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Long- and short-term impact of temperature on snake detection in the wild: further evidence from the snake *Hemorrhois hippocrepis*

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Abstract. Global change is causing an average temperature increment which affects several aspects of organisms' biology, especially in ectotherms. Nevertheless, there is still scant knowledge about how this change is affecting reptiles. This paper shows that, the higher average temperature in a year, the more individuals of the snake *Hemorrhois hippocrepis* are found in the field, because temperature increases the snakes' activity. Furthermore, the quantity of snakes found was also correlated with the temperature of the previous years. Our results suggest that environmental temperature increases the population size of this species, which could benefit from the temperature increment caused by climatic change. However, we did not find an increase in population size with the advance of years, suggesting that other factors have negatively impacted on this species, balancing the effect of increasing temperature.

Keywords. climate, *Hemorrhois hippocrepis*, population dynamics, temperature, Spain, global change.

Human activities are causing important changes in our planet, including a generalized average temperature increment (IPCC, 2007). The biology of organisms, especially ectotherms, depends on environmental temperature, and therefore many species are showing alterations in phenology, distribution, morphology, and population dynamics in response to those changes (reviews in Hughes, 2000; Walther et al., 2002; Parmesan and Yohe, 2003; Root et al., 2003; Parmesan, 2006; Weatherhead and Madsen, 2009). Some species will not be capable of responding adaptively to climatic change, so there will be an increasing number of extinctions (Thomas et al., 2004). In reptiles, climatic change is considered to be an important threat increasing the risk of extinction (Pounds et al., 1999; Gibbons et al., 2000; Araújo et al., 2006; Whitfield et al., 2007; Reading et al., 2010;

Sinervo et al., 2010). However, in temperate regions, an increase in environmental temperature could also enlarge the snake's available time for feeding (Peterson et al., 1993), body growth (Lindell, 1997), breeding success (Chamaillé-Jammes et al., 2006), and survival (Altwegg et al., 2005), which could lead to increased population sizes. In fact, a previous study showed that the number of Montpellier Snake (*Malpolon monspessulanus*) detected in the field in south-eastern Iberian Peninsula increased with the average temperature of the previous years, suggesting a positive effect of temperature on its population dynamics (Moreno-Rueda and Pleguezuelos, 2007). Therefore, the overriding impact of climate change of everything related to natural history of the snakes requires much more attention than has been apparent (Seigel and Mullin, 2009). In this work, we extend the previous investigation, examining the effect of temperature on the field detection of another Mediterranean snake: the Horseshoe Snake (*Hemorrhois hippocrepis*).

Hemorrhois hippocrepis is a thermophilic colubrid distributed over north western Africa and the southern two thirds of the Iberian Peninsula, being found in low- to midlands of south-eastern Spain, where the data for this article were collected (38º30'-37º15'N; 5º30'-2º30'W). The data used here were restricted to an altitudinal range of 0-1000 m a.s.l., extending over thermomediterranean and lower mesomediterranean bioclimatic stages, which this species mainly inhabits (Pleguezuelos and Feriche, 2002). These data were taken between 1980 and 2008, as a part of a long-term study on Mediterranean snakes biology (Feriche et al., 2008). During this period, the sampling effort was constant (about four sampling hours each work day, three days a month, every month, randomly encompassing the whole sampling area). Only individuals active (not those found in their refuge), or recently killed by traffic (time of death estimated as less than 24 h) were recorded. We assumed that snakes killed on roads were active at the moment when the accident happened. In fact, there is a positive correlation between the number of road-killed snakes and the number of alive-detected snakes every year (Moreno-Rueda and Pleguezuelos, 2007).

For each year we recorded the total number of snakes detected, and the average altitude (m a.s.l.) of records. Furthermore, data on the average total precipitation (mm) and temperature (ºC) in the study area were taken from the National Meteorology Institute. Meteorological stations ($n = 98$) used to gather these data were evenly distributed over the sampling area. Because of the elusive nature of snakes, as well as their patchy distributions, low population densities, and solitary behaviour, finding them has a strong stochastic character (Fitch, 1987), which makes long-term monitoring programmes difficult, and capture-recapture studies almost an utopia (Seigel and Mullin, 2009). Therefore, the sampling error in this study, referring to snakes' field abundance, may be relatively high. This error diminishes the statistical power of our tests, making it more difficult to find significant effects, and thus the conclusions have to be more conservative (Yezerinac et al., 1992).

We correlated yearly average temperatures and total precipitation with the number of snakes detected; correlations with the meteorological variables of the preceding year were also performed. The yearly number of snakes detected was log-transformed, and all variables approximated to a normal distribution according to the Shapiro-Wilk test ($P > 0.15$). Therefore, parametric statistics were used, namely Pearson's product-moment correlation (Quinn and Keough, 2002). In order to test for a possible independent effect of each meteorological variable over the detected snakes' abundance, a multiple regression was used, estimating the partial correlations.

