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Smooth snake population decline and its link with prey availability

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Abstract

The relationship between the numbers of smooth snakes, *Coronella austriaca*, and common lizards, *Zootoca vivipara*, was investigated in a 6.5ha area of lowland heath within Wareham Forest in southern England. With the exception of 2002 the numbers of lizards, small mammals and individual smooth snakes captured, or observed, were recorded during each of 21 annual surveys between May and October 1997-2018. Smooth snake diet was investigated annually between 2004 and 2015 by analysing faecal samples and showed that lizards, particularly the common lizard, and pigmy shrews, *Sorex minutus*, were important prey species. There was no significant correlation between the occurrence of any small mammal species and either snake numbers or their presence in smooth snake diet. Over the study period there was an overall decline in the number of smooth snakes captured whilst there was an overall increase in the number of common lizard sightings. The frequency of common lizards found in the diet of smooth snakes was positively correlated with their abundance within the study area. There was a significant correlation between the decline of smooth snake numbers and the subsequent increase in the number of common lizard sightings suggesting that lizard abundance may be controlled by snake numbers. Conversely, we found no evidence indicating that smooth snake numbers were dependent on lizard numbers suggesting that factors other than prey availability e.g. habitat change due to cattle grazing, blocking ground water drainage ditches, or climatic variables, were impacting on snake numbers, particularly between 2012 and 2018.

Introduction

Several long-term studies have demonstrated population declines in amphibians (Alford et al., 2001), fish (Light and Marchetti, 2007), reptiles (Winne et al., 2007; Böhm et al., 2013; Saha et al., 2018), birds (King et al., 2008; Spooner, Pearson and Freeman, 2008) and mammals (McCloughlin et al., 2003; Spooner, Pearson and Freeman, 2008) with various causes being identified for species known to be at risk (Leclerc, Courchamp and Bellard, 2018). These causes include anthropogenic effects that can result in habitat loss, habitat deterioration through inappropriate land management practices and pollution and are in addition to those resulting from wide scale changes in climate.

With respect to reptiles, about 20% of species are considered at overall risk of extinction (Böhm et al., 2013) but this figure varies geographically with about 20% at risk in Europe (Cox and Temple, 2009) and 10% at risk in southern Africa (Bates et al., 2014). A study of 194 reptile species, occurring in 549 populations, worldwide, estimated that about 55% had declined between 1970 and 2012 (Saha et al., 2018) with a strong bias in the dataset towards chelonians and crocodilians. Lizards and snakes were under-represented within the dataset at 1% and 2% respectively. There is also a recognised lack of population data for snakes that may mean that current estimates for their extinction risks are currently underestimated (Böhm et al., 2013).

Evidence suggesting a global cause for declining snake populations was found in snake populations from the UK, Europe, Africa and Australia (Reading et al., 2010) and although the causes of these declines were unknown, prey availability and habitat loss/deterioration, due to anthropogenic activities were all suspected with one potential, though not exclusive, common cause being climate change.

The smooth snake, *Coronella austriaca*, was one of the species that showed a marked population decline in the UK between 2000 and 2007 (Reading et al., 2010) and has subsequently continued to be studied intensively to the present time along with studies of its diet and the relative annual abundance of its main prey species. The aim of this study was to investigate the relationship between annual changes in smooth snake abundance and prey availability, and determine its importance as a possible cause of the previously reported decline of the snake population.

Materials and methods

Study site

The study site is an area of approximately 6.5ha within a larger 10ha study area of lowland heath located within a managed coniferous forest in southern England (50º44'N, 2º08'W) and comprises a mosaic of dry heath, dominated by a fragmented expanse of heather (*Calluna vulgaris*) and gorse (*Ulex europaeus* and *Ulex minor*) with small areas of open sandy ground, and wet heath, dominated by purple moor grass (*Molinia caerulea*) and cross-leaved heath (*Erica tetralix*). Bristle bent (*Agrostis curtisii*) is also present throughout the study area along with small (<2m high) regenerated conifers (*Pinus sylvestris*). Much of the ground surface, under the vegetation, is covered in moss. The study site was fenced off in 2010 to exclude cattle which have been used annually since 1996 to 'manage' the heathland within a large part of Wareham Forest.

