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ABUNDANCE OF BANK VOLE (*Myodes glareolus* Schreb.) AS AN INDICATIVE FACTOR OF DIFFERENT FOREST STRUCTURE AND MANAGEMENT IN THE DRAVA PLAIN REGION

BROJNOST ŠUMSKE VOLUHARICE (*Myodes glareolus* Schreb.) KAO INDIKATIVNI FAKTOR STRUKTURE ŠUMA I UTJECAJA ŠUMARSKOG GOSPODARENJA U ALUVIJALNOJ NIZINI DRAVE

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Summary

Differences in demographical patterns of the bank vole, *Myodes glareolus* Schreb. population, a frequent rodent species in the Drava plain region, were analysed through spatial and seasonal changes of survival and capture probability as well as through habitat dependence of abundance. As part of the Croatian-Hungarian interregional programme (DRAVA-INTERECO), small mammal population level monitoring was performed during 2007 applying the capture-mark-recapture method. Trapping sessions were implemented in three forest habitats with different vegetation structure, two sample areas in Lankoci forest, Hungary (protected old forest and reforested habitat) and one sample plot in Repaš forest, Croatia (habitat under forestry management) during a period of four months (July-October). The bank vole was an eudominant species in the three investigated habitats. The POPAN formulation of Jolly-Seber models was used to perform the comparative estimates of bank vole population traits. Based on model selection, the first two best candidate models supported our hypothesis that survival and abundance were influenced by forest age and structure. Our results confirmed that the bank vole is an appropriate indicator species to evaluate the population-level responses to the changes of forest structure and management.

KEY WORDS: *Myodes glareolus*, seasonality, population size, estimate, POPAN model

INTRODUCTION
UVOD

The remaining temperate zone deciduous forests are particularly sensitive to fragmentation, habitat reduction and different management processes. Because these ecosystems are species-rich communities, not only they represent higher taxonomic diversity due to their complex food chain system, but also have greater functional or ecological diversity (Angelstam *et al.*, 1997; Bengtsson *et al.*, 2000). These processes appear also along the green corridor of the Drava region where various types of forest (alluvial willow forest, floodland softwood groves, hardwood gallery forests) are present only in the form of smaller or somewhat larger pockets (Kevey *et al.*, 2008).

Because of the clear need for the long-term preservation of biodiversity in managed forests, it is required to consider

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how forestry practices such as clear-cutting or selective cutting correspond to natural disturbances and natural forest dynamics. Despite the main type of forest use has remained to be clear-cutting of areas in many places (Carey & Harrington, 2001). Throughout the world, small mammals are important model organisms to investigate the impact of forestry interventions as well as habitat fragmentation and degradation in different forest ecosystems (e.g. Bayne & Hobson, 1998; Fuller *et al.,* 2004; Pardini, 2004; Pardini *et al.,* 2005; Lindenmayer *et al.,* 2010). Small mammals increase species richness and functional diversity in forest ecosystems (Carey & Johnson, 1995). As secondary consumers, small mammals are high density elements of food webs, they have important role in dispersal of fungal spores, ectomycorrhizes, seeds and acorns (Birkedal *et al.,* 2010) and are diverse food resource for terrestrial predators and birds of prey (Carey *et al.,* 1992; Bontzorlos *et al.,* 2005). Due to demographical plasticity, rapid turnover and adaptability (Promislow & Harvey, 1990) both theory and empirical approach consider small mammals as appropriate subjects in the research of demographical patterns and population as well as community level response (Mortelliti *et al.,* 2010). Based on these elements the population and community parameters for forest-floor small mammals can be used as bio-indicators of sustainable forest management (Pearce & Venier, 2005; Sullivan *et al.,* 2013). Trend in indicator species' distribution and abundance as well as understanding their habitat use and preferences is fundamental for effective conservation and management strategies (Macdonald *et al.,* 1998; Hopkins & Kennedy, 2004; Flowerdew *et al.,* 2004).

The estimation of demographic parameters in natural populations has been recast in the comprehensive framework of capture-mark-recapture (CMR) methodology (Williams *et al.,* 2002; Lebreton, 2006) and has shifted towards the testing of hypotheses of biological interest rather than estimating numerical quantities such as population size, growth and survival rate or direct estimations of recruitment (Lebreton *et al.,* 1992; Pradel, 1996; Nichols *et al.,* 2000).

