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Diet of the American mink *Neovison vison* in an agricultural landscape in western Poland

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Abstract. We studied the diet of the American mink (*Neovison vison*) in small artificial watercourses located in a farmland area of the valley of the River Barycz in Poland. Rodents, mainly *Microtus* spp., were the most frequent prey identified, occurring in 88.3 % of all analyzed mink scat. Minks also fed willingly on fish, birds and amphibians, whereas insects, crayfish and reptiles accounted for only a small part of the biomass of food consumed. The food niche breadth of the mink's diet was wide, and varied significantly between seasons; in spring and autumn minks preyed mainly on rodents and fish, while the winter and summer diets consisted of a broad characterization of prey items. The proportion of mammals in the diet also decreased significantly during the summer months. These patterns differ from those previously reported in Europe, and demonstrate the plasticity of the mink diet across habitats.

Key words: invasive species, feeding ecology, farmland, predation, Mustelidae

Introduction

The American mink (*Neovison vison*) has been recently recognized as one of the most invasive alien mammal species in Europe, with negative environmental and economic impacts (Nentwig et al. 2010). Since its introduction to Europe in the late 1920s (Lever 1985), its area of occupancy has increased steadily, with almost a 40 % increase over the past decade (Nentwig et al. 2010). Now occupying more than half of the continent of Europe, this North American species has multiple adverse effects on native species. Numerous studies have reported the considerable impact of mink predation on waterfowl, small mammals, and fish, which are generally the preferred prey of the American mink (Macdonald & Strachan 1999, Clode & Macdonald 2002, Nordström et. al. 2003, Brzeziński et al. 2010). There is also some evidence that minks can significantly affect species from other systematic groups, such as crustaceans (Previtali et al. 1998, Fischer et al. 2009). The expansive negative impacts of minks on prey populations, as well as competition with other mustelids (Clode & Macdonald 2002, Bonesi & Palazon 2007, Rey 2008, Brzeziński et al. 2012) presents one of the biggest threats to native fauna, yielding a great demand for a more detailed understanding of mink predation.

The feral population of the American mink in Poland has increased and expanded to new territories since being introduced in the 1980s (Brzeziński & Marzec 2003). Similar to the rest of Europe, several studies have reported fish, birds, and mammals as the most important components of the mink diet (Jędrzejewska et al. 2001, Bartoszewicz & Zalewski 2003, Brzeziński 2008), with proportions varying by season (Bartoszewicz & Zalewski 2003), or between minks occupying neighbouring rivers (Skierczyński et al. 2008). None of these studies, however, have been conducted in landscapes with high human impact, in spite of the fact that mammals may display distinct behavioural responses to human disturbance as a function of their dietary habits (Dotta & Verdade 2007). Given the high proportion of agriculture-dominated land cover in Europe as a whole (Hannah et al. 1995), addressing such questions is important for uncovering the full impact of minks on native fauna. Western Poland is dominated by an expanse of farmland areas, making it an ideal place to address such questions.

The aims of this study were to (1) record the food niche of the invasive American mink in agricultural landscapes, (2) describe seasonal differences in the diet and investigate which groups of prey are most utilized by minks, and (3) determine the potential of this invasive species to harm bird populations by identifying the proportion of birds in the diet of minks from bird refuge areas. We expected some differences in mink diet composition between the farmland dominated areas on our study site, in comparison to more natural areas where studies have traditionally focused. Specifically, we expected a lower diversity of prey species and an inconsiderable share of aquatic prey in our agriculture-dominated landscape.

Material and Methods

Study area

The study was conducted in Barycz Valley Landscape Park in western Poland (51°34′ N, 17°40′ E). The study area is located in an extensive agricultural landscape characterized by a patchwork of fields, meadows and pastures. The composition of individual habitat types in the landscape are: urban areas 6.3 %, arable farmland 41.3 %, fallow lands 2.3 %, meadows and pastures 43.8 %, forests 6.1 % and water tanks 0.2 % (EEA, European Environment Agency 2006). Rivers of this region are midfield watercourses, the majority of which are highly human-transformed with removed riparian vegetation. The study area is located about 20 km from the biggest complex of fish ponds in Europe (The Milicz Ponds), and the richness of the local avifauna make it a Special Protection Area and Special Area of Conservation of the European ecological network Natura 2000. The study area contains numerous populations of carnivorous mammals, including the Eurasian otter (*Lutra lutra*), the red fox (*Vulpes vulpes*), the badger (*Meles meles*), the raccoon dog (*Nyctereutes procyonoides*), the European polecat (*Mustela putorius*), the stone marten (*Martes foina*), the pine marten (*Martes martes*), the stoat (*Mustela erminea*), and the weasel (*Mustela nivalis*) (Jankowiak et al. 2008, Krawczyk et al. 2011, Malecha & Antczak 2013).