Data collection and analysis

With the exception of 2002 (data excluded from analysis as only 3 surveys were completed), twenty-one surveys for reptiles were completed annually (1997-2018) from late April to late October. Consecutive surveys were separated by about one week depending on weather conditions. Reptiles and small mammals were surveyed using hexagonal refuge arrays, each comprising 37 refuges (corrugated steel sheet: 76 cm x 65 cm) spaced 10m apart. During each survey all refuge arrays were visited between 09.00 and 14.00 hrs with the order in which they were visited varying between surveys so that the same arrays were not always visited at the same time of day. The number of refuge arrays visited during each survey varied from five (1997-2000) to seven (2001-present). Due to this change in the number of arrays used annually, capture and/or observation data for reptiles and small mammals was standardised (mean per array) for the number of arrays visited each year. Only the capture/observation data for 1998 to 2018 were subsequently analysed to allow the reptiles and small mammals one complete season to find and start using the refuges. Similarly, the capture/observation data for the three new arrays added in 2001 were not included in the analysis for that year.

Within each array each refuge was visited in turn by walking a 360m transect walk and any reptiles and/or small mammals observed on, under, between or near each refuge were recorded (snakes were captured). All captured smooth snakes *C. austriaca*, were individually identified using subcutaneously implanted passive integrated transponder tags (pit-tags; see Reading, 2012 for a detailed description of individual snake identification and survey methodologies). The availability of each potential prey species within the study area was estimated annually from the total number of observations of reptiles (slow worm - *Anguis fragilis (Af)*, common lizard - *Zootoca vivipara (Zv)*, sand lizard - *Lacerta agilis (La)*, grass snake - *Natrix natrix (Nn)*), amphibians (common toad - *Bufo bufo (Bb)*) and small mammals (common shrew - *Sorex araneus (Sa)*, pygmy shrew - *Sorex minutus (Sm)*, wood mouse - *Apodemus sylvaticus (As)*, short-tailed vole - *Microtus agrestis (Ma)*) that were found during each survey for *C. austriaca*.

Between 2004 and 2015 the prey taken by *C. austriaca*, were identified from 'body parts' present in faeces obtained from captured snakes and preserved in 70% ethanol prior to examination under a binocular dissecting microscope. A detailed description of snake faecal sample analysis is given in Reading and Jofré, 2013 along with safeguards for avoiding pseudo-replication of data where samples were obtained from the same individual over a short period of time.

All statistical analyses were done using Minitab 16.

Results

Between 2004 and 2015 a total of 1306 captures were made of 101 individual smooth snakes. From these, 288 prey items were identified from faecal samples collected from 83 (28 ♀ and 55 ♂) smooth snakes (mean SVL ± SD = 38.9 ± 7.69 cm, range = 14.2 - 53.5 cm) within the lowland heath study area. The prey species included slow worms (*Af*: 5.2%), two *Lacertids* (*Lac-sp* + *Zv* + *La*: 51.4%), two *Soricids* (*Sor-sp* + *Sa* + *Sm*: 29.2%), two Murids (juvenile mammals + *Ma* + *As* + small mammals: 13.5%), grass snake (*Nn*: 0.3%) and common toad (*Bb*: 0.3%).

After allotting either *Zv* or *La* to the '*Lac-Sp*' group, in proportion to the ratio of positively identified *Zv* to *La*, and either *Sm* or *Sa* to the '*Sor-Sp*' group in proportion to the ratio of positively identified *Sm* to *Sa*, in the faecal samples, it was apparent that the most frequently found prey species were common lizards (38.2%) and pigmy shrews (20.5%) which together constituted 58.7% of the diet.

Regression analysis of the proportion (%) of potential prey species (*Af*, *La*, Zv, *Sm*, *Sa*, *As* and *Ma)* occurring in the diet of smooth snakes against the number of sightings of each prey species on the heath each year (2004-2015) showed that with the exception of *Zv* (r^2 = 79.3%; $P < 0.001$: fig. 1), and the possible exception of *La* (r^2 = 33.1%; $P = 0.05$), none of the remaining relationships were statistically significant ($P > 0.05$).

Regression analysis of the number of each of individual prey species, and the grouped prey categories (*Lacertids*, *Soricids* and *Murids*) present within the study area