The bank vole *Myodes glareolus* (Schreber 1780) is widely distributed species of Myodes genus in the Palaearctic, ranging from the Mediterranean to Scandinavia and from Great Britain to the Black Sea, although it is absent from southern Iberia and the Mediterranean islands (Sptizenberger, 1999). From some population biological aspect the bank vole has proved to be an especially appropriate model object throughout its geographical range (Bujalska & Hansson, 2000) in studies of multiannual vole cycles and population regulation (e.g. Henttonen *et al.,* 1985; Amori, 2000) and social behavior and reproductive success (Koskela *et al.,* 1997; Lemaître *et al.,* 2012) or habitat use in fragmented environment, movement and dispersal strategies (Gliwicz, 1993; van Apeldoorn *et al.*, 1992; Kozakiewicz *et al.,* 2007; Gerlach & Musolf, 2000). Many studies demonstrated that the bank vole is found in all forest habitats throughout its geographical range, preferring dense understorey cover (Mazurkiewicz & Rajska-Jurgiel, 1989; Pucek *et al.,* 1993; Ecke *et al.,* 2002; Suchomel, 2007). According to these studies the bank vole is considered as a habitat generalist species. In contrast, because of its avoidance of open habitats throughout its range, the bank vole was determined by other authors as a habitat specialist (Tattersall *et al.,* 2002; Torre & Arrizabalaga, 2008). The study of the effects of habitat structure on bank vole populations shows that habitat suitability is determined by abundance and spatial distribution (Hansson, 1978; Mazurkiewicz, 1994). Based on numerous studies, the bank vole is a typical forest-dwelling and suitable model species, because it plays an important indicator role in the dynamics of woodland habitats and ecosystem health (Ecke *et al.,* 2002; Flowerdew *et al.,* 2004; Suchomel, 2007) as well as in the evaluation of the impact of forest disturbance and management (Gliwicz & Glowacka, 2000; Gorini *et al*., 2011; Lešo *et al*., 2014; 2016). Moreover, bank vole population outbreaks can cause considerable damage in forestry (Imholt *et al*., 2015) and this rodent species can transmit the Puumala hantavirus to humans (Voutilainen *et al*., 2012; Bjedov *et al*., 2016).

As regards protected areas along Drava river small mammals are considered to be an adequate indicator group and suitable monitoring subject for following habitat conditions, different vegetation structure (softwood and hardwood gallery forests) as well as anthropogenic disturbance and forest management activities of remaining forested areas. The biodiversity monitoring of the upper sections of Drava River was started in 2000. Within that high priority programme, small mammal population and community monitoring was run as a sub-programme between 2000-2006 (Horváth et al., 2005; 2012). As part of the Croatian-Hungarian interregional programme (DRAVA-INTERECO), this monitoring could be continued in 2007, this time with an additional forest fragment located in Croatia also being part of the sampling. Thus, now there were three different habitats in which small mammal population monitoring could be pursued, focusing on vegetation structure, forestry management and nature conservation measures. The bank vole was described as dominant species by our survey in the investigated forest habitats of both countries. The response of bank vole to different forest structure, stand composition and traditional and alternative forest management types were often tested by microhabitat association. Numerous studies demonstrated that the high density of bank vole was associated with dense and structurally complex understorey vegetation (Mazurkiewicz & Rajska-Jurgiel, 1989; Chetnicki & Mazurkiewicz, 1994; Miklós & Žiak, 2002; Lešo *et al*., 2014; Suchomel *et al*., 2014) where it finds better food availability, shelters and nest sites (Chetnicki & Mazurkiewicz, 1994; Buesching *et al.*, 2008). In addition, many studies highlighted that the cover of dead wood was an important environmental factor for the bank vole's microhabitat selection, spatial distribution and abundance (Miklós & Žiak, 2002; Lešo *et al.*, 2016; Zwolak *et al.*, 2016). On the other hand, several studies focused on the survey of the difference between demographical parameters to investigate the response of small mammals to forestry practices (e.g. Savola *et al.*, 2013; Gasperini *et al.*, 2016).

In this study, to evaluate the response of bank vole on the protected (unmanaged), managed (by thinning interventions) and reforested habitat, we estimated the population biological traits of this species. Based on open population design, we have more specifically analysed the spatial and seasonal pattern of survival and capture probability as well as habitat dependence of population size.

MATERIAL AND METHODS
MATERIJALI I METODE

Study area and sampling method – *Područje istraživanja i metode uzorkovanja*

As part of the DRAVA-INTERECO project in 2007, trapping was performed in two sample areas in Lankoci forest, Hungary (46°18´N, 17°02´E) and one sample plot in the Repaš forest in Croatia (46°10´N, 17°05´E). One of the designated Hungarian sampling sites here was an old (> 100 yr) strictly protected alder gallery forest (*Paridi quadrifoliae-Alnetum*) in Lankóci Forest Nature Reserve, distinguished thereinafter as 'protected forest habitat' (PFH-HU). This association type occurs mostly on relatively lower terrain of higher floodplain areas, mostly on alluvial forest soil. Before river regulations, areas of this forest type used to be inundated only at times of higher floods. Such forest stands today are found almost exclusively along watercourses and oxbows in flood-prevented areas, thus they have developed during the course of gallery forest or bog forest succession. The second sample area is located besides a strictly protected forest, where clear-cutting was performed in the year 2000 on a plot of more than 1 hectare. This 'reforested habitat' (RH-HU) has been gradually becoming covered in forest re-growth, the development of vegetation having accelerated during recent years (2004-2006) with higher precipitation. Due to the higher ground level, this forest stand was characterized by the vegetation of oak-elm-ash gallery forest (*Fraxino pannonicae-Ulmetum*). The third area was selected in the Repaš forest in Croatia, in a more arid, mature (< 90 yr) oak-hornbeam forest (*Carpino betuli - Quercetum roboris "typicum"*) stand, which differed from the other two, besides microclimatic features, in its vegetation structure (dominance of pedunculate oak and common hornbeam) and fluvisol forest soil (Vrbek *et al.*, 2008). Due to the fact that it was subject to intensive forestry management, it was thereinafter distinguished as 'habitat under forest management' (HUFM-CRO).

