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Feeding plasticity and temporal behaviour of the alien American mink in Europe

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ABSTRACT

The American mink *Neovison vison* is an invasive species in Europe with a number of expanding populations in over 20 countries. In this work, we reviewed feeding habits and temporal behaviour of the American mink introduced to Europe. We summarised the results of 30 studies on diet of this mustelid and of 5 studies on activity rhythms. Trophic niche breadth was high in Europe and increased with increasing sampling period, thus emphasizing that American mink may shape its diet according to the seasonal availability of potential prey. American minks showed a polyphasic or cathemeral locomotor pattern, being active both during the day and the night in Europe and tending to limit encounter probabilities with native, larger mustelids. Acceptance of programs of eradication/numerical control are linked to the awareness of impact by this semiaquatic mammal and to recent sightings of free-ranging individuals. Numerical control of this charismatic, invasive mammal species may thus encounter a strong opposition by the general public, particularly because its presence and its impacts are poorly known. Educational campaigns and consultation with all potential stakeholders should be addressed to design effective decision-making processes.

1. Introduction

Biological invasions are widely recognised as one of the main threat to biodiversity (threat code 8.1: Salafsky et al., 2008; Battisti et al., 2016). The EU regulation 1143/2014 and its progressive updates have identified a number of alien species of European concern, for which rapid eradication and/or numerical control is strongly recommended (Carboneras et al., 2018; Nentwig et al., 2018). Many other invasive species are still under evaluation and some of those excluded by this "European black list" may represent remarkable threats for some countries (e.g. the Finlayson's squirrel *Callosciurus finlaysonii* in Italy and ring-necked parakeet *Psittacula krameri* in Spain: Mori et al., 2016; Hèrnandez-Brito et al., 2018).

Among alien species excluded from the black-list, the American mink *Neovison vison* is a North American carnivore (Mustelidae) which has been introduced to Europe for fur farms and now it is very widespread in at least 20 European countries (Bonesi and Palazon, 2007; Mori and Mazza, 2019), where it has been reported to threat local populations of water voles, amphibians, crayfishes and birds (e.g. Ferreras and Macdonald, 1999; Clode and Macdonald, 2002; Ahola et al., 2006; Sidorovich et al., 2010; Brzeziński et al., 2018). Furthermore, it may compete with native mustelids (e.g. Maran et al., 1998; Mcdonald, 2002; Harrington and Macdonald, 2008; Harrington et al., 2009). The strongest impact by the mink may occur where the trophic niche breadth is the widest (i.e. where this mustelid may consume and potentially affect the highest number of species), or where it is the lowest, with single native prey species killed up to strong population decline and local extinction. In Italy, at least 61,000 individuals of American mink have been released from farms between 1999 a 2018 (Table 1); other unreported escapes should have occurred in Sardinia (Dettori et al., 2016). Free-ranging, self-sustaining populations of American mink currently occur in North-Eastern regions, Latium, Abruzzi and Sardinia (Mori and Mazza, 2019).

Where native competitors are rare or absent, the diet of the American mink in Italy includes a wide range of species (Angelici et al., 2000; Mori and Mazza, 2019) and, among them, of species of high ecological and conservation interest, e.g. the endemic Italian water vole *Arvicola italicus*. Predation on fish farms may trigger local conflicts with human

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Table 1
Summary of known releases of American mink from Italian fur farms. Data were collected through a Google Research on national newspapers (Mezzetto, 2020).

