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Living on the edge: habitat selection of *Hierophis viridiflavus*

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Abstract. We analysed habitat choices of *H. viridiflavus* in a continental area of northern Italy and compared our results with those reported from central Italy by other authors. We used two different field techniques, visual encounter surveys (VES) and radio tracking (RT), and both pointed out a clear preference for edges, while uniform habitats (like mature woods or meadow) were avoided. The same pattern of habitat use is documented for other whip snakes and can be related to the high thermal quality of edges, although other factors could not be ruled out (e.g., prey/shelters abundance). Nevertheless, other researches on Mediterranean populations do not show such a preference, suggesting that at lower latitude habitat thermal quality is not the main constraint and H. viridiflavus can behave as a habitat generalist. Finally, comparing the two field techniques, we find that VES partially overestimates the importance of edge use, suggesting that caution should be used about its utilization to obtain information in this kind of research.

Keywords. *Hierophis viridiflavus*, habitat use, radio tracking, visual encounter surveys, latitude effect.

INTRODUCTION

Habitat selection data are necessary both for wildlife management/conservation policies and for basic ecological knowledge. In the former case, herpetologists focus their efforts mainly on endangered or threatened species in order to define adequate conservation strategies (e.g., Weatherhead and Charland, 1985; Prior and Shilton, 1996; Nilson et al., 1999; Kingsbury and Coppola, 2000; Webb and Shine, 2000; Filippi and Luiselli, 2003); in the latter case, they obviously prefer species characterized by high-density populations, because they are easily studied (Madsen, 1984; Luiselli and Rugiero, 1990; Luiselli et al., 1994; Larsson, 1995; Luiselli and Capizzi, 1997). In this scenario, *Hierophis viridiflavus* (Lacépède, 1789) represents an intermediate case: even though it is often very common, particularly in Italy (Vanni and Nistri, 2006), it is protected by European law (included in

Annex IV of Habitat Directive 92/43/EEC) because of its relatively restricted geographic range (Naulleau, 1997). As a typical member of the "whip snakes clan" (sometimes called "racers"), *H. viridiflavus* is a diurnal, thermophilic, generalist predator (Capizzi et al., 1995; Rugiero and Luiselli, 1995; Capula et al., 1997). It can make long-range movements (Ciofi and Chelazzi, 1991; Bonnet and Naulleau, 1996a; Bonnet et al., 1999) and it frequently lives also near human settlements (Luiselli and Capizzi, 1997; Filippi, 2003). All these features potentially allow it to exploit different habitats, including fragmented and partially anthropic ones.

So researchers have both a protected and common snake to study, but despite these favourable condition, habitat preferences of *H. viridiflavus* had never been investigated in detail and available publications report this kind of ecological information only as marginal note (Luiselli and Rugiero, 1990; Scali and Zuffi, 1994; Capizzi et al., 1995; Capula et al., 1997; Luiselli and Capizzi, 1997; Filippi and Luiselli, 2006).

The lack of targeted studies prevents from robust conclusions. The first problem concerns the adaptive meaning of habitat selection. Previous studies on *H. viridiflavus* ecology were conducted in Mediterranean areas (mainly near Rome), characterised by a hot temperate climate (Cs), according to the Köppen-Geiger classification (Hufty, 1980), with mean annual temperature (MAT) between 14.5 °C and 16.9 °C, and mean temperature in the coldest month (MCM) between 6 °C and 9.9 °C. Climatic conditions are very important in the ecology of ectothermic vertebrates, and their variations could heavily influence the activity of a thermophilic species, such as *H. viridiflavus*, and, as a consequence, influence its habitat choices (Shine and Madsen, 1996; Luiselli and Zimmermann, 1997; Webb and Shine, 1998, 2000; Blouin-Demers and Weatherhead, 2001a, 2002; Carfagno and Weatherhead, 2006). The Italian distribution of *H. viridiflavus* intersects very different climatic zones: from the temperate subtropical climate (CS) in the southern regions (MAT>17 °C; MCM>10 °C) to the temperate cool climate (Cf) in the northern part of the peninsula or in the Apennines (6<MAT<9.9 °C; -3<MCM<0 °C). So, rising in latitude/altitude, one may expect a gradient in whip snake preference for habitats that provide the greatest opportunity to reach and maintain optimal body temperatures.

