dissolved N, P, K, Ca Mg and S tendedto increase by distance from channel. Dissolved N, P, K, Ca, Mg and S were higher in more than 15 years old oil palm than that in 6-15 years old oil palm.

Keywords: *peatland, peat water macro nutrients, distribution, oil palm*

INTRODUCTION

The utilization of peatland for oil palm plantations has been increasingly widespread due to the limited availability of mineral land. Peatland area in Indonesia is about 14.93 million ha and about 15.1% in the form of peat that has been cultivated as farmland (annual crops, plantations and industrial plants) (Wahyunto, 2013). Approximately 1.54 million hectares or 20% of the total area of oil palm plantations in Indonesia are on peatlands (Ritung *et al.*, 2012). Utilization of peatlands for oil palm plantations become a major challenge not only related to the amount of input that should be given, but also related to specific management of peatlands in order to avoid land degradation.

Utilization of peatland for oil palm plantations will not only be challenged by problems of oil palm production, but also by efforts for preserving the environmental balance. Peatland management into productive land must comply to the principles of sustainability by utilizing environmentally friendly and low emission technologies. These technologies are including water management, setting up drainage network, amelioration, and fertilization (Las *et al.*, 2012).

Peatland that has been converted to other land uses such as oil palm plantation has to be well managed. Fertility of peatland will influence oil palm productivity. Tropical peatland usually has low fertility. Macro nutrients such as nitrogen, phosphorus, potasium, magnesium and sulfur is required by oil palm for optimal growth and production. Naturally, oil palm requirement of the nutrients could not be supplied sufficiently from the soil so that fertilization is needed. In oil palm plantation, fertilization is given regularly in the form of macro nutrients and micronutrients fertilizer. Fertilizer is given higher in older oil palm than younger oil palm. Nutrients from fertilizer are easily diluted and leached to the ground water due to high porosity of peat. Fertilizing has to be well carried out in order to increase nutrient absorbtion efficiency.

Objective of the research is to study peat water macro nutrients (N, P, K, Ca, Mg and S) distribution in oil palm plantation based on season, peat thickness, channel distance and plant age.

METHODS

The study was carried out at Kimia Tirta Utama Oil Palm Plantation Company at Siak Regency, Riau Province, Indonesia (0^0 43' 33" - 0^0 46' 9" N and 101^0 44' 24" - 101^0 46' 22" E). The study was conducted in rainy season (March) and dry season (August) of 2015 in peatland. The peatland used in this study was shallow (thickness less than 3 meters) and deep (thickness more than 3 meters) peat, with hemic level of decomposition stage (rate of 33 – 66 %) and clay substratum. The oil palm plantation used in this study were in two ages, ie 6 – 15 and more than 15 years old plantation. Fertilizer is given about 57 kg N, 7 kg P, 40 kg K, 15 kg Ca kg, 15 kg Mg , 0 S kg/ha/year and about 115 kg N, 41 kg P, 105 kg K, 17 kg Ca kg, 15 kg Mg , 6 S kg/ha/year for 6-15 and more than yers old plantation respectively. The observations were done in varies distances from chanel, those are 10, 25, 50, 75, 100, 150 meters by installing piezometer (Figure 1).

Peat water samples in piezometers were collected at 1 meter deph from surface. Peat water samples were analized to determine peat water macro nutrients (N, P, K, Ca, Mg and S). N was determined by micro Kjeldahl. P was extracted by Bray 1 and determined using UV Vis. K was determined using flame fotometer. Ca, Mg were determined using atomic absorption spectrophotometer and S was determined using UV Vis. The data were analyzed by descrptive analysis to understand distribution trend of the data.