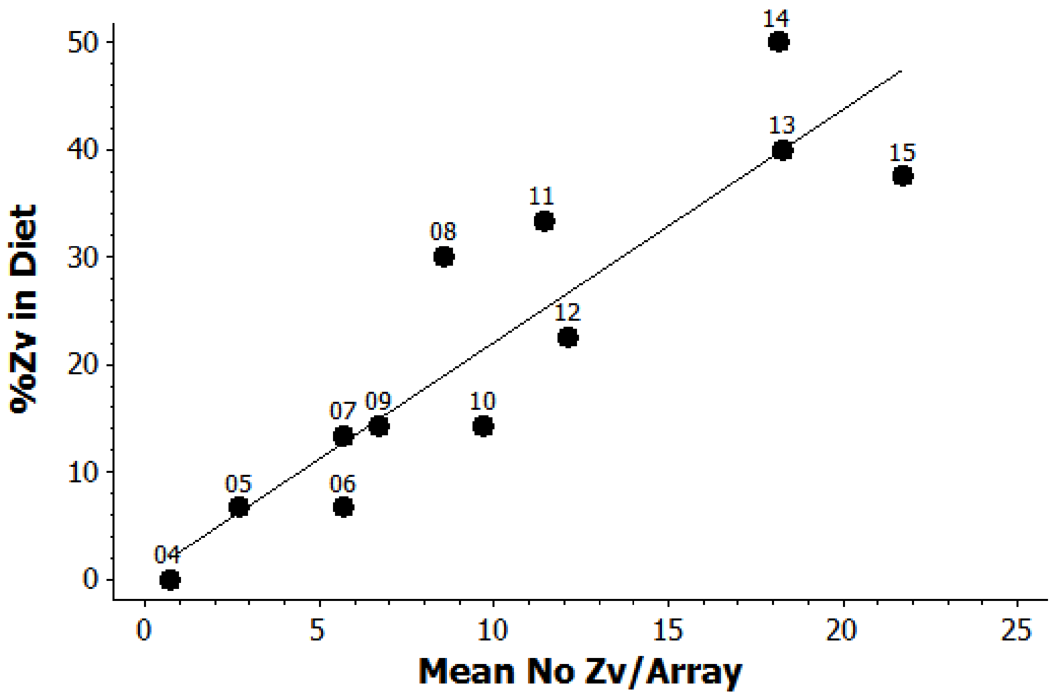

Figure 1. Percentage of smooth snake diet represented by common lizards (*Zv*) against the number of common lizard sightings per array (2004-2015). Years are shown against each point. %*Zv* Diet=0.492+2.161 Mean *Zv* per array; r^2=81.3%; *P*<0.001; n=12.

each year, against the number of individual smooth snakes also occurring within the study area between 1998 and 2018, showed a highly significant relationship for all combined *Lacertids* (*La* + *Zv*: *Lacertids* = 30.7 - 5.40 *Ca* Individuals; r^2 = 53.9%; $P < 0.001$; n = 20) but no significant relationship ($P > 0.05$) for slow worms or any of the individual small mammal species or small mammal groups (*Soricids* and *Murids*).

Within the *Lacertids* there was no significant relationship ($P > 0.05$) between sand lizard numbers and the number of smooth snake individuals occurring in the arrays whilst there was between the number of smooth snake individuals and common lizard numbers (*Zv* = 28.7 – 5.73 *Ca* Individuals; r^2 = 50.0%; $P < 0.001$; n = 20; fig. 2). There was an overall decline in the number of smooth snake individuals occurring within the study area