A second issue concerns the way habitat selection was assessed in previous studies. Habitat use was described as absolute frequencies (Capula et al., 1997; Filippi and Luiselli, 2006), but very few data were reported about habitat availability in those publications. So no deep comparison between use and availability was made and no conclusion about selection can be inferred.

Finally, the last problem deals with the technique used to obtained field data: previous researches were conducted only using visual encounter surveys (VES); only two papers reported radio-tracking use on this species (Ciofi and Chelazzi, 1991; 1994), but they were addressed to home-range and homing studies, and they did not deal with habitat selection. Applying VES to a fast moving species that often lives in inaccessible habitats, could lead to over- or under-estimate of habitat use (Kenward, 1987; Manly et al., 1993; Heyer et al., 1994; Bonnet and Naulleau, 1996b; Whiting et al., 1996). In this case, radio-tracking could be useful to collect more detailed and objective data and it could overcome this kind of problem.

The three main aims for our paper are: i) analysis of habitat preferences of *H. viridiflavus* in relation to habitat availability; ii) comparison of habitat choices of the European whip snake between Mediterranean and continental areas; iii) evaluation of the efficacy of visual encounter surveys and radio tracking techniques.

MATERIALS AND METHODS

Study area and field techniques

We conducted the research in a semi-natural area of the Groane Regional Park, in Lombardy (north-western Italy; 45°37'N, 9°06'E; mean altitude: 210 m a.s.l.). The study area covers 45 ha and it is surrounded by large urban areas and bordered by a major road to the north. It is a patchwork of different habitat types: open areas, bushes, woods and anthropic structures (a clay quarry and the associated kiln and buildings). It is included in the temperate continental climatic zone (Cf) (9.5<MAT<15.0 °C; -1.5<MCM<3.0 °C) (Hufty, 1980). To obtain a vegetation map that synthesized structural information from different areas, we chose 52 random points where we recorded the percentage cover of any biological form (Raunkiaer, 1934; Pignatti, 1997). Afterwards, all the sample areas were clumped into five vegetation types using a cluster analysis: mature wood, sparse wood with shrubby layer, brambles, meadow and wetland. We added two habitat types, defined as edge and anthropic structures: the former was a 10 m-wide buffer along habitats interfaces (Blouin-Demers and Weatherhead, 2001b; Carfagno and Weatherhead, 2006) and the latter included a clay quarry and the kiln. A detailed description of habitat categories is available in Table 1.

We searched for snakes from March to October, for two years (1998 and 1999), using VES (Blomberg and Shine, 1996). Surveys were conducted three times a week, starting approximately at 0800 h and ending at 1800 h and involving two operators. An overall sample of eleven individuals (7 males and 4 females, see Table 2 for details) were radio-tracked, using external transmitters implantation (see Ciofi and Chelazzi, 1991 for details), modified as described by Bonardi et al. (2001). We

Table 1. Description of the seven habitat categories in the study area.

Habitat type	Description	Total area (ha)
Meadow	Grassland with rare and sparse shrubs (mainly *Rosa canina* and *Rubus* spp.)	11.19
Mature wood	Wood with closed canopy (*Robinia pseudacacia, Prunus* spp.), scarce shrubby layer (<10%) and moderate herbaceous layers (30% on average).	12.61
Sparse wood with shrubby layer	Wood with non-continuous canopy (50% on average), with abundant shrubs coverage (*Rubus* spp. - >70% of the surface), and no herbaceous layer.	4.09
Brambles	Thick cluster of brambles (*Rubus* spp.) with no other vegetation layers	0.29
Wetland	Permanent still water. Depth from 30 to 130 cm. Presence of water-lily, reeds, *Carex* spp. and rush	0.14
Anthropic structure	The clay quarry, the kiln and their related buildings. All these structures were abandoned and with some pioneer plants.	3.47
Edge	10 m-wide buffers along habitats interface. Bushy, with several open spots, scarce or absent tree coverage, and often with handmade structures (bricks, ruins, iron bars and other similar materials)	11.61

Table 2. Characteristics of implanted snakes.

