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REVIEW

Feral American mink *Neogale vison* continues to expand its European range: time to harmonise population monitoring and coordinate control

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ABSTRACT

1. The American mink *Neogale vison* is an invasive alien species in Europe that threatens endemic biodiversity and can transmit zoonotic diseases, including the SARS-CoV-2 virus. The last attempt to map the geographic range of this species in Europe, at continental scale, dates back to 2007.
2. We aimed to update the distribution map of the feral American mink and assess its temporal trends. The information we collected was critically analysed with the aim of improving future monitoring protocols and data collection.
3. We gathered and standardised data from 34 databases, covering 32 countries. Through 3 five-year periods from 2007 to 2021, changes in range size, hunting bags and capture statistics were analysed. We also reviewed the current situation of mink farming in the different European countries and recorded population control schemes.
4. The American mink is now widespread in the Baltic States, France, Germany, Iceland, Ireland, Poland, Scandinavia, Spain and the UK. The species is reported to be absent in some areas (e.g. parts of the UK, Iceland and Norway). Data are deficient for several countries, mainly in south-eastern Europe. These findings indicate that, during the last 15 years, the species has continued to spread across the continent, increasing its potential extent of occurrence in most countries. Our effort to collect and harmonise data across international borders highlighted information gaps and heterogeneity in data quality.
5. Updated distribution data on the species provided here will aid risk assessment and risk management policies. These actions require a coordinated effort for population monitoring at continental level. Monitoring effort and data collection should be intensified in south-eastern Europe to improve data on the current distribution of this invasive species.

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INTRODUCTION

The American mink *Neogale vison* (formerly *Neovison vison* and *Mustela vison*; Patterson et al. 2021) is a mustelid carnivore introduced to Europe from North America during the 1920s for fur farming (Long 2003, Genovesi et al. 2009). Shortly after its introduction, individual American minks escaped from fur farms, either due to poor housing facilities or through deliberate releases by activists, and populations became established in the wild (Palazón & Ruiz-Olmo 1997, Macdonald & Harrington 2003).

The impact of feral American mink on native riparian predators (through competition and intra-guild aggression) and other aquatic and semi-aquatic vertebrates (through predation) has been broadly assessed (Põdra et al. 2013, Mathews et al. 2018, Brzeziński et al. 2020). The American mink is now considered an invasive alien species (Bonesi & Palazón 2007). Considering its potential impacts on biodiversity (Bouroş et al. 2016), the species was proposed for inclusion on the List of Invasive Alien Species of Union Concern via the European Union's Invasive Alien Species Regulation (EU1143/2014; Bonesi & Palazón 2007, Reynolds 2009, Zuberogoitia et al. 2018), but was ultimately not added (European Commission 2016, Zuberogoitia et al. 2018, Harrington et al. 2021).

The American mink is known to play a role in the transmission of several pathogens in Eurasia, including distemper and Aleutian mink disease, that may threaten other mustelids, or other wild and domesticated mammal species (Yamaguchi & Macdonald 2001, Mañas et al. 2016). Recently, captive mink were found to be capable of hosting SARS-CoV-2 virus and transmitting it back to humans, which occurred on mink farms in several countries, starting with the Netherlands and Denmark (Fenollar et al. 2021). Susceptibility of American mink to the virus could facilitate the transmission of SARS-CoV-2 in feral mink populations, creating potentially dangerous wildlife reservoirs (European Food Safety Authority and European Centre for Disease Prevention and Control et al. 2021, Harrington et al. 2021). A recent investigation of an outbreak of highly pathogenic avian influenza in farmed American minks in Spain suggests that the virus may have jumped from wild birds and mutated in the fur farm, acquiring the ability to transmit between mammals (Agüero et al. 2023).

Many European countries have control policies and eradication campaigns focused on American mink. Due to continued escapes and re-invasions, however, complete eradication is difficult to achieve and has been successful in only a few areas (Fraser et al. 2017, DIISE 2018, Global Invasive Species Database 2021, http://www.iucngisd.org/gisd/); on mainland areas, control has been the main objective in recent decades. The success of these strategies implies the need for recurrent and detailed information on mink densities and distribution (Melero et al. 2018). Updating the distribution map of feral American mink populations at a European level with the highest possible resolution is a necessary precursor to managing this invasive species and resolving the potential conflicts in which the species is implicated (e.g. Macdonald & Harrington 2003). Additionally, risk assessments of the species' introduction, entry into the wild, establishment, spread and impact on other species, including on humans as a disease host, requires high-resolution spatial data (raw or model projections), and, if possible, abundance estimations (baseline data).

Hunting bag statistics (records of the total number of animals killed in a given area and time span) have potential as reliable quantitative data (Teysseyre 2005, ENETWILD consortium et al. 2020b), but they are not available for all countries. Moreover, the absence of data on hunting effort undermines comparability in trend analyses (McDonald & Harris 1999, ENETWILD consortium et al. 2018). Organised monitoring programmes and control activities can provide validated observations that are systematically gathered across a given area, though data may not be representative of the entire population or area. Opportunistic observations are useful to determine the presence and geographic range of the American mink. Combined with other ecological parameters, observation data enable occupancy modelling or presence-only species distribution modelling (Phillips et al. 2009, Escamilla Molgora et al. 2022), and are useful for developing response actions. However, observation data are often subject to temporal, spatial and reporting biases (Beck et al. 2014, Jiménez & Soberón 2020, Probert et al. 2022).

The aims of this study were: 1) to assess the current distribution of American mink in Europe at the highest possible spatial resolution; and 2) to assess trends in the distribution since the last published account (Bonesi & Palazón 2007) and explore their relationships with the presence of American mink farms and feral mink control policies in each country. The information we collected was critically analysed with the aim of improving future monitoring protocols and data collection.

METHODS

Data collection

The area considered is the whole European continent, including the largest islands. Data collection included three sources: 1) the ENETWILD consortium network (www.enetwild.com), national wildlife institutes and respective ministries, 2) the Global Biodiversity Information Facility (GBIF.org (16 February 2022) GBIF Occurrence Download

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https://doi.org/10.15468/dl.9jztbu), 3) the available literature reporting information on the current knowledge of American mink presence and distribution in Europe.

A data request letter was sent to each data provider (i.e. the national wildlife institutes and relevant government ministries), asking for American mink records (including: hunting bags, captures, direct and indirect observations), and/or data on the density and abundance of the species. A template with standardised reporting fields compatible with Darwin Core standards (the Wildlife Data Model, available on the ENETWILD website, https://enetwild.com/2018/07/30/release-model-collect-data-on-wild-boar-distribution-and-abundance-europe/) was provided with the request. Data were demanded at the highest possible spatiotemporal resolution, starting from 2000. GBIF observations were downloaded using *Neovison vison* and *Mustela vison* as species filters with the *rgbif* package (Chamberlain et al., 2022) from 2000 to 2021 (Doi: 10.15468/dl.9jztbu), before being cleaned and filtered. Only observations with recording year, coordinates and coordinate uncertainty up to 10000 m were considered. Furthermore, for countries that provided hunting bag or capture data, we asked: 1) if population management had been implemented in the last 15 years; and, in case of a positive response, 2) the management methods used, 3) if the control effort had been increasing, decreasing, remained stable, or was variable (with peaks); and, in case of a variable trend, 4) a free text field was available to indicate when and which were the peaks in the total amount of captures (e.g. LIFE programmes).

