



## Spatio-temporal modeling of the invasive potential of wild boar—a conflict-prone species—using multi-source citizen science data



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### ABSTRACT

Denmark was considered not to have an established population of free-ranging wild boar. Today, sporadic observations of wild boar challenge that view. Due to its reservoir role for economic devastating swine diseases, wild boar represents a potential threat for Denmark's position as a large pig- and pork-exporting country. This study assessed the prospects of wild boar invasion in Denmark.

Multi-source citizen science data of wild boar observations were integrated into a multi-modelling approach linking habitat suitability models with agent-based, spatially-explicit simulations. We tested whether the currently observed presence of wild boar is due to natural immigration across the Danish–German border, or whether it is more likely that wild boar escaped fenced premises. Five observational data sources served as evaluation data: (1) questionnaires sent to all 1625 registered owners of Danish farm land, located in the 60 parishes closest to the border, (2) an online questionnaire, (3) a mobile web-based GPS application, (4) reports in the media or by governmental agencies, and (5) geo-referenced locations of fenced wild boar populations.

Data covering 2008–2013 included 195 observations of wild boar, including 16 observations of breeding sows. The data from the Danish Nature Agency and the mailed questionnaires were consistent regarding the location of wild boar observations, while data from the Danish Veterinary and Food Administration, the media and the electronic questionnaires documented individual scattered observations in the rest of Jutland. Most observations were made in the region bordering Germany.

It is uncertain whether the relatively few observations represent an established population. Model outcomes suggested that the origin of wild boar in about half of the area with sporadic observations of wild boar could be attributed to spatial expansions from a local Danish population near the border and consisting of wild boar originally of German origin. However, the other half, located distant to the border, were likely a result of animals escaping fenced premises inside the country. The approach serves as a template to assess the status of an invading species and improve the knowledge base for risk assessment and management decision.

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## 1. Introduction

In densely populated landscapes there is a potential conflict between human land use and the existence of large feral/wild mam-

mals unless properly managed (Miller and Hobbs, 2002). In essence, such larger mammals compete with farmers for land, and in many cases ungulates browse on farm crops, and predators prey on livestock. A balance may be reached, where large mammals can thrive even in rather intensively managed cultural landscapes such as in northern Europe where increasing numbers of wild boar are common phenomena (Massei et al., 2011; Honda, 2009).

Species invasions are typically divided into two groups; natural dispersal and human-caused dispersal—intended or unintended (Mack et al., 2000). Understanding the mechanisms behind the

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invasion of a species is important in order to guide management. In absence of evidence, modelling is a useful tool in predicting future dispersal of an invasive species (Wiegand et al., 2004; Smith et al., 2002). Citizen science is often used to collect data that otherwise are unavailable to the researcher due to limited resources (Dickinson and Bonney, 2012). Moreover, it represents a novel way of engaging the general public or specific sectors. By combining spatially-explicit agent-based models and observational data, we can help understanding the mechanisms behind species invasions and in the long run prevent or solve conflicts and guide future management of the invasive species.

Denmark serves as an example of the challenge represented by the management of large mammals. In the last three decades, ongoing discussions have dealt with the introductions or natural re-colonization of native species such as beaver (*Castor fiber*), European bison (*Bison bonasus*), wolf (*Canis lupus*), and wild boar (*Sus scrofa*). Beaver were introduced in year 2000, after approximately 2000 years of absence (Sørensen, 2013), wolves have been observed after 200 years of absence (Trolle, 2013), and European bisons and wild horses (*Equus caballus*) are gradually being reintroduced starting in fenced areas (Brandtberg and Dabelsteen, 2013; Buttenschön, 2013).

In this guild of large mammals, the wild boar is a special case both because it is not at risk of being extirpated at the European level and due to its potential role as a vector for diseases, which may threaten the Danish pig production sector (Alban et al., 2005).

Denmark is part of the north-western European lowland with high human population density and ubiquitous pig farming. In 2014, the pig and pork sector represented €4.1 billion corresponding to 4.9% of the Danish total export value (Danish Agriculture and Food Council, 2015).