Number of released animals	Year	Location	Region
300	1999	Invillino di Villa Santina (Udine)	Friuli Venezia Giulia
5000	2001	Parma	Emilia Romagna
3000	2001	Forlì-Cesena	Emilia Romagna
5000	2002	Treviso	Emilia Romagna
700	2003	Campisico di Capralba (Crema)	Lombardia
2000	2003	Invillino di Villa Santina (Udine)	Friuli Venezia Giulia
20000	2003	Ferrara	Emilia Romagna
2000	2005	San Cesareo (Roma)	Lazio
400	2005	Sabbioncello San Pietro (Ferrara)	Emilia Romagna
2000	2006	Padova	Veneto
250	2006	Sabbioncello San Pietro (Ferrara)	Emilia Romagna
500	2006	Savona (Savona)	Liguria
2000	2007	Sabbioncello San Pietro (Ferrara)	Emilia Romagna
600	2007	Savona (Savona)	Liguria
2000	2008	Conco (Vicenza)	Veneto
4500	2008	Conco (Vicenza)	Veneto
2000	2008	San Cesareo (Roma)	Lazio
130	2010	Castel di Sangro (L'Aquila)	Abruzzo
500	2011	San Cataldo di Borgoforte (Mantova)	Lombardia
100	2012	San Cataldo di Borgoforte (Mantova)	Lombardia
1200	2013	Cascina Pomina (Cremona)	Lombardia
100	2013	Fiesso d'Artico (Venezia)	Veneto
22	2013	San Marco (Ravenna)	Emilia Romagna
200	2013	Calvagese della Riviera (Brescia)	Lombardia
200	2013	Calvagese della Riviera (Brescia)	Lombardia
3	2013	Padova	Veneto
600	2013	Fiesso d'Artico (Venezia)	Veneto
3	2013	Cremona	Lombardia
250	2014	San Marco (Ravenna)	Emilia Romagna
60	2014	Scorzè (Venezia)	Veneto
90	2014	Scorzè (Venezia)	Veneto
800	2014	San Marco (Ravenna)	Emilia Romagna
250	2014	San Marco (Ravenna)	Emilia Romagna
60	2014	Scorzè (Venezia)	Veneto
800	2014	Scorzè (Venezia)	Veneto
800	2014	San Marco (Ravenna)	Emilia Romagna
800	2015	Jolanda di Savoia (Ferrara)	Emilia Romagna
800	2017	Ravenna	Emilia Romagna
1000	2018	Noceto (Parma)	Emilia Romagna
TOTAL = 61018		***N LOCATIONS = 23***	***N REGIONS = 7***

activities (Bertolino and Genovesi, 2007; Kapitza et al., 2019). Iordan et al. (2012) suggested that eradication of the American mink is still possible in North-Eastern Italy, where the main Italian populations are known to occur (Bon, 2017; Iordan et al., 2017). American minks are reported to be an elusive species and their presence is less detectable where they show nocturnal habits (Lapini, 1991).

In our work we aimed at reviewing activity rhythms and diet of the American mink in the introduced range in Europe. Then, we assessed the local trophic niche breadth in comparison with other studies on the diet of this invasive species in Europe. We predicted a wide trophic breadth of the American mink in Europe and also a temporal plasticity which may allow this species to adapt to different environmental conditions, so to increase its invasive potential. We also suggest that trophic richness in diet would seasonally change, as non-permanent water environments may provide a further hunting area for the mink apart from terrestrial ones (Boitani et al., 2003). We then discussed our results also in terms of potential management actions.

2. Materials and methods

2.1. Review of activity rhythms and diet of the American mink in Europe

We searched studies on activity rhythms and diet of alien American mink in Europe on ISI Web of Science, Scopus, and Google Scholar, using all combinations of the following terms in eight languages (English, German, Spanish, Portuguese, Russian, Greek, French, and Italian): *Neovison*, vison*, nativ*, alien*, introduc*, invas*, allochthonous, activity, rhythm*, temporal, mink*. We selected the most commonly used languages in the scientific literature (Ammon, 2001), as well as those most commonly spoken in Europe. We are aware that we may have missed some relevant literature published in other languages, but we are almost confident that we provided a quite complete scenario of our research topic. Trophic richness in diet was computed through the Shannon index following Tsuji et al. (2019). The Shannon index was used to calculate the diversity of diets by using this formula: $H' = -\Sigma F_i \times \log F_i$, where F_i represents the frequency of occurrence of food category "*i*" (Tsuji et al., 2019). Then, we tested whether season and sample sizes were correlated to the trophic richness in diet in each study (Spearman's correlations).

