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ORIGINAL ARTICLE

European beaver (*Castor fiber*) in open agricultural landscapes: crop grazing and the potential for economic damage

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Abstract

The European beaver (*Castor fiber*) has extended its range into most Central European countries over the past 30 years, resulting in increased forestry damage and water management issues. As the number of beavers increases populations become established in new types of habitat. In the Czech Republic, for example, established beaver populations are now found on rivers flowing through agricultural landscapes, where living conditions differ significantly to those found in forest landscapes. To date, there have been no studies on the impact of beavers on agricultural production. The aim of this study was (1) to describe how beavers graze field crops, and (2) to estimate potential damage to agricultural production. This 2-year study examined five beaver territories in agricultural landscapes where crops were separated from watercourses by a narrow strip of bank vegetation. Beavers fed on all crop types grown in their territories throughout the growing period (May–October), peaking from mid-June to mid-July. The beavers clearly preferred oilseed rape, which (along with wheat and barley) represented the largest part of the grazed area. Rape was usually grazed at during vegetation growth and flowering, while cereals were usually grazed from the milk ripe kernel stage to harvest. Damage to agricultural production was up to €20–30 per ind./year. While beaver population density in the agricultural landscape remains low, damage to agricultural production is relatively insignificant; however, field crops clearly represent an important part of the beavers' diet in such areas, helping them survive in such open landscapes.

Keywords Beaver · Diet · Field crops · Damage · GIS

Introduction

The range of European beavers (*Castor fiber*) has expanded considerably in Europe in recent decades (Halley et al. 2012), with populations settling not only in forests but also in agricultural landscapes (John and Kostkan 2009). In the 1990s, beavers were reintroduced into the Czech Republic, and these have gradually spread into most forested areas of the country (Vorel et al. 2008). However, such introductions can be controversial; while they have been shown to have a positive influence on the biodiversity of entire ecosystems (Rosell et al. 2005), they can also cause considerable economic damage as regards forestry and water structures, primarily through flooding caused by their dams (Harkonen 1999; Hartman 1999).

Indeed, it was for this reason that beavers were deliberately eradicated in southern Bohemia in order to protect the historically, environmentally and economically important fishpond systems (Kostkan et al. 2014). In Moravia, beavers have settled along many watercourses, with populations thriving in alluvial forests of the Morava River basin (Kostkan and Lehky 1997). However, as numbers have increased in those regions providing optimal living conditions, so populations have begun to expand onto smaller watercourses and into less forested areas that provide less favourable living conditions (Havens et al. 2013), including agricultural landscapes (John et al. 2010).

Beavers are generalist herbivores that display two different foraging behaviours during the year. From the end of autumn to the beginning of spring, they mostly feed on woody plants, shifting to herbaceous plants and shoots of some deciduous woody plant species during the main growing season (Jenkins 1979; Müller-Schwarze and Sun 2003; Henker 2009;

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Krojerová-Prokešová et al. 2010). Beavers are food opportunists that utilise the highest quality food resources in an optimal manner (Nolet and Rosell 1994; Haarberg and Rosell 2006); as such, their diet can differ significantly depending on local food availability and time (Jenkins 1979; Harkonen 1999; Haarberg and Rosell 2006). Previous studies have shown that, for certain periods, field crops in agricultural landscapes may provide the highest quality component in herbivore diet, and this is also true for both European beaver (Schwab and Schmidbauer 2003; Gaywood et al. 2008) and the North American beaver (*Castor canadensis*) (Swenson et al. 1983; Dieter and McCabe 1988). While crop damage by beavers is an increasingly recognised phenomenon in both Europe (Schwab and Schmidbauer 2003) and North America (Baker and Hill 2003), little attention has been paid to beaver damage to agricultural production, primarily as damage levels are relatively low, and there is a general lack of information on beaver dietary behaviour in open landscapes. In the Czech Republic, there is little or no specific data available on the character and extent of crop damage, primarily as the relatively low levels of damage are obscured by the much larger-scale damages caused by other herbivores such as voles (*Microtus arvalis*), wild boar (*Sus scrofa*) and deer (*Cervus elaphus*) (Vecellio et al. 1994; Schley et al. 2008; Jacob and Tkadlec 2010).

