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Habitat use by smooth snakes on lowland heath managed using 'conservation grazing'.

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Running title: Habitat use by smooth snakes

ABSTRACT

Heathland in the UK, and parts of mainland Europe, is being managed increasingly by landowners and statutory conservation bodies e.g. Natural England, using cattle grazing which is often referred to as 'conservation grazing' in an attempt to justify its use in the absence of any detailed prior research into its actual benefits for wildlife species, whose individual habitat requirements are likely to vary, therefore requiring different management techniques to conserve them. Over four years, between 2010 and 2013, cattle were excluded from six hectares of lowland heath that had been subject to annual summer cattle grazing between May 1997 and autumn 2009 and in which reptile numbers had been monitored annually since 1997. Changes in smooth snake (*Coronella austriaca*) numbers were recorded annually in the ungrazed area and in a four hectare area of heathland adjacent to it that continued to be grazed. The number of individual smooth snakes, and the total number of smooth snake captures, were significantly higher in the ungrazed heath than the grazed heath and were associated with increased habitat structure, resulting principally from tall heathers and grasses. The results of the study suggest that the use of cattle grazing as a management tool on lowland heath is detrimental to smooth snake populations and that their recovery, following the cessation of grazing, may take many years.

Key words: *Coronella austriaca*, cattle grazing, habitat degradation, habitat structure, *Calluna vulgaris*, *Molinia caerulea*, *Ulex minor*, *Agrostis curtisii*

INTRODUCTION

Habitat change is now recognised as a primary cause of declines in biodiversity generally and the biggest threat to the conservation status of many taxa worldwide (Sala et al., 2000). In particular, it is considered to be the main driver of global declines in herpetofauna (Gardner et al., 2007). The causes of habitat change are various, often linked to human land use practices and include forestry, agriculture and domestic livestock grazing (Lindenmayer & Fischer, 2006; Böhm et al., 2013). Livestock grazing has a direct impact on plant biomass, plant species composition and vegetation structural components, such as height and cover which, together, may affect a habitat's ability to support the animal communities that rely on it for food and shelter (Kie et al., 1996; Hay & Kicklighter, 2001).

Within the UK the lowland heaths of southern England have declined in area significantly since 1759 (Rose et al., 2000) due mainly to fragmentation and the loss of many resultant small areas to development. Heathland is also often viewed as 'waste land' and Government policy, under the GAP (Grazing Animals Project) scheme, encourages its exploitation. As a consequence, Natural England, the UK's statutory body tasked with protecting England's fauna and flora, under direction from the UK Government's Department of Environment, Food and Rural Affairs developed a habitat management policy designed to 'conserve wildlife and maintain biodiversity' (see NE[a]). This policy includes the use of domestic livestock, primarily cattle, to manage lowland heath and encourages landowners to do so by providing financial incentives, partly based on the size of areas to be grazed, under the Higher Level Stewardship (HLS) scheme, part of the Environmental Stewardship (ES) scheme (see NE[b]). To promote its acceptance by landowners and the general public this policy has been called 'conservation grazing'. Unfortunately, no investigation into its benefits for wildlife species inhabiting lowland heath was undertaken prior to its implementation as a management tool in the 1990's, and so its impacts on them were unknown. However, evidence from The Netherlands has shown that reptile populations either disappeared or declined significantly (Strijbosch, 2002; Stumpel & van der Werf, 2012) in cattle grazed heathland whilst a review of its impacts on heathland in north-west Europe concluded that more monitoring and experimental research was required to establish its effectiveness as a management technique (Newton et al., 2009).

In the UK, all six species of native British reptiles (adder *Vipera berus*, grass snake *Natrix natrix*, smooth snake *Coronella austriaca*, common lizard *Zootoca vivipara*, sand lizard *Lacerta agilis*, slow worm *Anguis fragilis*) occur on lowland heath in southern England, where the smooth snake is restricted to it (Frazer, 1983) and where the sand lizard and smooth snake (European protected species) are at the north-western edge of their geographical range.

In 2010, cattle were excluded from part of an area of heathland where the reptiles had been studied intensively since 1997 and where habitat deterioration was the suggested cause of a reported decline of smooth snakes between 1997 and 2009 (Reading et al., 2010). This presented a rare opportunity to investigate the potentially changing relationship between habitat structure and the occurrence of all six native species of British reptile on grazed and ungrazed heath. Here we report on habitat use by smooth snakes and how their numbers have changed since 2010.

MATERIALS AND METHODS

Study area

The study site was a 10 ha area of lowland heath situated within Wareham Forest, a managed coniferous forest in the south of the UK (50°44′N, 2°08′W). The area is surrounded on three sides by conifer plantations and on the fourth by heathland. The area comprises a mosaic of dry and wet heath, the dry heath dominated by a discontinuous cover of ling (*Calluna vulgaris*), bell heather (*Erica cinerea*), common gorse (*Ulex europaeus*) and dwarf gorse (*Ulex minor*), and the wet heath by purple moor grass (*Molinia caerulea*) and cross-leaved heath (*Erica tetralix*). Bristle bent (*Agrostis curtisii*), moss and dead grass leaves, of varying depth, also occurred throughout the study site along with small areas of bare sandy ground in the dry heath.

The study area is part of a much larger area (approximately 300 ha) that has, since 1997, been managed annually using cattle grazing between early May and mid-September. This area includes a mixture of managed conifer plantations of varying age (0-60+ years old), heathland, acid bog and forest rides. In February 2009 a small part of the study area (≈0.2 ha) was subject to a controlled burn by the Forestry Commission. In February 2010 cattle were excluded from approximately six hectares of the study area (hereafter referred to as 'ungrazed' area), with the remaining four hectares (adjacent to it), including the partially burnt area, continuing to be grazed (hereafter referred to as 'grazed' area).