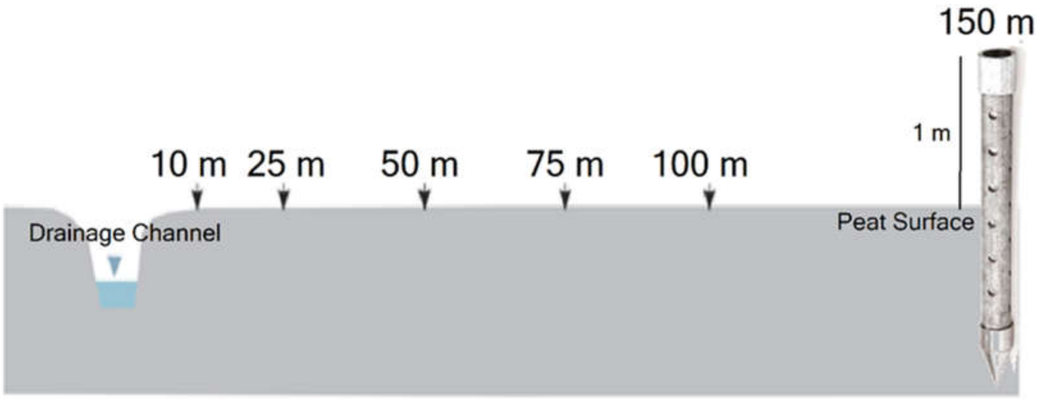

Figure 1: Peat water colection from piezometers installed based on distance from chanel.

RESULTS AND DISCUSSION

Results of the research showed that content of dissolved P, K, Ca, Mg and S were lower in dry rainy season compare to that in dry season (Table 1). Contrary to these results dissolved N was higher in rainy season (Table 1). Oil palm plantation was fertilized with almost complete nutrients, especially those that contain N, P, and K. These results suggested that N fertilizer in peatland was easily subject to leaching such that dilution of nutrients in rainy season was not causing lower N concentration in peat soil water. On the other hand, other studied nutrients in particular P and K were subject to dilution in rainy season as indicated by their low concentration in rainy season compare to that in dry season.

Table 1: Peat water macro nutrient of oil palm plantation in dry and rainy seasons.

Season	N (ppm)	P	K	Ca	Mg	S	(n)
Rainy	23.40 (13.45-53.82)	0.68 (0.08-2.29)	2.80 (0.37-9.38)	5.46 (2.01-12.04)	1.16 (0.44-4.80)	1.92 (0.35-5.26)	24
Dry	21.95 (13.45-53.82)	1.64 (0.1-5.87)	4.14 (0.25-17.41)	9.15 (1.54-12.04)	1.91 (0.43-16.02)	2.03 (0.42-4.42)	24

In shallow peat, content of dissolved N, P, K, Ca and Mg were higher, except dissolved S that was lower compare to that in deep peat (Table 2). There are two reasons that might explain these results. Firstly, shallow peat has shallow mineral soil substratum such that some parts of the nutrients supplied by this mineral substratum. Secondly, water and water movement in deep peat are expected to be in higher amount and more dynamic compare to that in shallow peat such that dilution effect was higher in deep peat which in turn resulted in lower concentration of nutrients in the water of the deep peat. Sulfur is an exception probably due to the amount of S fertilization was lower compare to fertilization of other nutrients.

Table 2: Peat water macro nutrient of oil palm plantation in deep and shallow peat.

Peat Thickness	N (ppm)	P	K	Ca	Mg	S	(n)
Shallow	24.08 (13.45-53.82)	1.49 (0.08-5.87)	3.67 (0.25-17.41)	5.52 (1.61-12.04)	1.93 (0.44-16.92)	1.92 (0.35-7.30)	24
Deep	21.64 (13.45-53.82)	0.88 (0.1-5.10)	3.29 (0.37-11.73)	4.58 (1.54-12.04)	1.14 (0.43-16.02)	2.02 (0.42-4.42)	24

Dissolved N, P, K, Ca Mg and S are in general tended to increase by distance from channel (Table 3). The data, however, very fluctuated. The channel networks in oil palm plantation on peatland functioned more as a controlled and limited drainage of excess water in the land. Sites that is closer to the channel was expected to experienced higher leaching that accompany the drainage process to the channel, in particular in rainy season. This higher tendency of losing nutrient content in the site closer to the channel has resulted in the tendency of lower nutrient concentration of peat water closer to the channel.

Table 3: Peat water macro nutrient of oil palm plantation based on distance from channel.