The aim of this research, therefore, was to analyse beaver foraging behaviour in such open agricultural landscapes and to estimate the potential damage to agricultural production. As there has been no detailed study focusing on the influence of beavers on field crops in the Czech Republic to date, this work will contribute to our knowledge of beaver dietary ecology and address a potential new conflict area between the interests of nature conservation and farming.

Material and methods

Study area

Based on previous monitoring of beaver distribution in the Czech Republic, five localities were chosen to investigate beaver influence on field crops (Fig. 1; Table 1). Each locality represented the area with permanently inhabited beaver site (river and surroundings). Localities met the following requirements: (1) Beaver activity throughout the growing period (April–October); (2) clear signs of residence (food remnants, scent marks, gnawing, walkways, burrows, dams) and (3) easy access to fields for beavers via a relatively narrow strip (3–12 m) of bankside. All rivers in our localities had been channelised historically, the banks presently being of a relatively natural character with a well-developed herb layer and with shrub and tree cover. In all territories, it was assumed that quantity and attractiveness of food supply available on the banks was sufficient for beavers throughout the growing season. While the vegetation on the banks differed in each locality, herb, shrub and tree species attractive for beavers were usually present at each site (Table 1). The possible influence of bankside vegetation on beaver foraging behaviour was therefore not considered. Availability of field crops for beavers was expressed as percentage length of riverbank with crop (Fig. 2).

Data collection

Presence and feeding behaviour of beavers

All localities were monitored from May to November over 2017 and 2018. Grazing on each crop was determined at

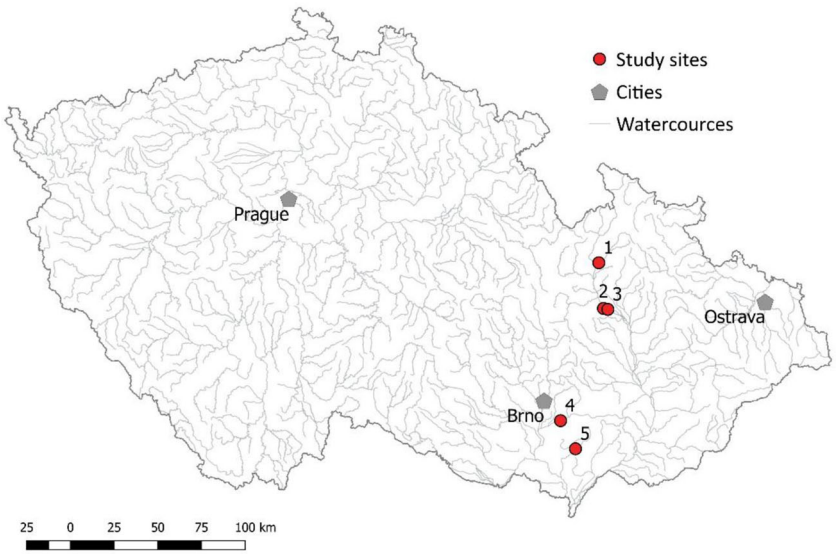

Fig. 1 Distribution of beaver foraging sites investigated in the Czech Republic. 1 = Šumperk, 2 = Mladeč, 3 = Litovel, 4 = Újezd, 5 = Krumvíř; Prague, Brno, Ostrava = capitals of Bohemia, Moravia and Silesia, respectively

Table 1 Basic characteristics of European beaver territories in the agricultural landscapes where dietary behaviour was investigated