The capture-mark-recapture (CMR) method was applied for population- and community-level monitoring (Horváth *et al.*, 2008a; b). Based on the established monitoring protocol, a standard trapping grid of 11×11 traps was applied in each of the three habitats, with the same box-type live-traps (75×95×180 mm) positioned 10 m apart, thus the estimated demographical values were projected onto an area of 1 hectare (Horváth & Kovačič, 2007). Small mammal synchronous monitoring in the forest habitats was pursued for four sampling periods in 2007 (July, August, September and October) and a standard 5-night trapping session was carried out in every month. Based on the number of trap stations being operated in particular grids, and on the number of sampling nights, we used the entire 2007 pool of 7260 trap night data for the population dynamical evaluation of the character species. Just like the traps themselves, the trapping technique was also alike in all cases: bacon and cereals mixed with aniseed extract and vegetable oil were used as bait. The traps were checked two times a day starting at 7 am in the morning and 7 pm in the evening, with the traps being left triggered during the day. The captured individuals were tattoo-marked on their toes, this method ensuring individual identification for the entire capture history of every small mammal individual. Upon capture, we recorded the sex (also gravidity or lactation in females), age, body mass, trap number and individual code for each animal. Age was determined from body mass and external body features.

Statistical analysis – *Statistička analiza*

Three capture parameters were specified based on the CMR method: total number of animals (n_i) (Table 1), number of recaptures (r_i) and number of known individuals (m_i). The difference in the success of the recapture we tested based on ratio of recapture ($rr_{\%} = r_i / n_i \times 100$). Based on daily data, these parameters were investigated by variance analysis, comparing three habitats and four months considering each area. Firstly, we examined variables for normality using

Table 1. Monthly values of total number of captured animals (n_i)
Tablica 1: Vrijednosti ukupnog broja ulovljenih životinja po mjesecima(n_i)

Seasons / months	Summer 2007		Autumn 2007		
Sampling sites	July	August	September	October	Total
PFH-HU	159	91	160	204	614
RH-HU	88	70	152	166	476
HUFM-CRO	103	52	38	118	311
Total	350	213	350	488	1401

Shapiro-Wilk test and homogeneity of variances using Levene test. If the criterions of one-way ANOVA were not fulfilled, then we used nonparametric Kruskal-Wallis median test. When significant differences were detected in the Kruskal-Wallis test, we employed Dunn's procedure for *post hoc* multiple comparisons. The seasonal (spring, autumn) difference of capture parameters was tested by Mann-Whitney U test (Zar, 2010). These statistical tests were computed in Statistica 8.0 software (StatSoft Inc. 2007).

The POPAN formulation (Schwarz & Arnason, 1996) of Jolly-Seber models (Jolly, 1965; Seber, 1965) was used to perform the comparative estimates of bank vole population size. The encounter history of POPAN models included the different forest habitats as three groups. To test the assumptions of open models we used Goodness-of-fit tests (RELEASE tests 2 & 3) which indicated that this model is suitable for estimating population parameters from data of three habitats. Using an information-theoretic approach (Burnham & Anderson, 2002; Mazerolle, 2006), we built 10 candidate models to determine the effects of three monitored forest stands. The global model included the following parameters: $\{\varphi_{(\mathrm{habitat+period})}, p_{(\mathrm{habitat+period})}, pent_{(\mathrm{habitat+period})}, N_{(\mathrm{habitat})}\}$. It assumes that (i) φ (survival rate) differs between habitats and periods (the four 5-day trapping sessions), (ii) p (capture probability - given the animal is alive and available for capture) differs between forests and periods; and (iii) *pent* (probability of entry into the population per occasion) differs between forests and periods and it estimates N (superpopulation size) for habitats separately. Models were fitted using the logit link function for φ and p, the identity link function for N, and the multinomial logit link function to *pent* (White & Burnham, 1999). The model selection procedure was based on Akaike's Information Criterion modified for small sample size (AICc). The model with the lowest value of the AICc (ΔAICc = 0) was the most parsimonious. To help evaluate the fit of the models, we also considered the difference in AICc (ΔAICc), as models which differ by less then 2 AICc units (ΔAICc < 2) receive substantial support from the data (Burnham & Anderson, 2002). All models were run in MARK 6.1 (White & Burnham, 1999).