Distance from Channel (m)	N (ppm)	P	K	Ca	Mg	S	(n)
0	17.94 (13.45-40.36)	0.13 (0.08-0.23)	2.41 (0.25-7.04)	2.51 (1.54-3.77)	0.64 (0.43-0.95)	1.78 (0.56-3.72)	8
10	21.14 (13.45-40.36)	1.69 0.13-5.87()	5.06 (0.86-10)	6.02 (3.55-17.04)	1.96 (0.71-11.67)	1.55 (0.35-4.07)	8
25	23.54 (13.45-53.82)	2.13 (0.13-5.10)	4.89 (0.75-11.73)	5.89 (1.88-7.26)	1.28 (0.55-16.02)	1.55 (0.63-4.91)	8
50	26.91 (13.45-40.36)	0.57 (0.13-1.50)	2.36 (0.37-6.03)	5.54 (2.21-12.44)	0.84 (0.58-1.88)	2.37 (0.84-5.26)	8
75	23.06 (13.45-53.82)	0.81 (0.12-2.29)	3.24 (0.37-8.27)	4.88 (3.05-7.72)	1.50 (0.51-5.21)	2.26 (0.77-4.91)	8
100	23.06 (13.45-40.36)	0.64 (0.17-1.88)	2.67 (1.74-6.67)	4.36 (2.93-7.06)	1.77 (0.44-4.80)	2.23 (0.42-4.21)	8
150	17.94 (13.45-40.36)	0.81 (0.21-1.90)	1.91 (0.62-3.82)	7.45 (2.01-9.07)	1.67 (0.54-5.94)	1.94 (1.05-4.42)	8

Dissolved N, P, K, Ca, Mg and S were higher in more than 15 years old oil palm than that in 6-15 years old oil palm (Table 4). Fertilization of nutrient on oil palm plantation of > 16 years old oil palm was higher than fertilization on oil palm plantation of 6 – 15 years old. This is the cause of higher dissolved nutrients in peat water of the > 16 years old oil palm plantation.

Table 4: Peat water macro nutrient of oil palm plantation in 6-15 years old and more than 15 years old.

Oil Palm Age (year)	N (ppm)	P	K	Ca	Mg	S	(n)
6-15	18.35 (13.45-40.36)	0.88 (0.1-4.71)	2.46 (0.37-9.38)	4.47 (1.54-8.36)	1.47 (1.45-6.79)	1.35 (0.35-2.53)	24
>16	27.58 (13.45-53.82)	1.49 (0.08-5.87)	4.72 (0.62-17.41)	5.54 (1.22-12.44)	1.51 (1.44-16.92)	2.72 (0.7-4.91)	24

CONCLUSION

Dissolved P, K, Ca, Mg and S were higher in dry season whereas N was higher in rainy season. In shallow peat content of dissolved N, P, K, Ca and Mg were higher than that in deep peat however S was lower. Dissolved N, P, K, Ca Mg and S tended to increase by distance from channel. Dissolved N, P, K, Ca, Mg and S were higher in more than 15 years old oil palm than that in 6-15 years old oil palm.

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MICRODISTRIBUTION AND COMMUNITY STRUCTURE OF AQUATIC MACROINVERTEBRATES IN THE LARGEST PEAT BOG IN CROATIA

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SUMMARY

Peat bogs are generally characterised by great internal diversity that provides a plethora of various aquatic and semiaquatic habitats. Data on microdistribution and ecology of aquatic macroinvertebrates from the Southern Europe, including the Western Balkan peat bogs, are very scarce. The current study was conducted at the largest peat bog in Croatia influenced by the rapid successional changes causing its area to decrease significantly. Aquatic macroinvertebrates were sampled at four main habitat types: lake, hollow, ditch and pool. Sampling was conducted monthly during one vegetation season, from April to October 2015, using a 25x25 cm benthos net. In total, we recorded taxa from 18 different taxonomic groups, with aquatic insect orders and Crustaceans having the highest richness. Crustaceans, Diptera and Coleoptera were the groups recorded in the highest densities. However, our study shows that the aquatic macroinvertebrate assemblages in the Đon močvar peat bog differ between studied microhabitats, most probably related to differences in physico-chemical water properties of studied habitats. Among the environmental variables analysed, physical water properties (such as temperature, depth and habitat size) were the most important in affecting the spatial distribution of aquatic macroinvertebrates at this peat bog. Our study supports the view that the peat bogs in Croatia are extremely endangered habitats. With the current trends of decreasing traditional agricultural activities, it is of a crucial importance to protect Croatian largest remaining peat bog from rapid successional changes.