Since May 1997 the number of cows released annually has varied between 35 and 91 individuals giving overall minimum cattle densities at the start of each season of 0.12-0.30 cows per hectare. These densities increased within each year following the birth of calves. The cattle also split into small cohesive groups of up to 30 individuals that roamed, grazed and rested together on preferred areas of heathland (heathland, conifer plantations, forest rides and tracks but excluding bog). The breeds used were mainly Aberdeen-Angus crossed with Hereford, Simmental and Friesian.

Reptile surveys

Reptiles were surveyed using randomly placed arrays of 37 artificial refuges (corrugated steel sheet: 76cm x 65cm), spaced 10m apart, and arranged in a hexagonal pattern with each array covering an area of approximately 0.29 hectares (Reading, 1997). With the exception of 1997 (18 surveys) and 2002 (only 3 surveys due to injury) 21 surveys were completed annually (1998-2013) between late April and late October (approximately one survey every 7-10 days). There were five refuge arrays in the ungrazed area between 1997 and 2000 which was increased to seven in 2001. There were four within the grazed area that had been continuously managed, between 1997 and 2013, using cattle. The data from 2002 were excluded from the analysis.

During each survey each array was visited in sequence and a transect walk (360 m long) completed within each array such that each refuge was visited in turn and checked for reptiles on and under it. Reptiles observed during the walk between refuges were also identified and recorded. To avoid checking the same array at approximately the same time of day, during each survey, the starting point of each survey was varied. Captured smooth snakes were individually identified using implanted passive integrated transponder (PIT) tags (see Reading, 2012 for a detailed description of individual snake identification methodologies).

Vegetation surveys

Vegetation surveys were completed annually in late summer between 2010 and 2013 using a 2m x 2m quadrat at each of 10 fixed locations within each of the 11 reptile refuge arrays. The location pattern of the 10 quadrats within each array was the same for all arrays. The height and percent cover of each plant species (live and standing dead), depth of litter and proportion of bare ground occurring within each quadrat were recorded. All height and depth measurements were made using a one metre ruler and up to 12 measurements were taken for each species in each quadrat depending on its abundance.

Overall the height/depth of 37 habitat variables (live plants, standing dead plants, litter) and the percent cover of these, plus bare ground, were measured annually in each of the 110 fixed vegetation quadrats between 2010 and 2013 (Table 1). The habitat within each of the 11 reptile refuge arrays was subsequently classified, using the NVC, as either '*Calluna vulgaris-Ulex minor*' (*Cv-Um*) heath or '*Ulex minor-Agrostis curtisii*' (*Um-Ac*) heath, the former being characteristically dry lowland heath whilst the latter is wet lowland heath. Four of the '*Cv-Um*' arrays and three of the '*Um-Ac*' arrays were within the ungrazed area and two of each in the grazed area.

Table 1 List of the 38 habitat variables, with abbreviations (Abbrev.), measured during each vegetation survey. *-species selected for Fig. 2.

Abbrev.	Species	Abbrev.	Species
Heathers		Bushes	
Cv*	*Calluna vulgaris*	Ue	*Ulex europaeus*
D.Cv	Standing dead *C. vulgaris*	Um*	*Ulex minor*
Ec*	*Erica cinerea*	D.Um	Standing dead *U. minor*
D.Ec	Standing dead *E. cinerea*	Cs	*Cytisus scoparius*
Et*	*Erica tetralix*	Rp	*Rhododendron ponticum*
D.Et	Standing dead *E. tetralix*	Rf	*Rubus fruticosus agg.*
Grasses and Sedges		Herbs	
Ac*	*Agrostis curtisii*	Dp	*Digitalis purpurea*
Acap	*Agrostis capillaris*	Pe	*Potentilla erecta*
Mc*	*Molinia caerulea*	Ra	*Rumex acetosella*
Mm	*Mibora minima*	Gs	*Galium saxatile*
Cp	*Carex pilulifera*	P	*Plantago sp.*
Sedge	*Carex sp.*	Sv	*Senecio vulgaris*
Trees		Litter	
Pine	*Pinus sp.*	Pn	Pine needles
Bp	*Betula pendula*	DPa	Dead *P. aquilinum* fronds
Qr	*Quercus robur*	DGr	Dead grass leaves
		Dw	Dead wood
Lower plants		HLit	Heather litter
Pa	*Pteridium aquilinum*	GLit	Gorse litter
Fern	Unidentified Fern		
Ci	*Cladonia impexa*	Other	
Moss*	Unidentified Moss	BGr	Bare ground