Beaver site	Šumperk	Mladeč	Litovel	Újezd	Krumvíř
River width/depth (m)	9/0.65	3.5/0.60	11/0.80	6/0.30	3/0.30
Beaver sites length (m)	2930	860	2910	2240	2760
Elevation (m a.s.l.)	302	236	231	195	175
Number of ind. in beaver sites	2–3	2–3	3–4	1–2	1–2
Vegetation characteristics	*Reynoutria* spp., *Impatiens glandulifera*, *Sambucus nigra*, *Salix* spp., *Rosa canina*, *Cornus mas*, *Alnus* spp., *Prunus* spp.	*Urtica dioica*, poaceae, *Reynoutria* spp., *Populus* spp., *Salix* spp., *Sambucus nigra*, *Corylus avellana*, *Prunus* spp.	poaceae, *Urtica dioica*, *Alnus glutinosa*, *Salix* spp., *Sambucus nigra*, *Crataegus* spp., *Cornus mas*, *Prunus* spp.	poaceae, *Phragmites australis*, *Solidago Canadensis*, *Astra* spp., *Prunus* spp., *Sambucus nigra*, *Acer negundo*, *Crataegus* spp., *Rosa canina*	poaceae, *Phragmites australis Solidago Canadensis*, *Astra* spp., *Prunus* spp., *Rosa canina*

intervals of 10–14 days. It was monitored area up to 50 m from the water. In each visit, the area of each crop grazed was measured (m^2) using a GPS device (Trimble Juno SC) and the crop's phenological stage was determined according to Coufal et al. (Coufal et al. 2004; Table 2). As beavers usually grazed on crops continuously, estimation of area grazed was relatively simple. However, in maize (*Zea mays* subsp. *mays*) fields, beavers sometimes grazed on individual stems spaced widely apart; in such cases, the number of stems grazed was counted and converted to a total area based on the density of stems in the field. In each case, areas grazed by other herbivores like European hare (*Lepus europaeus*), coypu (*Myocastor coypus*) and wild boar were carefully excluded.

In order to characterize the movement of beavers to and from the crop grazing sites, distances were measured between the edge of the river and the edge of each field and each grazed area (measuring tape), as well as the distance between each grazed area and the main burrow using the 'distance to nearest hub (point)' tool in QGIS 3.1 software (Quantum 2019) (Fig. 2). We used to relative frequency and number of square metres damaged crops. Data were expressed every 50 m from the burrow. It was determined confidence index (CI) and regression analysis. We analysed data in (PROGRAM) by regression analysis/linear model. In analysis, we used the relative frequency of feeding places and area in square metres of damaged crops as the response variables. As an explanatory variable we used distance from the burrow which was recorded in 50 m interval and log transformed before analysis.

Calculations of crop preference were based on Ivlev's electivity index $E_i = (r_i\text{-}n_i)/(r_i + n_i)$, where r_i is the proportion of the field crop i grazed to the total grazed area of all crops and n_i is the proportion of crop i available (i.e. the length of bank represented by crop i as a proportion of the total length of bank with all field crops). The weighted generalized linear model with Gamma distribution and inverse link were used to assess differences in the size of area grazed per individual per year between years and among crops, estimated number of individuals in each area was used as a weight. The differences were considered significant at $p \leq 0.05$. (We used R 3.6.1).

Beaver density

All other signs of beaver presence in each stretch, including tree gnawing, scent mounds, depressions in the bank (e.g. slides), tracks, lodges, branch piles (unfinished lodges) and burrows in the bank, were recorded and GPS coordinates taken. These data were recorded at each visit (10–14 days). These signs were then used to assess summer beaver site size and to confirm whether burrows were permanently inhabited. The number of beavers in each site was estimated