Additional information was gathered for each country on: 1) the presence and number of mink fur farms and, if applicable, 2) ban year and law, 3) management actions and plans. The literature search aimed to fill the gaps of direct data collection (1 and 2), by using the main scientific online libraries, namely PubMed, Web of Science and Scopus, during April and May 2021. The keywords algorithm was: ("Neovison vison" OR "Mustela vison") AND "Europe" AND ("presence" OR "occurrence" OR "abundance" OR "density"), filtering the period since 2000. As the new nomenclature (*Neogale vison*) was introduced after the search was performed, we did not introduce it in the algorithm. A further search was performed by adding, one by one, the European countries into the search algorithm. All georeferenced data at a resolution not bigger than subregional were included in our database for map creation.

Creation of maps

Data compilation, data standardisation and data management were performed through the Wildlife Data Model (ENETWILD consortium et al. 2020a) with *tidyverse* 1.3.0 (Wickham et al. 2019) and *sf* 0.9–7 (Pebesma & Bivand 2018) packages with R 4.0.4 (R Core Team 2021). The compiled georeferenced data corresponded to regional areas (polygon layer) and coordinates (point layer). A buffer of the size of coordinate uncertainty of the data (point layer, including GBIF observations and all other collated point observations) was used, when available, to provide a more realistic delimitation of the presence or absence of the species. Layers were transformed into the coordinate reference standard for Europe, ETRS89-LAEA Europe (EPSG: 3035). Numeric information was grouped and translated into presence/absence/information unavailable in each cell of the European 10 × 10 km grid (https://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-2) using ArcGIS v10.7 (Environmental Systems Research Institute, Redlands, California, USA). Absence data were accepted only when the recording method allowed them to be distinguished from no data.

To overcome different temporal and geographical resolution issues and missing information, following the work by Põdra and Gómez (2018), data were grouped into three periods: 2007–2011, 2012–2016 and 2017–2021. We plotted on maps the cells with reported absence and presence of American mink for each period, as well as the changes in the species' status: for countries that provided data at the same spatial resolution for two successive periods, we identified cells in which the species was previously reported as present and was then reported as absent in the following period, or vice versa.

Data analysis

To compare our data to the range reported by Bonesi and Palazón (2007), we calculated the geographic range of the American mink in each country using the area of the minimum convex hull with 95% percentile from the cells reporting presence (excluding marine areas). In this way, we attempted to standardise the potential extent of occurrence (EOO) of the species. This approach was chosen as it is an internationally accepted, standard method for estimating species' ranges, particularly in circumstances in which presence-only data are the only spatially explicit data available (IUCN 2001). However, as American mink is a riparian animal, the minimum convex hull overestimates the real EOO and a plot of presence-absence cell records was still necessary to understand the most likely extent of the distribution of the species.

We then calculated the percentage of each country's surface represented by the EOO, using as a reference the NUT0 (country) layer of the grid (https://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-2); calculation was performed with the *adehabitat* R package (Calenge 2006). Only data with good spatial resolution

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were considered. Therefore, data expressed by administrative polygon units such as NUT0, NUT1 (major socio-economic regions), NUT2 (basic regions for the application of regional policies), as well as the hunting management units of Finland, were excluded due to insufficient detail.

Countries were then classified using the distribution categories used by Bonesi and Palazón (2007), as detailed in parentheses: not reported, not reproductive (either not established or sporadic), occurrence <10% (localised in a few areas), occurrence 10–50% (widely distributed, but less than 50%), occurrence >50% and data not available. Additionally, we marked countries where the available data did not allow the percentage of occupancy to be calculated.

For countries that provided hunting bags or records of captures from consistent trapping programmes (i.e. where capture records were available yearly for at least five consecutive years), a hunting bag/capture index (called Variability Index, *VI*) was calculated as the mean of the change from 1 year to the next:

$$VI = \left(\frac{Y_{i+1} - Y_i}{Y_i} \right) / n \qquad 1$$

where Y_i expressed the total hunting bag or number of captures for the first year, and Y_{i+1} the total hunting bag or number of captures for the following year. This information allowed us to represent the trend of the hunting bags or captures numerically. In the same way, a Farm Index (*FI*), representing changes in the abundance of fur farms, was calculated. To test relationships among the EOO, the *VI* and the *FI*, we used Kendall's Tau-b tests performed in R (R Core Team 2021). We expected: 1) a positive relationship between *VI* and potential EOO, because, when the cause of a bigger potential EOO is an increased density, this may also increase capture rates; 2) a negative relationship between *FI* and potential EOO and 3) a negative relationship between *FI* and *VI*, because fur farm shut-downs would contribute to releases and, thus, an expansion of the area of mink potential EOO and an increase in capture rates. However, banning fur farms may also have the opposite effect: lowering the chance of mink escapes.

RESULTS

The publications we collated that provided geographical data on American mink presence and distribution are summarised in Tables 1 and 2, updating the information available from Bonesi and Palazón (2007). We retrieved literature confirming the presence of American mink in 15 countries, but only five of those countries (Germany,

Table 1. Available literature on feral American mink *Neogale vison* per European country – Literature with presence/distribution information, not representable on maps

Geographic scale	Year	Presence	Method	Citation
Belarus (Central-Western)	2018	41.1–14.9 ind/100 km^2	Census and roadkill	Sidorovich et al. (2020)
Belgium (Flanders, northern part)	2008	Present	Observations, captures, roadkills	Van Den Berge (2008)
Belgium (Flanders, northern part)	2014	Present	Observation	Adriaens et al. (2015)
Bulgaria (Stara Zagora District)	2019	103 ind. in total	Biosecurity check, observations, captures, tracks	Koshev (2019)
Czech Republic (Krkonoše/Giant Mountains)	2013	Present	Census with floating rafts	Poledník et al. (2016)
France	2015	Present	Surveys	Léger et al. (2018)
Germany	2013	Present	Observations	Hiery et al. (2013)
Iceland	2015	Increasing	Hunting bags	Stefansson et al. (2016)
Italy	2019	Present	Literature	Mori and Mazza (2019)
Lithuania	2017	Present	Roadkill	Nugaraitė et al. (2019)
Poland	2019	7 mink / 100 trap nights	Live trapping	Brzeziński et al. (2020)
Romania (Southwest)	2017	98 ind. in total	Data request letter	Kopij (2017)
Russia (Caspic, Balkan)	2018	Present	Dead animals	Korablev et al. (2018)
Slovakia	2019	Present		Šimková et al. (2019)
Spain	2012	Present	Trapping	Põdra and Gómez (2018)
Sweden	2006	Present	Hunting bags	Carlsson et al. (2010)
The Netherlands	2016	Present	Observations	Hollander (2017)
The Netherlands	2017	Present	Observations	Bouwens (2017)
The UK (Scotland -except northern Sc., Wales, England)	2017	Present	Literature	Mathews et al. (2018)
The UK	2019	Widespread	National surveys	Harrington et al. (2020); Martin and Lea (2020)
The UK	2019	Declining	Observations	Crawley et al. (2020)

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Table 2. Available literature on feral American mink *Neogale vison* per European country – literature used for mapping

Country	Year	Method	Citation
Germany	2006–2019	Hunting bags	Baudach et al. (2021)
Greece	2000–2016	Data request letter	Adamopoulou and Legakis (2016)
Italy	2013	Live trapping	Iordan et al. (2017)
Romania	2015–2018	Camera and live trapping	Ionescu et al. (2019)
Romania	2003–2011	Scat survey, camera trapping	Marinov et al. (2012)
Romania	2007–2012	Opportunistic records	Hegyeli and Kecskés (2014)
Slovakia	2000–2012	Opportunistic records	Krištofík and Danko (2012)