For each study on mink diet, we recorded season and sample size. Relative frequency (i.e., number of occurrences of each food category, when present/total number of occurrences of all food items × 100) of seven prey category was obtained from each study: 1) mammals; 2) birds; 3) reptiles; 4) amphibians; 5) fishes; 6) crustaceans and 7) other invertebrates. We are aware that also absolute frequencies (i.e. number of occurrences of each food category, when present/total number of scats × 100) and estimated volumes (i.e. volumes of each prey category, when present, estimated by eye/total estimated volume × 100) may provide important information, but these values were not reported for most published works. For each study on activity rhythms of the American mink, we extrapolated the time of activity peaks. When original data were available, activity rhythms were computed by using the through the R package *overlap*, with the function [densityPlot] (Meredith and Ridout, 2014). This package calculates activity levels and patterns of animal species throughout the 24-h cycle through kernel density models (Chen et al., 2019). The activity level is the ratio of the area under and above the curve of the circular probability density function f(x), which represent the percentage of time in the 24 h when the species is active; activity pattern is the shape and trend of the same curve. For all mink photos, we reported the date and the solar hour of capture (directly shown on each photo) on a dataset. Before analyses, we removed from our datasets records of the same species (i.e. the American vison) occurring in <30 min, to limit the pseudoreplication bias (i.e. keeping only the first record: Meredith and Ridout, 2014).

3. Results

We collected a total of 30 studies on the diet of the American mink in Europe carried out through scat analysis (Fig. 1; Table S1 in Supplemental Material 1). Most works were conducted in Northern and Eastern Europe, whereas studies from Southern countries were the least. American mink showed a wide trophic plasticity in Europe, ranging from small mammals, which built up the staple of the diet, to reptiles and invertebrates (Fig. 2). We showed that study time period was the only variable positively correlated to the trophic niche breadth ($R^2 = 0.655$), therefore suggesting that mink diet varies with seasons.

As to activity rhythms, we collected four published works (Niemimaa, 1995; García et al., 2009; Brzeziński et al., 2010; Zschille et al., 2010) and a MSc thesis (Mezzetto, 2020). Among those, we get original data only from Mezzetto (2020) from North-Eastern Italy (Supplemental Material 1). All these studies confirmed polyphasic activity rhythms of this species, peaking at dusk and dawn, but for Germany and Spain, when the peak appeared were reached in daylight hours.