ID	Sex	Body mass (g)	SVL (cm)	Year	no. of days	no. of fixes
12	M	235	95	1998	16	23
13	M	230	96	1998	13	27
14	F	230	90	1998	30	39
15	M	290	89	1999	37	55
16	F	200	82	1999	42	67
18	M	330	88	1999	36	58
27	M	300	93	1999	11	20
28	F	155	79	1999	10	15
30	M	90	64	1999	10	19
32	F	200	83	1999	14	22
33	M	465	101	1999	31	19

used TW4 radio tags (weight 3.0 g; size 22×13×7 mm) and a Mariner Radar Ltd. M57 receiver with a three elements Yagi antenna (Biotrack, Wareham, Dorset, UK). Transmitters weight never exceeded 3.5% of snake weight. Radio tracking was conducted from July to October in 1998 and from March to October in 1999. Snake location was determined once in the morning (between 0800 h and 1000 h) and once in the afternoon, about five hours later.

Data analyses

To analyse VES data, we superimposed a grid on the area map, identifying 555 cells of 30×30 m (SU = sample unit), being 30 m the mean daily distance moved by radiotelemetered snakes. Forty-seven were excluded because less than 30% of their surface belonged to the study area, leading to a sample of 508 SUs.

We described habitat composition of each SU overlaying the vegetation map to the grid, using ESRI ArcView 3.2 GIS software. In this way, each SU was characterised as the area covered by each habitat type. Each cell was also classified as "present" code (pSU) if at least one snake was observed in it, otherwise as "absent" code (aSU).

All the habitat variables were included in the logistic regression (LR) analysis, using the backward stepwise likelihood-ratio method, with the presence/absence of snakes as the dependent variable. Model significance was assayed by model chi-square test, while its accuracy was tested by comparing SUs values predicted by the model with observed ones (Field, 2000). Single variable effect on the model was deduced by the regression coefficients (B) sign: a positive B-value means that the probability to find a snake in a given SU increased, and vice versa. To assess the contribution of each variable to the model, and so B-values significance, we tested the change in deviance (-2 log likelihood or -2LL) when the estimator was removed (Field, 2000).

To describe habitat preferences of radio tracked snakes, we used a type III experimental design, as defined by Thomas and Taylor (1990), where both the resource use and its availability are identified for each individual. We chose the compositional analysis (CA) to analyse data, overcoming any autocorrelation problem (Aebischer et al., 1993; Otis and White, 1999; Garshelis, 2000; Millspaugh and Marzluff, 2001). For each snake we calculated the proportional use of each habitat (no. of fixes in habitat *i*/total no. of fixes). To estimate habitat availability, first we calculated the minimum convex polygon (MCP) for each individual; this home range was increased by a 30 m-wide buffer (mean daily movement calculated for all snakes) to obtain a better approximation of available area. In fact, the MCP is calculated on the basis of most external fixes, so a snake could hypothetically move 30 m daily in any direction starting from one of those points. Secondly, we calculated habitat availability for each snake as area covered by i^{th} habitat/total area within extended MCP (EMCP) (Moore and Gillingham, 2006).

