ECOLOGIA BALKANICA

2009, Vol. 1 | November 2009 | pp. 41-50

Effects of a High Intensity Fire on the Abundance and Diversity of Reptiles in the Eastern Rhodopes Mountains, Southeastern Bulgaria

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Abstract. The numerous fires during the past decade in the Eastern Rhodopes (southeastern Bulgaria) resulted in extensive loss of habitat for multiple species. In this study on the reptilian fauna found near Kolets village (Haskovo District, Bulgaria) we compared two adjacent territories during 2004–2006, a control and a recently burned. We found no effect on the *Shannon-Wiener* index of biological diversity (mean for the three years: $\boldsymbol{H}_{\mathrm{burned}} = 0.488$, $\boldsymbol{H}_{\mathrm{control}} = 0.498$). However, fire led to decrease of abundance (***Ab***, individuals / 1000 m), best detected for the following species: *Testudo hermanni* ($\boldsymbol{Ab}_{\mathrm{burned}} = 1.8$, $\boldsymbol{Ab}_{\mathrm{control}} = 5.6$; p = 0.003316), *T. graeca* ($\boldsymbol{Ab}_{\mathrm{burned}} = 1.1$, $\boldsymbol{Ab}_{\mathrm{control}} = 3.2$; p = 0.071786), *Lacerta viridis* ($\boldsymbol{Ab}_{\mathrm{burned}} = 16.8$, $\boldsymbol{Ab}_{\mathrm{control}} = 40.6$; p = 0.000263), and *L. trilineata* ($\boldsymbol{Ab}_{\mathrm{burned}} = 6.8$, $\boldsymbol{Ab}_{\mathrm{control}} = 19.2$; p = 0.000879), where values for ***Ab*** are combined for 2004–2006.

Key words: herpetofauna, fire, abundance, Bulgaria.

Introduction

Fires are a major factor in the modification, fragmentation, and loss of habitats across the globe (COCHRANE, 2001; COCHRANE & LAURANCE, 2002; BENNETT, 2003). The effects of fire on biological diversity and specifically on the herpetofauna are diverse (ERWIN & STASIAK, 1979). Direct effects have been extensively documented (TEVIS, 1956; ERWIN & STASIAK, 1979; FÉLIX *et al.*, 1989; DUCK *et al.*, 1997; CHEYLAN & POITEVIN, 1998; HAILEY, 2000). Multiple indirect effects have also been studied, such as changes in the vegetation composition and structure (WHELAN, 1995; BROOKS & ESQUE, 2002), altered refugia, increased predation risk (EVANS, 1984; ESQUE *et al.*, 2003), and increased diel temperature amplitudes (EVANS, 1984; ESQUE *et al.*, 2003).

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While the indirect effects of fire are detrimental to some species, fire is beneficial to others and is necessary for maintaining suitable habitat for them (MUSHINSKY, 1985; PIANKA, 1996; PINTO *et al.*, 2006; ROZNIK & JOHNSON, 2009). In Australia and the United States, prescribed fires are used extensively to manage fire-dependent ecosystems. Such small, low-intensity fires are effective in partial removal of accumulated dead biomass, thus preventing devastating high-intensity natural fires (ANDERSEN *et al.*, 2005) and maintaining natural communities.