Diet analysis

The diet of the American mink was studied by scat analysis. A total of 115 mink scats were collected from September 2009 to April 2012. All the samples were divided into four seasons: spring (N = 51), summer (N = 18), autumn (N = 27) and winter (N = 19). The scats were found on riverbanks and under bridges along five watercourses. To avoid incorrect identification of scat, only those near mink footprints were collected.

The mink scats were washed on a sieve, dried, and analyzed following standard procedures (Goszczyński 1974, Jędrzejewska et al. 2001). Undigested prey remains were identified using a binocular microscope, separated into fractions, and weighed with 0.1 g accuracy. Mammals were recognized based on skeletal elements using the key for mammals of Poland (Pucek 1984). Where bones and teeth were missing, mammals were not identified to species and instead classified as micromammalia. Identification of birds to order was not possible since found remains consisted only of bone fragments and bottom parts of chick feathers. Fish were identified by scales and pharyngeal teeth based on a fish atlas (Brylińska 1991) and on the authors' reference collection of fish remains. The other remains were divided into the following groups: birds, reptiles, amphibians, crayfish and insects. Diet composition was expressed as frequency of occurrence, relative frequency of occurrence, and biomass of prey. Frequency of occurrence (FO) was calculated as a percentage of occurrences of each food category in all analyzed samples. Relative frequency of occurrence (RFO) was calculated as a percentage of occurrences of each prey category in relation to the sum of all preys (Carss 1995, Clavero et al. 2004). The percentage of the biomass of food eaten was calculated using appropriate coefficients of digestibility: fish – 25, amphibians – 18, birds – 12, rodents – 9, crayfish – 7, insects – 5 (Jędrzejewska et al. 2001). The food niche breadth was calculated using B index (Levins 1968).

Statistical analysis

Scat samples from all watercourses were grouped because all rivers are closely connected (the proximity being less than or equal to a few hundred meters). We analyzed mink diet composition in four seasons: winter (December-February), spring (March-May), summer (June-August) and autumn (September-November). We performed a randomization chi-squared test of independence to compare differences in the frequency of diet components between seasons. We analyzed seasonal changes in different prey biomass content using a generalized linear model with focal prey biomass as the response variable and season as an explanatory variable. We used model validation graphs and tested for homogeneity of variances (fitted values versus residuals) and normality (QQ plots). All statistics were computed using the basic stats package in R (R Development Core Team 2012).

Results

Frequency and biomass of prey

We found prey belonging to several systematic groups in mink scats: mammals, reptiles, amphibians,

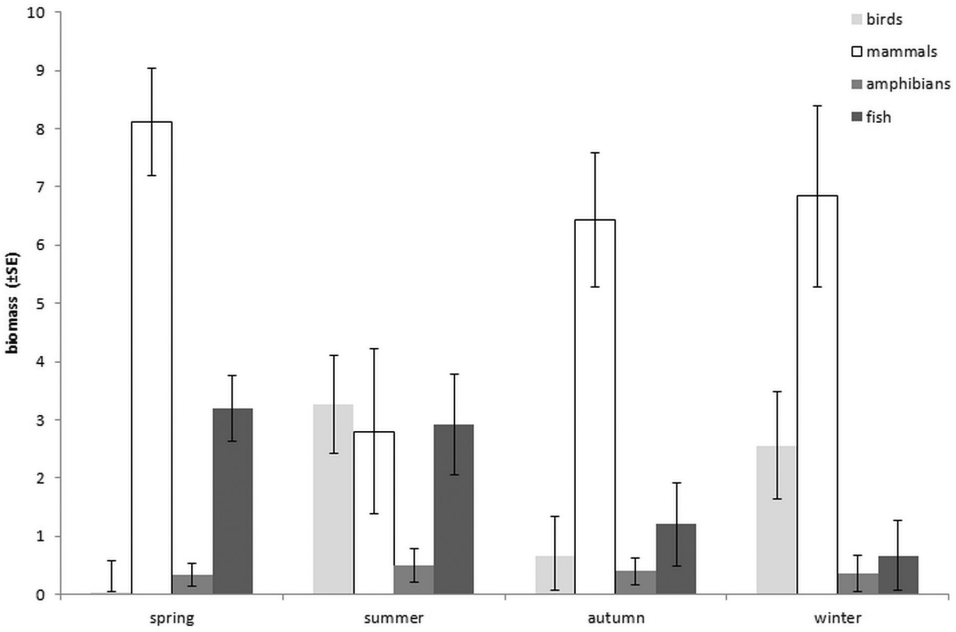

Fig. 1. Seasonal variation in biomass of main components of mink's diet.