Habitat use data were transformed using arbitrarily the category "mature wood" as reference, accordingly with the formula proposed by Aebischer et al. (1993):

$$d_i = ln(x_{ui}/x_{ai}) - ln(x_{uj}/x_{aj})$$

where, given a snake, x_{ui} is the proportional use of the i^{th} habitat; x_{ai} is the available proportion of the i^{th} habitat; x_{uj} is the proportional use of the reference habitat (*j*); x_{aj} is the available proportion of the reference habitat. When x_{ui} was equal to 0, its value was arbitrarily changed to 0.0001 to allow computation (Aebischer et al., 1993). For the test of overall selection we calculated Wilks' lambda statistic (Λ), using MANOVA techniques, as suggested in Millspaugh and Marzluff (2001). We used snake ID as a fixed factor and five habitats (meadow, mature wood, sparse/shrubby wood, anthropic structures, edge) as dependent variables. Brambles and wetland were omitted because they occurred in a small portion of the study area and their proportional use was marginal. To obtain test significance we compared $-n \times ln \times (\Lambda)$ to χ^2 distribution with D-1 degrees of freedom (n is the number of snakes; D is the number of habitat types) (Aebischer et al., 1993). To assess which habitats are preferred, we ranked them on the basis of the average d_i values ($\bar{d}_i$) across all the eleven individuals. Obviously d_i is equal to zero for the reference category "mature wood". To test ranking significance, first we compared $\bar{d}_i$ with the reference value using a one-sample t test to verify if the use of each habitat was significantly different from the use of the reference one. Finally, we verified the relative use of each habitat, comparing all pairs of them with a paired t test (Aebischer et al., 1993; Carfagno and Weatherhead, 2006).

Field techniques comparison

We compared VES and radio-racking results to verify their reliability. A problem arose from the non-independence of radio tracking data, so we decided to compare pSUs obtained simultaneously by visual surveys and radio tracking data (called "cross" pSU and coded as "0") with pSUs obtained by radio tracking alone (called "tracking" pSU and coded as "1"). We then conducted a LR using pSU type (cross or track) as the dependent variable and the significant habitat descriptors coming from the previous regression as covariates: if the model is significant, than the two techniques give different results; on the contrary the two methods are equivalent.

RESULTS

Habitat selection

A total of 172 snakes were observed using VES and a distribution map with regard to the vegetation was drawn (Fig. 1). Overlapping the 30 × 30m grid to the area map, we obtained 59 pSUs and 449 aSUs. The visual comparison (Fig. 2) of the mean values of each

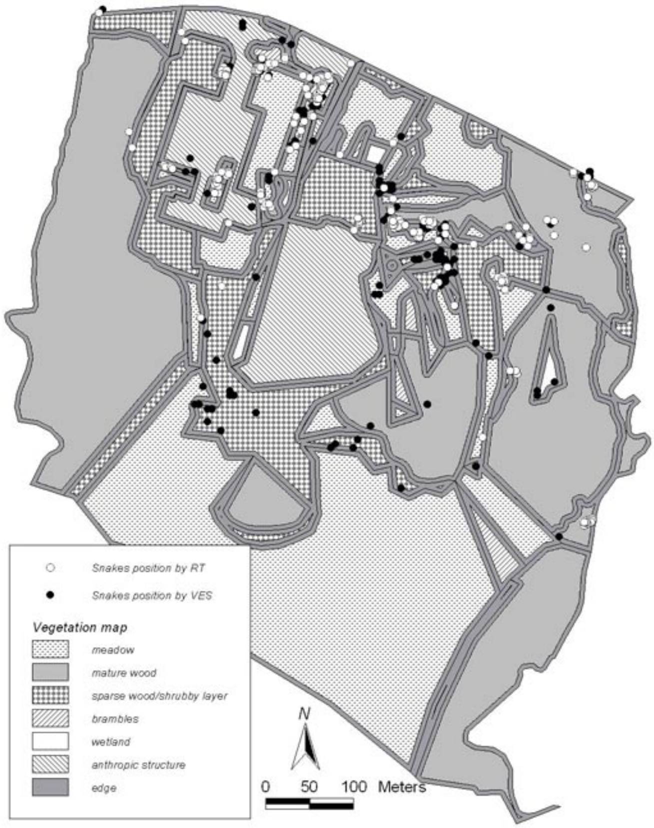

Fig. 1. Spatial relations among habitat features and snakes distribution both by VES (filled circles) and RT (open circles). See legend for habitat types and Table 1 for their detailed description.