Data analysis

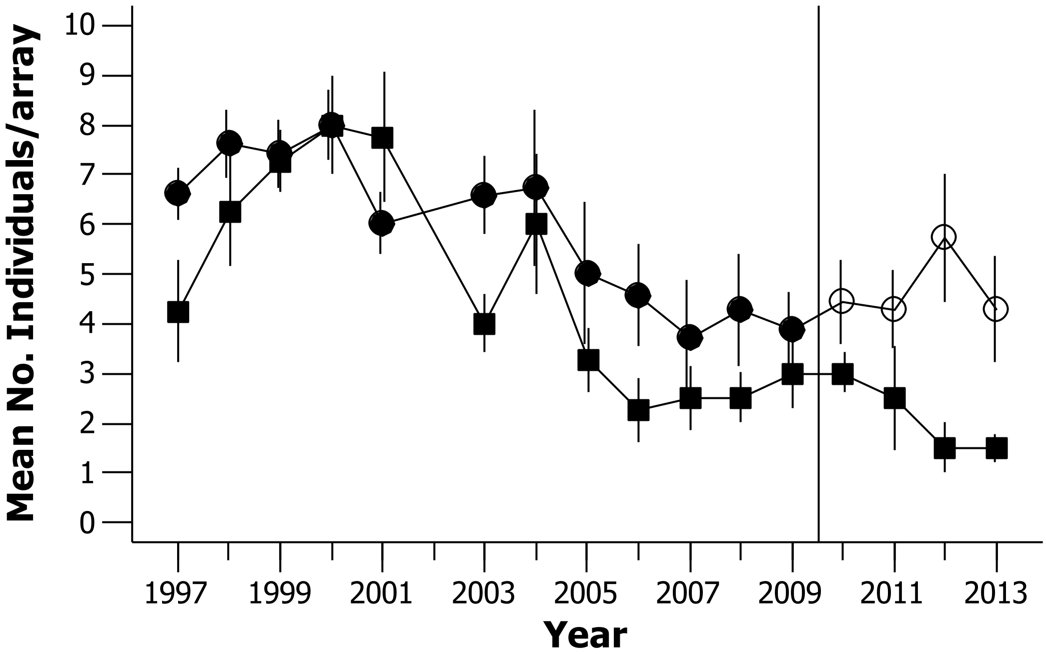
All statistical analyses were completed using Minitab 16 (Minitab 2010). The type of heath present in each refuge array was determined according to National Vegetation Classification (NVC) criteria using TABLEFIT v.1.1 (Hill, 2011). Mean values were compared using Student's t-test and linear regression analysis was used to describe the relationships between smooth snake occurrence and habitat variables. All statistical tests were considered significant at $P<0.05$.

RESULTS

Changes in smooth snake numbers (1997-2013)

The mean number of smooth snake individuals recorded annually from both grazed and subsequently ungrazed arrays (after 2009), between 1997 and 2009, showed a small increase after the introduction of cattle grazing in 1997, reaching a peak in 2000 in both (grazed: mean=8.0; SD=2.00; *n*=4; ungrazed: mean=8.0; SD=1.581; n=5; Fig. 1). In both array subsets the mean numbers then declined to a minimum in 2006 (grazed: mean=2.25; SD=1.258; *n*=4) and 2007 (ungrazed: mean=3.71; SD=3.039; n=7) and remained at, or about, this level until 2009.

Fig. 1. Mean (± SE) number of individual smooth snakes (♀ + ♂) found in grazed (■: 1997-2013, ●: 1997-2009) and ungrazed (○: 2010-2013) arrays. The vertical line shows when the cattle exclusion fence was erected.



Following the exclusion of cattle in 2010 the mean number of smooth snakes occurring in the ungrazed arrays increased to a maximum of 5.7 in 2012 (SD=3.450; n=7) before declining back to 4.3 (SD=2.811; n=7) in 2013 whilst in the grazed arrays it declined to a minimum in 2012 and 2013 (mean=1.50; SD=1.000; n=4). Prior to the exclusion of cattle the mean number of individuals per array in the grazed and ungrazed array subsets, with the exception of 2003, did not differ significantly ($P>0.05$). Following the exclusion of cattle there was a divergent trend in the two array subsets with the mean numbers of individuals in the ungrazed arrays in 2012 and 2013 being significantly greater than in the grazed arrays (2012: t=-3.02, P=0.019, d.f.=7; 2013: t=-2.53, P=0.045, d.f.=6).

Over the whole four year period significantly fewer (t=-4.75; $P<0.001$; d.f.=41) individuals occurred in all the grazed arrays (mean=2.1; SD=1.29; n=16) compared to all the ungrazed arrays (mean=4.8; SD=2.55; n=28) and the overall total number of smooth snake captures was also significantly lower (t=-3.56; P=0.001; d.f.=32) in grazed arrays (mean=4.25; SD=3.21; n=16) than ungrazed arrays (mean=13.07; SD=12.41; n=28).

Smooth snake associations with heathland plant species

The data provided in Table 1 was used to select five plant species/assemblages, denoted with an '*' (heather: live *C. vulgaris*, *E. cinerea*, *E. tetralix*; *U. minor*; *A. curtisii*; *M. caerulea* and moss), with which to investigate smooth snake occurrence. This selection was based on their perceived ability to provide cover for smooth snakes and structure to the overall habitat (a combination of tall plant height and high maximum % cover) and, in the case of moss, its presence within most arrays and to varying depths. Tree saplings, plant species that did not occur in both grazed and ungrazed areas, species providing a mean ground cover below five percent or those with a mean height below five cm were excluded from further analysis.

The number of smooth snakes occurring within any array was defined both in terms of the total number of individuals, and the total number of captures of all individuals, as any single array may have had one resident smooth snake that was captured many times or a number of 'transient' individuals that were each captured once or rarely. The total number of individual smooth snakes and the total number of smooth snake captures recorded in each array during each of the four years (2010-2013) were plotted against the mean height and percent cover of the plant species within each array (Fig. 2). No smooth snakes were found in the burnt array.