RESULTS
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During the four sampling months 740 individuals of bank vole were marked in the three different forests. The number of captures was 1401 while the total number of recaptures of our model species was 661. In case of three investigated forest habitats the capture data of trapping success for bank vole populations, and also their seasonal variations, showed differences. The total number of captures (n_i) (Kruskal-Wallis test: H (2, N=60) = 16.14, $P < 0.001$) and the ratio of recapture (%) (H (2, N=60) = 14.74, $P < 0.001$) differed significantly between the forest habitats, while the number of marked animals (m_i) did not show significant differences in the comparison of forest stands. Based on post hoc Dunn-test, both the number of captures (PFH-HU vs HUFM-CRO: z = 3.98, $P < 0.001$; RH-HU vs HUFM-CRO: z = 2.41, P .05) and recapture success (PFH-HU vs HUFM-CRO: z = 3.73, $P < 0.001$; RH-HU vs HUFM-CRO: z = 2.61, $P < 0.05$) were significantly higher in the two Hungarian forest habitats than in Croatia (Fig. 1).

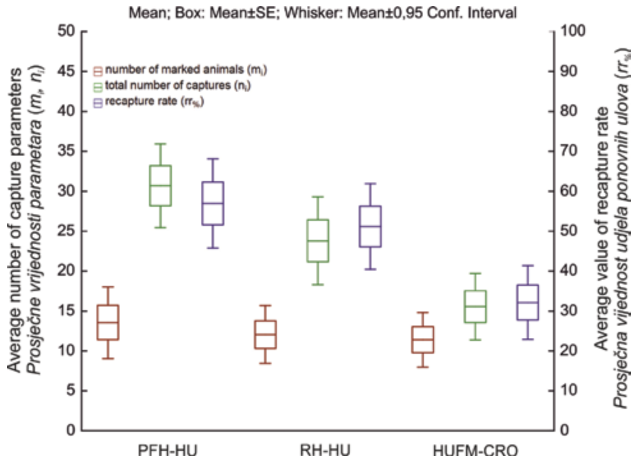

Figure 1. Distribution of average number of capture parameters in comparison with three forest habitats

Slika 1. Distribucija prosječnih vrijednosti parametara ulova u trima šumskim staništima

Comparing the two investigated seasons, the total number of animals differed significantly in the Hungarian protected forest habitat (Mann-Whitney test: z = 2.08, $P < 0.05$) while the other two parameters did not show significant difference between summer and autumn (z = 0.34-1.62, n.s.) (Fig. 2). In case of the reforested habitat, the values of two capture parameters were significantly higher in the autumn than in the summer (n_i: z = 2.79, $P < 0.01$; $rr_{\%}$: z = 2.23, $P < 0.05$), but in case of the number of known individuals, there were no significant results (m_i: z = 0.37, n.s.) revealed by the Mann-Whitney test in comparing the two seasons. Based on data of the habitat under forest management, only the recapture rate was significantly higher in the autumn than in the summer ($rr_{\%}$: z = 2.38, $P < 0.05$), although the mean of recapture success was lower than in the other two forests in both two periods. The values of the other two parameters did not differ significantly between the two seasons (m_i: z = 1.21, n.s.; n_i: z = 0.19, n.s.) (Fig. 2).

Based on the analysis of capture-mark-recapture data, the Goodness-of-fit tests (Test 2 + Test 3: χ^2 = 5.03 - 7.19, n.s.) indicated that the candidate POPAN models are suitable to estimate the population size of bank vole in all three investigated forest habitats. According to model selection, the best reduced model (smallest AICc value and the largest Akaike (AICc) weight (w_i)) was used to estimate the parameters (Table 2).