vegetation type among pSUs, aSUs and the whole study area shows that pUSs have larger surfaces covered by edges, sparse wood and anthropic structures than aSUs and the whole area. Before attempting LR we randomly extracted 59 aSUs to obtain balanced samples. The model built by LR was highly significant ($\chi^2 = 59.707$, df = 3, $P < 0.001$) and included three variables: wood with shrubby layer ($B = 2.49 \times 10^{-3}$; $\chi^2 = 5.988$, df = 1, $P < 0.05$); anthropic structures ($B = 1.90 \times 10^{-3}$; $\chi^2 = 2.894$, df = 1, $P < 0.10$) and edge ($B = 7.73 \times 10^{-3}$; $\chi^2 = 55.826$, df = 1, $P < 0.001$). All of them had a positive effect on the probability of finding snakes in a SU (positive *B*-values), but the most significant one was the edge. The model correctly classified 81.4% of pSUs and 72.9% of aSUs, with an overall accuracy of 77.1% and an increase of 27.1% in comparison to the null model.

The proportional use of each habitat for each radio tagged snake and the overall habitat availability are summarized in Table 3 and in Fig. 3. The mean values show a preference for edges, while mature wood, meadow, sparse/shrubby wood and anthropic structure were less used. In particular, it is interesting to note from Fig. 3 that MCP-availability is quite different from the total area one, showing that selection may occur also at this level.

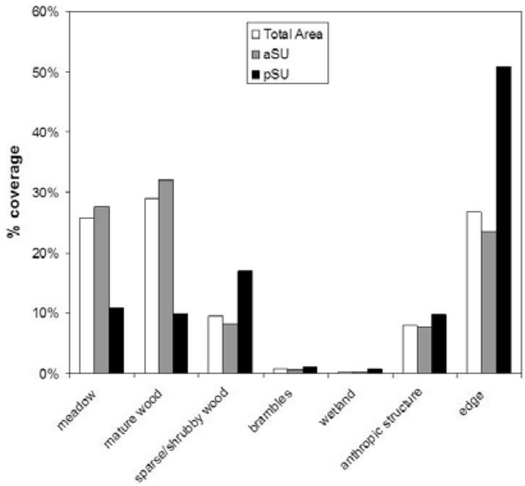

Fig. 2. Comparison among mean percentages of each habitat types calculated respectively for the whole area (Total Area), for the absent SUs (aSU; n = 449) and for the present SUs (pSU; n = 59). See text for more detailed definitions.

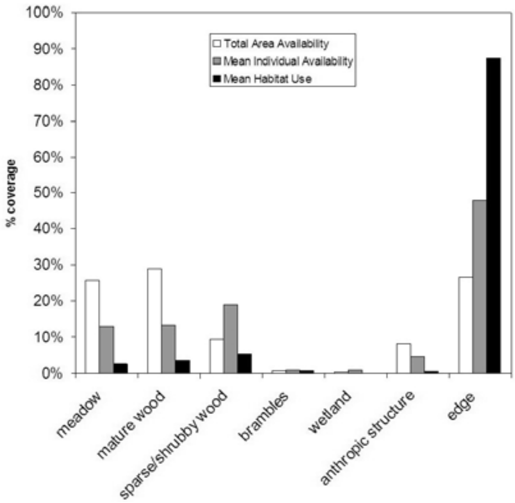

Fig. 3. Comparison among use and two different levels of availabilities for the eleven radio tracked snakes. Bars represents respectively: percentage coverage of each habitat type in the whole study area (total area availability); mean percentage of habitat availability calculated on the basis of buffered individual MCP (mean individual availability); mean percentage of fixes occurring in each habitat types (mean habitat use).

Data in Table 3 were used to calculate the differences in log ratios (d_i), setting mature wood as the reference category. Wetland and brambles were excluded from the analyses because their availability is too scarce (Bingham and Brennan, 2004). We conducted a MANOVA on the d_i matrix, and we obtained a significant Wilks' lambda statistic (Λ =

Table 3. Percentage use and availability of each habitat types for radio-tracked snakes (in parenthesis the sex).