Heather (*C. vulgaris* + *E. cinerea* + *E. tetralix*)

Fewer individuals and total captures were recorded from grazed arrays than from ungrazed arrays. Most individuals and captures occurred in arrays with a mean heather height of 35-40cm and the fewest in arrays with a mean heather height lower than about 25cm or greater than approximately 50cm (Fig. 2). Where both grazed and ungrazed arrays had heather of a similar mean height, or percentage cover, fewer snakes occurred in the grazed arrays than the ungrazed arrays. The highest number of smooth snake individuals and captures were recorded from ungrazed dry (*Cv-Um*) heath and the lowest from grazed wet (*Um-Ac*) heath. There were significant positive relationships between the percent cover of heather and the total number of smooth snake individuals (Ca Individuals = 0.783 + 0.096 %cover; r^2=32.6%; P<0.001; n=48) and captures (Ca Captures = -2.431 + 0.408 %cover; r^2=35.4%; P<0.001; n=48).

Dwarf gorse (*U. minor*)

The total number of smooth snake individuals and captures were highest in dwarf gorse with a height of approximately 25cm with fewest individuals or captures occurring in gorse with a height below 13cm or above 35cm (Fig. 2). In arrays where gorse heights and percentage cover were similar fewer snakes were recorded in grazed arrays than ungrazed arrays. However, in

Fig. 2. Plots of the total number of smooth snake individuals and total captures against mean plant height/depth (a, b) and percent cover (c, d) for each refuge array located in dry (circles) and wet (squares) heath within the grazed (●, ■) and ungrazed (○, □) areas (2010-2013). Heather: *C. vulgaris* + *E. cinerea* + *E. tetralix*; Um: *U. minor*; Ac: *A. curtisii*; Mc: *M. caerulea*.