Keywords: *biodiversity, physico-chemical water properties, species richness, peatland, microhabitats*

INTRODUCTION

Climate change, agricultural activities (i.e. drainage and peat extraction), as well as secondary succession (i.e. soil formation and vegetation colonisation) are the main factors involved in surface modification of peatlands (Więcek *et al.,* 2013). They are amongst the most fragile and endangered ecosystems worldwide (Langheinrich *et al.,* 2004). The biodiversity of the peatlands in South-Eastern Europe is generally poorly understood even though they are clearly distinctive parts of the landscape (Topić & Stančić 2006). The studies of the microdistribution and ecology of aquatic macroinvertebrates were mainly conducted in the area of Northern and Central Europe (e.g. van Kleef *et al.,* 2012, Svobodova *et al.,* 2013), while the data from the Southern Europe, including the Western Balkan peat bogs are very scarce (e.g. Previšić *et al.,* 2013). Accordingly, no previous study has dealt with diversity and ecology of aquatic macroinvertebrates of peat bogs in Croatia.

Peat bogs are characterised by great internal diversity that provides a plethora of various aquatic and semiaquatic habitats. These habitats differ in water level, chemistry and vegetation composition and structure. That is way they are areas of high interests to study the relationship between aquatic macroinvertebrates and their microhabitats. Thus, the aims of this study were to: (1) describe the density and diversity of aquatic macroinvertebrate assemblages at different habitat types in the peat bog and (2) analyse environmental variables that affect spatial distribution of aquatic macroinvertebrates.

METHODS

Study area

The study was conducted in the Đon močvar bog located in the Central Croatia (N 45; E 15), at 130 m a.s.l. It spreads over an area of 10 ha, representing one of the largest and oldest peat bogs in Croatia. Moreover, it is a complex ecosystem, encompassing a mosaic of different habitats from open woodless *Sphagnum* L. sites, deep hollows, and small ponds, to swampy areas dominated by *Phragmites* Adans. Abandonment of traditional land-management practices, such as mowing and grazing, has led to a severe process of succession.

Consequently, its area decreased from 40 ha to 10 ha by the beginning of the 20th century. However, the bog and surrounding area are protected as a Botanical Reserve and it is a potential NATURA 2000 site (Alegro & Šegota 2008).

Macroinvertebrate sampling & water properties measurements

Aquatic macroinvertebrates were sampled at four main habitat types: lake, hollow, ditch and pool. The study sites differed in physico-chemical water properties, size and vegetation composition (Table 1). The triplicate samples of macrozoobenthos were collected at each site, once a month, using a benthos net (25×25 cm = 0.0625 m^2; mesh size = 500 µm) for a total of 24 samples. The samples were collected during one vegetation season, from the end of April to the end of October 2015. The specimens were sorted, counted and identified to the lowest possible taxonomic level.

The physico-chemical water properties (temperature, pH, dissolved O_2, and conductivity) were measured at each site, with a multiparameter probe (WTW Multi 3430). Alkalinity, as a concentration of calcium carbonate (mg/L), was measured using Standard Analytical Procedure (APHA).

Data analysis

In order to compare physico-chemical water properties, one-way ANOVA or Kruskal-Wallis H tests were used, followed by post hoc Fischer LSD or Multiple comparison tests. The selection of parametric or non-parametric tests depended on the normality of the data, which were tested using a Shapiro-Wilk W test. These tests were performed using Statistica 12.0 software package (StatSoft Inc. 2013). Shannon diversity index (H') was calculated based on order taxa level, using PRIMER 6 software package (Clarke & Gorley 2006).