However, the effects of fires on the herpetofauna in Europe are understudied. For reptiles, the different taxa have also received unequal attention. For chelonians data are available for *Testudo hermanni* Gmelin, 1798 (STUBBS *et al.*, 1981; CHEYLAN, 1984; STUBBS *et al.*, 1985; FÉLIX *et al.*, 1989; HAILEY, 2000; POPGEORGIEV, 2008), *T. graeca* Linnaeus, 1758 (POPGEORGIEV, 2008), and *Emys orbicularis* Linnaeus, 1758 (CHEYLAN & POITEVIN, 1998). Few studies focus on species belonging to suborder Sauria, although studies have addressed *Lacerta viridis* (Laurenti, 1768) (ELBING, 2000; POPGEORGIEV & MOLLOV, 2005), *L. trilineata* Bedriaga, 1886 (POPGEORGIEV & MOLLOV, 2005), *L. agilis* Linnaeus, 1758 (NCC – report 1983), *Zootoca vivipara* (Jacquin, 1787) (SIMMS, 1969), *Podarcis siculus* (Rafinesque-Schmaltz, 1810) (PINTO *et al.*, 2006), *P. muralis* (Laurenti, 1768) (PINTO *et al.* 2006; RUGIERO & LUISELLI, 2006), *L. bilineata* Daudin, 1802 and *Chalcides chalcides* (Linnaeus, 1758) (RUGIERO & LUISELLI, 2006). However, virtually nothing is known about the impacts of fire on species of suborder Serpentes. Our study expands on the limited understanding of fires on reptiles (order Chelonii, suborder Sauria, and suborder Serpentes), and to our knowledge, this is the first peer-reviewed publication that investigates the effects of fire on representatives of Serpentes in Europe.

Materials and methods

The study site was located in Haskovo district and was part of the Haskovo and Mechkovo ridges (Fig. 1), situated in the northwest of the Eastern Rodopes Mountains of Bulgaria (YORDANOVA, 2004). The vegetation composition consisted of formations of *Quercus cerris, Q. frainetto, Carpinus orientalis, Paliurus spina-christi, Cornus mas,* as well as 30–50 cm tall grasses.

The fire near Kolets village (N41°51.930, E25°20.995; WGS 84 GCS) started on 31 August and burned until 3 September, 2003. The total burn area was 352.1 ha (data from Regional Forestry Board, Kurdzhali), although the fire was of high intensity in the core and of low intensity in the periphery. Detailed information about the study site is presented in POPGEORGIEV (2008).

We present data collected during yearly visits in the spring (April–May) and summer (August–September) from 2004–2006. We chose six transects that allow sampling of different parts of the burned area (average length = 2500 m), and six transects in two adjacent control areas (average length = 2000 m); transects were 10 m wide (Fig.1).

Species were identified based on ARNOLD & OVENDEN (2002), and scientific names are given according to SPEYBROECK & CROCHET (2007). For each observed reptile we recorded species, date, time, and GPS location of the observation using a Garmin "eTrex Summit" GPS receiver (accuracy±5 m),.