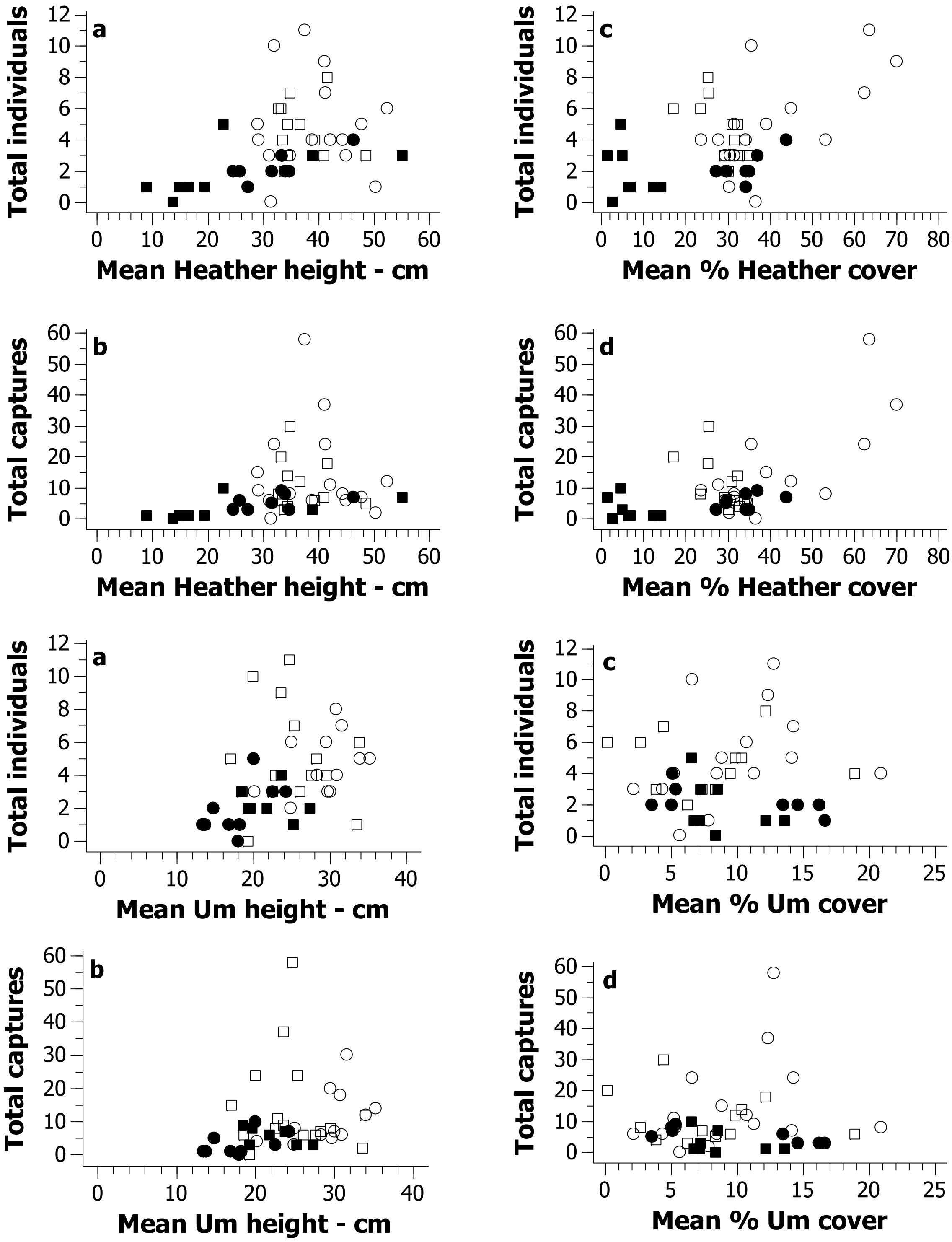


Fig. 2. Cont'd

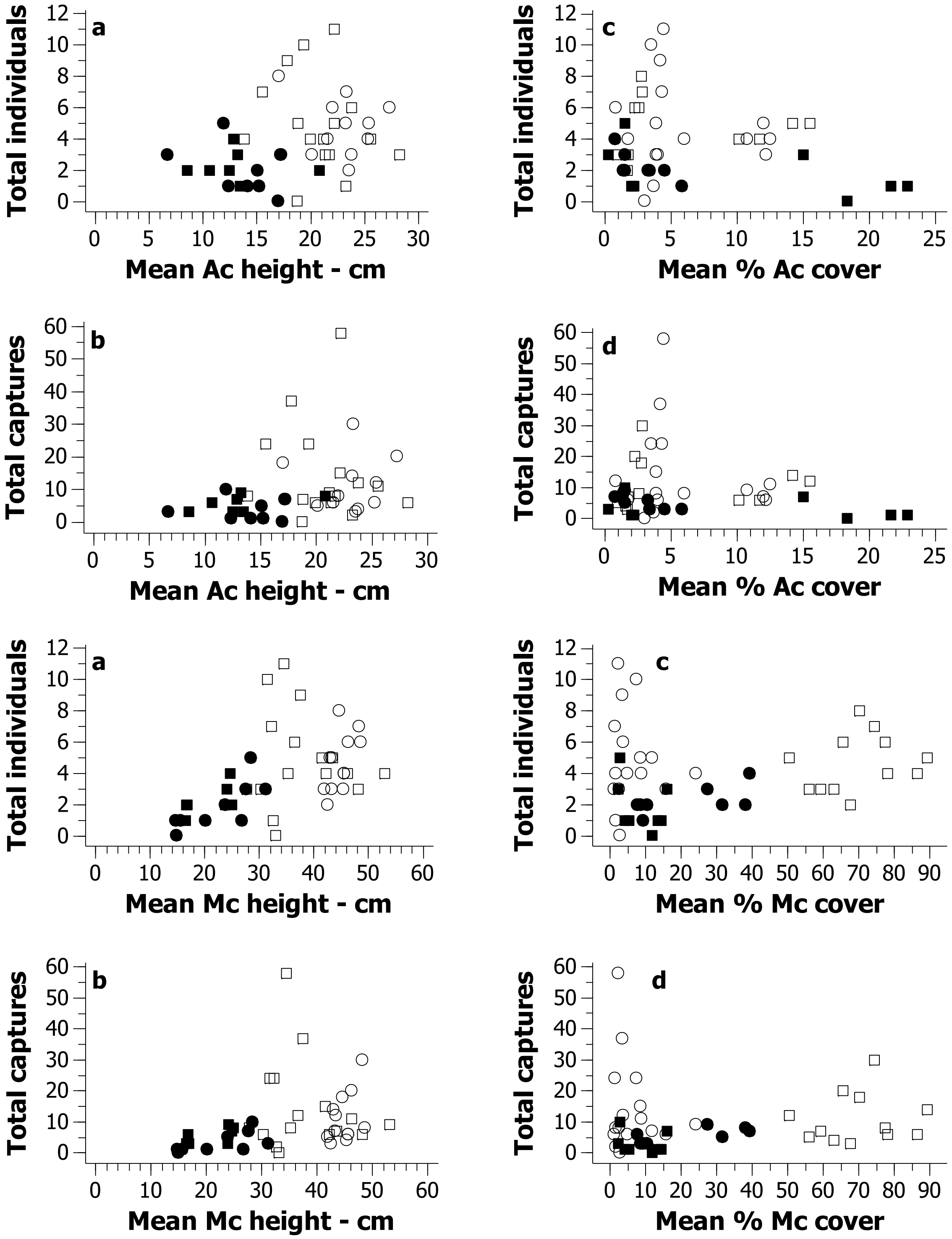
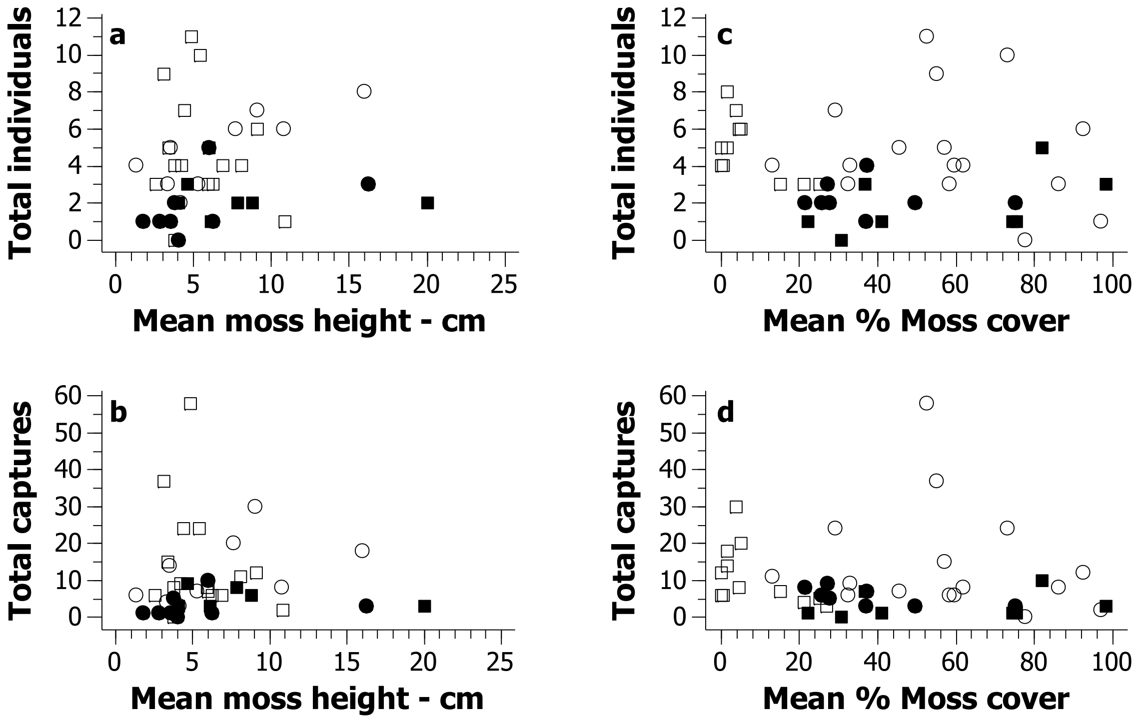