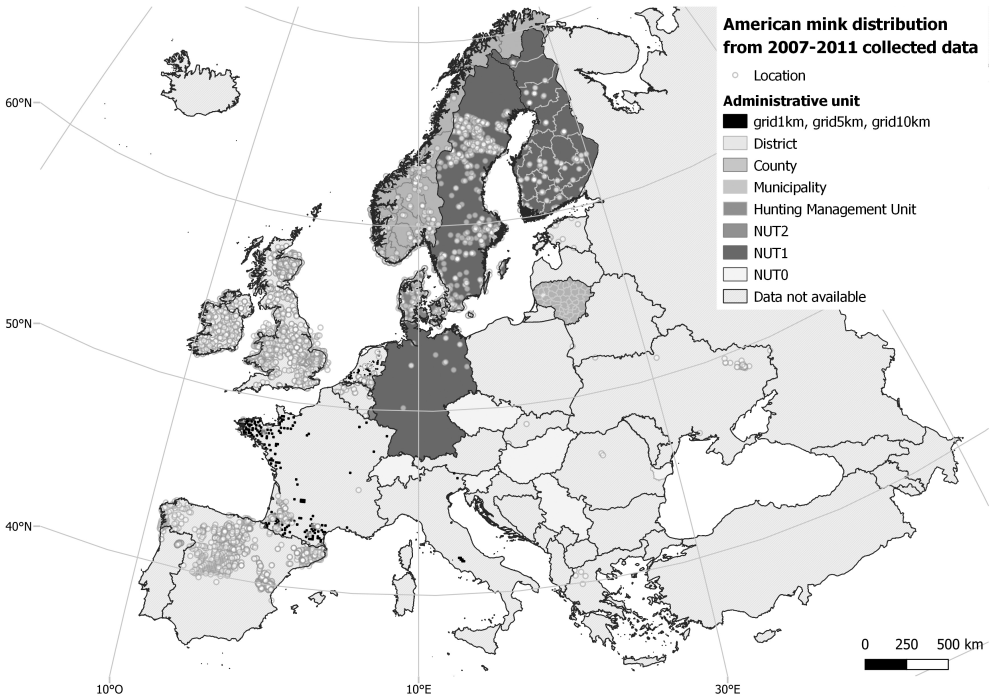

Fig. 1. Distribution of feral American mink *Neogale vison* in Europe: spatial resolution of mapped data in 2007–2011, before standardisation in the 10 × 10 km grid. NUT codes refer to the European Nomenclature for Territorial Units for Statistics: NUT0 (countries), NUT1 (major socio-economic regions), NUT2 (basic regions for the application of regional policies).

Greece, Italy, Romania and Slovakia) possessed georeferenced information at a sufficient resolution for mapping purposes.

All European Union member states, except Bulgaria and Croatia, provided data, as did Belarus, Norway, Iceland, Russia, Switzerland, the UK and Ukraine (metadata reported in Appendix S1). We also included publications, as previously mentioned. The timespan was not equal for every country, and information about some years was missing. This was the case for Austria, for which we only obtained data for 2016, and for Italy and Romania, for which we had specific reports from scientific publications. Spatial resolution was also very variable (see Figs 1–3): although most of the countries provided a fine resolution (hunting grounds, municipalities, county, points or grids), data from Austria and the Czech Republic were provided at a lower resolution. Hunting bags or capture statistics from national systematic trapping were available for 12 countries. Mink records (dead, alive or sign of presence) were, in some cases, centralised from national entities: this was the case for Ireland, the UK, the Netherlands, Belgium and France. GBIF data were available for most countries (Appendix S2 for complete citation).

Distribution maps

The American mink is now widespread in Northern and Western Europe, but data are lacking for eastern and south-eastern Europe (see Figs 4–6 for the three different periods). Four countries (Hungary, Serbia, Slovenia

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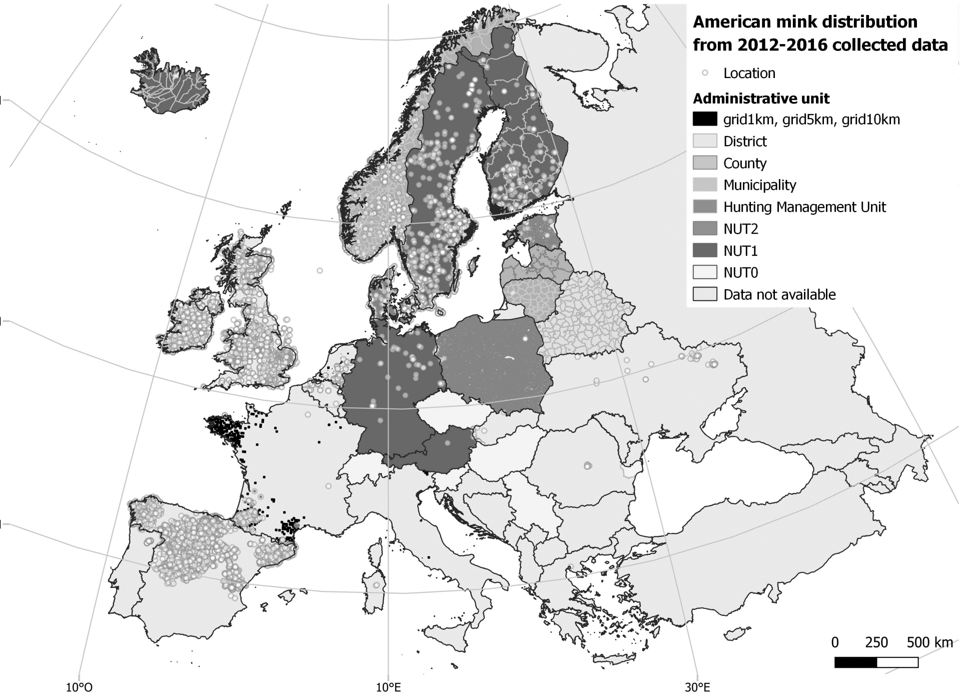

Fig. 2. Distribution of feral American mink *Neogale vison* in Europe: spatial resolution of mapped data in 2012–2016, before standardisation in 10 × 10 km grid. NUT codes refer to the European Nomenclature for Territorial Units for Statistics: NUT0 (countries), NUT1 (major socio-economic regions), NUT2 (basic regions for the application of regional policies).