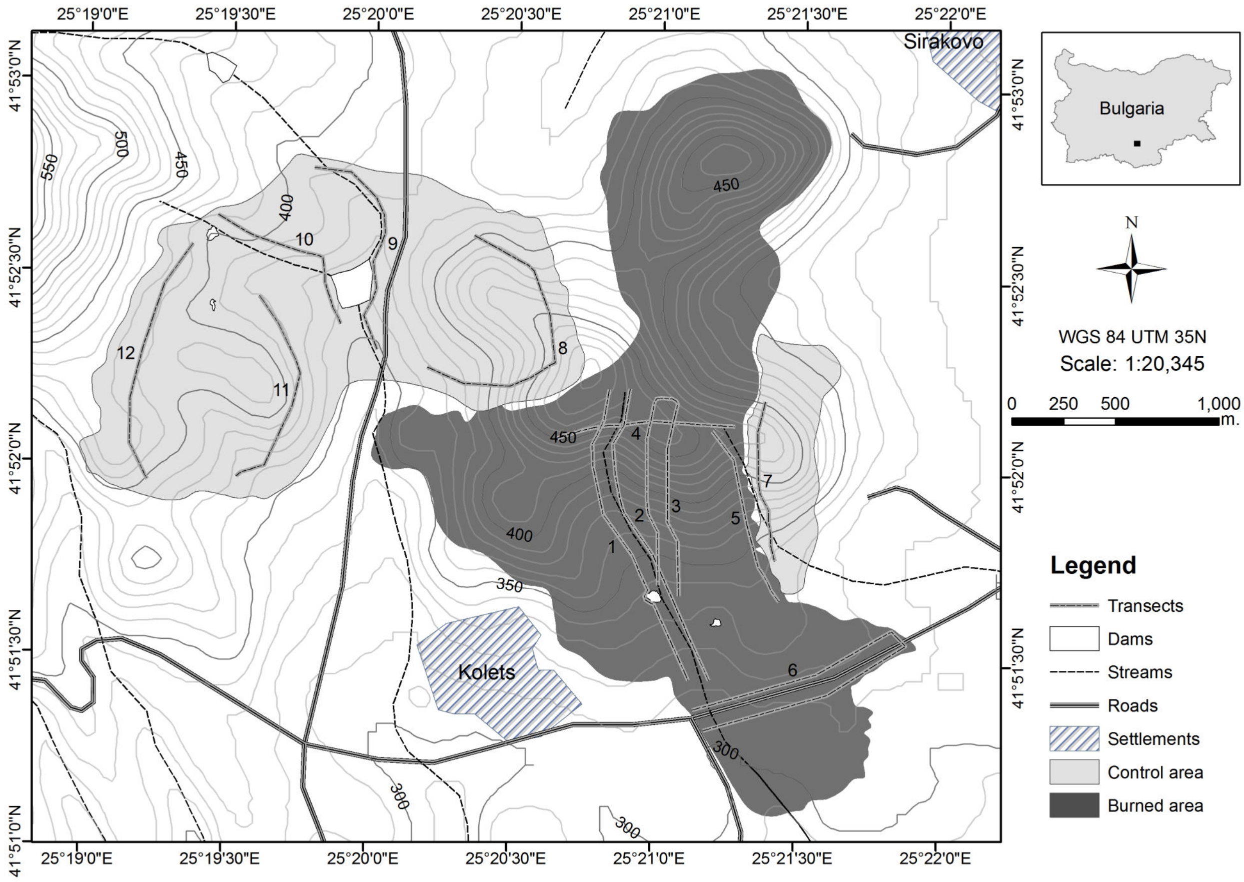

Fig. 1. Indicative map of the study site.

sex (if possible), vegetation composition nearby and elevation above sea level

We described species diversity with the *Shannon-Wiener* index (***H***) using the program *BioDiversity Pro* (ver. 2; McAleece *et al.*, 1997). To compare the numbers of detected reptiles, we used the abundance index (***Ab***). Abundance is defined as the total number of individuals of a given species detected in a territory (Turpie, 1995). Because of the differences in the lengths of transects, we used the number of individuals per 1000 m, and computed ***Ab*** using the formula:

$$Ab = \frac{n}{L} \times 1000,$$

where ***Ab*** – abundance (number of individuals per 1000 m); **n** – number of observed individuals; **L** – length of transect in meters. For statistical computations we used program *Statistica* ver. 7 for Windows (StatSoft, 2004). We compared data using the parametric t-test for independent variables. Data were analyzed for normalcy of distribution using *Shapiro-Wilk* test (Shapiro *et al.*, 1968), and then normalized using the log (x + 1) function. We considered results to be significant at $p < 0.05$ [$\alpha = 5\%$]. Species with less than 15 observations of individuals were not tested for significance.

Results

Species diversity. In the burned and control areas we detected 12 species of reptiles belonging to ten genera from six families (Testudinidae, Emydidae, Lacertidae, Anguidae, Colubridae, and Viperidae). A comparison of species diversity using the *Shannon-Wiener* index did not show a significant difference between burned and control area (average for the three years $\boldsymbol{H}_{\text{burned}} = 0.488$, $\boldsymbol{H}_{\text{control}} = 0.498$; Table 1).