RESULTS

Majority of physico-chemical water properties differed significantly between studied habitats (Table 1). Microclimatic conditions were more stable in deep hollows and lake, while in shallow pools of *Rhynchosporetum albae* association and small and shallow ditches were highly prone to oscillations. Moreover, some values exceeded the biological limits for some macroinvertebrate taxa. For example, during the summer in unshaded ditches the water temperature was elevated (28.6 °C), while in the hollows pH values decreased (5.02) due to low groundwater level. Values of majority of other measured physico-chemical water properties in hollows surrounded by trees of *Alnus glutinosa* were stable, except the values of dissolved oxygen concentration that markedly fluctuated during the study period.

Table 1: Comparison of different habitat types using 1-way ANOVA or Kruskal Wallis sum rank tests and the values (mean ± SD) of measured physico-chemical water properties (N=7, per site) in the peat bog Đon močvar.

Microhabitats	**Lake**	**Hollows**	**Ditches**	**Pools**	**Anova/Kruskal Wallis**	**Comparisons ($p < 0.05$)**
Main vegetation	*Carex acutiformis*, *Typha latifolia*	*Sphagnum* spp., *Alnus glutinosa*	*Sphagnum* spp., *Carex echinata*	*Rhynchospora alba*, *Sphagnum* spp.		
Vegetation coverage	medium	high	medium	low		
Water depth, range (cm)	60 ± 0.90	100 ± 0.6	22.5 ± 0.08	20 ± 0.03	15,01	H>P>D=L
Width of microhabitat (m)	0.3 ± 1.15	0.2 ± 0.8	0.1 ± 0.21	20 ± 1.77	24,09	P>H>D=L
Length of microhabitat (m)	0.4 ± 1.52	5 ± 0.5	10 ± 0	10 ± 1.76	27,88	P>H>L; L=H
Water temperature (°C)	14.2 ± 6.7	11 ± 0.7	14.9 ± 6.6	18.7 ± 8.5	2,21	P>H=D=L
Oxygen (mg/L)	5.4 ± 3.3	6.6 ± 3	6.1 ± 3.2	7.2 ± 1.8	0,91	ns
pH	5.5 ± 0.3	5.5 ± 0.2	5.5 ± 0.3	5.8 ± 0.4	1,17	ns
Conductivity (µS/cm)	33.5 ± 5.4	22.35 ± 8.4	28 ± 45	31.5 ± 64	4,53	ns
CaCO3 (mg/L)	16.2 ± 3.5	15 ± 2.3	15 ± 4	16.2 ± 3.52	5,41	ns

In total, we recorded taxa from 18 different groups at the Đon močvar bog, with aquatic insect orders and Crustaceans having the highest richness (Figure 1). The dominant taxa in ditches and hollowes were

Amphipoda, while Diptera prevailed in pools. The majority of Ostracoda and Copepoda were recorded from the lake and Isopoda from the hollows. The relative frequency of Oligochaeta was the highest in ditches. Ephemeroptera occurred rarely in the lake and sporadically in pools (Figure 1).

The values of Shannon diversity index (H') were as it follows: lake (2.05 bits/ind.), ditches (1.80 bits/ind.), hollows (1.42 bits/ind.) and pools (1.34 bits/ind.; Figure 2). The highest macroinvertebrate density was recorded in hollows surrounded by *A. glutinosa* trees, followed by ditches. The lowest macroinvertebrate density was recorded in the lake and pools (Figure 3). Additionally, the density differed between the seasons, being the highest in spring (May and June) and the lowest during the summer (July and August).