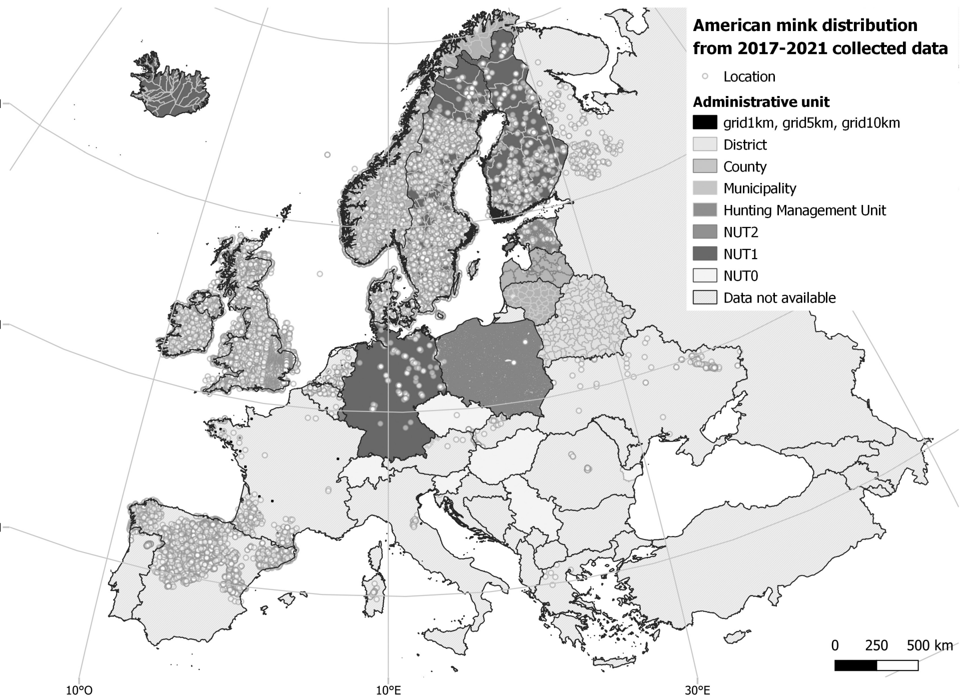

Fig. 3. Distribution of feral American mink *Neogale vison* in Europe: spatial resolution of mapped data in 2017–2021, before standardisation in 10 × 10 km grid. NUT codes refer to the European Nomenclature for Territorial Units for Statistics NUT0: (countries), NUT1 (major socio-economic regions), NUT2 (basic regions for the application of regional policies).

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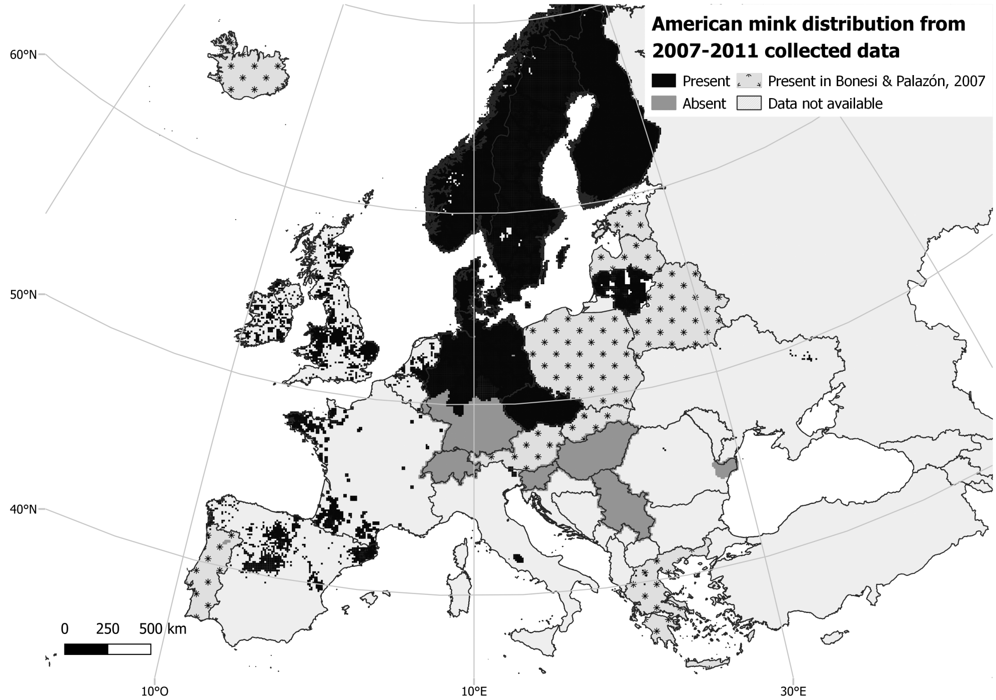

Fig. 4. Distribution of feral American mink *Neogale vison* in Europe in 2007–2011.

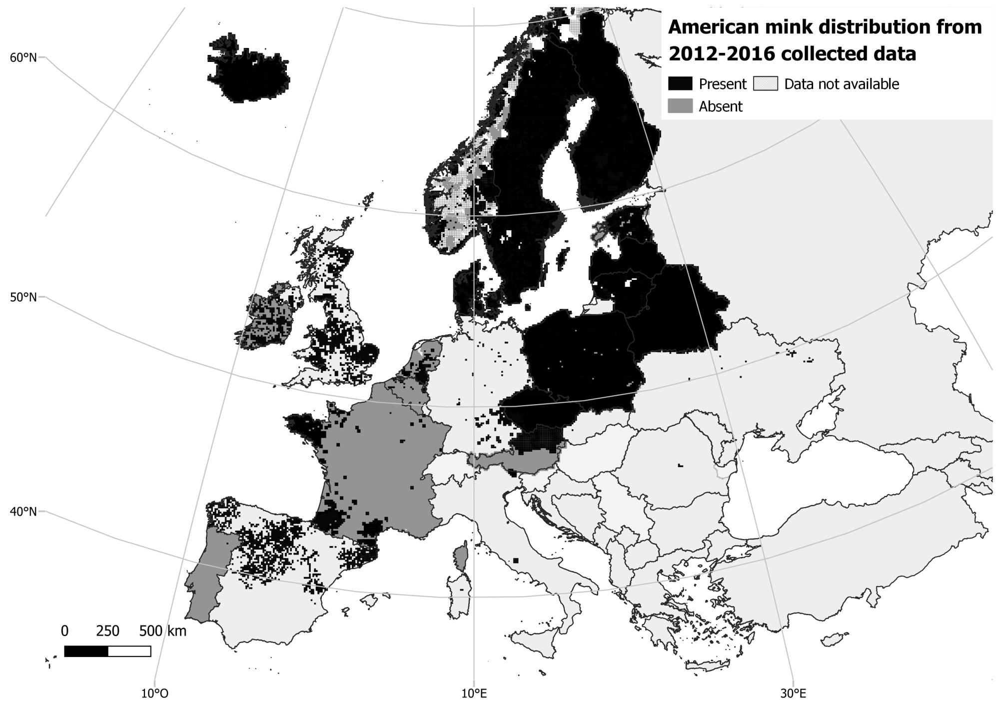

Fig. 5. Distribution of feral American mink *Neogale vison* in Europe in 2012–2016.