Table 1. *Shannon-Wiener indexes in the burned ($\boldsymbol{H}_{burned}$) and control ($\boldsymbol{H}_{control}$) territory for the total duration of the study (2004–2006).*

	Transects – Burned (Control)						Combined area
Index	1 (7)	2 (8)	3 (9)	4 (10)	5 (11)	6 (12)	
$\boldsymbol{H}_{\text{burned}}$	0.524	0.464	0.536	0.346	0.579	0.301	0.488
$\boldsymbol{H}_{\text{control}}$	0.548	0.488	0.399	0.462	0.496	0.516	0.498

Species abundance. Combining the mean values of abundance by order and suborder, abundance was significantly higher in the control areas for order Chelonii ($\boldsymbol{Ab}_{\text{burned}} = 3.06$, $\boldsymbol{Ab}_{\text{control}} = 8.94$; $\mathbf{t} = 3.29$, $\mathbf{p} = 0.006$) and suborder Sauria ($\boldsymbol{Ab}_{\text{burned}} = 23.71$, $\boldsymbol{Ab}_{\text{control}} = 59.89$; $\mathbf{t} = 5.86$, $\mathbf{p} = 0.0002$). However, no significant statistical differences were detected for suborder Serpentes ($\boldsymbol{Ab}_{\text{burned}} = 0.44$, $\boldsymbol{Ab}_{\text{control}} = 1.18$; $\mathbf{t} = 1.90$, $\mathbf{p} = 0.087$). For the common species, abundance was higher in the control area than the burned area in all years (*T. hermanni:* $\mathbf{t} = 2.81$, $\mathbf{p} = 0.0018$; *T. graeca:* $\mathbf{t} = 1.92$, $\mathbf{p} = 0.0834$; *L. viridis:* $\mathbf{t} = 5.50$, $\mathbf{p} = 0.0003$; *L. trilineata:* $\mathbf{t} = 4.67$, $\mathbf{p} = 0.0009$; Table 2). Six less common species (*Podarcis tauricus* (Pallas, 1814), *Pseudopus apodus* (Pallas, 1775), *Dolichophis caspius* (Gmelin, 1789), *Elaphe sauromates* (Pallas, 1814), *Natrix natrix* (Linnaeus, 1758), and *Zamenis longissimus* (Laurenti, 1768)) were also more abundant in the control area, but this could not be tested due to small sample sizes (Table 2). Higher mean abundance in the burned area was detected only for *Vipera ammodytes* (Linnaeus, 1758) ($\boldsymbol{Ab}_{\text{burned}} = 0.15$, $\boldsymbol{Ab}_{\text{control}} = 0.12$), but also was not analyzed statistically for significance.

Discussion

Fire did not have a significant effect on the species diversity of reptiles in the burned and control areas in the Eastern Rhodopes Mountains. One reasons for this is that even a high intensity fire does not kill all individuals, especially at the periphery. Reptiles are capable of surviving fires, depending on the structure of the habitat, the season and time of day, fire intensity and duration (KAHN, 1960; VOGL, 1973; ERWIN & STASIAK, 1979). Another explanation for equal species diversity is that animals in unburned areas were able to move into burned areas and recolonize them. However, in fires that extend over larger area individuals might have difficulties in reaching and repopulating the core. We detected movements (using capture-mark-recapture) of individuals of *T. graeca* and *T. hermanni* from the burned area to the control and back, but only in the periphery of the burned area (POPGEORGIEV, 2008). This is

Table 2. *Mean values and differences in the abundance of reptiles in burned and control areas, and results from statistical analysis comparing the two areas.* ***Mean*** *– mean value;* ***SD*** *– standard deviation;* ***n*** *– number of observed individuals;* ***t*** *– test statistic. Note that species with < 15 observations of individuals were not tested for statistical significance between sites.*

