Grass snakes (*Natrix natrix*) in Sweden decline together with their anthropogenic nesting-environments

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In this paper we show that the number of grass snake (*Natrix natrix* L.) specimens deposited in Swedish museum collections has declined in the last eighty years, and that this is correlated with a dramatic national decrease in the number of livestock holdings. These results support the hypothesis that Swedish grass snakes are declining and that this may be linked to a loss of important nesting-environments provided by open manure heaps in small-scale farming. Our study suggests that information obtained from museum databases potentially may be used to explore population trends for snakes and other reptiles.

Key words: conservation, databases, manure heaps, museum mining, oviparity

Grass snakes (*Natrix natrix*) are semi-aquatic colubrids that range from north-western Africa across Europe (including Great Britain), to the north in Scandinavia and in a wide swath eastwards to Lake Baikal in western Asia. These snakes are unusual in that they occur in climates that are atypically cold (i.e. at high altitudes and latitudes) for an oviparous reptile (Steward, 1971; Thorpe, 1975; Street, 1979; Madsen, 1983, 1984; Beutler et al., 1993; Szczerbak, 2003; Isaac & Gregory, 2004; Luiselli et al., 2005; Reading & Jofre, 2009). As a case in point, all sympatric reptile species at the northern edge of the grass snake's range are viviparous (a reproductive mode that is widely considered to be an adaptation to cold climates: Shine, 1995). It is well known that grass snakes lay their eggs in anthropogenic heat sources such as manure heaps, compost piles and mounds of sawdust where decomposition occurs (e.g., Smith, 1954; Street, 1979; Madsen, 1984; Günther, 1996; Beebee & Griffiths, 2000). A popular hypothesis is that this unusual nesting behaviour has allowed them to overcome the climatic constraints that limit the occurrence of other oviparous reptiles (Löwenborg et al., 2010).

Like many other reptiles (e.g., Gibbons et al., 2000; Reading et al., 2010), grass snakes appear to be in widespread population declines (e.g., Beebee & Griffiths, 2000; Weatherhead & Madsen, 2009). Loss of manure heaps is often implicated as a factor (e.g., Weatherhead & Madsen, 2009), but this is largely based on subjective reasoning rather than empirical study (the search string "grass snake OR Natrix AND manure OR dung OR sawdust" did not give any hits in any of the major data bases of peer reviewed literature, apart from Löwenborg et al. (2010)). A relative lack of long-term data often imposes a limit on assessments of reptilian population trends (Reading et al., 2010). For example, most countries that have well-established national monitoring programmes for birds and mammals lack corresponding programmes for reptiles and amphibians. The population data available for snakes and other reptiles thus rarely embrace more than a decade or two, and are often restricted to a single population that was monitored for some time by a researcher.

In this paper we argue that this deficiency may be overcome by using museum collections, and that these may be a useful data source in ecology and conservation. We use information on grass snake specimens deposited in Swedish museum collections over time to assess the national population trend. We call this approach 'museum mining'. We also use data from the Swedish Board of Agriculture to test if a change in the number of manure heaps is associated with a change in the number of grass snakes. The objective is to empirically test the hypothesis that grass snake population declines are linked to a loss of these anthropogenic nesting-environments. Our analysis is based on three assumptions. The first is that the number of specimens deposited in museum collections mirrors changes in nature. Presumably fewer individuals are encountered in the field when populations decline and vice versa. The second assumption is that the number of manure heaps available in the landscape correlates with the number of livestock holdings. Finally we assume that the public's propensity to collect and deposit specimens in museum collections has remained unchanged.

We downloaded data on grass snake specimens deposited in all major Swedish natural history museums (Gothenburg, Uppsala, Lund and Stockholm) from the Global Biodiversity Information Facility Sweden (www.gbif.se). We used only records of specimens that were collected in Sweden and included the year of collection. To avoid skewing the data we excluded one record of whole clutches of laboratory-hatched young deposited by a single researcher in 1991. Inspecting the data visually we found no other obvious biases. The specimens thus remaining in the analysis appeared to have been deposited randomly by members of the general public and there were no frequently recurring collector names in the dataset (n=159 collectors). Altogether our dataset comprised 193 grass snakes collected between 1930 and 2009. The average number of snakes deposited by any given collector was 1.2 (±1.07 SD). This supports the assumption that these museum records reflect the frequency at which grass snakes have been encountered in the field. To control for the possibility that the museum