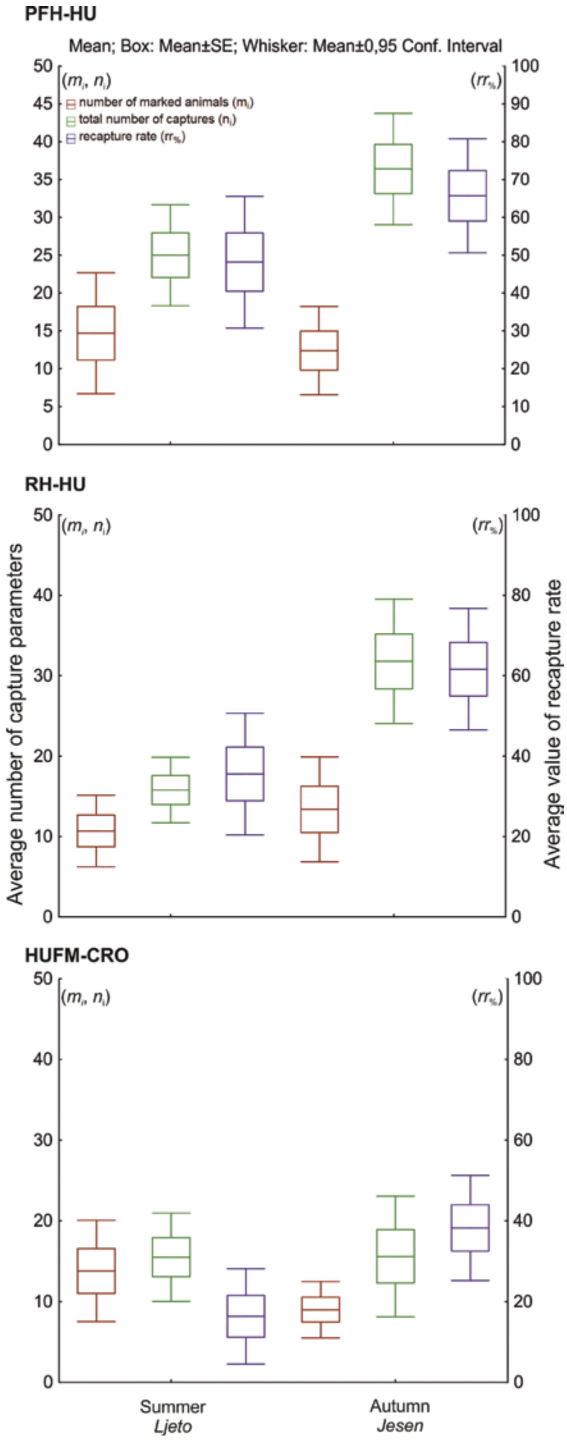

Figure 2. Average number of capture parameters during the two affected seasons in three forest stands

Slika 2. Prosječne vrijednosti parametara ulova tijekom dvije sezone u trima šumskim staništima

The model {$\varphi_{(hab)}$, $p_{(hab+t)}$, $pent_{(t)}$, $N_{(.)}$} indicates that probabilities of survival varied between habitats while being constant over time, probabilities of recapture were different between habitats and between study periods, the estimated values of entry rate varied only over time, while the estimated size of super-population was constant ($N = 424$, $\pm SE = 16.65$, $CV = 3.9\%$) over the study periods and did not differ between forest habitats. However, the hypothesis that the abundance of bank vole is different between the three forest stands was supported by the second best candidate model {$\varphi_{(hab)}$, $p_{(hab+t)}$, $pent_{(t)}$, $N_{(hab)}$} in model ranking due to small ΔAICc value (ΔAICc < 2), thus we used the estimated number of super-population of this model.

Table 2. The used POPAN models and their parameters (Akaike's information criterion adjusted for small samples (AICc), the difference between the model AICc (ΔAICc), model weights (w) and number of parameters (n_{par}))

Tablica 2: POPAN modeli i njihovi parametri (korigirana Akaike vrijednost (AICc) za mali uzorak, razlike između vrijednosti AICc modela (Delta AICc), težina modela (w) i broj parametara (n_{par}))

Model	AIC_c	ΔAIC_c	w	n_{par}
$\varphi_{(hab)}\ p_{(hab+t)}\ pent_{(t)}\ N_{(.)}$	1313.66	0.00	0.582	17
$\varphi_{(hab)}\ p_{(hab+t)}\ pent_{(t)}\ N_{(hab)}$	1315.43	1.77	0.241	20
$\varphi_{(t)}\ p_{(hab+t)}\ pent_{(t)}\ N_{(hab)}$	1317.24	3.57	0.098	19
$\varphi_{(hab)}\ p_{(hab+t)}\ pent_{(hab+t)}\ N_{(hab)}$	1318.87	5.20	0.043	23
$\varphi_{(t)}\ p_{(hab+t)}\ pent_{(t)}\ N_{(.)}$	1320.01	6.34	0.024	17
$\varphi_{(hab+t)}\ p_{(hab+t)}\ pent_{(hab+t)}\ N_{(.)}$	1323.51	9.84	0.004	25
$\varphi_{(t)}\ p_{(hab+t)}\ pent_{(hab+t)}\ N_{(.)}$	1324.36	10.70	0.003	19
$\varphi_{(hab+t)}\ p_{(hab+t)}\ pent_{(hab+t)}\ N_{(hab)}$	1324.81	11.15	0.002	27
$\varphi_{(hab+t)}\ p_{(hab+t)}\ pent_{(t)}\ N_{(.)}$	1325.65	11.99	0.001	25
$\varphi_{(hab)}\ p_{(hab+t)}\ pent_{(hab)}\ N_{(.)}$	1333.62	19.96	0.000	18
$\varphi_{(hab)}\ p_{(hab+t)}\ pent_{(hab)}\ N_{(hab)}$	1335.33	21.67	0.000	20
$\varphi_{(hab+t)}\ p_{(hab+t)}\ pent_{(hab)}\ N_{(hab)}$	1337.93	24.27	0.000	25
$\varphi_{(hab+t)}\ p_{(t)}\ pent_{(hab+t)}\ N_{(.)}$	1347.89	34.23	0.000	20
$\varphi_{(hab+t)}\ p_{(hab)}\ pent_{(hab+t)}\ N_{(hab)}$	1350.10	36.44	0.000	18