		Burned		Control		Difference	
	Species	**n**	**Mean ± SD**	**n**	**Mean ± SD**	**t**	**P**
2004	*Testudo graeca*	15	1.14 ± 1.28	25	3.24 ± 4.21	1.38	0.1977
	Testudo hermanni	16	1.36 ± 1.16	41	4.18 ± 2.78	2.61	0.0261
	Lacerta viridis	139	10.92 ± 4.23	357	33.42 ± 9.38	5.74	0.0002
	Lacerta trilineata	74	5.69 ± 2.52	192	23.41 ± 20.10	3.41	0.0066
	Podarcis tauricus	0	–	3	0.33 ± 0.38	–	–
	Dolichophis caspius	1	0.11 ± 0.27	2	0.29 ± 0.53	–	–
	Elaphe sauromates	1	0.05 ± 0.12	0	–	–	–
	Natrix natrix	0	–	2	0.08 ± 0.19	–	–
	Vipera ammodytes	0	–	1	0.06 ± 0.16	–	–
2005	*Testudo graeca*	15	1.03 ± 0.64	32	3.24 ± 2.67	1.52	0.1590
	Testudo hermanni	34	2.30 ± 1.88	87	7.65 ± 2.86	4.05	0.0023
	Emys orbicularis	1	0.14 ± 0.22	2	0.26 ± 0.63	–	–
	Lacerta viridis	213	14.98 ± 5.09	420	37.48 ± 6.21	5.77	0.0002
	Lacerta trilineata	82	6.05 ± 1.76	181	17.17 ± 6.83	4.80	0.0007
	Podarcis tauricus	0	–	6	0.61 ± 0.99	–	–
	Pseudopus apodus	1	0.15 ± 0.36	2	0.10 ± 0.25	–	–
	Dolichophis caspius	4	0.23 ± 0.36	8	0.79 ± 0.68	–	–
	Natrix natrix	1	0.06 ± 0.14	3	0.22 ± 0.25	–	–
	Vipera ammodytes	6	0.35 ± 0.67	4	0.26 ± 0.41	–	–
2006	*Testudo graeca*	18	1.18 ± 1.07	41	3.04 ± 1.35	2.60	0.0263
	Testudo hermanni	27	1.84 ± 2.02	59	5.05 ± 2.67	2.81	0.0186
	Emys orbicularis	6	0.20 ± 0.31	10	0.70 ± 1.28	–	–
	Lacerta viridis	425	24.47 ± 7.49	696	50.80 ± 17.72	3.62	0.0047
	Lacerta trilineata	130	8.54 ± 3.07	219	16.95 ± 6.37	3.33	0.0076
	Podarcis tauricus	6	0.30 ± 0.55	9	0.62 ± 0.80	–	–
	Pseudopus apodus	5	0.27 ± 0.56	6	0.34 ± 0.63	–	–
	Dolichophis caspius	7	0.35 ± 0.40	6	0.53 ± 0.81	–	–
	Elaphe sauromates	0	0.12 ± 0.29	5	0.38 ± 0.62	–	–
	Natrix natrix	1	0.04 ± 0.10	2	0.24 ± 0.37	–	–
	Zamenis longissimus	1	0.01 ± 0.03	1	0.08 ± 0.12	–	–
	Vipera ammodytes	2	0.10 ± 0.16	1	0.05 ± 0.11	–	–
2004–2006	*Testudo graeca*	48	1.11 ± 0.97	98	3.17 ± 2.38	1.92	0.0834
	Testudo hermanni	77	1.83 ± 1.25	187	5.63 ± 2.54	4.21	0.0018
	Emys orbicularis	7	0.11 ± 0.17	12	0.14 ± 0.23	–	–
	Lacerta viridis	777	16.79 ± 5.32	1473	40.57 ± 9.87	5.50	0.0003
	Lacerta trilineata	286	6.76 ± 1.80	592	19.18 ± 10.01	4.67	0.0009
	Podarcis tauricus	6	0.10 ± 0.18	18	0.52 ± 0.69	–	–
	Pseudopus apodus	6	0.14 ± 0.20	8	0.44 ± 0.61	–	–
	Dolichophis caspius	12	0.23 ± 0.22	16	0.54 ± 0.63	–	–
	Elaphe sauromates	1	0.06 ± 0.10	5	0.13 ± 0.21	–	–
	Natrix natrix	2	0.03 ± 0.05	7	0.18 ± 0.17	–	–
	Zamenis longissimus	1	0.01 ± 0.03	1	0.08 ± 0.12	–	–
	Vipera ammodytes	8	0.15 ± 0.21	6	0.12 ± 0.15	–	–

corroborated by the higher values for the *Shannon-Wiener* index that we obtained for transect №5, situated at the periphery of the fire (Fig. 1, Table 1).