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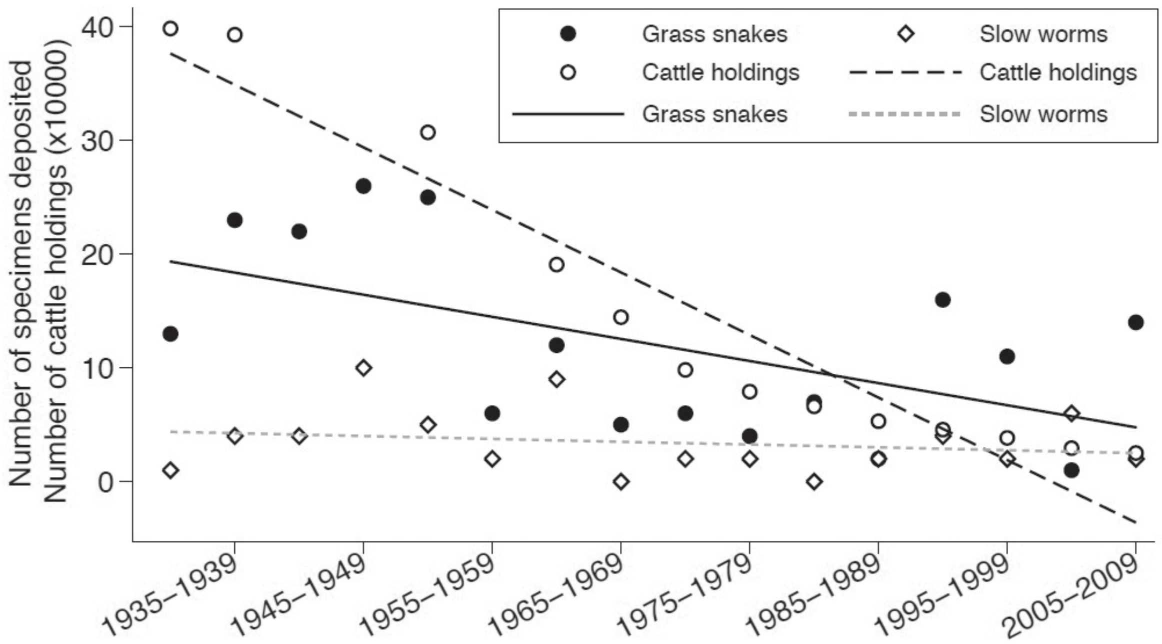

Fig. 1. The relationship between the number of holdings with livestock and the number of grass snakes (*N. natrix*) deposited in Swedish museum collections between 1930 and 2009. Data for slow worms (*A. fragilis*) were included as a control group for the possibility that the trend in grass snakes was due to changed reporting rate to museum collections rather than reflecting population trends.

records are biased by changes in the public's propensity to collect and deposit specimens, rather than random encounter rates, we also downloaded data for slow worms (*Anguis fragilis*) from the same database and used that as a control group. The slow worm's Swedish range is almost entirely sympatric with that of the grass snake, and both species are commonly found in the same habitats. However, slow worms are viviparous and hence do not require nesting-environments. Loss of manure heaps can therefore be expected to have a direct impact on grass snakes but not on slow worms. As with the grass snakes we included only slow worms collected in Sweden between 1930 and 2009.

We obtained data on the number of holdings with livestock from the online database of the Board of Agriculture (www.jordbruksverket.se), which is the authority responsible for Sweden's official statistics for the agricultural sector. Based on these data we compiled the average number of holdings with livestock in Sweden by five-year periods starting from 1930. The museum data were summarized in corresponding five-year periods and analyzed using a multivariate regression with grass snake and slow worm numbers as the dependent variables and holdings with livestock and time period as the independent variables.

The result of our analysis supports the hypothesis that Swedish grass snakes are declining, and that this may be linked to a loss of the seemingly important nesting-environments provided by manure heaps on farms. Between 1930 and 2009 the number of holdings with livestock in Sweden dropped from approximately 400,000 to 25,000 (Fig. 1). It is likely that the number of manure heaps declined at a similar rate, or actually even faster because concomitant with a decrease in the number livestock holdings there has also been a development for the remaining to be bigger and to store their manure in more industrial closed systems that are inaccessible to grass snakes. The number of grass snakes deposited in Swedish museum collections declined over the same period and was correlated with a decrease in the number of holdings with livestock (F=7.03, df=1,13, P=0.01; Fig. 1). By contrast, our analysis showed no significant change in the number of slow worms deposited in Swedish museum collections over the same time period (F=0.45, df=1,13, P=0.65; Fig. 1). This taken together, we argue, suggests that a decline in Swedish grass snakes is associated with a decrease in the number of manure heaps available in the landscape.

