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Adult sex-ratio distortion in the native European polecat is related to the expansion of the invasive American mink

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ABSTRACT

Biological invasions represent a threat to worldwide diversity, but large scale patterns of their impacts are rarely reported. The population sex-ratio influences many other population parameters such as the effective population size, the mating system or the population persistence in the long run. At a local scale, the presence of American mink (*Neovison vison*), a successful invader, has been shown to distort the adult sex-ratio (ASR) in the native European polecat (*Mustela putorius*). The aim of the current work is to determine whether this process is generalized across the entire native species range, by studying 71 datasets and 10,847 polecats with a meta-analytic approach. Datasets were male-biased when these included adult individuals. The different sampling methods (trapping/hunting, live trapping or road-kills) did not affect the sample sex-ratio (SSR). The polecat ASR is more skewed toward males in the presence of American mink, representing a conservation concern due to the reduction of reproductive females. The potential repercussions of ASR distortion on the effective population size, the mating system or the population persistence are discussed. This is the first time that ASR distortion across the entire range of a native species is linked to competition with an invasive species.

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1. Introduction

Global change is causing the sixth major extinction event at an unnaturally rapid rate (Pimm et al., 1995; Chapin et al., 2000), and the human-related spread of non-native species is one of the main drivers contributing to this change (Sala et al., 2000). Nevertheless, few causal relationships have been clearly identified, as it is difficult to distinguish the mechanisms, often intercorrelated, involved in native species declines (Mooney and Cleland, 2001; Roy et al., 2012). The impacts of invasive species are numerous, including predation, disease transmission, hybridization and niche displacement via competitive exclusion, which can ultimately drive the extinction of native biota in the most severe cases (Mooney and Cleland, 2001). If these impacts affect one of the sexes more severely, the 'Adult Sex-Ratio' (ASR, i.e. proportion of males *vs.* females among reproductively mature individuals; also known as 'tertiary sex-ratio') of the native population will become skewed from its basal value (although this is not necessarily 0.5, see Bessa-Gomes et al., 2004). Despite the vital importance of the ASR to several evolutionary aspects of animal populations, including effective population size, mating system, recruitment rate, natal dispersal and population persistence in the long run (Donald, 2007; Wedekind, 2012; Saino et al., 2013), the impact of invasive species has received little attention in studies of sex-related behavioral or demographic factors that can lead to ASR distortions in native populations (Donald, 2007; Wedekind, 2012). This could be due to the fact that, in contrast to the great deal of attention that has been devoted to sex-ratio allocation in early stages (that is, 'primary sex-ratio' or the ratio at fertilization, and 'secondary sex-ratio' or the ratio at birth; e.g. Clutton-Brock and Iason, 1986; West and Sheldon, 2002), little is known regarding the causes of ASR variation (Bessa-Gomes et al., 2004; Donald, 2007; Saino et al., 2013). This lack of studies is probably linked to the complications of sampling potential breeders from age- and sex-structured populations (Veran and Beissinger, 2009; Kosztolányi et al., 2011), as detectability/catchability can differ between sexes due to sex-related behaviours (Härkönen et al., 1999; Palomares et al., 2012; Arendt et al., 2014). However, this gap should be investigated, as sex-related mortality, often associated with habitat alteration, can imperil population viability after causing pronounced shifts in the ASR (Donald, 2007; Wedekind, 2012; Lambertucci et al., 2012). Indeed, there is evidence of a general correlation between ASR distortion and the population conservation status due to the influence of skewed ASRs in demographic stochasticity via Allee effects (Solberg et al., 2002; Donald, 2007; Wedekind, 2012).

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The American mink, *Neovison vison*, is an invasive species widespread in Europe. Its ecology has been well studied in relation to a sibling species, the European polecat, *Mustela putorius*, in the Belarusian population (Sidorovich, 2000a). The invader species is aggressive, and dominant in relation to smaller, native species (Sidorovich, 2000a). This is likely the reason behind the decline in polecat populations in those habitats preferred by the mink and previously widely used by its native counterpart (Sidorovich, 2000a; see also Sidorovich, 2000a for similar patterns in European mink *M. lutreola* and stoat *M. erminea* declines). Native females are at an even greater competitive disadvantage due to their smaller body size (Sidorovich, 2000a). Indeed, there is some evidence suggesting that the expansion of American mink could be driving ASR distortion in polecats via sex-related differential survival. Namely, Sidorovich (2000a) found that, whereas male polecats remain stable after the expansion of American mink, female polecats have increased in size. This could be the result of the disappearance of smaller polecats as female mortality increased (Sidorovich, 2000a). We, however, must be cautious with the mechanisms causing ASR distortion, as Sidorovich's sample sizes are small. Whatever the reason, the expansion of American mink has led to an ASR distortion, as the polecat population has shifted from 59% male to 95% in only 12 years in those habitats used by minks (Sidorovich, 2000a). Meanwhile, the ASR has remained stable where the mink is absent. Similar results have been found in Russian populations (Sidorovich, 2000a).