The first candidate model presented that the survival of bank vole differed between the two habitats. The estimated value of survival was significantly higher in protected forest than in the reforested habitat, which was shown by the non-overlapping 95% confidence intervals of estimation. In case of the other two habitat pairings (PFH-HU vs HUFM-CRO, RF-HU vs HUFM-CRO) due to the large overlap of confidence intervals, the survival rate of bank vole population did not differ significantly (Fig. 3).

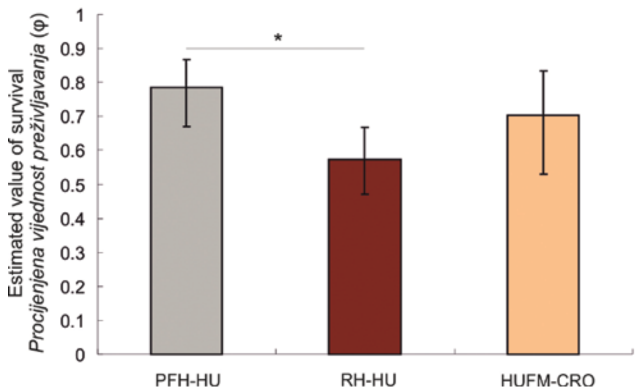

Figure 3. Estimated values of bank vole population survival in the comparison of three habitats, based on the best candidate POPAN model

Slika 3. Procijenjena vrijednost preživljavanja populacija šumske voluharice u tri šumska staništa prema najboljem POPAN modelu

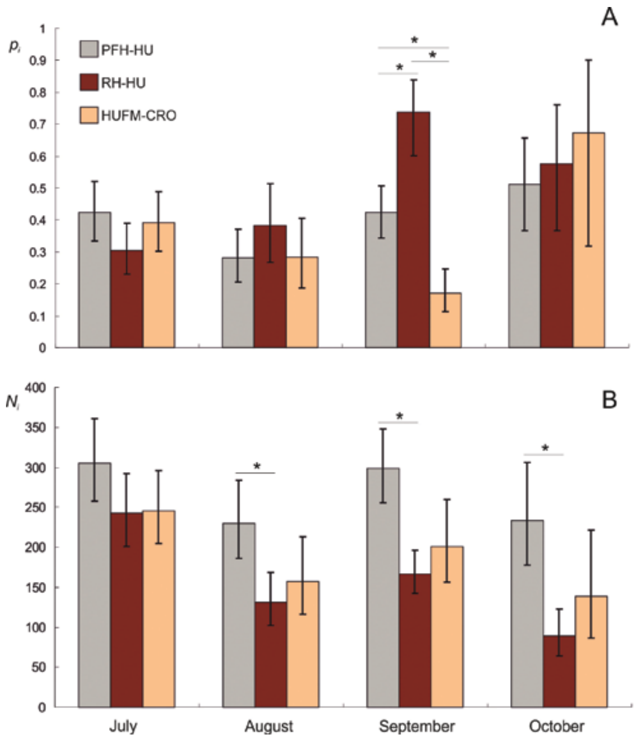

Figure 4. Estimated values of capture probability (*p*) (A) and derived size of population (*N*) (B) of bank voles during the sampling periods, based on the best candidate POPAN model

Slika 4. Procjena vjerojatnosti ponovnih ulova šumske voluharice pomoću najboljeg modela POPAN i dobijene veličine populacija tijekom uzorakovanja

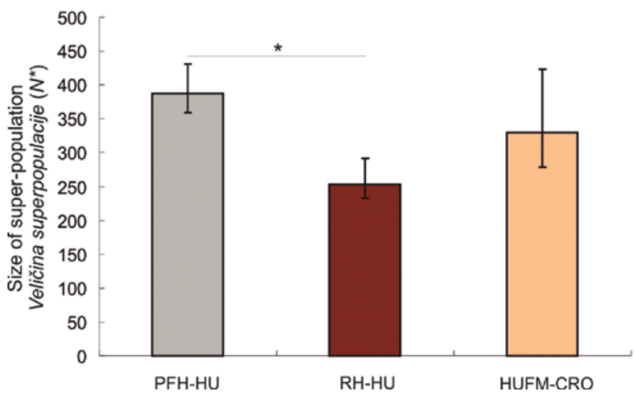

Figure 5. Estimated number of bank vole super-population in three investigated forest stands, based on the second best candidate POPAN model

Slika 5. Procjena brojnosti superpopulacija šumske voluharice pomoću drugog najboljeg modela PROPAN i usporedba tih vrijednosti u tri šumska staništa

Capture probability (p) was dependent on the periods, however the estimated monthly values of this parameter did not differ significantly when comparing the investigated forest habitats except in August. In this month the largest capture probability was estimated by the accepted model in case of the reforested habitat which was significantly higher than the capture probability value of the other two habitats due to the non-overlapping 95% confidence intervals. Similarly, the estimation showed significant difference between the protected forest and the habitat under forest management (Fig 4.A).