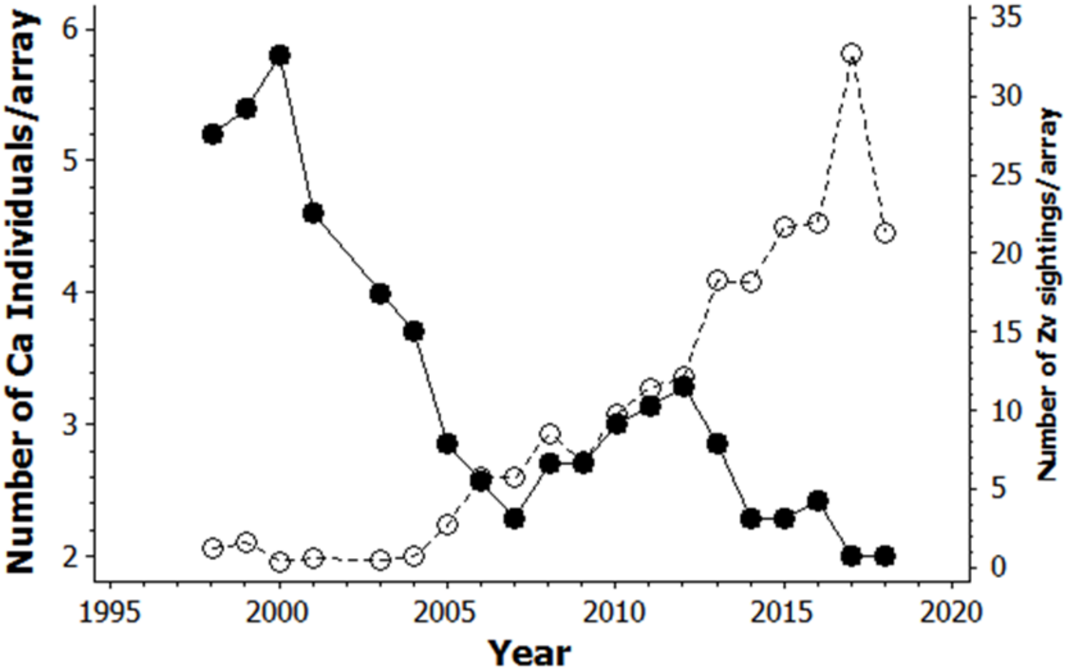

Figure 2. Mean numbers of *Ca* individuals (●) and *Zv* sightings (○) per array each year (1998-2018).

between 1998 and 2018, that coincided with an overall increase in the number of common lizard sightings over the same period. However, depending on how smooth snake and common lizard numbers changed with respect to each other, the study period can also be divided into three distinct periods, 1st: 1998 - 2007, 2nd: 2007 - 2012 and 3rd: 2012 - 2018.

There were significant negative relationships between the number of smooth snake individuals and the number of common lizard sightings during the first and third periods (1^{st}: $Zv = 7.40 - 1.30\ Ca$; $r^2 = 60.7\%$; $P = 0.013$; $n = 9$; 3^{rd}: $Zv = 46.0 - 10.3\ Ca$; $r^2 = 59.8\%$; $P = 0.041$; $n = 7$) but a significant positive relationship during the second period (2^{nd}: $Zv = -10.2 + 6.75\ Ca$; $r^2 = 91.6\%$; $P = 0.003$; $n = 6$).

There was also a time lag between the decline of smooth snake numbers and the increase in common lizard sightings. Further analysis showed that although there were significant relationships ($P < 0.001$) between the number of common lizard sightings and the number of smooth snake individuals with time lags greater than one year the most significant of these occurred when the number of common lizard sightings in year *t+3* was plotted against the number of smooth snake individuals in year *t* (fig. 3). Regression analysis of $\log_{10}$ common lizard sightings against the total number of smooth snake individuals captured each year showed a strong negative correlation between the occurrence of the two species within the study area.

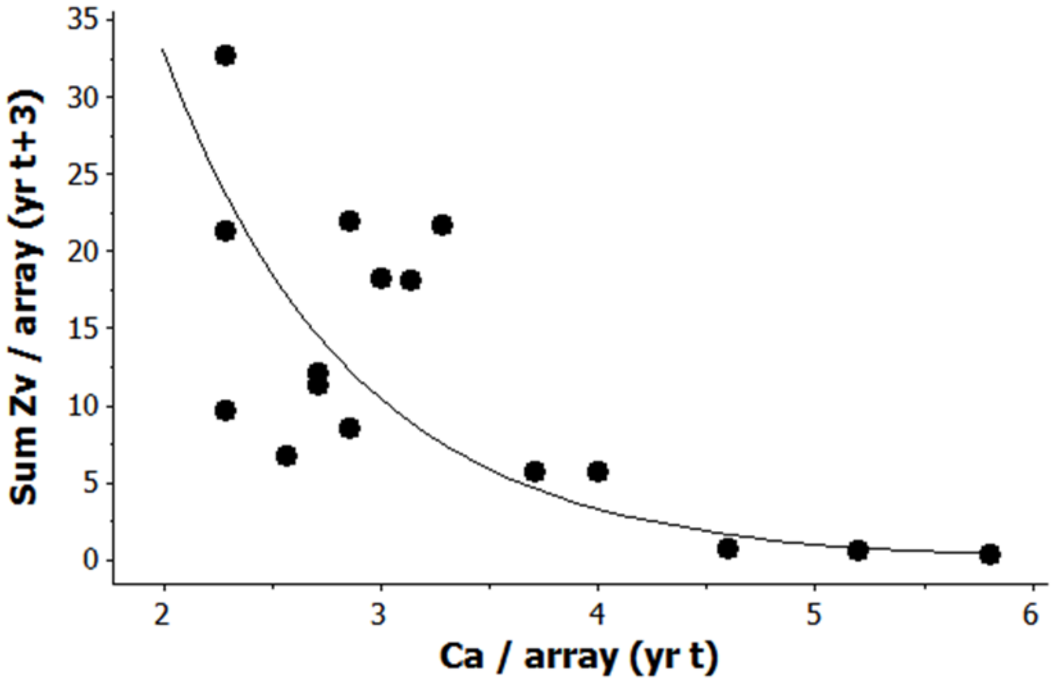

Figure 3. Plot of mean number of *Zv* sightings per array (year *t+3*) against number of *Ca* individuals per array (year *t*: 1998-2018).