Here, whether the presence of American mink biases the European polecat ASR toward males at a continental scale was examined, as both species are widely distributed in Europe (Mitchell-Jones et al., 1999; Bonesi and Palazón, 2007). While the knowledge of such an interaction is not as detailed as in the Belarusian population, the resulting outcome (i.e. ASR) is available from many populations. I hypothesize that the process observed in the well-studied Belarusian population is generalized throughout Europe, implying that the invasive American mink could be threatening polecat population persistence by distorting its ASR. Whether the different sampling methods evaluated affect the 'sample sex ratio' (SSR, i.e. proportion of males in a certain sample) is also studied, since some authors have shown consistency in the SSR among sampling methods (Donald, 2007), and others working with mustelids suggest that some biases may occur, as SSR may not be an accurate estimate of actual ASR (Buskirk and Lindstedt, 1989). Most of the literature on ASR concerns single populations, with a lack of large-scale approaches (Promislow, 1992; Donald, 2007; but see Ibañez et al., 2009; Lambertucci et al., 2012; Reichard et al., 2014). However, these studies can provide key insights into both evolutionary and conservation issues, as spatial ASR patterns may be related to causal factors by removing local-related effects (Lambertucci et al., 2012).

2. Methods

2.1. Study species

The American mink was introduced in Europe in the early/mid-twentieth century as a result of escapes from fur farming, and its intentional release in some countries. It is now naturalized in more than 30 European countries, as well as in some others from Asia to South America (Bonesi and Palazón, 2007). Its degree of abundance and density greatly varies among countries, as do the resulting impacts (Bonesi and Palazón, 2007). The European polecat is distributed throughout Europe, from the Iberian Peninsula to Russia, and Bulgaria to southern Norway and Finland. It is also present in the United Kingdom, but absent in the Mediterranean islands (Mitchell-Jones et al., 1999; Fig. 1). The invader species is larger, and both species present a marked sexual dimorphism (mean weight, male/female, 1325/781 g for American mink and 1093/507 g for European polecat; Sidorovich, 2000a; see also Johnson et al., 2000).

2.2. Sample collection

Data were collected from as many sources as possible to include the range of different life histories and ecological conditions in polecat populations across Europe. The scientific literature was searched, and polecat specialists and curators from museums were contacted to obtain references or databases. If more than one publication presented results from the same study area and period, data from the most complete study or from the study allowing the extraction of raw data, were used following a similar methodology to other meta-analyses (e.g. Barrientos et al., 2011).

2.3. SSR explanatory variables

Meta-analysis was used to evaluate the factors that can modulate the SSR in polecat populations. The 'rate difference' (% males − % females in every sample; Table S1) was used as effect size (Borestein et al., 2009). If this is not homogeneous among the different individual studies (see Section 3), explanatory variables must be investigated (Rosenberg et al., 2000). Namely, we studied five explanatory variables. Sex-ratio variation throughout the polecat lifespan was first explored. Thus, (i) the sample 'age' was divided into three levels: 'cubs', directly sampled in their litter; 'juveniles', sampled outside of their litter but <1 year old, and 'adults', $\geqslant$1 year old. When samples were not specified as juveniles/subadults, they were assumed to be adults. If one dataset included samples from more than one age category, different sex-ratios were calculated for every level. As age affected sex-ratio (see Section 3), cub and juvenile datasets were excluded to focus on adult SSR variation in a second meta-analysis. Two categorical variables were explored: (ii) the sampling 'method'. Despite that some authors have shown consistency in SSR among methods (Donald, 2007), it has been claimed that fur trapping is a biased method for ASR estimation in mustelids (Buskirk and Lindstedt, 1989). Thus, the variable method was separated into three levels: 'trapping/hunting', including those animals collected for commercial purposes, and potentially the most biased (Buskirk and Lindstedt, 1989); 'live trapping', where the population structure remains unchanged as individuals are released after trapping (Buskirk and Lindstedt, 1989); and, 'road-kills', a very important source of polecat mortality (Barrientos and Bolonio, 2009; Barrientos and Miranda, 2012) that can modify ASR due to specimen losses, but which is not affected by trapping-related biases (e.g. baiting, trapping design). Also, (iii) the influence of American 'mink' presence on polecat SSR was explored. Its presence was established based on the information available in the given study, in Bonesi and Palazón (2007) or in national atlas surveys. Datasets with and without mink and those with data before and after mink colonization were included. In the latter cases, the dataset was divided into two and two sex-ratio rates were calculated, when the species was absent *vs.* when it was widespread, removing the transition period. If American mink was present in some areas and absent in others within a dataset (typically, country-scale database), the sample was divided based on its presence/absence (behind/ahead the invasion front). Finally, two continuous variables were analyzed: (iv) 'latitude' and (v) 'longitude', as the degree of ASR can vary geographically, linked to climatic or habitat characteristics (Ibañez et al., 2009; Lambertucci et al., 2012; Reichard et al., 2014). When the exact coordinates were not provided in a study, they were calculated using Google Earth™. When necessary, values were averaged for latitude and longitude to obtain a single value per dataset. Only

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