However, despite the difference in August, the distribution of estimated capture probability was not significant between forest habitats (one-way ANOVA: $F = 0.498$; n.s.). Regarding the seasonal change of capture probability, there was no significant difference when comparing the primary (monthly) capture periods in the protected mature and old-growth forest habitat while the estimated *p* value was significantly higher in September than in the previous two months in this sampling plot. In case of the Repaš forest in Croatia, the estimated capture probability reduced from July to September, although the decrease of this parameter was considered to be significant between July and September but not for consecutive periods (see the overlap of 95% confidence intervals of estimation). Capture probability increased by October in this area, too. Despite the high confidence interval of the estimated value in October, a significant increase of capture probability was characterized by the accepted POPAN model between September and October (Fig. 4.A).

The POPAN models calculated the size of population in each sampling period in each habitat as derived parameters. Based on the best candidate model the population size of bank vole in the protected forest habitat and the habitat under forest management changed periodically along sampling periods. However, in case of these habitats, the difference of population size was not significant between months due to the overlap of 95% confidence interval. The temporal change of abundance was similar in the reforested habitat but population size in July was significantly higher than in the further months and the difference of abundance in September and October was also significant (see the non-overlapping 95% confidence intervals) (Fig. 4.B). When comparing the calculated population size of the three habitats in a given sampling period, abundance did not differ significantly in July while in the another three months population size of bank voles in the protected forest habitat was significantly higher than in the reforested habitat. Based on the overlap of confidence intervals, abundance did not differ significantly between the reforested habitat and the managed forest (Fig. 4.B).

According to the second best candidate model where the estimate of population size (*N*) depended among the different habitats, the estimated number of super-population in the protected forest was significantly higher than in the reforested habitat. Based on the overlap of confidence intervals, super-population size did not differ significantly between the protected and the managed forest as well as between the reforested area and the habitat under forestry management. This result showed that the protected forest stand was the most suitable habitat for the bank vole (Fig. 5).

DISCUSSION
RASPRAVA

Capture-recapture (CR) models currently represent a widely used analytical framework for the estimation of demographic parameters such as survival, size and density in wildlife populations (Williams et al., 2002; Lebreton et al., 1992; 2009; Sanz-Aguilar *et al*., 2016). Using the POPAN formulation of Jolly-Seber models, in the present study we examined the population parameters of bank vole, as a comparison of three different forest areas along the upper River Drava in Hungary and Croatia, based on a parallel live-trapping monitoring.

Numerous studies described that forest-floor small mammals are generally more abundant in complex, natural forests than in simplified, managed forests (Carey & Johnson, 1995; Wilson & Carey, 2000). According to our results, the bank vole was eudominant in all three investigated forest stands. This rodent is generally known to be a typical forest-dwelling species but may also occur in open habitats (Hansson,1969; 1978) and rather avoids or is rare in shrublands and grasslands (Torre & Arrizabalaga, 2008). Numerous studies reported that the bank vole occurs in all forest age classes (Ecke *et al*., 2002; Bryja *et al*., 2002; Margaletić *et al*., 2005). However, the abundance of this species varied considerably depending on the forest structure and forestry management (Ecke *et al*., 2002; Bogdziewicz & Zwolak, 2014; Lešo *et al*., 2016). Our result suggested that the survival and abundance of the bank vole were influenced by the difference in forest age and stand structure, despite its general eudominant character. This result is consistent with other studies performed in Central Europe, according to which the bank vole was characterized as an eudominant species in several types of lowland (Suchomel *et al*., 2012) and mountain forests (Suchomel *et al*., 2014), too. According to a study carried out in Finland, the bank vole was typical in all succession stages, but its abundance was the highest in old-grow (> 100 yr) stands, especially during the low phase of population fluctuation (Savola *et al*., 2013). Earlier studies which were conducted in the Boreal region suggested that clear-cutting has a negative effect on primarily granivorous-folivorous species of Myodes while this impact is positive on predominantly folivorous species of Microtus (Hansson, 1978; 1999). Our results showed that the abundance of bank vole was the highest in protected old-grow forest, but this rodent was characterized by a higher density in managed closed-canopy mature forests (Repaš), too. Regarding European forest ecosystems, the assessment of the impact of clear-cutting on changes in abundance of small mammals showed that the bank vole was unaffected by this often used forestry practice in both temperate and boreal forest stands (Bogdziewicz & Zwolak, 2014). However, regarding the response of bank voles on forest management, the voles had the highest abundance in mature and young forests and showed the lowest abundance in clear-cuts (Gorini *et al*., 2011). Accordingly to our result, the bank vole was characterized by higher abundance in a reforested habitat, seven years after clear-cutting. In case of this habitat, due to the developing dense undergrowth vegetation and shrub cover, bank vole successfully colonized during the seven years in which the adjacent protected old-growth forest stand had a crucial role as optimal or source habitat. As shown by a recent study in central Italy, the density of bank vole population was affected strongly by different forest management (Gasperini *et al*., 2016) which corresponds to our results. Although survival was not influenced significantly by silvicultural activities, this study suggested that the reason for these results was the difference in carrying capacities between habitats rather than source-sink dynamics (Gasperini *et al*., 2016).