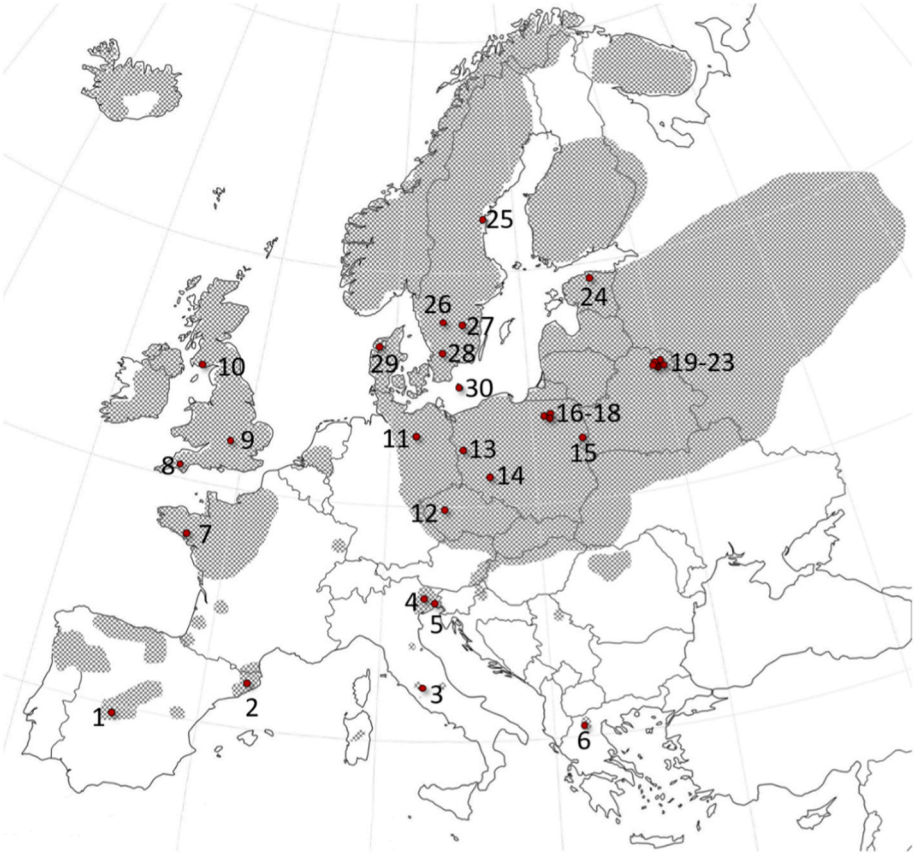

Fig. 1. Locations of studies on the diet of invasive mink in Europe: 1) Bueno (1996); 2) Melero et al. (2009) 3) Angelici et al. (2000); 4) Mori and Mazza (2019); 5) Lapini (1991); 6) Mezzetto et al. (2019); 7) Lode (1993); 8) Bonesi et al. (2004); 9) Ferreras and Macdonald (1999); 10) Dunstone and Birks (1987); 11) Zschille et al. (2014); 12) Novakovà and Koubek, 2006; 13) Bartoszewicz and Zalewski (2003); 14) Krawczyk et al. (2014); 15) Jędrzejewska et al. (2001); 16–18) Brzeziński (2006); 19–23) Sidorovich (2000), Sidorovich et al. (2010); 24) Maran et al. (1998); 25–27) Gerell (1967); 28) Erlinge (1969); 29–30) Hammershøj et al. (2004). Shaded areas represent the range of the American mink in Europe.

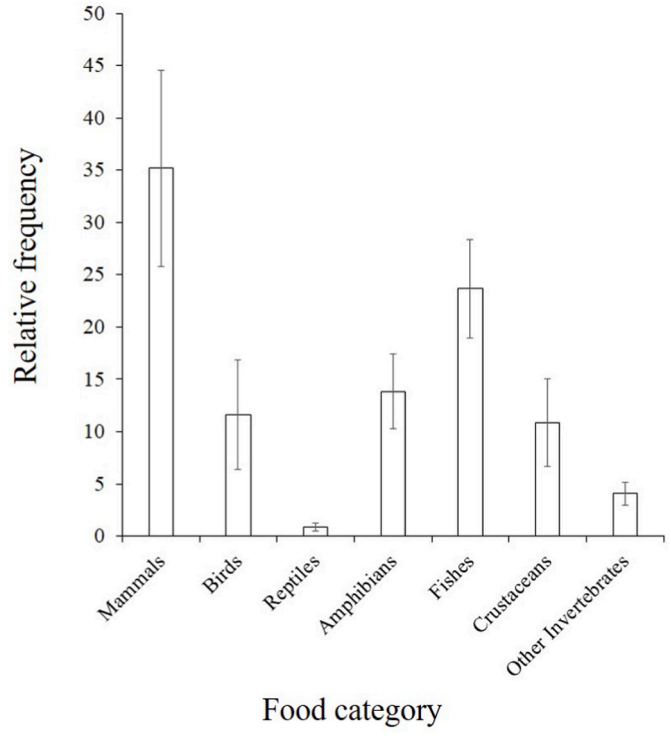

Fig. 2. Average relative frequencies (%) of prey categories in American mink diet in Europe, and relevant error standards.

4. Discussion

Our review showed the American mink is an extremely plastic species in terms of food habits, which may adapt to many environments close to permanent waterways. The trophic richness in American mink diet increased with increasing sampling period, suggesting that it may use a number of prey items depending on their seasonal availability. This adaptation allows the American mink to get prey otherwise not accessible (e.g. in seasons when these prey are not active or migrated), e.g. fish, amphibians, crustaceans (especially crayfish) and wading birds, thus potentially making it as a threat to native ecosystems (Harrington and Macdonald, 2008; Branquart, 2013). However, where trophic niche breadth is low (e.g., on islands: Clode and Macdonald, 2002; Ahola et al., 2006; Jiménez et al., 2014), impact may be high on breeding birds or native voles.