Table 1. Diet composition of the American mink in an agricultural landscape. %FO – frequency of occurrence, %RFO – relative frequency of occurrence, %B – percentage biomass consumed.

Food component	%FO	%RFO	%B	N
Mammals	88.3	43.3	61.3	91
Arvicola terestris		5.3		5
Apodemus sp.		3.2		3
Microtus sp.		34.7		33
Sorex sp.		1.1		1
Unidentified micromammalia		55.8		53
Birds	16.5	8.1	11.0	
Reptiles	2.9	1.4	0.5	3
Amphibians	16.5	8.1	3.8	17
Fish	52.4	25.7	22.0	54
Perca fluviatilis		50.0		32
Gasterosteus aculeatus		9.4		6
Esox lucius		4.7		3
Cyprinidae		17.2		11
Unidentified fish		18.8		12
Crayfish	2.9	1.4	0.2	3
Insects	15.5	7.4	0.8	16

fish and invertebrates (mainly crustaceans and insects, see Table 1). The most frequent group was mammals, which appeared in the majority of all studied samples and constituted almost half of all eaten prey. Moreover, the largest part of the biomass of food eaten consisted of mammals. The second most frequent group was fish. Birds and amphibians (*Rana* sp.) were found with equal frequency in scats, but the biomass of birds was higher than amphibians. Insects (*Dytiscus* sp.) occurred in similar frequency to birds and amphibians, but the biomass of insects consisted of about 1 % of all food eaten. The rarest groups in the minks' diet were reptiles and crayfish (*Astacus* sp.), which jointly composed < 1 % of biomass.

The most frequent mammals identified were rodents of the genus *Microtus*. We identified three *Microtus* vole species: the root vole (*Microtus oeconomus*), the common vole (*Microtus arvalis*) and the field vole (*Microtus agrestis*), and found remains of the European water vole (*Arvicola terrestris*), mice of genus *Apodemus,* and one specimen of the common shrew (*Sorex araneus*). Unfortunately, more than half of all found mammal remains were unidentifiable due to the lack of diagnostic skeleton elements.

Minks preyed on fish from four families: Percidae, Cyprinidae, Esocidae and Gasterosteidae. Percidae (only one species: *Perca fluviatilis*) were the most frequent group of fish identified, found in half of the studied scats, followed by Cyprinidae. Minks also preyed on sticklebacks (*Gasterosteus aculeatus*) and pikes (*Esox lucius*).

Seasonal variation in diet

The frequency of all prey categories differed between all seasons in analyzed samples ($\chi^2 = 167.78$, $p < 0.001$). In spring, minks most often preyed on mammals ($\chi^2 = 324.18$, $p < 0.001$), which were found in 93 % of all studied samples. Fish were found in 63 % of scats, insects in 14 %, amphibians in 7 %, and birds only in 2 % of analyzed samples. In summer, both fish (67 %) and mammals (61 %) were found in more than half of analyzed samples, and birds and amphibians consisted of 44 % and 28 %, respectively, of all prey taken. Both insects and crayfish were found in 11 % of samples ($\chi^2 = 130.27$, $p < 0.001$). The autumn diet was dominated by mammals, which were present in 100 % of samples. Fish were found in 41 %, amphibians in 22 %, and birds and insects in 11 % of analyzed autumn samples ($\chi^2 = 284.45$, $p < 0.001$). Only in winter diet did we find all prey groups represented. Mammals dominated (87 %), and other categories were more evenly represented: birds 33 %, fish 27 %, amphibians 20 %, reptiles 20 %, and crayfish 7 % ($\chi^2 = 133.91$, $p < 0.001$). We found significant differences in the biomass of prey of three main food categories (mammals, fish and birds) between seasons (Fig. 1). The estimated biomass of mammals was the lower in summer than in all other seasons (summer *vs.* autumn: $t_{4,102} = 1.97$, p = 0.05; summer *vs.* winter: $t_{4,102} = 1.91$, p = 0.58; summer *vs.* spring: $t_{4,102} = 3.13$, p = 0.002). The fish biomass was the highest in spring, and significantly higher than in autumn and winter (spring *vs.* autumn: $t_{4,102} = -2.19$, p = 0.03; spring *vs.* winter: $t_{4,102} = -2.28$, p = 0.02; spring *vs.* summer: $t_{4,102} = -0.27$, p = 0.78). The biomass of birds was highest in summer, and significantly higher than in spring ($t_{4,102} = -3.26$, p = 0.001) and autumn ($t_{4,102} = -2.41$, p = 0.01). Similarly, the biomass of birds in winter was also higher than in spring ($t_{4,102} = -2.38$, p = 0.01) because of the low bird biomass in spring. We found no between-season difference in amphibian biomass in the diet.