The role of the habitat scale, whether micro- or macrohabitat-level characteristics are better predictors of spatial use and segregation of small mammals is controversial (Jorgensen & Demarais, 1999; Jorgensen, 2004; Morris, 1984; 1987; Coppeto et al., 2006). Our study suggested that the different abundance of bank vole may be a suitable indicative factor of different forest structure and management at the macro-habitat level.

The estimation and evaluation of population size and other population parameters of a single species play an important role in evaluating the impact of different forest structure, age and forestry practice (e.g. Gorini *et al.,* 2011, Savola *et al*., 2013, Sullivan & Sullivan, 2014). However, it was suggested that multiple demographic parameters need to be examined in multiple species systems to be able to make generalizations about the response of small mammal populations to forestry intervention and management (e.g. Panzacchi *et al*., 2010; Lee *et al*., 2012; Gasperini *et al*., 2016).

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Sažetak

Očuvanje bioraznolikosti u šumama u kojima se provodi gospodarenje moguće je pod uvjetom da se razmotri koliko su šumarski zahvati (završna sječa ili sječa radi obnavljanja) u skladu s prirodnim procesima degradacije i prirodne dinamike u šumskim staništima. S obzirom da sitni sisavci djeluju na povećanje bioraznolikosti i funkcionalne kompleksnosti šumskih ekosustava, koriste se kao važan element za izradu modela u istraživanju utjecaja šumarskih zahvata, fragmentacije i degradacije na različita šumska staništa.

Šumska voluharica (*Myodes glareolus* Schreb.) česta je vrsta glodavca u šumama u aluvijalnoj nizini rijeke Drave. Istraživali smo razlike u demografskoj strukturi, prostorne i sezonalne razlike u vjerojatnosti ulova i ponovnog ulova te gustoću populacija ove vrste u različitim staništima. Monitoring populacije sitnih sisavaca proveden je tijekom četiri mjeseca, od srpnja do listopada 2007. godine u okviru Hrvatsko-Mađarskog prekograničnog programa (DRAVA-INTERECO). Pritom su korištene metode hvatanje-obilježavanje-ponovno hvatanje (CMR) opisane u protokolu Horváth & Kovačić (2007). Izlovljavanje je provedeno u tri šumska staništa različite strukture: u Mađarskoj u šumi Lankoci na dva lokaliteta (stara, zaštićena šuma i pošumljeno stanište), u Hrvatskoj u šumi Repaš (gospodarena šuma).

Prema CMR metodi određena su tri parametra (čimbenika): ukupan broj ulova (ni), broj ponovnih ulova (ri), broj ulovljenih jedinki (mi). Razlike u uspjehu ponovnog ulova testirali smo prema udjelu ponovnog ulova (rr%).

Šumska voluharica je bila eudominantna vrsta na sva tri staništa. Uzorkovanjem provedenim tijekom četiri mjeseca na trima šumskim lokalitetima ukupno je obilježeno 740 jedinki šumske voluharice. Ukupan broj ulova bio je 1401, a ponovnih ulova bilo je 661. Parametri uspjeha ponovnog ulova razlikovali su se na tri istraživana staništa i mijenjali su se tijekom sezone. Za procjenu i uspoređenje parametara populacija šumske voluharice koristili smo Jolly-Seber model, POPAN formulu. Prilikom selekcije modela, prva dva najbolje odgovarajuća modela potvrdili su našu hipotezu, prema kojoj gustoća populacija i preživljavanje ove vrste ovise od starosti i strukture šumskih staništa. Prema najboljem modelu procijenjeno preživljavanje u starijoj sastojini zaštićene šume bilo je signifikantno veće nego u pošumljenoj sastojini. Drugi model je pokazao da je procijenjena vrijednost superpopulacije bila najveća u starijoj sastojini zaštićene šume.

Ovi rezultati su potvrdili da je stara, zaštićena šuma najpogodnije stanište za šumsku voluharicu, čije populacije brzo reagiraju na promjene u strukturi staništa uzrokovane gospodarenjem, te da se ova vrsta može koristiti kao indikator.

KLJUČNE RIJEČI: *Myodes glareolus,* sezonske promjene, veličina populacije, procjena, POPAN model