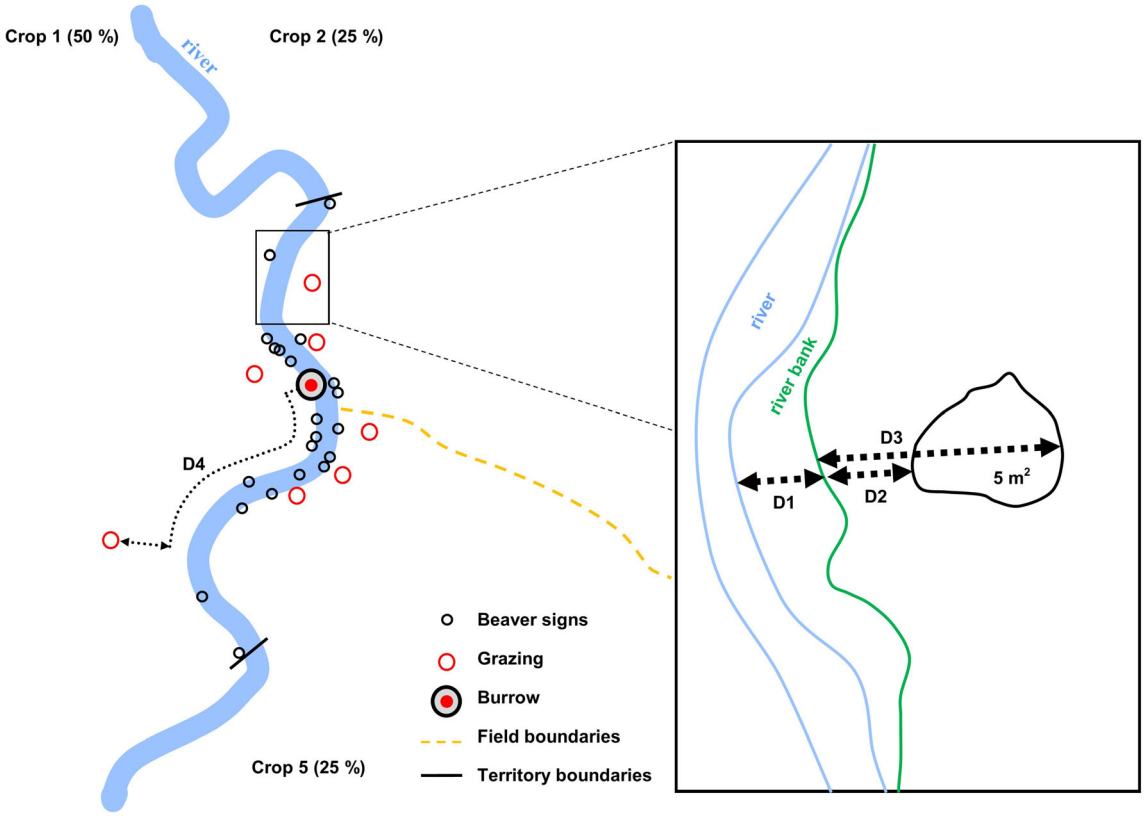

Fig. 2 Measurement scheme in beaver site. D1—distance between the edge of the river and the edge of each field, D2, D3—distances between and each grazed area (nearest and furthest point), D4—distance between each grazed area (nearest and furthest point) and the main burrow

at the end of winter and in summer by direct counting of individuals using thermal camera (Pulsar Quantum XQ38). The beaver site was regularly monitored in the evening around the burrow and in places where beaver was looking for food. Monitoring was repeated 2 times in each site (in winter and summer). The number of individuals found was then averaged.

Damage estimation

The amount of potential economic damage to each crop was determined on the basis of average yield per hectare for individual crops and the average purchase price of the crop according to the Czech Statistical Office (2019). The area grazed (m^2) for each crop was then multiplied by the estimated yield of the crop and converted to economic impact based on the average purchase price.

Results

Extent of grazed area

A total watercourse length of 25.3 km was studied, with a mean length of 2.53 km of stream per locality per year (range 0.91–3.84 km). In total, 41 farming plots containing eight field crop types were recorded along the riverbanks, the average length of a single field being 1400 m (min. 160, max. 3480 m). Beavers grazed field crops in all territories in both years (Fig. 3), with a total area of 3.995 m^2 grazed over all five territories (mean 399.5 m^2/site/year; min. 459, max. 1262).