Our analysis on temporal activity was based on a very low amount of published studies. We are aware of the limitations linked to such a small sample size. However, based on available data, we may confirm a polyphasic activity for the American mink in Europe (Niemimaa,1995; García et al., 2009; Brzeziński et al., 2010; Zschille et al., 2010; Mezzetto 2020). Cathemerality (i.e. the ability of an animal to remain active for short periods throughout the 24 h) is rare among mammals, but it underlies a high adaptability and a high ability to limit competition with phylogenetically related species (Fonda et al., 2017; Torretta et al., 2017). Probably, this plasticity could be attributed to the interactions with the main prey species (water voles and rail birds, diurnal; crayfish and other rodents, nocturnal) and any native competitor species. Where the polecat *Mustela putorius* is present (Brzeziński et al., 2010), the American mink is more active at dawn, whereas the polecat - probably the "inferior" competitor - has significant peaks of activity at sunset and at the beginning of the night. Conversely, the diurnal activity of the American mink in Spain could be due to the coexistence with a larger predator, i.e the European otter *Lutra lutra*. García et al. (2009) and

Bonesi et al. (2004) showed that the otter may shape the local distribution of the American mink, relegating it to peripheral areas, confirming a form of potential competition between the two species to the advantage of the native species. In North-Eastern Italy, the American mink showed a very limited overlap with the stone marten (Supplemental Material 1), despite the low sample size prevented us to drive strong conclusions. Given that the stone marten is about 5–7% larger than the American mink (Boitani et al., 2003), it is probable that the latter tries to reduce encountering rates with the former, larger-sized native mustelid.

In recent times, the need for the management of alien minks have been highlighted by the COVID-19 pandemic outbreak. Over 50,000,000 American minks/year are bred for their fur in Eurasia. Mink kept in large numbers in European mink farms have also been infected by the COVID-19 virus from infected workers. Mutations in some mink-related strains involve the spike protein of the virus, which is targeted by most developed vaccines. In Denmark, the virus has "spilled back" from mink to humans, picking up genetic changes on the way and infecting over 200. Outbreaks of COVID-19 in mink fur farms have been reported in the Netherlands, Denmark, Spain, Greece, Sweden and Italy, and several millions of animals have had to be culled (https://www.bbc.com/news/science-environment-54842643. Accessed on December 06, 2020). Management of free-ranging populations may be considered also in countries where escapes are frequent, e.g. in Denmark (https://www.sciencealert.com/escaped-danish-mink-could-spread-coronavirus-to-wild-animals. Accessed on December 06, 2020) and Italy (cf. Table 1). However, no information is available on COVID susceptibility in free-ranging alien populations which do not live at high densities as in fur farms.

In our work, we have provided Europe-wide evidence of trophic plasticity and temporal patterns of activity rhythms which may represent a baseline information to carry out effective removal of wild populations (see Martin and Lea, 2020). Accordingly, feeding plasticity highlights that increasing populations of this semiaquatic carnivore may threaten native species of conservation interest including native crayfish *Austropotamobius pallipes* complex and water voles. Cathemeral patterns of activity rhythms imply frequent control to traps to increase capture success. A first assessment of human perception of impacts free-ranging American mink in Europe (i.e. a case study in Northern Italy: cf. Supplementary Material 2) have shown that it is poorly perceived as a threat to human wellness and economy, highliting the importance to incorporate human dimension into conservation programs and the organisation of educational campaigns, illustrating the main damage caused by this species where introduced, with particular emphasis on human activities and health (La Morgia et al., 2017).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.actao.2020.103700.

Author contributions

DM and EM conceived the study; DM and FD organized and conducted field work, as well as literature search; EM conducted statistical analyses and wrote the first draft; all authors approved the final version of the MS.

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