a
Total individuals
Mean Ac height - cm
c
Total individuals
Mean % Ac cover
b
Total captures
Mean Ac height - cm
d
Total captures
Mean % Ac cover
a
Total individuals
Mean Mc height - cm
c
Total individuals
Mean % Mc cover
b
Total captures
Mean Mc height - cm
d
Total captures
Mean % Mc cover

Fig. 2. Cont'd



contrast to heather, in arrays where gorse heights were similar the highest numbers of individuals were recorded from ungrazed wet heath, rather than ungrazed dry heath, and the lowest from grazed dry heath. There was no significant relationship between gorse cover and either the total number of individuals (P>0.05) or captures (P>0.05).

Grasses (*A. curtisii and M. caerulea*)

The highest numbers of smooth snake individuals and captures were recorded from arrays on wet heath where the mean heights of *A. curtisii* and *M. caerulea* were approximately 22cm and 35cm respectively (Fig. 2). The lowest numbers were found where the height of these two species were below 7cm and 15cm or above 28cm and 53cm respectively. In arrays where grass heights were similar the highest numbers of both individuals and captures were recorded in ungrazed wet heath and the lowest in grazed dry heath. In arrays where the percentage cover of *A. curtisii* and *M. caerulea* were similar the highest numbers of individuals and captures occurred in ungrazed dry heath with relatively low grass cover (<5%) and the lowest in grazed wet heath. There were no significant relationships between grass cover and either the total number of individuals (P>0.05) or captures (P>0.05).

Moss

The mean depth and percent cover of moss were similar in both grazed and ungrazed arrays (Fig. 2). However, as with heather, gorse and the grasses the total numbers of smooth snake individuals and captures were lower in the grazed arrays than the ungrazed arrays. There was no significant relationship between moss cover and either the total number of individuals (P>0.05) or captures (P>0.05).

DISCUSSION

This study reports the observed annual changes in smooth snake *C. austriaca* numbers in an area of wet and dry lowland heath that had been grazed annually for 13 years (1997-2009) before cattle were excluded from part of it in 2010.

Prior to the exclusion of cattle from part of the study area in 2010, the patterns of change in the number of smooth snake individuals recorded from both subsets of arrays were similar with the observed decline in numbers, from about 2000, suggesting a possible delayed response to the introduction of grazing in 1997. However, these declines may have been coincidental with the introduction of grazing as similar declines were reported for a number of other snake species from around the world, over the same period, where the cause was unknown though habitat quality deterioration/change is suggested as one possibility (Gardner et al., 2007; Reading et al., 2010).

The divergent trends in the mean number of smooth snake individuals occurring in the subsequently grazed and ungrazed arrays following the cessation of grazing in 2010 support the argument for grazing being the likely causal agent of the observed declines. Our data also agree with the results of two studies of reptiles on heathland in The Netherlands where either fewer reptiles were found in grazed heathland than ungrazed heathland (Strijbosch, 2002; Stumpel & van der Werf, 2012) or they totally disappeared from grazed areas e.g. smooth snake *C. austriaca*, common lizard *Z. vivipara* and slow worm *A. fragilis* (Strijbosch, 2002).

One possible explanation for the observed differences in smooth snake occurrence, between the grazed and ungrazed areas (2010-2013), were changes to habitat structure, that occurred over the same period, and the observed association of smooth snakes with particular plant species and habitat attributes (plant height and percentage ground cover). Smooth snakes are stated to prefer a well-structured habitat comprised predominantly of mature heather *C. vulgaris* and *M. caerulea* with a deep litter layer of bryophytes (Braithwaite et al., 1989; Corbett, 1990; Edgar *et al*., 2010). Our results support these assertions. Smooth snakes occurred most frequently in ungrazed dry heath with a mean heather height of 35-45 cm and the highest heather ground cover.

Cattle are known to graze heather *C. vulgaris* (Putman et al., 1987) and although it is capable of vegetative regeneration, following light grazing, this ability declines with age. Heavy grazing, or continued light grazing, also removes a substantial proportion of the foliage-bearing shoots (Mohamed & Gimingham, 1970) and substantially reduces the litter layer (Hancock et al., 2010). In addition, mature heather is also more vulnerable to trampling than young heather (Corbett, 1990) such that the overall impact of cattle grazing is to reduce its vertical structure (Newton et al., 2009).