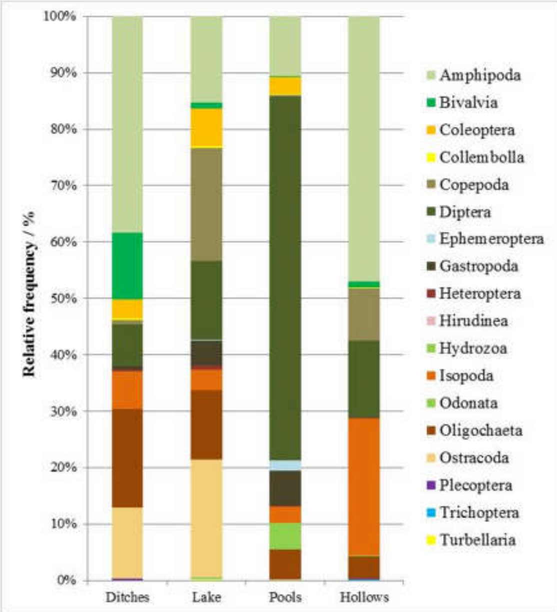

Figure 1: Relative frequency of aquatic macroinvertebrates at the study sites (ditches, lake, pools and hollows) in the Đon močvar peat bog.

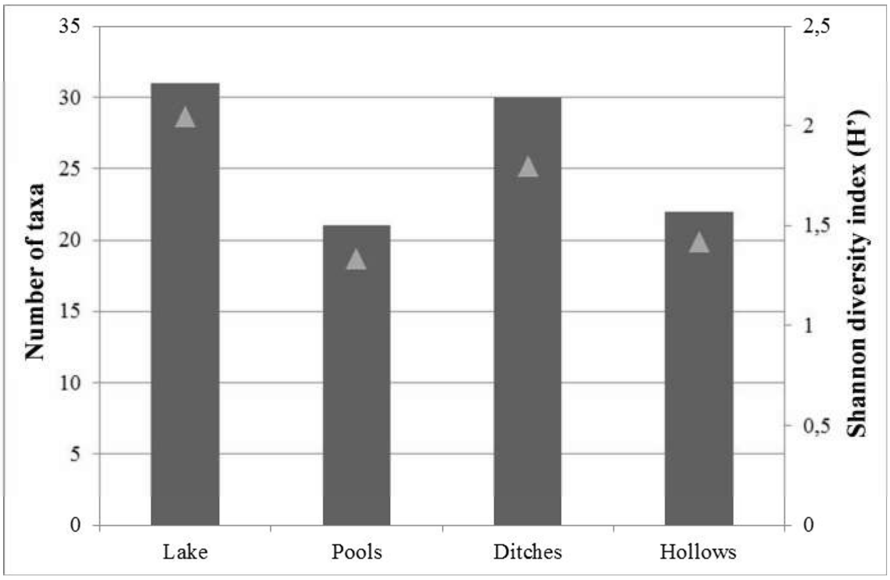

Figure 2: Number of aquatic macroinvertebrate taxa per each microhabitat in the Đon močvar peat bog.

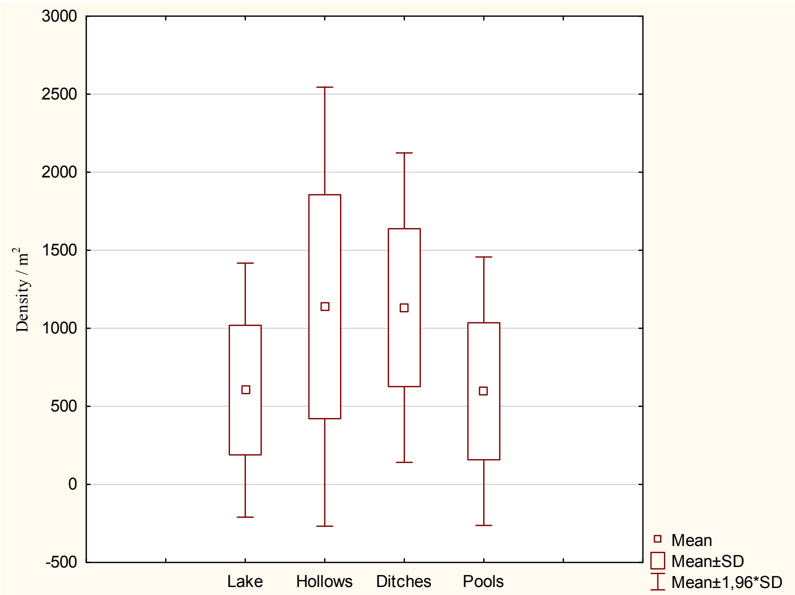

Figure 3: The range of aquatic macroinvertebrate density (m^2) at the study sites (ditches, lake, pools and hollows) in the Đon močvar peat bog during the study period between April and October 2015.