The effects of the fire on the herpetofauna depend on several factors such as type and quantity of accumulated flammable biomass (WHELAN, 1995; ANDERSEN *et al.*, 2005), area of the fire, presence of roads and diversity of the relief and landscape (WHELAN, 1995; RUPP *et al.*, 2000). The time of year of the burning also has a significant effect on the biological diversity and the severity of the disaster (RIBA & TERRIDAS, 1987; WHELAN, 1995; ANDERSEN *et al.*, 2005). Studies demonstrate that some reptiles are capable of surviving fires, depending on the structure of the habitat, the season and time of day, fire intensity and duration (KAHN, 1960; VOGL, 1973; ERWIN & STASIAK, 1979).

In a study on lizard responses to experimental fires in Kakadu National Park, Australia, TRAINOR & WOINARSKI (1994) obtained similar results to our study: $\boldsymbol{H}_{\mathrm{control}} = 0.6$, $\boldsymbol{H}_{\mathrm{early\ fire}} = 0.7$ and $\boldsymbol{H}_{\mathrm{late\ fire}} = 0.6$. The authors suspect that differences are the result of differences in the habitats rather than the direct effect of fire.

Our results suggest that fire has negative impact on the abundance of most reptiles that occur at our sites. Species from orders Chelonii and suborder Sauria were affected the most, while species of suborder Serpentes were the least impacted.

Some species suffer higher levels of mortality due to fire because of certain aspects of their biology (ERWIN & STASIAK, 1979). For example, species with limited mobility, such as *T. hermanni* and *T. graeca* were significantly less abundant in burned areas than in control areas. The detected mortality for the same territory was 64.3% for *T. hermanni* and 18.4% for *T. graeca* (POPGEORGIEV, 2008). Several other studies report similar results for mortality of *T. hermanni* due to fire: 40% for a population next to the Alyki lake in northern Greece (STUBBS *et al.*, 1985; HAILEY, 2000), 85% for a population in southern France (CHEYLAN, 1984), and 30% for a population in the Albéres Massif, Spain (FÉLIX *et al.*, 1989).

Abundance of species of suborder Sauria was also lower in burned areas, especially for the common species – *L. viridis* and *L. trilineata* (Table 2). Similar data were obtained by ELBING (2000) in a study on effects of fire on *L. viridis* in Brandenburg, Germany, where density in the control was eight times that of the burned area ($\boldsymbol{D}_{\mathrm{control}} = 20.0$, $\boldsymbol{D}_{\mathrm{burn}} = 2.5$). Elbing concluded that fire had a devastating effect on the studied population.

After a fire, PINTO *et al.* (2006) detected large increase in the numbers of *P. siculus* that moved into the burned area and a decreased numbers of *P. muralis*; a rapid decrease in the number of *P. siculus* followed with the regrowth of vegetation. Similar data on sympatric distribution of species is presented in RUGIERO & LUISELLI (2006) who determined no significant differences in the abundances between burned and control areas for *L. bilineata*, small differences for *P. muralis*, and large differences for *C. chalcides*.

The differences in the degree of survival for different species also depend on their dependency and preference to a habitat. Species like *L. viridis* and *L. trilineata* often utilize bases of shrubs (e.g., *P. spina-christi*, in this study) or coarse woody debris in forested habitats for refugia. During a fire the temperature in these microhabitats is high (WHELAN, 1995) due to the accumulation of flammable biomass, likely leading to high mortality and a subsequent decrease in abundance of the lizard species that utilize such habitats for refuge, rest, or reproduction (FITCH, 1963; FITCH, 1989; FITCH & SHIRER, 1971; CHARLAND & GREGORY, 1995; JAMES & M'CLOSKEY, 2003).