The food niche breadth of the American mink differed between seasons and was similar in autumn (B = 2.77, N = 27) and spring (B = 2.85, N = 51), and far wider but also similar in summer (B = 4.82, N = 18) and winter (B = 4.56, N = 19).

Discussion

The American mink is an opportunistic species that exploits broad spectrum of available habitats and resources. As such, diet plasticity in conjunction with habitat flexibility are considered the main factors that make the American mink such a successful invasive species (Nentwig et al. 2010). We found the main prey of American mink in the Barycz Valley were rodents, which were found in almost 90 % of all samples, and with biomass exceeding 60 % of all food eaten during all seasons, except from summer when the amount of preyed mammals clearly decreased. The fertile meadows and pastures surrounding studied watercourses are inhabited by numerous rodents (Krawczyk et al. unpublished), and ground-dwelling small mammals are generally known to be abundant on such habitats (Bogdziewicz & Zwolak 2013), making these mammals one of the most available terrestrial prey for minks. The second most frequent prey were fish, which occurred in more than half of all studied samples. In contrast to our assumptions, birds consisted only 8 % of mink prey, and their share was very variable throughout the seasons. Finally, amphibians, reptiles, and crustaceans made up a small part of the mink diet. The occurrence of native coexisting predators (e.g. otters) with overlapping trophic niches may provoke considerable shifts in mink food niche (Bonesi & Palazon 2007), accounting for the broad food niche breadth documented here. In addition, minks are riparian predators foraging both on terrestrial and aquatic food, and the proportion of these prey groups in the mink diet is expected to be variable (Macdonald & Strachan 1999).

Similar to previous studies which have found pronounced intraspecific differences in diet composition between individuals, sexes, seasons, and even years (Sidorovich et al. 2001, Macdonnald & Harrington 2003, Skierczyński & Wiśniewska 2010, Magnusdottir et al. 2012), the diversity of taxa that we identified in the diet of minks differed across seasons. First, we found a decline of mammals in the summer diet of minks, in accordance with the findings of Bartoszewicz & Zalewski (2003), whom also described a high proportion of mammals in the mink diet, highest in autumn and winter and declining in spring when minks preyed mostly on birds and accessible fish (but see Brzeziński 2008 and Zschille et al. 2013). In addition, the decrease of mammals in the diet coincided with an increase in birds in the summer months, evidence of a clear shift to the most available prey in each season (Bartoszewicz 2003). Second, we also found seasonal variation in fish content in the mink diet, most likely reflecting a change in fish availability in the studied watercourses. The share of fish in the winter diet is lower than in other seasons because of short-term freezing of small rivers, while the increased occurrence of fish in spring and summer can be attributed to the drop in the river water level, or partial drying combined with overgrown by vegetation on the river. This overgrowth and drying causes fish crowding in shallow water, making them more accessible for minks, and these results reflect other studies in which minks foraging at small watercourses prefer aquatic prey (Jędrzejewska & Jędrzejewski 1998), and in which summer drying of the rivers led to a diet of mainly fish (Melero et al. 2008). Third, the biomass of birds differed across seasons, being highest in summer (44 %), likely because of the moulting time of Anseriformes and coots (Rallidae). On the other hand, the number of birds in the mink diet during spring was unexpectedly low (only 2 %). Although there are studies where birds constituted a low percentage of the mink diet (Kiseleva 2012), we expected minks to prey more often on birds in our study site since it was located in a bird refuge area with high bird abundance (Witkowski et al. 1995). The low occurrence of birds in the mink diet in spring is especially surprising, as other studies conducted in areas with high bird richness show contrasting patterns (e.g. Bartoszewicz 2003, Zschille et al. 2013).