Table 2 Phenological stages of crops used for analysis of vegetation grazing intensity. Cereals include wheat, barley, rye and oat

	F1	F2	F3	F4	F5	F6
Rape	Germination	Veg. growth	Flowering	Flowering finished	Turning yellow	Ripe
Cereals*	Germination	Stem extension	Heading	Flowering	Milk	Ripe
Maize	Germination	Veg. growth	Heading	Flowering	Milk	Ripe
Beet	Germination	Veg. growth	Incomplete cover	Complete cover	Tuber	Ripe
Sunflower	Germination	Veg. growth	Complete cover	Flowering	Ripening	Ripe

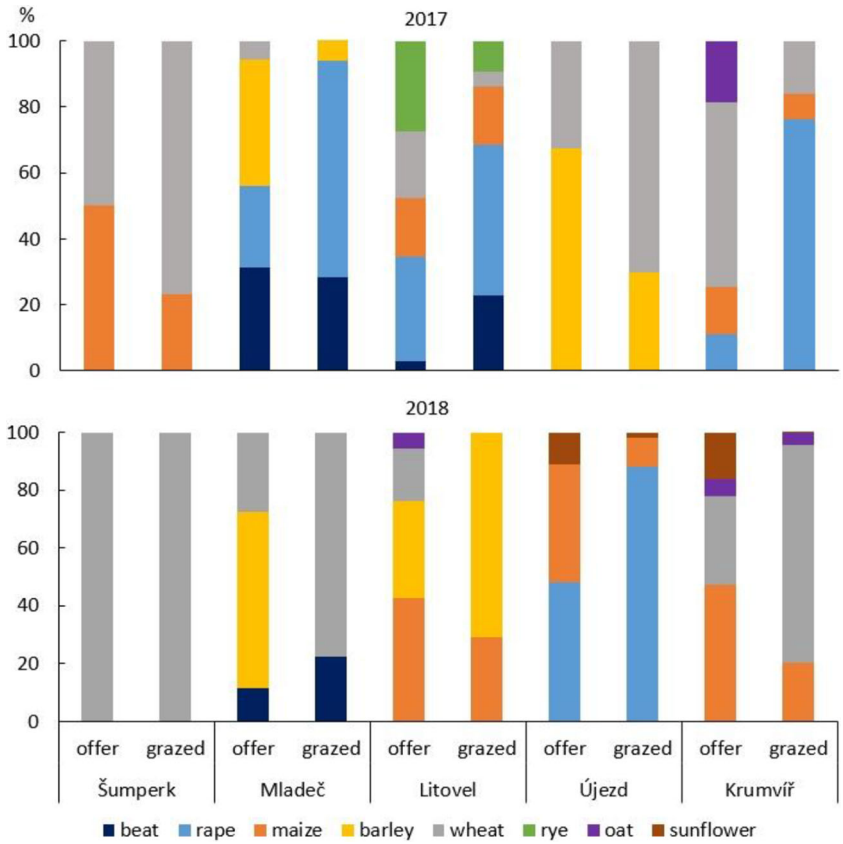

Fig. 3 Offer crops and their consumption within the beaver sites

We found significant differences in grazed area among crops (df = 64, F = 8.01, $P < 0.001$), with wheat a rape most grazed. There was no difference between years in overall grazed area per individual per year (df = 64, $F = 0.36$, $P = 0.552$), but there was significant interaction between crop and year (df = 64, $F = 5.70$, $P < 0.001$), but with nonsignificant results for each crop individually. 37.6% of variability in data. At Šumperk, Litovel and Krumvíř, the area grazed in 2018 was 22–71% less than in 2017, while the area increased by 33% at Újezd and remained similar at Mladeč. These differences appeared to be driven by the presence of oilseed rape as this crop was only grown at Šumperk, Litovel and Krumvíř in 2017, and in 2018 only at Újezd (also see below). Field crops at Mladeč were grazed most intensively at 287 m^2/riverbank km/year, while those at Šumperk were grazed least at 71 m^2/ riverbank km/ year). In all other territories, beavers grazed 164–190 m^2/riverbank km/year.