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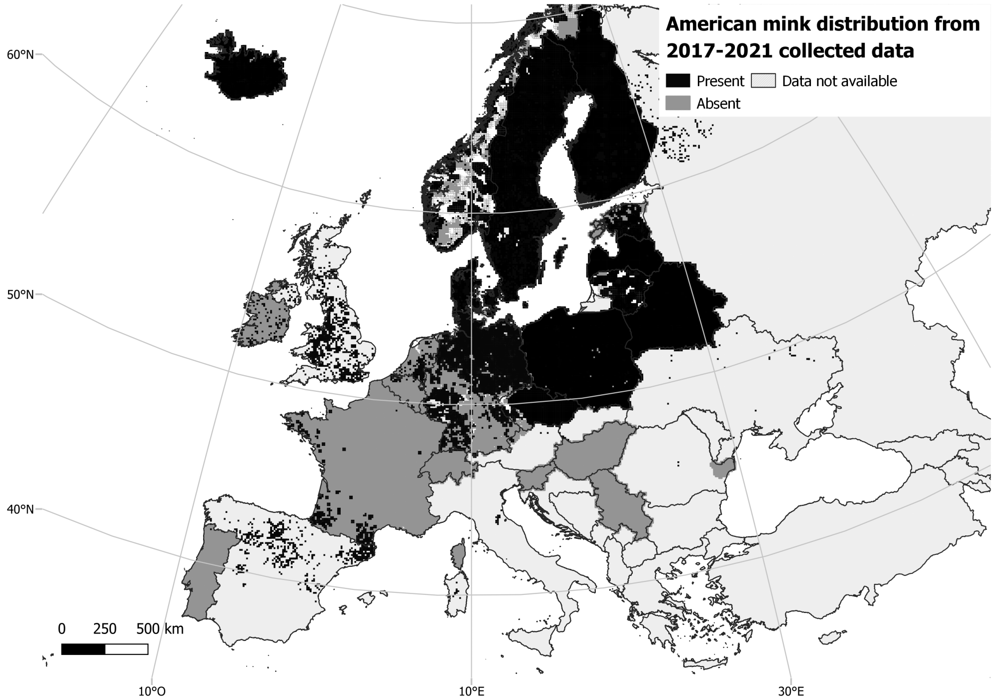

Fig. 6. Distribution of feral American mink *Neogale vison* in Europe in 2017–2021.

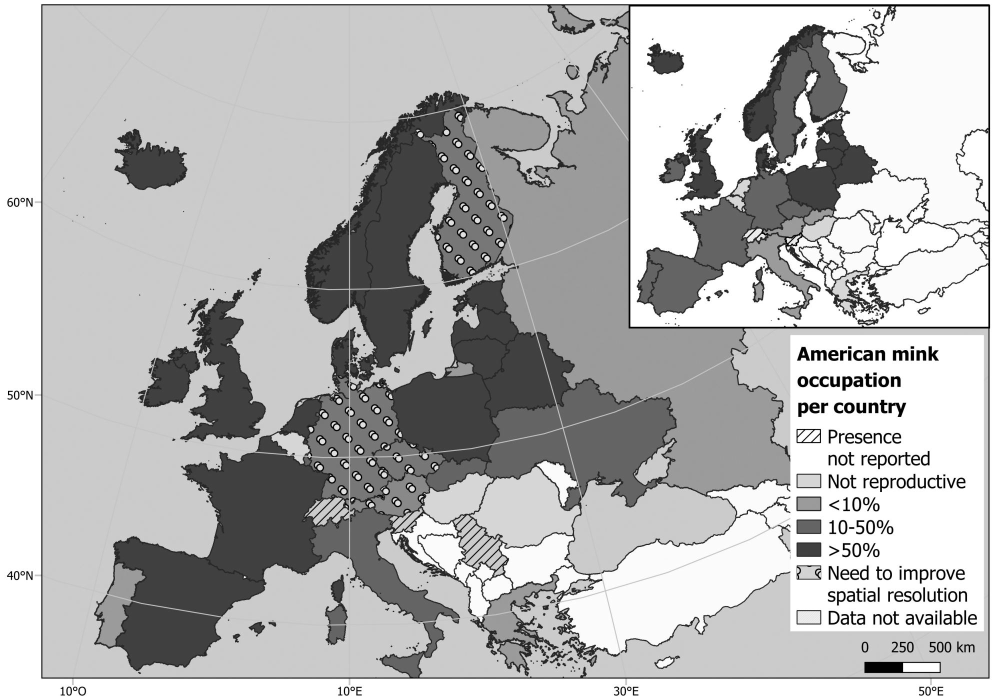

Fig. 7. Feral American mink *Neogale vison* in Europe: updated potential extent of occurrence (EOO, as a percentage for each country), calculated from minimum convex hull in each country, using the categories defined by Bonesi and Palazón (2007). The previous reference map (Bonesi & Palazón 2007) is shown in the top right corner.

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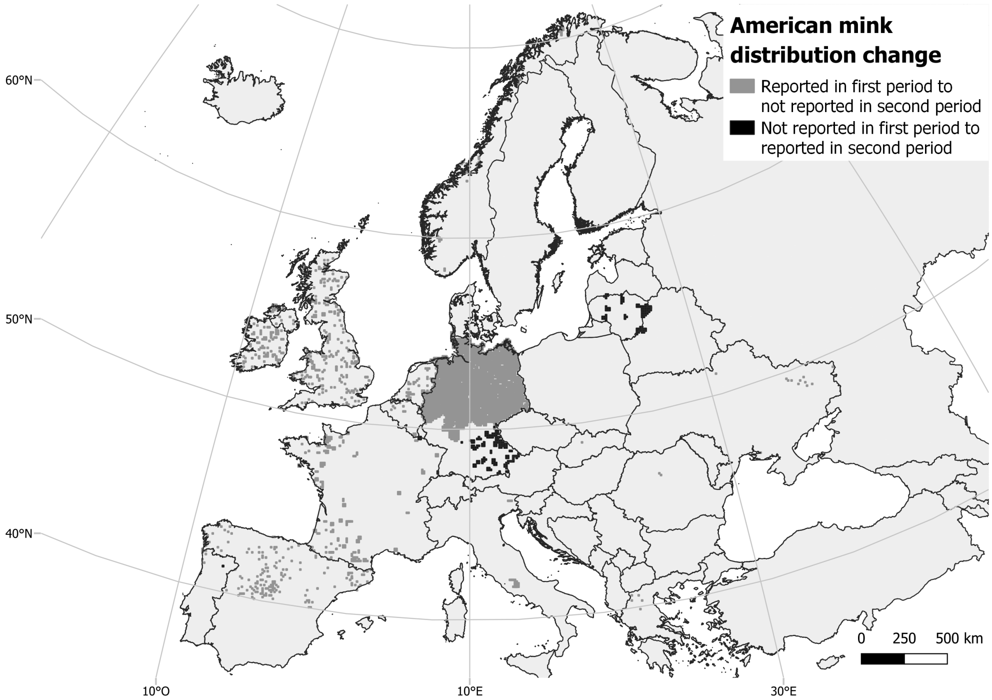

Fig. 8. Changes in the distribution of feral American mink *Neogale vison* in Europe between the first and second periods (2007–2011, 2012–2016), based on collated data of reported presence of this species. Only data comparable between both periods (having the same spatial resolution) are reported.