The most noticeable differences between the grazed and ungrazed areas were in the height and ground cover of *M. caerulea*, which in the grazed area were both less than half that of the ungrazed area and which had clearly been cropped by cattle. The highest numbers of smooth snake individuals, and captures, were associated with tall grass which was virtually absent from the grazed areas as was grass litter. A critical prey species for juvenile smooth snakes is *Z. vivipara* (Reading & Jofré, 2013), which prefers areas with a high cover of relatively tall *M. caerulea* (Strijbosch, 1988; Edgar et al., 2010; Stumpel & van der Werf, 2012) and for which grazing has been shown to have significant negative effects (Wallis de Vries et al., 2013). The relatively low ground cover of short *M. caerulea* in the grazed area is therefore unlikely to provide either sufficient protective cover or potential prey, particularly for juvenile smooth snakes. In addition, major dietary components of adult smooth snakes are adult common and pigmy shrews (*Sorex araneus* and *S. minutus*) and nestling small mammals, particularly wood mice *Apodemus sylvaticus* and field voles *Microtus agrestis* (Reading & Jofré, 2013) which are also negatively affected by grazing (Tubbs, 1997; Offer et al., 2003).

Along with habitat degradation, disturbance was considered to be an important threat to the survival of local smooth snake populations in the southern Iberian Peninsula (Santos *et al*., 2009) and may explain the lower number of smooth snake individuals and captures recorded in the grazed area in our study. This possibility is supported by our finding that where the vegetation height and/or percentage ground cover were similar in both grazed and ungrazed arrays the number of smooth snake individuals and/or captures were almost always lower in the grazed arrays.

The cattle stocking densities used in the study area were consistent with those recommended by Lake et al. (2001). However, the total number of cows used in habitat management employing ‘conservation grazing’ is based on the size of the area to be managed and assumes that cattle will be evenly dispersed over all of it. If cattle avoid some areas (e.g. bogs) then the true size of the area grazed will be smaller resulting in an underestimate of stocking density. Similarly, the herding behaviour of cows also results in higher than anticipated densities on those areas where they do roam, graze and rest by at least two orders of magnitude, resulting in overgrazing e.g. cows introduced onto an area at an overall stocking density of 0.2 cows/ha that then form groups of 20 individuals that occupy less than one hectare when grazing, roaming or resting.

Our results suggest that cattle grazing has resulted in a slow degradation of the heathland habitat structure within the study area, reducing its carrying capacity with respect to smooth snakes and that its recovery, following the cessation of grazing, is also likely to be slow (Lindenmayer & Fischer, 2006). Although *M. caerulea* is an important species in providing part of the habitat structure on heathland, and recovers quickly once cattle grazing is removed, the major structural component is provided by heather, mainly *C. vulgaris*, which has a relatively slow annual growth rate resulting in a much longer recovery time.

Important questions that result from this study are what exactly is meant by 'conservation grazing' and what, precisely, is it aiming to conserve? In the UK, Natural England states that its policy of using grazing on heathland is designed to 'conserve wildlife and maintain biodiversity' (see NE[a]) despite numerous studies, worldwide, demonstrating that with the exception of a few species that are adapted to early successional stages (Kie et al., 1996; Buckley, Beebee & Schmidt, 2013), grazing is usually damaging to species that require a habitat with high structural complexity (Lindenmayer & Fischer, 2006; Jofré & Reading, 2012). The crux of the problem is that every species requiring conservation has its own unique set of habitat requirements and that the policy of using grazing as a 'one-size-fits-all' solution for their conservation is a nonsense.

There is an increasing need for those bodies charged with conserving the natural environment to make potentially difficult decisions about which species within given habitats, or parts of habitats, should be targeted for conservation measures. It is, therefore, almost inevitable that more than one conservation management protocol will be required within any given habitat to address the specific habitat requirements of each species considered to be at risk. It is also extremely important that the areas managed for each target species should be sufficiently large to support sustainable populations.

Regrettably, 'conservation grazing', particularly of heathland, is a management tool that works at the landscape level (Stumpel & van der Werf, 2012) when the real problem lies at the species habitat level (Lake et al., 2001) and at this level, the specific habitat requirements of many species, which may vary with life stage, remain largely unknown. There is, therefore, an urgent need for research into the specific habitat requirements of threatened species before the implementation of untested and untargeted management protocols to conserve them, followed by detailed monitoring to determine their real, as opposed to anticipated, impact (Bullock & Pakeman, 1997; Newton et al., 2009; Böhm et al., 2013).

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REFERENCES

Braithwaite, A.C., Buckley, J., Corbett, K.F., Edgar, P.W., Haslewood, E.S., Haslewood, G.A.D., Langton, T.E.S. & Whitaker, W.J. (1989). The distribution in England of the smooth snake (*Coronella austriaca* Laurenti). *Herpetological Journal* 1, 370-376.

Böhm, M., Collen, B., Baillie, J.E.M., Bowles, P., Chanson, J., Cox, N., Hammerson, G. et al. (2013). The conservation status of the world's reptiles. *Biological Conservation* 57, 372-385.

Buckley, J., Beebee, T.J.C. & Schmidt, B.R. (2013). Monitoring amphibian declines: population trends of an endangered species over 20 years on Britain. *Animal Conservation* 17, 27-34.

Bullock, J.M. & Pakeman, R.J. (1997). Grazing of lowland heath in England: Management methods and their effects on heathland vegetation. *Biological Conservation* 79, 1-13.

Corbett, K.F. (1990) Management of lowland heath for rare reptiles. *In:* Proceedings of the heathland conference (eds. Auld, M.H.D., Pickess, B.P. & Burgess, N.D.), RSPB, Sandy, UK.

Edgar, P., Foster, J. and Baker, J. (2010). *Reptile Habitat Management Handbook.* Amphibian and Reptile Conservation, Bournemouth.

Frazer, D. (1983). *Reptiles and Amphibians in Britain*. The New Naturalist No 69. Collins, London.

GAP. Grazing Animals Project. (http://www.grazinganimalsproject.org.uk/what_is_gap.html).

