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Identifying potential areas for an expanding wolf population in Sweden

Therese Eriksson[a], Fredrik Dalerum[a,b,c,*]

[a] Department of Zoology, Stockholm University, 10691 Stockholm, Sweden
[b] Research Unit of Biodiversity (UMIB, UO-CSIC-PA), University of Oviedo, Mieres Campus, 33600 Mieres, Spain
[c] Mammal Research Institute (MRI), Department of Zoology and Entomology, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa

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ABSTRACT

Large carnivores have historically been decreasing worldwide, often as a result of human-carnivore conflicts. However, large carnivores are recovering throughout Europe, and European management scenarios can provide important insights into broad issues related to human-large carnivore existence. After becoming almost extinct in Sweden during the mid-19th century the Swedish grey wolf (*Canis lupus*) population has now recovered. Current national wolf management aims to promote distribution shifts from the current areas in central Sweden, potentially also into a previously exempt reindeer husbandry area. Prior wolf re-introductions have highlighted the necessity of pro-active management for colonization success. Identification of likely range expansion areas could therefore be paramount for a successful Swedish wolf management. We characterized the demographic and spatial progression of Swedish wolves during 2001–2015 and used a MaxEnt approach to species distribution models to identify potential range expansion areas. The Swedish wolf population had expanded from 10 to almost 60 reproductions or territorial pairs, and increased in both range size and density. Our distribution models suggested that Swedish wolf management may face trade-offs between costs of hosting wolves in densely populated areas in southern Sweden with cattle and sheep and the costs of allowing wolves to expand into reindeer husbandry areas with associated cultural and economic consequences. Spatially explicit data on the economic, social and cultural factors associated with wolf conflict and acceptance may be paramount for developing optimal management strategies in the face of such a trade-off.

1. Introduction

The distributions of many large carnivore species have historically been decreasing worldwide, partly due to conflicts with humans involving over-hunting or competition for territory (Dalerum et al., 2009). Conflicts occur when the needs of either humans or carnivores lead to a negative impact on the other. Finding ways towards promoting co-existence between humans and conflict prone species such as large carnivores is particularly relevant within the current paradigm of conservation biology, which is focused on finding sustainable solutions towards human-environmental co-existence (Mace, 2014). Carnivores can cause damage to crops, injure or kill domestic animals or even people (Penteriani et al., 2016). Illegal killing of carnivores as retaliation can have severe effects on their populations (Madden, 2004, but see Dalerum and Swanepoel, 2017). Human-carnivore conflict also has economic implications, which tends to increase as human populations and their needs for agriculture and housing grow (Treves and Karanth, 2003). Conflict is particularly prone to arise if management authorities fail to address the needs of communities living in proximity to wildlife (Madden, 2004). Carnivore conservation is therefore becoming an increasingly political issue, with a subsequent need for pro-active rather than re-active management strategies (Ripple and Beschta, 2011).

Although Europe is one of the most populated and industrially developed regions on Earth, many large carnivore populations have been restored and persist outside protected areas (Chapron et al., 2014). Hence, conflict resolution is important for European large carnivore management (Boitani et al., 2015), and Europe can function as an important region for developing and evaluating strategies towards sustainable integration of large carnivore populations into human dominated landscapes. Sweden is a country in northern Europe with relatively low human population densities, and is one of the few countries that hosts all four of Europe's large carnivore species (grey wolf *Canis lupus*, brown bear *Ursus arctos*, Eurasian lynx *Lynx lynx* and wolverine *Gulo gulo*) (Boitani et al., 2015). Despite large tracts of largely unpopulated, commercial coniferous forest, Sweden's expanding large carnivore populations have been causing an often intense and politically charged conflict, fuelled by public debate (Eriksson, 2016). This is particularly prominent for the Swedish grey wolf population,

* Corresponding author at: Research Unit of Biodiversity (UMIB, UO-CSIC-PA), University of Oviedo, Mieres Campus, 33600 Mieres, Spain.
E-mail address: dalerumjohan@uniovi.es (F. Dalerum).

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which has attracted public attention and polarized emotional arguments far beyond what can be regarded as proportional to the potential problems it has caused (Eriksson et al., 2015).

Large carnivores in Sweden, including wolves, are owned and managed by the government, with the overall management responsibility resting on the Environmental Protection Agency (EPA). The Swedish wolf population was formally protected in 1966, at which point there were only about 10 individuals left in Scandinavia and no reproductive population in Sweden (Naturvårdsverket, 2016). After protection, the first reproduction occurred in 1978, although the wolf population did not start to grow until approximately 15 years later (Wabakken et al., 2001). Since then the wolf population has continued to grow and the Swedish part of the Scandinavian population, which is shared between Sweden and Norway, is estimated to over 300 individuals (Wabakken et al., 2016). Human-wolf conflict in Sweden is primarily associated with semi pastoralist Sámi reindeer herders, politically powerful hunting organizations and to lesser extent rural livestock farmers (Nyrén, 2012). The conflict between wolves and the Sámi reindeer husbandry has been particularly intense and politically charged. The Sámis form Swedens only indigenous cultural group. Much of the Sámis' current cultural identity is associated with reindeer husbandry practises (Daerga et al., 2008), which are made very difficult in the presence of wolves. This has lead previous Swedish policies for wolf management to exclude the reindeer husbandry area, which has a legally defined boundary (Swedish Reindeer Husbandry Act, 1971), from areas were Swedish wolves are allowed to establish (Swedish Government, 2009). Moreover, a significant portion of the conflict is also associated with people who have no more direct contact with wolves than that they reside in wolf territories. This dimension of the conflict appears to primarily be based on fear (Frank et al., 2015), and the concept that resident wolf populations diminish the values of rural life styles (Karlsson and Sjöström, 2007).