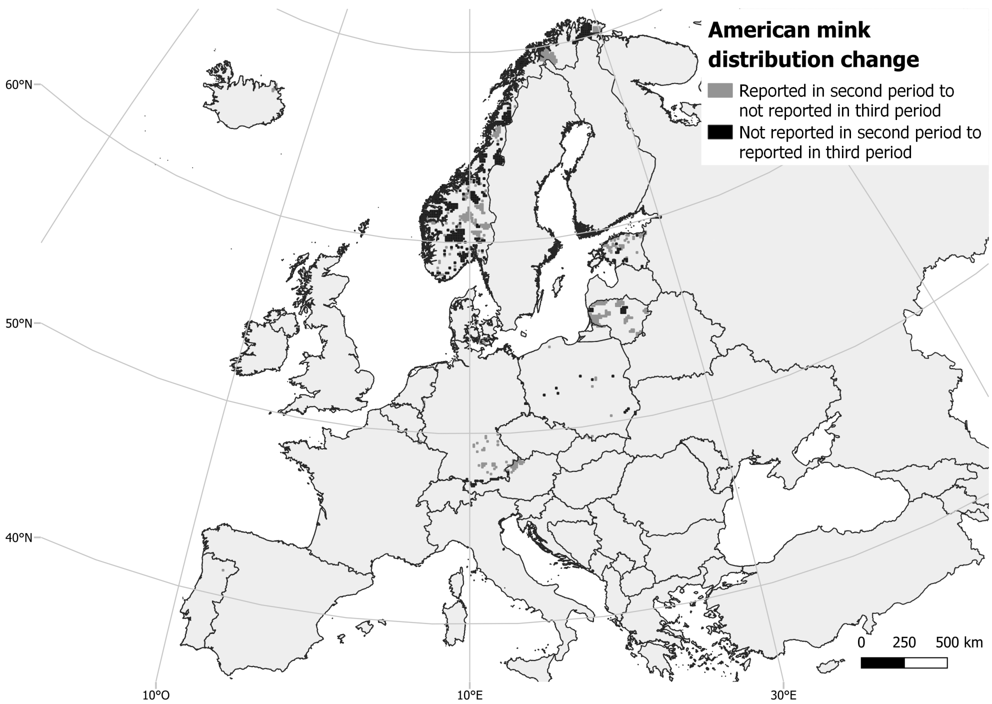

Fig. 9. Changes in the distribution of feral American mink *Neogale vison* in Europe between the second and third period (2012–2016, 2017–2021), based on collated data of reported presence of this species. Only data comparable between both periods (having the same spatial resolution) are reported.

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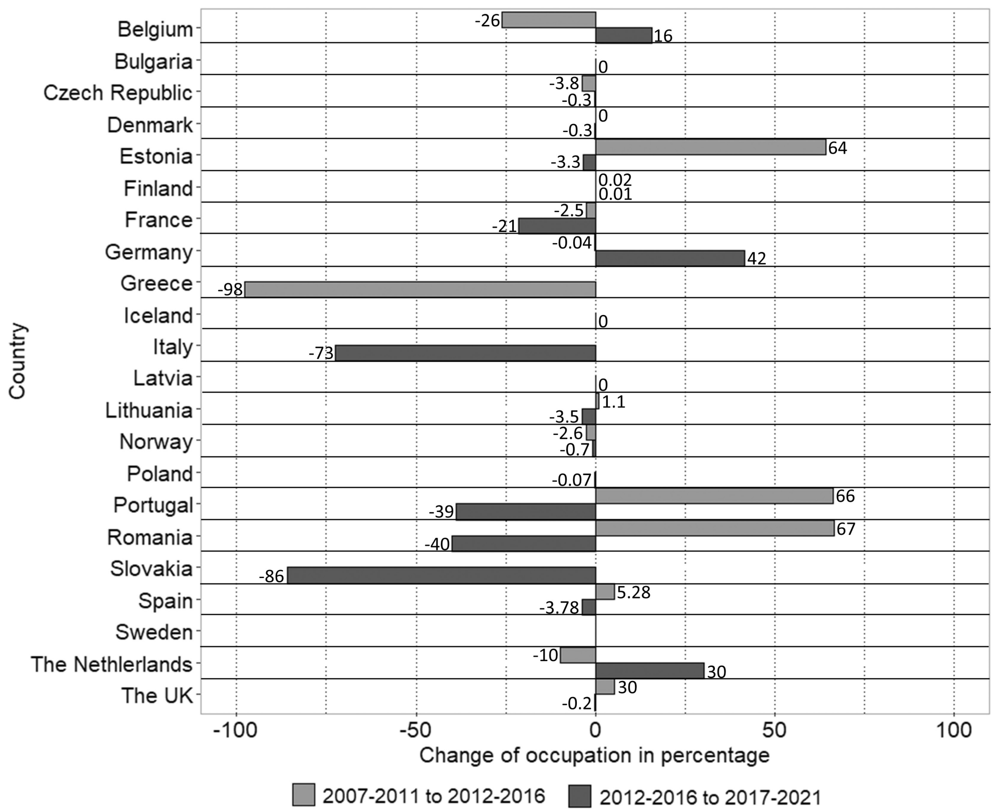

Fig. 10. Percentage change in extent of occurrence (EOO) feral American mink *Neogale vison* for each country in Europe, from 2007–2011 to 2012–2016 (dark grey bars) and from 2012–2016 to 2017–2021 (light grey bars).

and Switzerland) reported the absence of feral American mink (Fig. 6). In Luxembourg, a record of a dead animal in 2013 was the only American mink reported since 1993 (Schley 2001). Compared to records provided by Bonesi and Palazón (2007; Fig. 7), the American mink's distribution category has remained constant in 13 countries, increased in 10 countries, and decreased only in Portugal.

Analysing the changes in distribution (Figs 8 and 9) and EOO (Fig. 10) shows that the scenario is rather more complex. The majority of countries show a fluctuating trend, albeit not always sufficient to change distribution category. Eight countries had increased EOO between the first and second periods, with a mild decrease afterwards, and four countries increased between the second and third periods, after an initial phase of decrease. Most presence reports in new cells belong to the transition from the first to the second period (eight countries), while the absence of mink records was newly reported in only four countries (Estonia, Germany, Latvia and Norway), considering all periods. Finally, changes in the distribution categories used by Bonesi and Palazón (2007) occurred only in: Luxembourg (not reproductive), Romania (<10%), European parts of Russia (spreading, <10%), Serbia (absent) and Ukraine (10–50%). For Russia, it was possible to collate only sporadic GBIF occurrences; therefore, in the discussion, we consider further the EOO from the published literature for Russia, which is remarkably different.

Temporal trends in hunting bags, capture statistics and farming

Species management and control is mostly performed through hunting in northern countries and by national or regional control plans in southern countries (e.g. in Spain). Some northern countries (e.g. Sweden) also implemented control plans. In Finland, Latvia, and Spain, *VI* tended to decrease, although with large yearly fluctuations (Table 3). Iceland was the only country that consistently increased its hunting bags over time (Fig. 11). The *VI* was negative for most countries. Some countries (Denmark, Germany, Norway, Spain and Sweden) have or have had a targeted control plan, whilst others (Czech Republic, Iceland) rely on ad hoc hunting policies. All control programmes involved both hunting and trapping, and the effort trend of control programmes was either constant (Poland, Latvia, Iceland) or variable (Sweden). Despite a negative trend in *FI* (except

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Table 3. Hunting bags for feral American mink *Neogale vison* in 12 European countries: the hunting bag Variability Index (*VI*; representing variation in hunting bags and captures, see text for details); potential extent of occurrence (EOO; % of land surface area occupied by mink in the third period, 2017–2021); Farm Index (*FI*; representing changes in the abundance of fur farms, see text for details) and information from the formal data request letter submitted to ask the respective country data provider in each country about control plans. NA = not applicable