Individual snake ID	Use/availability (%)						
	Meadow	Mature wood	Sparse wood/ shrubby layer	Brambles	Wetland	Anthropic structure	Edge
12 (M)	0.00/12.95	4.35/2.39	4.35/28.84	0.00/0.00	0.00/0.00	0.00/12.45	91.30/43.38
13 (M)	0.00/4.97	0.00/13.12	44.44/25.41	0.00/0.00	0.00/0.00	0.00/0.00	55.56/56.50
14 (F)	5.13/4.67	10.26/46.21	0.00/15.07	0.00/0.00	0.00/0.24	0.00/0.00	84.62/33.81
15 (M)	0.00/10.10	5.46/29.69	3.64/12.93	0.00/0.98	0.00/0.96	0.00/3.33	90.91/42.02
16 (F)	1.47/25.90	0.00/2.17	0.00/4.68	4.41/3.64	0.00/1.65	1.47/7.36	92.64/54.61
18 (M)	0.00/19.55	3.45/2.86	5.17/12.43	3.45/3.07	0.00/1.64	0.00/2.82	87.93/57.63
27 (M)	0.00/15.58	0.00/3.33	0.00/20.47	0.00/1.01	0.00/1.11	0.00/6.00	100.0/52.50
28 (F)	6.67/31.33	0.00/1.47	0.00/5.63	0.00/0.00	0.00/1.70	0.00/2.33	93.33/57.53
30 (M)	10.53/18.17	0.00/0.01	0.00/11.85	0.00/0.94	0.00/2.16	0.00/14.52	89.47/52.35
32 (F)	4.35/0.35	0.00/1.66	0.00/53.38	0.00/0.00	0.00/0.00	4.35/3.26	91.30/41.36
33 (M)	0.00/0.36	15.79/45.66	0.00/19.04	0.00/0.00	0.00/0.00	0.00/0.00	84.21/34.94

5.70×10^{-2}; $\chi^2 = 31.441$, df = 4, $P < 0.001$), showing a non-random habitat selection. So, the habitats were ranked on the basis of $\bar{d}_i$ from the least to the most selected as follows: i) sparse wood, ii) meadow, iii) anthropic structures, iv) mature wood, and v) edge. The pairwise comparison among all the habitats gave significant result only for edges, which were preferred over all other categories (all $P < 0.01$).

Techniques comparison

LR used to discriminate between "cross" and "tracking" pSUs gave significant result ($\chi^2 = 12.877$, df = 3, $P < 0.01$). Among the three previously selected variables, only "edge" had a correspondent *B*-value significantly different from zero ($B = -4.28 \times 10^{-3}$; $\chi^2 = 9.070$, df = 1, $P < 0.01$). A negative value means that an increase in edge surface produced a decrease in the probability that a pSU is a "tracking" unit (coded as "1"). In other words: VES detects that snakes prefer edges to greater degree. The model correctly classified 71.4% of "cross" pSUs (20 out of 28) and 63.0% of "tracking" pSUs (10 out of 17).

DISCUSSION

Habitat selection

Our study demonstrates that *H. viridiflavus* prefers edges and does not appreciate homogeneous habitats, such as meadows and woods. LR extracted three main variables that directly influence the occurrence probability of the European whip snake: edges, anthropic structures and sparse woods with a shrubby layer. All these variables have a positive effect on the snakes presence. Also CA pointed out a clear preference for edges, and a lesser use of all other habitats. The different importance of anthropic structures and sparse/shrubby woods assessed by the two analyses could seem ambiguous, but it could be explained by their different approaches: CA only takes into consideration the occurrence habitat (e.g., the edge) while LR weighs the habitat composition giving indirect information about adjacent habitats that form the edge (e.g., an edge between meadow and mature wood). In our study anthropic structures and sparse/shrubby woods are common elements in defining edges used by snakes (see Fig. 1).