DISCUSSION

Wheeler and Proctor (2000) divided peatlands into two disctinct types: bogs having pH below 5.0 and fens having pH above 5.5, rather than into minerothrophic fens and ombrothrophic bogs. In the review of Hájek *et al.,* (2006) the peatland subdivision has been made based on the pH/calcium (poor-rich) gradient and in the light of the studies of the biodiversity of various aquatic macroinvertebrate taxa, especially molluscs. Based on the aquatic macroinvertebrate community composition and the measured physico-chemical water properties, the peat bog Đon močvar cannot be classified as a true ombrothrophic (mineral poor) peat bog according to Hájek *et al.,* (2006).

Our study shows that the aquatic macroinvertebrate assemblages in the Đon močvar peat bog differ between studied microhabitat, which is most probably related to differences in physical water properties of studied habitats, such as temperature, depth and the habitat size. The water in this peat bog originates from both, the rainfall and from the groundwater, in many ways causing the differences between the small shallow pools and permanent deep water sites. Although vegetation composition and structure at each study site played an important role in physico-chemical water properties in the studied peat bog, it is also possible that seasonal influence of groundwater could be more intensive. Consequently, the particular microhabitats with specific peat bog invertebrate species have not been recorded. On the other hand, depressions at the peat substrates surrounded by hummocks rich in *Sphagnum* spp. and *Rhynchosporetum albae* association had higher fluctuations of physico-chemical water properties, especially pH values which even dropped below 5.1. The acidic aquatic habitats of peatland pools are poor in inorganic ions (Ca^{2+}, Cl , SO_4^{2}), which could have caused low values of conductivity in the most of the microhabitat exposed to the moss cushions in the peat bog Đon Močvar (Wheeler & Proctor 2000, Horsák 2006).

In this study, we found high density of Crustaceans, Diptera and Coleoptera, which is in accordance with studies conducted in Canadian and North European peatlands (Danks & Rosenberg 1987, Rydin & Jeglum 2006). Crustaceans and Diptera are overall very important components of aquatic fauna, crucial to peat bog food webs. Taxa recorded at this peat bog are mostly common at peatlands, but due to overall rareness of such habitats in the Southern Europe these are also rare in this region, including Croatia (e.g. Previšić *et al.,* 2013). Seasonal variations in density and richness of macroinvertebrates recorded here are in line with those observed in other peatlands, e.g. in small peatland lakes in Ireland Baars *et al.,* (2014) recorded highest taxa richness during the spring. Taxa richness and diversity of macroinvertebrates were quite similar among different habitat types, with the lake having the highest values. Habitat permanency was identified as important in structuring the invertebrate assemblages of aquatic peatland habitats with larger pools hosting higher abundance and different community composition than smaller habitats more at risk of drying out (Baars *et al.,* 2014). Since diversity presented here is based on the taxa order level, the real diversity in this peat bog is much higher than the presented. The highest macroinvertebrate density was recorded in the hollows, mainly due to higher density of Crustaceans (Amphipoda and Isopoda), most likely related to the relatively stable conditions and dependence on groundwater levels. Oscillations in water temperature, depth and the pH value most likely play an important role as an environmental barrier for species occurrence in shallow water microhabitats (Baars *et al.,* 2014).

CONCLUSION

Biodiversity of aquatic macroinvertebrates in the peat bog Đon močvar in Croatia is shaped by the taxonomic group, environmental conditions and microhabitat specificity. Due to the presence of numerous rare species, the peat bog habitats in Croatia are considered to be extremely endangered habitats. With the current trends of decreasing traditional agricultural activities, it is of a crucial importance to protect Croatian largest remaining peat bog from rapid successional changes.

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