Country	*VI*	EOO (%)	*FI*	Control plan
Czech R.	−0.03	NA	−0.33	No proper control plan, mink are culled by hunting managers or guards when required (e.g. when damage occurs)
Denmark	−0.09	100	−0.08	Management carried out by Danish environmental protection agency
Estonia	−0.13	89	−0.36	Hunting allowed all year round. No special control programme. Effort unknown. Successful eradication programmes were carried out on main islands (Saaremaa and Hiiumaa).
Germany	−0.03	100	−0.66	Hunting bags are not a reliable source to evaluate fluctuations in mink populations, as 1) this species is not regulated by the same laws in all German states, 2) hunting is not extensively practiced and 3) other control programmes apart from hunting are usually performed.
Finland	−0.08	99.54	−0.05	Successful eradication programmes on Islands
Iceland	0.07	99.24	−0.17	Both hunting and trapping, by bounty system. Effort has been constant despite population decline since 2000. Eradication was attempted in two areas of Iceland in 2007–2009.
Latvia	0.02	100	−0.02	Hunting allowed all year round. No special control programme. Effort unknown
Lithuania	−0.05	96.94	−0.05	American mink are hunted all year round, although no trapping or specific control plans are reported
Norway	0.02	81.63	0.10	Control plan in 2011 (Norwegian directorate) and engaging hunters (Stien & Hausner 2018).
Poland	−0.12	96.73	−0.10	Hunting allowed all year round. There are some regional programmes, implemented in small, limited areas.
Sweden	−0.09	85.16	−0.19	Control plans that involve both trapping and hunting, with variable effort, implemented with an interregional control programme of 3 years, ended January 2020.
Spain	0.65	62.40	−0.05	Control programmes are coordinated by single regions (e.g. Com. Valenciana), by national plans (MITECO in 2003) and several LIFE projects (LIFE Lutreola Spain, IREKIBAI, INSAVEP, DESMANIA)

in Norway), the American mink is still widespread in all countries, with many of them being invaded entirely (Table 3). *FI*, *VI* and EOO were not correlated (*VI* – potential EOO: tau = −0.015, $P = 0.9449$, $n = 12$; *VI* – *FI*: tau = 0.317, $P = 0.1636$, $n = 12$; *FI* – potential EOO tau = 0.015, $P = 0.9449$, $n = 12$).

Mink fur farming is banned or absent in 13 of the 35 countries we collected data for. It is still legal and active in 22 countries, 12 of which are either discussing a ban or have planned a ban in the coming years (Fig. 12, Appendix S3).

DISCUSSION

Since the review by Bonesi and Palazón (2007), little new information on the presence and distribution of American mink in Europe has become available. Bouroș et al. (2016) added some information in a risk assessment for the European Union, stating presence at country level. Further publications have given an even more fragmented picture (e.g. Poledník et al. 2016, Kopij 2017, Koshev 2019). Although robust data were available for a few European countries (e.g. Léger et al. 2018, Harrington et al. 2020, Baudach et al. 2021), an updated overview for the continent was lacking. In this work, we synthesised available information for all of Europe, showing an increase in the range of this invasive species.

European distribution of American mink: 15 years later

Although many countries have issued bans on fur farming and implemented control policies, American mink is still widespread and expanding its range in Europe. Populations that were originally related to different nuclei of escape are now connected (Lecis et al. 2008, Põdra & Gómez 2018).

Distribution is hard to constrain, but density can be reduced, with different impacts on the environment. In the United Kingdom, for example, there is evidence of a continuous expansion, but intensive control programmes have helped to reduce densities and even achieve eradication in large areas (Robertson et al. 2017, Crawley et al. 2020, Martin & Lea 2020). This fact highlights the importance of good-quality data for further analysis and density estimation. Given gaps in our data collection, the range we report here could

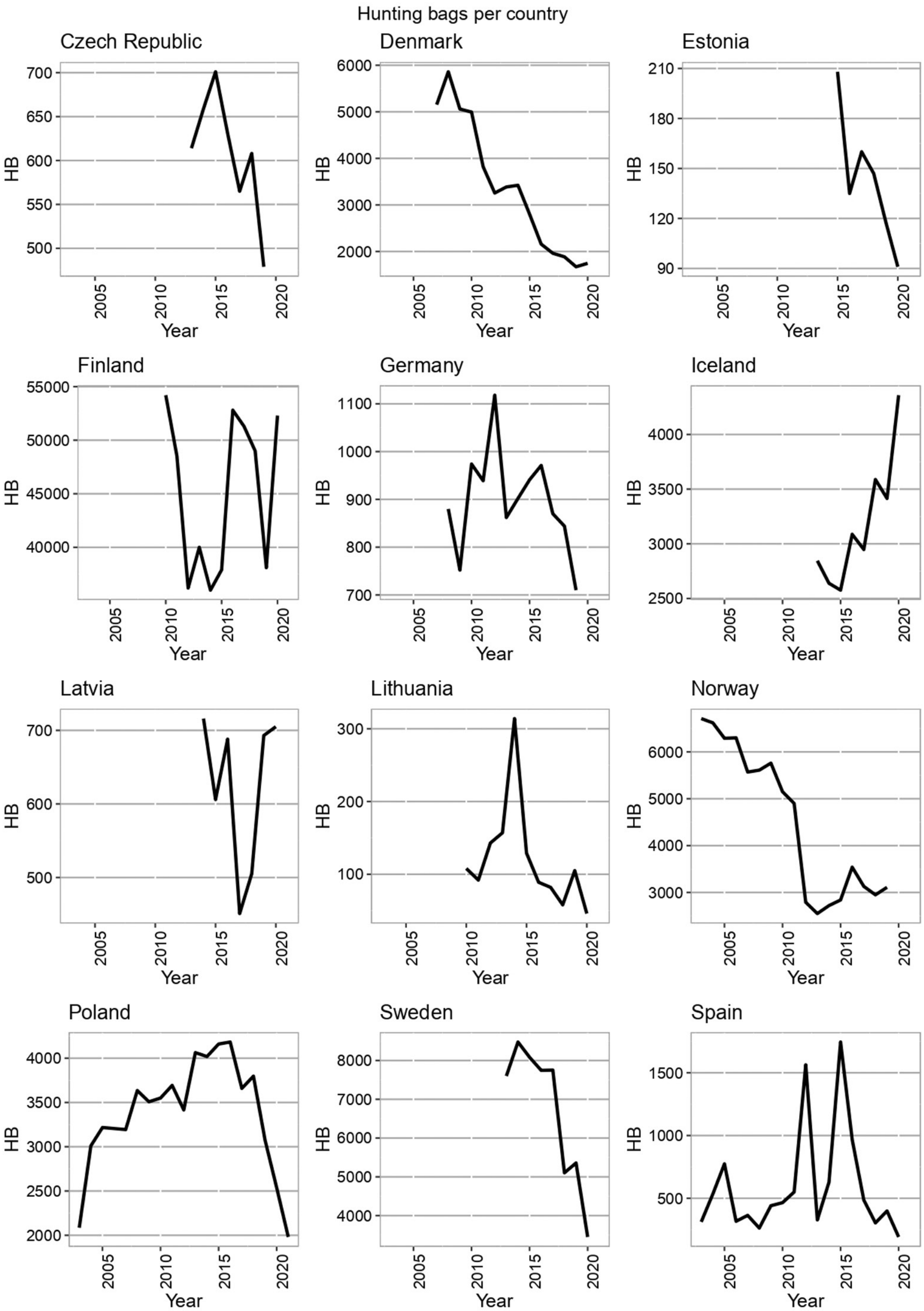

Fig. 11. Trends in feral American mink *Neogale vison* hunting bags (HB, number of individuals killed year year) for European countries that submitted them.

be underestimated. For instance, the EOO reported in Russia with our collated data (which comes from GBIF observations only) is different from the one reported by Khlyap et al. (2011), who described American mink as widespread in the country. In contrast, the very localised distribution of the species in Italy presented by our data is in accordance with the range plotted by Mori and Mazza (2019). On the other hand, the appearance of new presence cells from one period to the next is, in some cases, linked to different spatial resolutions and different data availability.