For the species in suborder Serpentes we did not observe significant differences in abundance. We stipulate this is due to their higher vagility and propensity for extended short-term movements compared to the other observed reptiles. Such behavior allows them to escape from the approaching fire. On 4 March 2006, two adult *D. caspius* were observed rapidly escaping from the approaching flames of a fire near Kondovo village, Eastern Rhodopes; mortality due to the fire was not detected (G. Popgeorgiev & L. Topalova, unpub. data). Most snakes inhabiting the study site utilize burrows of rodents, crevices, hollow spaces underneath rocks, and similar microhabitats for refuge, where the temperature during a fire often stays within the physiological limit of the organisms. For example, during a fire, the temperature on the surface may reach 1000°C, but no more than 100°C only 3 cm below the surface (KAHN, 1960; LAWRENCE, 1966).

Still, some authors found high mortality due to fire. DURBIAN (2006) documented mortality of three out of seven radiotagged *Sistrurus catenatus* (RAFINESQUE, 1818) rattlesnakes. Similarly, MCLEOD & GATES (1998) detected much higher abundance in control versus burned areas for three snake species – *Carphophis amoenus* (SAY, 1825), *Storeria dekayi* (HOLBROOK, 1836), and *Thamnophis sirtalis* (LINNAEUS, 1758). CAVITT (2000) on the other hand found significant differences in abundances only for *Coluber constrictor* LINNAEUS, 1758, out of ten species of snakes in Kansas, USA.

Conclusions

1. The fire next to Kolets village did not have a significant effect on the reptilian diversity, calculated using the *Shannon-Wiener* index.

2. Fires during the active season for reptiles have a negative effect on the abundance of *T. hermanni, T. graeca, L. viridis,* and *L. trilineata.*

3. The highest impact from the fire was on species from order Chelonii, followed by representatives of suborder Sauria. Species from suborder Serpentes were the least impacted.

Acknowledgements

The study was possible due to financial support provided to GP by Ruford Small Grants and Bulgarian Society for the Protection of Birds. We thank Dimitar Plachiyski, Ognyan Todorov, Georgi Georgiev and Jamie Carr for assistance during the field work. We are indebted to Borislav Naumov and Elizabeth Roznik for reviewing the manuscript and providing valuable comments.

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Влияние на високоинтензивни пожари върху обилието на влечугите в Източни Родопи, Югоизточна България

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Резюме. Многобройните пожари през последното десетилетие в района на Източни Родопи (Югоизточна България) довеждат до висока загуба на местообитания за голям брой видове. Проведеното проучване върху влечугите през периода 2004–2006 г. сравнява територия, скоро горяла със съседна контролна територия. Пожарът в района на с. Колец (Хасковско) не е оказал влияние върху индекса на *Shannon-Wiener* за биологично разнообразие (средно за трите години $\boldsymbol{H}_{\text{пожар}}$ = 0.488 и $\boldsymbol{H}_{\text{контрола}}$ = 0.498). Въпреки това огънят е оказал силно въздействие върху обилието на някои влечуги. Най-силно е въздействието на пожара върху обилието (***Ab***, екз./1000 m) при следните видове: *T. hermanni* ($\boldsymbol{Ab}_{\text{пожар}}$ = 1.8 и $\boldsymbol{Ab}_{\text{контрола}}$ = 5.6; p = 0.003316), *T. graeca* ($\boldsymbol{Ab}_{\text{пожар}}$ = 1.1 и $\boldsymbol{Ab}_{\text{контрола}}$ = 3.2; p = 0.071786), *L. viridis* ($\boldsymbol{Ab}_{\text{пожар}}$ = 16.8 и $\boldsymbol{Ab}_{\text{контрола}}$ = 40.6; p = 0.000263), и *L. trilineata* ($\boldsymbol{Ab}_{\text{пожар}}$ = 6.8 и $\boldsymbol{Ab}_{\text{контрола}}$ = 19.2; p = 0.000879), където стойностите за ***Ab*** са усреднени за периода 2004–2006 г.

Received: 07.10.2009
Accepted: 21.10.2009