Habitat use in Mediterranean populations of *H. viridiflavus* has both similarities and differences with our results. While the minor utilization of forest and woodland is confirmed, in Mediterranean areas snakes show a strong preference for open habitats, represented by grassy pastures and bushlands, often associated with tall grass (Capula et al., 1997; Filippi and Luiselli, 2006; Luiselli, 2006). The importance of handmade structures is also pointed out in Capula et al. (1997) which reported that over 70% of the observations were done in dry-stone walls and rocky sites surrounded by spiny shrubs. Dry-stone walls are not typical of northern Italy plains but their role could be performed by other buildings and by ruins such as those associated to the kiln in the present study. These habitats, simulating rocky or semi-natural zones, guarantee the presence of many basking sites, shelters and prey abundance (Scali and Zuffi, 1994; Capizzi et al., 1995; Rugiero and Luiselli, 1995; Webb and Shine, 2000). In the meanwhile, they provide low disturbance sites, because the buildings were abandoned, and only small portions of the kiln were occasionally used. Under this assumption, our results are similar to those obtained in central Italy. The main difference remains the intensive use of grassy pastures in Latium, while open and uniform habitats, such as meadows, were not suitable for this species in northern Italy. This difference could correspond to a specific selection pattern or to a difference in habitat characterization: the lack of the edge category in the past researches might lead to a subjective assignment of the observations to "pure" habitat types, increasing its importance. Analogous problems are reported in Carfagno and Weatherhead (2006) in their comparative studies of habitat selection of the black rat snake (*Elaphe obsoleta*). The use of edges as habitat category is not usual, but should be more considered by researches, because data from our study and from Carfagno and Weatherhead (2006) confirm their importance for snakes. According to Blouin-Demers and Weatherhead (2002), edges show the highest thermal quality, because they are located at the interface of cool habitats (e.g., forests) and warm habitats (e.g., grasslands, or other open habitats). Thus, edges provide the best opportunities for behavioural thermoregulation of all the habitats, and snakes can invest less in thermoregulation than in areas of low thermal quality. Racers are generalist predators, that need a more precise body temperature control to allow greater sprint speeds than more specialized species (Shine, 1980; Carfagno and Weatherhead, 2006). So, it is not surprising that *H. viridiflavus* prefers edges in colder habitats, where it is more difficult to achieve the preferred body temperature. Similar patterns of habitat choice are documented also for *Coluber constrictor* (Plummer and Congdom, 1994; Carfagno and Weatherhead, 2006).

The differences in the use of open habitats between northern and central Italy could be explained considering that Mediterranean areas have the optimal thermal characteristics for the thermophilic *H. viridiflavus*. So, this species can behave as a habitat generalist in those areas, avoiding only wetlands and cultivations (Filippi and Luiselli, 2006) that do not satisfy other ecological needs (e.g., prey or refuge density). On the opposite, in colder areas, the European whip snake could have stronger thermal constraints, that force it to use only optimal habitats, such as edges.

Techniques comparison

The two field techniques (VES and RT) provide comparable results, highlighting the same main habitat choice descriptor (edge). The main difference is that VES partially overestimates the importance of edges that are characterized by discontinuities in vegetation cover which make sightings more likely than in other habitats (Kenward, 1987; Manly et al., 1993; Heyer et al., 1994; Bonnet and Naulleau, 1996; Whiting et al., 1996). This problem suggests caution about VES results. Detailed researches on habitat use by colubrid snakes are only available for radio tracking studies (Weatherhead and Charland, 1985; Plummer and Congdon, 1994; Keller and Heske, 2000; Blouin-Demers and Weatherhead, 2001a, b, 2002; Rodriguez-Robles, 2003; Carfagno and Weatherhead, 2006), because this technique guarantees a high detail level and a homogeneity of used habitat sampling. Snakes have always very cryptic habits, so VES cannot be considered a bias-free research technique for them. The methodological consequence of our data is that VES could be successfully used for habitat selection studies provided that: the target species do not spend most of their time underground or in heavy undergrowth; selected areas can be easily and completely surveyed; the research effort is homogeneous among all the available habitats (Manly et al., 1993; Garshelis, 2000; Millspaugh and Marzluff, 2001).

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