Gardner, T.A., Barlow, J. & Peres, C.A. (2007). Paradox, presumption and pitfalls in conservation biology: The importance of habitat change for amphibians and reptiles. *Biological Conservation* 138, 166–179.

Hay, M.E. & Kicklighter, C. (2001) *Grazing, effects of*. Pages 265-276. In Levin, S. (*ed.*) *Encyclopedia of Biodiversity*, Vol. 3, San Diego: Academic Press.

Hancock, M.H., Summers, R.W., Amphlett, A., Will, J., Servant, G & Hamilton, A. (2010). Using cattle for conservation objectives in a Scots pine *Pinus sylvestris* forest: results of two trials. *European Journal of Forest Research* 129, 299-312.

Hill, M.O. (2011). Tablefit version 1.1. Centre for Ecology and Hydrology, Wallingford. http://www.ceh.ac.uk/products/software/tablefit/download.asp

Jofré, G. M. & Reading, C. J. (2012). *An assessment of the impact of conservation grazing on reptile populations.* Amphibian & Reptile Conservation Research Report 12/01.

Kie, J.G., Bleich, V.C., Medina, A.L., Yoakum, J.D. & Thomas, J.W. (1996). *Managing Rangelands for Wildlife.* Pp. 663-688, In Bookhout, T.A. (*ed.*). Research and management techniques for wildlife and habitats, Fifth ed., rev. The Wildlife Society, Bethesda. MD.

Lake, S., Bullock J.M. & Hartley S. (2001). Impacts of livestock grazing on lowland heathland. English Nature Research Reports No. 422. English Nature. Peterborough PE1 1UA.

Lindenmayer, D.B. & Fischer, J. (2006). Habitat fragmentation and landscape change – An ecological and conservation synthesis. Island Press. Washington. DC 20009.

Minitab.16 Statistical Software (2010). [Computer software]. State College, PA: Minitab Inc. (www.minitab.com).

Mohammed, B.F. & Gimingham, C.H. (1970). The morphology of vegetative regeneration in *Calluna vulgaris*. *New Phytologist* 69, 743-750.

NE[a].https://www.gov.uk/government/policies/protecting-biodiversity-and-ecosystems-at-home-and-abroad

NE[b].http://webarchive.nationalarchives.gov.uk/20140523111208/http://www.naturalengland.org.uk/ourwork/farming/funding/es/hls/default.aspx

Newton, A.C., Stewart, G.B., Myers, G., Diaz, A., Lake, S., Bullock, J.M., Pullin, A.S. (2009). Impacts of grazing on lowland heathland in north-west Europe. *Biological Conservation* 142, 935-947.

Offer, D., Edgar, P. & Edwards, M. (2003). Grazing heathland: A guide to impact Assessment for insects and reptiles. English Nature Research Reports No. 497. English Nature (UK), Peterborough.

Putman, R.J., Pratt, R.M., Ekins, J.R. & Edwards, P.J. (1987). Food and feeding behaviour of cattle and ponies in the New Forest, Hampshire. *Journal of Applied Ecology* 24, 369-380.

Reading, C. J. (1997). A proposed standard method for surveying reptiles on dry lowland heath. *Journal of Applied Ecology* 34, 1057-1069.

Reading, C.J., Luiselli, L.M., Akani, G.C., Bonnet, X., Amori, G., Ballouard, J.M., Filippi, E., Naulleau, G., Pearson, D. & Rugiero, L. (2010). Are snake populations in widespread decline? *Biology Letters* 6, 777-780.

Reading, C. J. (2012). Ranging behaviour and home range size of smooth snake inhabiting lowland heath in southern England. *Herpetological Journal* 22, 241-247.

Reading, C.J. & Jofré, G.M. (2013). Diet composition changes correlated with body size in the Smooth snake, *Coronella austriaca,* inhabiting lowland heath in southern England. *Amphibia-Reptilia* 34, 463-470.

Rose, R.J., Webb, N.R., Clarke, R.T & Traynor, C.H. (2000). Changes on the heathlands in Dorset, England between 1987 and 1996. *Biological Conservation* 93, 117-125.

Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Kackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M. & Wall, D.H. (2000). Global biodiversity scenarios for the year 2100. *Science* 287, 1770-1774.

Santos, X., Brito, J.C., Caro, J., Abril, A.J., Lorenzo, M., Sillero, N. & Pleguezuelos, J.M. (2009). Habitat suitability, threats and conservation of isolated populations of the smooth snake (*Coronella austriaca*) in the southern Iberian Peninsula. *Biological Conservation* 142, 344-352.

Strijbosch, H. (1988). Habitat selection of *Lacerta vivipara* in a lowland environment. *Herpetological Journal* 1, 207-210.

Strijbosch, H. (2002). Reptiles and grazing. *Vakblad Natuurbeheer* 2002, 28-30.

Stumpel, A.H.P. & van der Werf, D.C. (2012). Reptile habitat preference in heathland: implications for heathland management. *Herpetological Journal* 22, 179-182.

Tubbs, C.R. (1997). The ecology of pastoralism in the New Forest. *British Wildlife* 9, 7-16.

Wallis de Vries, M.F., Noordijk, J., Sierdsema, H., Zollinger, R., Smith, J.T. & Nijssen, M. (2013). Grazing in Brabant moorlands - Effects on wildlife. Report VS2012.017, Butterfly Conservation, Wageningen / EIS Netherlands, Leiden / SOVON Ornithology, RAVON Foundation and Foundation Bargerveen, Nijmegen.