To minimize human-wolf conflict and simultaneously maintain a viable wolf population, the EPA has suggested a shift in wolf distribution across the country (Naturvårdsverket, 2016). The shift would consist of decreasing wolf density in areas where density is currently high and facilitating the establishment of new territories where densities are currently low, including in the reindeer husbandry area as long as it does not have negative impacts on reindeer husbandry practises. Such a distribution shift, coupled with the often intense conflicts that arise in areas of recent colonization makes it imperative to predict suitable expansion areas (Mladenoff et al., 1999). Predictions of possible wolf distribution in Sweden have been made previously (e.g. Karlsson et al., 2007; Milleret, 2016), and the range expansion of Swedish wolves has been linked to both intra- and interspecific population processes (Ordiz et al., 2015). However, previous approaches have focused on the scale of wolf home ranges within the current distribution range, which may be an inappropriate scale for current management practises (e.g., Balme et al., 2013). Consequently, none of the previous approaches have explicitly identified potential range expansion areas at suitable management scales.

In this study, we characterized the demographic and spatial progression of the Swedish wolf population during a phase of rapid expansion, from 2001 to 2015, and used a maximum entropy approach to environmental niche modeling to provide a nationwide perspective on potentially suitable areas for the geographic distribution of wolves in Sweden. Maximum entropy models have become an increasingly popular group of species distribution models because of their utility for presence-only data, their predictive accuracy even with limited sample sizes, and user friendliness (Baldwin, 2009; Bassi et al., 2015; Merow et al., 2013; Phillips et al., 2006). Using a presence-only modeling technique can be favorable when dealing with wide-ranging species like wolves where reliable absence data might be difficult to obtain (Bassi et al., 2015). We used the freely available software MaxEnt (Phillips et al., 2006; Phillips et al., 2017) for our modeling exercises. Briefly, MaxEnt characterizes locations with species occurrences using the environmental variables, and then classifies all locations based on their similarities to these characteristics (Elith et al., 2011).

We have specifically; (i) evaluated demographic and spatial change of Swedish wolves over time, (ii) identified areas which are suitable for forming part of the geographic range of Swedish wolves, (iii) identified potential range expansion areas as suitable but previously unutilized areas, (iv) evaluated the impact of the previous exclusion of the reindeer husbandry area on wolf range suitability and range expansion areas, and (v) evaluated what environmental variables are associated with range expansion areas.

2. Materials and methods

2.1. Study region

Sweden takes up the majority of the Scandinavian Peninsula, and is stretching from 55° 20 N to 69° 03 N. The country covers a land area of 438,600 km^2, excluding the four largest lakes. Sweden is characterized by vast forested areas, which make up nearly 70% of the country's surface. Most of this area is commercial forest. Approximately 3% of the land consists of built up areas and 8% of agriculture (Statistics Sweden, 2013). Human population in Sweden is approximately 9 million people, with a density of 24.2 people/km^2 (Statistics Sweden, http://www.scb.se). Population density varies a lot with most of the densely populated areas being concentrated to the southern part of the country and along the Baltic sea coast. Sweden has varied climatic and environmental conditions, noticeable foremost on a north-south gradient. The climate is cold continental (Peel et al., 2007), with mean summer temperature ranging from 12 to 18 °C and mean winter temperature from −18 to 2 °C. Northern boreal forests are dominated by scots pine (*Pinus sylvestris*) and Norwegian spruce (*Picea abies*) trees, although birch (*Betula* sp.) is also common. The southernmost part of the country harbors some deciduous forest including beech (*Fagus sylvatica*), aspen (*Populus tremula*), birch (*Betula* sp.) and common oak (*Quercus robur*).

About half of Sweden's land area, from the central parts and northwards, is defined as a reindeer grazing zone, and can be utilized for semi domesticated reindeer husbandry by the native Sámi people (Swedish Reindeer Husbandry Act, 1971). Within this area native Sámi people use the land for reindeer husbandry. Approximately 250,000 reindeer are kept under free ranging conditions, primarily in the mountainous regions during the summer and in the boreal forest during the winter. Reindeer husbandry activities are often in conflict with large carnivores, and the conflicts with wolves are particularly intense. Most other livestock in Sweden are fenced. However, livestock related damages do occur on sheep, with approximately 400 sheep being killed annually by wolves, as well as on cattle and dogs, although damages on these latter species are less intense (approximately 10 and 35 killed annually, respectively; http://www.slu.se/viltskadecenter). Most of these livestock damages occur in the central management region (Selby, 2016).

Although the EPA has the ultimate responsibility of carrying out national policies regarding large carnivore management, practical management is largely carried out on a regional level. Each of Sweden's 21 counties are responsible for defining and carrying out their own regional carnivore management plans, under the condition that they do not conflict with the overall national goals defined by the EPA. Responsibilities resting with each county include defining regional minimum population sizes and geographic distributions, as well as defining and implementing regional strategies regarding sustainable hunting (Naturvårdsverket, 2016). To facilitate the necessary coordination under this regionalized management, the counties are clustered into three carnivore management regions.

Our study focused on 20 of Sweden's 21 counties. We omitted the county of Gotland, since this Baltic island lacks wolf presence and was excluded from the latest national management plan for wolves (Naturvårdsverket, 2016). The island of Öland has also lacked wolf