Our analysis has a number of caveats. The most important is that we demonstrate correlation and not causation. In other words, we cannot conclude that loss of manure heaps has indeed had a negative impact on grass snakes, only that there is a correlation between these variables. There are, however, many anecdotal reports from the public and field herpetologists to support causation, noting and reporting decline or local extinction soon after the use of open manure heaps was discontinued. In any case, our present analysis is exploratory and we can conclude that the results warrant experimental testing of the hypothesis. Another caveat relates to our assumptions about the data. We do indeed think that a correlation between the number of manure heaps and livestock holdings is very realistic to assume, but whether the number of specimens deposited in museum collections over time reflects population trends is more difficult to say. The fact that the number of slow worms deposited has not declined suggests that the public's willingness to supply museum specimens has been stable over time.

Accordingly, we argue that the temporal decline seen in deposited grass snake specimens may reflect a genuine change unrelated to reporting propensity.

If our assumptions are correct, then our analysis is the first empirical corroboration of the hypothesis that a decrease in the number of manure heaps available in the landscape has a negative effect on grass snakes. Our analysis is based on Swedish data only, but the results are likely to apply to a number of European countries within the grass snake's range. The species has been reported to be in decline over much of Europe and many countries have therefore listed it as a protected species under biodiversity action plans, as well as under individual government programs (e.g., Beebee & Griffiths, 2000; Ahlén et al., 2001; Cox & Temple, 2009; Reading et al., 2010). Moreover, agricultural intensification in countries such as England (Chamberlain et al., 2000) and Denmark (Fox, 2004) shows trends that are similar to those in Sweden with larger but fewer livestock holdings (and presumably a corresponding decrease in the number of manure heaps suitable for grass snakes). Populations of grass snakes occurring at high altitudes or latitudes may be particularly vulnerable to such loss because these unusually warm nesting-environments are more likely to be a limiting factor in such areas (Madsen, 1984; Weatherhead & Madsen, 2009; Löwenborg et al., 2010). However, the fact that grass snakes in warm climates also may lay their eggs in manure heaps (e.g., Zuiderwijk et al., 1993, Beshkov & Nanev, 2006), suggests that these and other anthropogenic nesting-environments may be important habitat components throughout their range. Indeed, high temperatures may actually be a problem in some climates and one possibility is that manure heaps and other anthropogenic nesting-environments buffer against temperatures exceeding the embryo's lethal thermal maximum (Löwenborg et al., 2010).

Our finding also has implications for conservation biology. If grass snakes are declining due to a lack of nesting sites then providing open manure heaps of appropriate quality in strategic locations (i.e. in areas with suitable habitats and food resources) may offer a simple and inexpensive way of sustaining populations. Based on the present study we predict that populations should respond positively following the provision of open manure heaps in the landscape. Ideally, several manure heaps should be scattered across the landscape in order to distribute nesting females, eggs and hatchlings over a wider area and decrease vulnerability to any disturbances that reduce survival (Shine & Bonnet, 2009). Manure mixed with straw is loose and airy and may offer a better nesting substrate than pure and dense manure (Blosat et al., 2011). Grass snakes may also nest successfully in other anthropogenic environments such as compost heaps and piles of sawdust (e.g., Smith, 1954; Street, 1979; Blosat et al., 2011). Further work should also explicitly explore the effects of differences in heap volume, type of manure (cattle, horse, etc.), placement in the environment and so forth on the frequency of nesting and hatching success.

Another issue addressed in this paper is the general lack of long-term population data that is evident for snakes and other reptiles (Reading et al., 2010). This paucity of data may often impose a limit on assessments of reptilian population trends. The new interactive databases that allow the public to upload reports of faunistic observations promise to become future research tools (for an example see the Species Gateway project; www.artportalen.se). In any case and already at this point, our study strongly suggests that 'museum mining' (using information obtained from museum databases) can overcome some of these problems.

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