The presence of amphibians and reptiles in the diet varied across seasons. Amphibians consisted of a variable proportion of the overall diet in different seasons, but we found no significant differences in amphibian biomass between seasons. The low biomass of this group in our results indicates that amphibians are a food category of secondary importance for minks in the Valley River Barycz, and supports previous findings in the Słońsk Reserve (Bartoszewicz & Zalewski 2003). On the other hand, a small share of frogs in the mink diet in our study is counter to results obtained by Maran (1998) or Brzeziński (2008), who noted amphibians as the most important prey of mink. Moreover, in studies conducted in Białowieża Primeval Forest, hibernating frogs were the main prey of minks in winter (Jędrzejewska & Jędrzejewski 1998). The presence of reptiles only in the winter diet could suggest that minks do not actively hunt for them, but may have found them while searching for hibernating amphibians. The occurrence of reptiles in winter diet could also be caused by lower abundances of preferred food sources in winter leading to foraging on less preferred foods.

Crustaceans were only a supplement in the mink diet in the Barycz Valley farmland area, and were present mainly in summer. The low share of crayfish in the diet probably reflects low abundance in the habitat (Krawczyk unpublished). Crustaceans may be a desirable food category for minks and can even become the staple food of minks, depending on their availability in the habitat (Previtali et al. 1998, Brzeziński 2008, Melero et al. 2008, Fisher et al. 2009, Sidorovich et. al. 2010, Fasola et al. 2011). Other invertebrates, specifically insects, seem to be of minor importance in mink diet because of their low biomass (0.8 %), though they were found in 15 % of analyzed samples, mainly *Dytiscus* spp. Moreover, the size of their remains indicated that beetles were directly preyed on by minks, and not present as a part of the stomach content of ingested fish. Despite the fact that the insects are not an important part of mink diet in our study area, minks often complement their diet with arthropods.

We found the widest food niche breadth in summer and winter when mink used the highest number of prey categories. The wide trophic niche in winter may be the result of decreased food accessibility caused by severe weather conditions. Foraging on fish in these seasons is probably more difficult because of ice layer on river surface, and hunting on small mammals could be harder because of a thick snow layer (Merrit 2010), resulting in the our observation of a decrease in frequency of occurrence of preferred prey groups in winter diet in comparison to other seasons. Reptiles, on the other hand, were found only in winter scats, likely due to the lower overall prey availability in winter, forcing the mink as a generalist predator to use other more accessible food resources. In summer the overall prey availability is probably high, and therefore mink as generalist predator uses all accessible food resources. All main food categories (small mammals, fish and birds) constituted a similar share in summer diet. A similarly diverse array of summer prey was observed in Belarus by Sidorovich (2000), where aquatic prey decreased and terrestrial prey increased during dry summer months. The narrower food niche in spring and autumn results from the large number of mammals in mink diet in these periods. This could be caused by a high abundance of voles in the habitat, combined with the decreased availability of other prey groups.

The large number of mammals in minks diet in the Barycz Valley could be also an evidence of food niche shifting towards terrestrial prey, possibly resulting from the presence of a large population of its main competitor in this area, the otter. Resource competition between the mink and the otter is one of the most often described examples of competition among carnivorous species (Chanin 1981, Clode & Macdonald 1995, Bonesi et al. 2004). It is known among carnivorous mammals that larger species usually win the competition and consequently, in the long term, one of the competitors may yield by changing its diet (Krebs 2011). It is possible that exactly this phenomenon was observed in our study area, where the otter diet was composed almost exclusively of fish (Krawczyk et al. 2011), and minks were forced to prey mostly on terrestrial prey (rodents), suggesting that a stable population of native species can be an important factor regulating the impact of this invasive predator.

Our work shows that, on small midfield watercourses, rodents are the main food resource for mink across seasons. The results obtained in an agricultural landscape differ from the results obtained in studies conducted in different habitats. For example, studies conducted at lakes showed that the largest part of the mink diet consisted of aquatic species (fish and amphibians, Brzeziński 2008), and in fish ponds minks preyed mainly on fish and birds (Zschille et al. 2013).

The shift from aquatic to terrestrial prey in mink diet in our study area is most likely caused by high rodent abundance in farmland areas (Briner et al. 2005, Heroldová et al. 2007), in possible combination with interspecific competition with otters. Our results are another confirmation of the plasticity of the mink diet and the great capacity of this invasive species to adapt to a broad range of environments, including agricultural landscapes.

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