During the study period, local temperature increased an average of 0.015 °C per year (Moreno-Rueda et al., 2009). We found 337 *H. hippocrepis* in the restricted study area, with an average of 11.6 snakes per year (S.E. = 1.59, range 1-36, n = 29 years). The number of snakes found did not vary over the years ($r = 0.07$, $P = 0.70$, n = 29 years). The same happened with average altitude of the records ($r = -0.07$, $P = 0.73$, n = 29 years), suggesting that average altitude did not affect our results. The number of snakes found was significantly correlated with the average temperature of the current year ($r = 0.43$, $P = 0.02$, n = 28; Fig. 1a), and tended to be correlated with temperature of the preceding year ($r = 0.36$, $P = 0.06$, n = 28; Fig. 1b) as well as two years before ($r = 0.32$, $P = 0.10$, n = 27 years; Fig. 1c). Precipitation of a given year or of the preceding year was not related to the number of records of this species ($r = -0.01$, $P = 0.95$, and $r = 0.25$, $P = 0.20$, respectively; n = 28 years for both cases). Temperature or precipitation of a specific year were not correlated with temperature or precipitation of the preceding year ($r = -0.02$, $P = 0.91$, and $r = 0.05$, $P = 0.79$, respectively; n = 27 years for both cases), suggesting an absence of temporal autocorrelation. The multiple-regression analysis showed an independent significant effect of average temperature of the sampling year ($\beta = 0.44$, $t_{22} = 2.77$, $P = 0.01$), the previous year ($\beta = 0.38$, $t_{22} = 2.34$, $P = 0.03$), and two years before ($\beta = 0.34$, $t_{22} = 2.09$, $P < 0.05$) on the number of individuals detected ($R^2 = 0.43$, $F_{3, 22} = 5.61$, $P = 0.005$). There was no significant effect of precipitation when it was included in the model ($\beta = -0.05$, $t_{21} = 0.30$, $P = 0.77$), and the R^2 value increased by only 0.002. Lastly, we found a strong positive correlation between the number of *H. hippocrepis* and *M. monspessulanus* specimens detected in the field (from data in Moreno-Rueda and Pleguezuelos, 2007; $r = 0.72$, $P < 0.001$, n = 26 years; Fig. 2).

Species responses to global warming include short-term effects on populations (e.g., changes in abundance), but also long-term effects (e.g., shifts in species distribution; Weatherhead and Madsen, 2009). This study shows that the number of *H. hippocrepis* found in the field increased with average temperature of the current year. This result is not surprising, since the higher the temperature, the more active snakes are (Nelson and Gregory, 2000; Pough et al., 2004; Moreno-Rueda et al., 2009), particularly this species, considered the most thermophilous Iberian snake (Feriche, 2004). It bears noting that the preceding years' temperature also affected the number of snakes detected in the current year. The same result was found in *M. monspessulanus* (Moreno-Rueda and Pleguezuelos, 2007), and the number of records of both species in the last 25 years was strongly correlated. Both results suggest that high temperatures increases the survival and/or breeding success of both species, fostering a higher population size (and thus more detected individuals) the next year. There may be several causes for this (Peterson et al., 1993). As temperature of a given year is higher, snakes have more time available for foraging and basking (Sinervo and Adolph, 1994), which might diminish their mortality rate for different reasons: less torpor (Bennett, 1980), which diminishes predation risk (Goode and Duvall, 1989), and improved feeding ability (Greenwald, 1974), which increases immune capacity (French et al., 2007) and the quantity of resources to survive the winter (Naya et al., 2008). In fact, several studies in temperate regions have shown that as temperature increases, reptile survival rates also increase (Altwegg et al., 2005; Chamaillé-Jammes et al., 2006; but see Sinervo et al., 2010). Reproductive rates also rise with temperature (Lourdais et al., 2002), and a higher temperature also boosts juvenile growth rate (Sinervo