In this study we focus on the prospects of natural immigration and possible establishment of a free-ranging wild boar population in Denmark. Free-ranging wild boar went extinct in Denmark in 1801 as a result of intensive hunting and deforestation (Hald-Mortensen, 2010). Since then the only wild boar in Denmark were reared in fenced areas. During the last decades, Danish hunters and nature conservationists have argued for reintroducing wild boar. These groups contemplate wild boar as enhancing biodiversity and nature experiences (Beck, 2008). A risk assessment conducted by the Danish Institute for Food and Veterinary Research concluded that although the probability of pathogen introduction through wild boar was low, the possible consequences may be too severe to be acceptable (Alban et al., 2005). In that risk assessment, presence of wild boar increased the estimated total costs of a Classical Swine Fever (CSF) outbreak, by approximately 36–53% corresponding to costs of € 67–93 million. CSF is a viral disease that has caused highly significant economic losses in Europe (Meuwissen et al., 1999) and is now followed by the threat of African Swine Fever, with the first outbreaks in the EU seen in January 2014 (Anon, 2014). Findings of Aujeszky's disease—another devastating viral infection in pigs—in free-range wild boar just south of the Danish border in February 2014 further increased the negative perception of free-range wild boar among pig producers (Kremling, 2014).

In Denmark, both natural dispersal and animals escaping fences can probably explain the occasional presence of wild boar. Wild boar was included in the Danish hunting bag statistic for the first time for the hunting season 2011–2012, with an estimated 20 wild boar shot in Denmark in the hunting season 2011/12 (Asferg, 2013a). Similarly, the hunting bag statistic for 2012/13 estimated that approximately 34 free-ranging wild boar had been shot in Denmark in that season (Asferg, 2013b). The locations were not reported.

This spawned debate on whether wild boar should be considered as part of the contemporary wild fauna in Denmark. The observations of wild boar in Denmark have been attributed to

three potential causes: (1) The wild boar population of Schleswig-Holstein, the German region bordering Denmark to the south, is on the increase (Anon, 2013), and the associated population pressure may have led to population expansion northwards, (2) The forest coverage in Denmark is expanding (Johannesen et al., 2013), thereby resulting in more high quality wild boar habitat, and (3) Fenced wild boar occasionally escape the fences (Skriver, 2002). It is unknown when and where the first wild boar in Denmark was observed. A report from 1976 indicates presence of escapees in a couple of geographical locations as well as presence of a minor population in Southern Jutland close to the border to Germany (Pedersen et al., 1976).

The purpose of this study was to develop a cross-disciplinary method integrating advanced ecological modelling with multi-source data. The detailed objectives were: (a) to summarize where free-ranging wild boar have been observed in Denmark, (b) to predict where wild boar and thus observational data should be expected based on habitat distribution and population dynamics; and (c) to match predicted wild boar population spread with observations of wild boar and thereby identify the origin of the population (wild boar immigrating from Germany and/or wild boar escaping from fenced premises inside Denmark). Moreover, a series of hypotheses were tested regarding effect of the habitat quality, source populations, and dispersal ranges on the rate of population expansion.

## 2. Materials and methods

### 2.1. Citizen science data, survey and general statistics

We used a number of different sources to estimate the spatial and quantitative occurrence of wild boar in Denmark, including citizen science data methodology, which involves the general public in environmental policy and management (Dickinson and Bonney, 2012). Prior to the onset of this study, we were aware of presence of wild boar in Schleswig-Holstein, the German region bordering Denmark. Moreover, observations done by the Danish Nature Agency indicated presence of wild boar on the Danish side of the border, potentially a result of a spill-over from a German population. This was in line with earlier studies by Alban et al. (2005). Therefore, the focus was on the border region. However, information was also available indicating single observations of wild boar in other parts of the country due to animals escaping fenced premises. Thus, it was intended also to include the remaining part of the country in the study although with a lower sampling intensity due to financial constraints.

#### 2.1.1. Mailed questionnaire

On April 19, 2013, a questionnaire (Appendix S1 in Supplementary material) including a stamped envelope was mailed to all 1625 registered owners of Danish farm land located in the 60 parishes closest to the German–Danish border (Fig. S1 in the Supplementary material). The farmers were asked whether they had observed free-range wild boar or signs of wild boar in their local parish. They were informed that results were registered per parish, and the exact location would remain unknown. This approach was taken to increase willingness to report. Answers which were received before July 2, 2013 were included in the study.

#### 2.1.2. Online questionnaire

A similar questionnaire was published online (<http://tinyurl.com/susscrofa>) and in a newsletter addressed to people working in the pig and pork production sector in Denmark. This survey covered the entire country. The results were registered as total per postal district.

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