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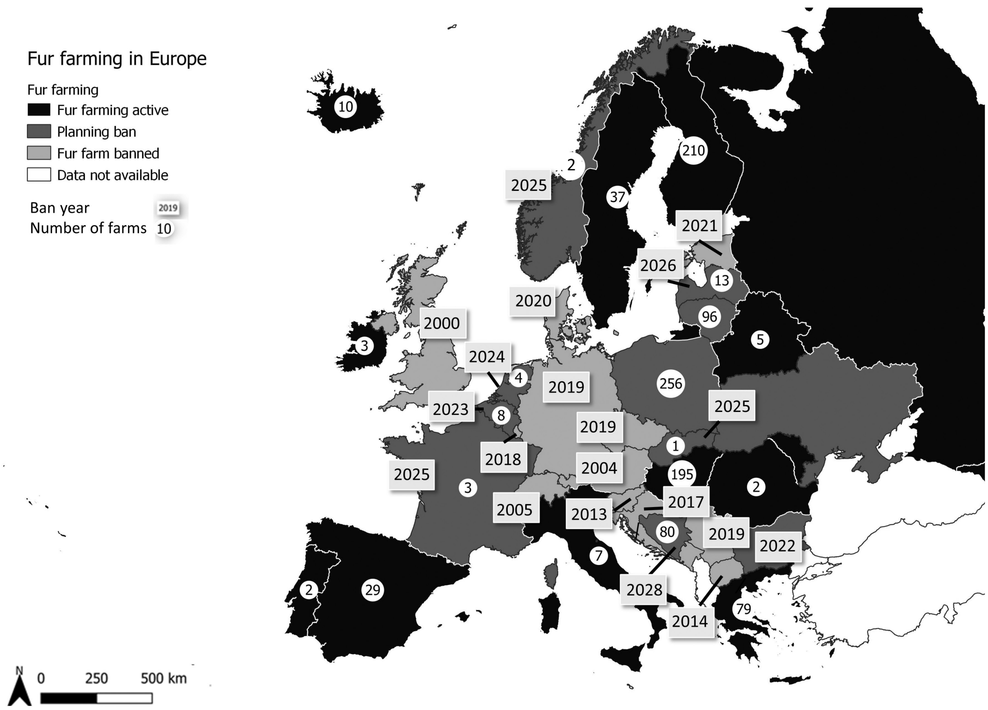

Fig. 12. Fur farming legislation in Europe. Countries are shaded by the legal status of fur farming ('Fur farming active' if it is permitted; 'Planning ban' if it is soon to be banned and 'Fur farm banned' if it is no longer permitted), with ban year in the squares and farm numbers in the circles.

Also, changes in the distribution categories since the publication of Bonesi and Palazón (2007) may be linked to the different protocols used for gathering data.

The contribution of fur farms

In north-eastern European countries, mink farming is often present and observations of feral mink are sporadically recorded (Horecka 2019, Sidorovich et al. 2020). In Poland, transboundary natural dispersal from eastern countries seems to be the main reason for mink establishment in the country (Horecka 2019). However, the lack of data for Balkan areas could indicate a real absence of American mink, considering that the species does not occur in neighbouring countries and that there are bans on fur farming in several Balkan countries (see Appendix S3). In Greece, with 79 fur farms, since 2010, a consistent number of feral American mink has occurred in a limited area in northern regions, a situation which was addressed by a LIFE project to control the American mink population (http://lifeatias.gr/).

Fur farming bans, boosted by the outbreaks of COVID-19 in mink fur farms in 2020 (Fenollar et al. 2021), are spreading across Europe, and the closure of mink farms may, despite recommendations, coincide with illegal releases into the wild (Bonesi & Palazón 2007, Brzeziński et al. 2019). Nonetheless, the real impact of escaped or released individuals on the demographics of feral populations is still under debate (e.g. see Hammershøj et al. 2005, Zalewski et al. 2010). The fur trade sector has hindered the inclusion of this species in the List of Invasive Alien Species of Union Concern, which would impose European Union member states to improve prevention and control (Zuberogoitia et al. 2018), underlining the complexity of aligning stakeholders involved in the issue of American mink control.

Success or failure?

Countries differ strongly in their American mink management objectives. Many have projects aimed at eradication or control, either at a national or local level (Roy et al. 2009, Norwegian Directorate for Nature Mangement 2011, Fraser et al. 2017, Regione Emilia Romagna 2019). However, coordinated approaches aligning management objectives across countries, crucial for effective control policies (Santulli et al. 2014), are currently lacking.

Some control operations seem to have been successful (Roy et al. 2009, Léger et al. 2018, Martin & Lea 2020), although apparent reduction of the mink's geographic range may also result from monitoring biases. The reduction of hunting bags in Sweden, following an interregional control programme begun in 2017 (FAMNA: Förvaltning av Amerikansk Mink i Botnia-Atlantica Området, Management

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of American mink in the Botnia-Atlantic area; https://www.botnia-atlantica.eu/about-the-projects/project-database/famna-forvaltning-av-amerikansk-mink-i-botnia-atlantica-omradet) shows the potential effectiveness of control programmes. However, the American mink was already declining in Sweden before 2017, possibly due to competition with the red fox *Vulpes vulpes* (Carlsson et al. 2010). In Norway, where a control plan is still operating in coastal areas (www.miljodirektoratet.no), hunting bags are increasing. In Spain, control projects are often restricted in time and space, and trapping effort varies across years and regions (Ministerio de Agricultura, Alimentación y Medio Ambiente (MAGRAMA), TRAGSATEC 2014). In general, high-quality information on trapping effort is needed to draw sound conclusions about the effectiveness of eradication or control projects.

Need for harmonised data

A general emerging issue was the low quality and lack of comparability of the available data across countries, emphasising the need for continental-scale, standardised survey methods. Although all data types were valuable to map the distribution of the American mink, they often did not allow us to estimate abundance or perform spatial modelling of abundance and distribution ranges. As American mink naturally disperse across the borders of many countries (Bonesi & Palazón 2007, A. Kranz, personal communication), these data need to be as accessible and open as possible; governments and European institutions could provide guidance on minimum reporting standards for data on management (hunting, trapping) and the design of structured monitoring schemes. Citizen science initiatives are also addressing the issue, with standardised recording protocols and strict validation processes (Adriaens et al. 2021, Price-Jones et al. 2022).

CONCLUSIONS

The American mink is a widespread invasive alien species in Europe. Its geographic range has continued to increase over the last 15 years: the species now ranges across the entire continent and is reported in almost all countries. Confirmed mink-free areas are scarce and small. The species' spread is currently unaffected by closures of fur farms, which may play a more important role than feral mink for emergence and/or spread of epidemics (including of zoonotic pathogens). Evaluating the distribution and population trend is constrained by the lack of (reliable) data for many countries, as well as by heterogeneity in the available data. Large data gaps exist, primarily in Eastern Europe, and secondarily in southern Europe. Moreover, hunting bag data are incomplete, and reporting on national and local control plans (captures, observations) is scant. An open attitude towards data publication and the provision of minimum standards for reporting on management data are needed. These are necessary steps for risk assessment and management which, in turn, will provide a foundation for policies aimed at controlling the ongoing invasion of this non-native species with significant conservation and human health impacts.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's website.

Appendix S1. Summary of metadata for collated data represented in maps.

Appendix S2. GBIF downloaded observations citation.

Appendix S3. American mink fur farming and control programmes across Europe.

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