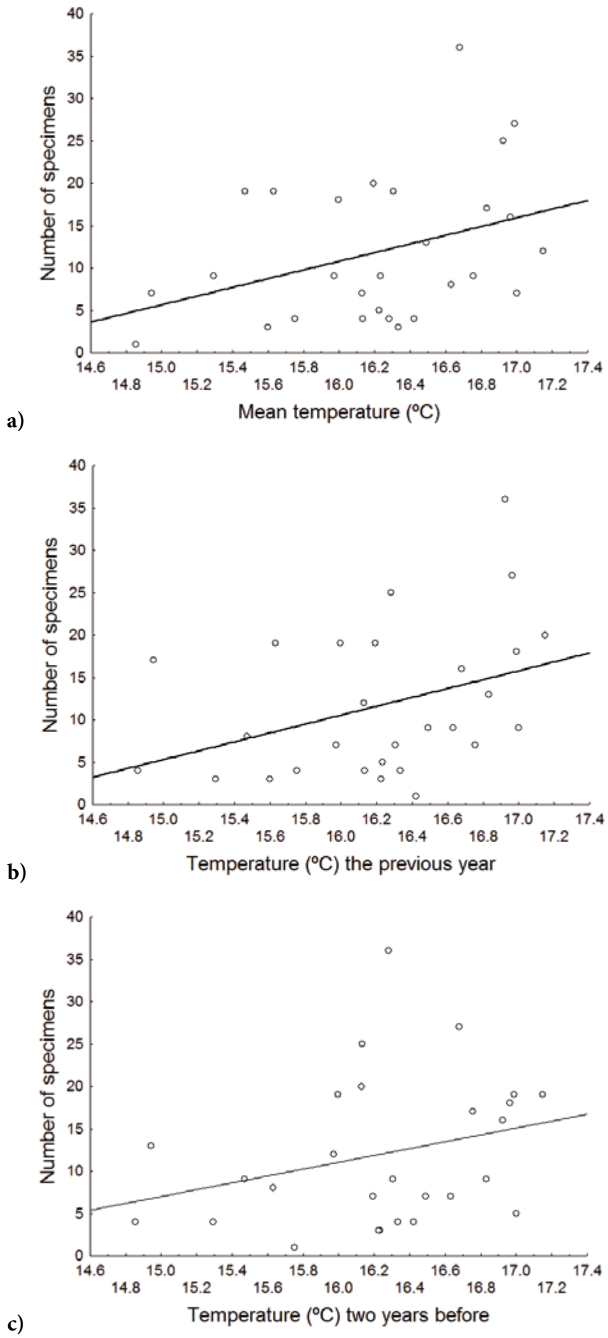

Fig. 1. Relationship between average temperature of the current year (a), the previous year (b), and two years before (c), with the number of Horseshoe Whip Snake (*Hemorrhois hippocrepis*) detected in the field in SE Iberian Peninsula. For the number of specimens, raw data are showed, although the analyses were performed with log-transformed data.

and Adolph, 1989). Moreover, the two studied species (*H. hippocrepis*, *M. monspessulanus*) share a North African origin (Carranza et al., 2006), and are the only two European continental snakes that exhibit a vernal spermatogenetic cycle (Pleguezuelos and Feriche 1999; Feriche et al., 2008). The vernal spermatogenic cycle has strong thermal requirements that constrain its maintenance and distribution to regions with long and overall, warm springs (Saint Girons, 1982).

The fact that the number of individuals found for *H. hippocrepis* and *M. monspessulanus* are mediated by temperature, and the number of individuals recorded for both species are strongly correlated, even in spite of the altitudinal ranges of the populations studied were rather different, suggests that more general conclusions can be proposed concerning the effect of a rising temperatures on Mediterranean snake-population dynamics. Similarly, Weatherhead et al. (2002) found that population dynamics of two North-American populations of the Black Rat Snake (*Elaphe obsoleta*) were strongly correlated, probably because of a climatic effect (see also Reading et al., 2010). Thus, in general, it may be expected that higher temperatures will be beneficial for Mediterranean snake populations, except if other factors counteract these effects, as has been found in France for the Ocellated Lizard (*Timon lepidus*; Cheylan and Grillet, 2005). In fact, in the present study, the density of snakes did not increase over the years, suggesting that other unknown factors offset the benefits of higher temperatures, such as deleterious effects on metabolism or prey availability. In conclusion, our study suggests that the rising temperature favours an increase in the population sizes of Mediterranean snakes, as deduced by the number of individuals observed in the field. We encourage other snake biologists to use their long-term data sets to identify population trends, because these trends may be associated with changes in climate (Wheatherhead and Madsen, 2009).

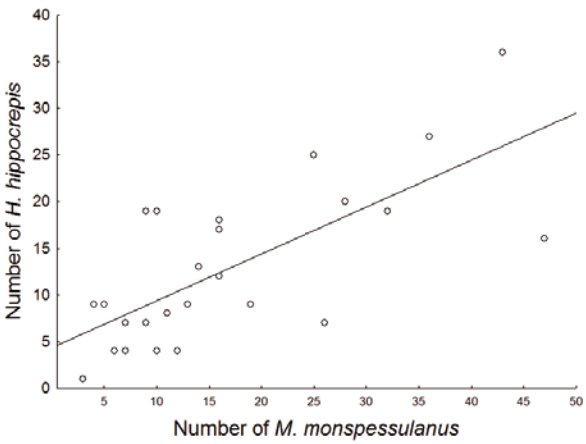

Fig. 2. Relationship between the number of Horseshoe Whip Snake (*Hemorrhois hippocrepis*) and Montpellier Snake (*Malpolon monspessulanus*) detected in the field in the SE Iberian Peninsula during 25 years (1980-2005 period). Raw data are showed, although the analysis was performed with log-transformed data.

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