Fitted line: Log_{10} *Zv* sightings=2.517-0.4983 *Ca* individuals: r^2=80.4%; P<0.001; n=16.

Discussion

Analysis of the three years of faecal sample data (2013 - 2015), in addition to the previous nine years of data (2004-2012) reported for the same population (Reading and Jofré, 2013), confirmed the importance of *Lacertids* (particularly the common lizard) and small mammals (particularly *Soricids* and juvenile *Murids*) in the diet of smooth snakes. The observed decline in the numbers of smooth snakes in the study area between 2000 and 2007 was subsequently followed by an increase in the number of common lizard sightings suggesting that the density of this prey species may have been impacted by the relatively high numbers of smooth snakes (48 individuals) up to 2000. Between 2007 and 2012 both smooth snake and common lizard numbers increased at a similar rate. However, between 2012 and 2018, whilst common lizard numbers continued to increase, smooth snake numbers declined sharply and, in 2017 and 2018, were at their lowest since the beginning of the study. It might be argued that the overall decline in smooth snake numbers (2000 - 2018) was the result of low prey availability (particularly common lizards) but this was not found. Results from the study of smooth snake diet (2004 - 2015) showed that the proportion of common lizards in the diet was at its highest between 2013 and 2015, when snake numbers had declined to their lowest density since 1998, suggesting that the decline between 2012 and 2018 was the result of factors other than prey availability. This view was first postulated by Reading et al. (2010) in a study of snake declines in 17 populations from Europe, Africa and Australia between 1987 and 2009, and where 11 of these showed similar significant declines between 1998 and 2005. Habitat change, or degradation, possibly, but not exclusively (e.g. anthropogenic causes), driven by climate change was suggested as a potential cause of these observed declines.

Although the absence of any significant relationships between smooth snake numbers and small mammal numbers may be a reflection, more, of the probable inadequacy of the sample methodology (artificial refuges) with respect to small mammals and the subsequent low numbers observed, rather than a true estimate of their availability, the methodology was, nevertheless, consistent throughout the study and thus the change in their abundance over the duration of the study could be measured.

We suggest three potential factors for the first observed steep decline in smooth snake numbers between 2000 and 2007 and their second decline between 2012 and 2018. First, in 1996 cattle were introduced into an area of Wareham Forest that included the study area, to 'manage' the grasses (principally *M. caerulea*) that occurred within parts of the heath and to increase habitat heterogeneity (Rhodes, 2014). The decline in smooth snake numbers started 3-4 years after the introduction of 'conservation grazing' suggesting a possible link between the two events particularly as the impact of cattle grazing on heathland makes it less favourable for many reptile species including the smooth snake and common lizard (Reading and Jofré, 2015, 2016). Second, at about the same time as the introduction of cattle, the drainage ditches taking surface water away from low lying areas of heath, including the study area, were blocked by the Forestry Commission thereby encouraging the development of wet heath/mire as part of a program of 'habitat restoration' from conifer plantation to open habitat (Moody, Hodder and Diaz, 2011; Rhodes, 2014).

In 2010 the study area was fenced off, to exclude cattle, resulting in an increase in the ground cover and vegetation height, particularly of *M. caerulea*, an important plant species for common lizards (Reading and Jofré, 2016). Third, since the study area was surrounded by grazed heath, and given the recognised impact of cattle grazing on heathland and its reptile communities (Reading and Jofré, 2015, 2016), the decline in overall smooth snake numbers during the study may also be the result of a possible decline in the number of 'new' snakes, particularly young snakes, potentially able to colonise the study area from the surrounding grazed and potentially unsuitable heath.

Over the 22 year period (1998 - 2018) covered by this study the data suggest that smooth snake numbers were having an initial negative impact on common lizard numbers, up to about 2004. After 2004, when common lizard numbers started increasing there was no subsequent sustained increase in smooth snake numbers despite the increasing occurrence of common lizards in their diet. This is strong evidence indicating that factors other than prey availability e.g. habitat loss, habitat deterioration (McLoughlin et al., 2003), possibly resulting from inappropriate habitat management practices, or from climate change (Reading et al., 2010), may therefore be responsible for the observed decline in smooth snake numbers between 1998 and 2018. Whilst prey availability can now be reasonably excluded as a direct cause of the observed decline of smooth snakes, in the Wareham Forest study area since 2000 further research into the impact of different forms of habitat management on reptile, and other wildlife, communities is essential and should be completed before the implementation of any management regime.

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