Field crop preference

Beavers grazed on all field crops grown within their foraging territories. Ivlev's electivity indices indicated a distinct preference for oilseed rape and sugar beet (Table 3). When comparing the total amount of each crop consumed, however, oilseed rape and wheat were the most important crops, with barley and maize of slightly lower importance (Fig. 4; Table 3). In comparison, sugar beet, while a preferred item, contributed relatively little to the diet as it was only grown over a small area (3% of total area cultivated). Though consumed by beavers, oats, rye and sunflowers represented < 5% of total food availability, making calculations of food preference difficult (see the "Discussion" section).

Shifts in grazing over time

Beavers grazed on field crops throughout the May–October monitoring period (Fig. 4). While oilseed rape represented the largest proportion of food consumed, it was only consumed over a 46-day period. In comparison, beavers fed on maize for 105 days, while cereals (wheat and barley), and beet were grazed for approximately 75 days. In spring, the beavers mainly consumed the vegetative parts of oilseed rape; though there was also some evidence that rape had been consumed as far back as midwinter. After flowering, rape became less attractive and was only consumed occasionally. The vegetative parts of cereals and other field crops were only grazed to a limited extent in spring; however, cereal consumption peaked at the start of summer as the kernels reached the milk ripe stage, the cereals then being consumed intensively until harvest. In late summer, after the cereal harvest, beavers began consuming small amounts of the vegetative parts of maize and beet. Maize consumption then increased as the kernels

Table 3 Percentage of each crop in the grazed area with associated electivity indices

	Rape	Beet	Wheat	Barley	Maize	Rye	Oat	Sunflower
Electivity index	0.50	0.43	− 0.10	− 0.13	− 0.29	− 0.42	− 0.78	− 0.82
Proportion of grazed area (%)	34.72	7.31	29.59	13.16	13.13	1.60	0.28	0.22
Proportion of field crops area (%)	11.60	2.93	36.20	17.04	23.90	3.94	2.21	2.21

reached the milk ripe stage at the end of July, after which the kernels themselves were eaten until harvest. In autumn, the only field crops consumed by beavers were maize and beet tubers.

Except for rape, which was grazed mostly at the stage of flowering (16% of area grazed), beavers preferred crops at the vegetative growth and ripening stages (38% of area grazed), with 18% of the total area grazed represented by fully ripe crops (Fig. 5).

Movement to and from fields

Before moving to a field to feed, the beavers passed over a strip of bank vegetation with a mean width of 6.7 m (min. 3 m, max. 12 m), at which point they usually began grazing a crop from the field border, moving to a distance of 20 m from the edge at most (mean distance 7.5 m from water, range 3–26 m). The average distance travelled from a main burrow to a feeding place was 200–250 m; however, in April and August, the average distance travelled was significantly greater at 350 to 500 m. The frequency of visits decreased significantly with increasing distance from water (CI = 0.9048). Within 5 m of the water, only 1% of the area of all the crops consumed was grazed, while 29% of the area was grazed within 6 to 10 m of the water. The greatest area grazed (34%) was at a distance of 11 to 15 m of the water. Overall, the greater the distance from the water, the smaller the area grazed. At a distance of 26 to 30 m, beavers only grazed around 2% of the total area.

Beavers mainly grazed on crops in close proximity to their burrows, with more than a half of the total area (56.5%) consumed at a distance of 50 m, with only 10% of the area grazed at a distance of 400 m or more. The number of feeding places decreased with increasing distance, with 90% of all feeding sites within 500 m of the burrow (Fig. 6). Moreover, as the distance from the burrow increased, the average surface area grazed decreased. Within 50 m of a burrow, the average grazed surface area was 18 m^2, and less than half that (8 m^2) at a distance of 500 m.

Estimated damage to crops

The estimated cost of damage to the total area of field crops grazed (3995 m^2) over 2 years was estimated at €459 (using the average Czech purchase price of the same field crops in 2018), based on an estimated 8–12 beavers living in all five territories, each causing damage amounting €20–30 per year. There are probably 1300 beavers living on the main watercourse of the River Morava; however, the majority of these (approx. 60%) live in forested areas and have no access to farming plots. As such, we calculate that around 550 have access to farming plots. Thus, the maximum estimated damage to field crops could reach €11,000 in Moravia each year.

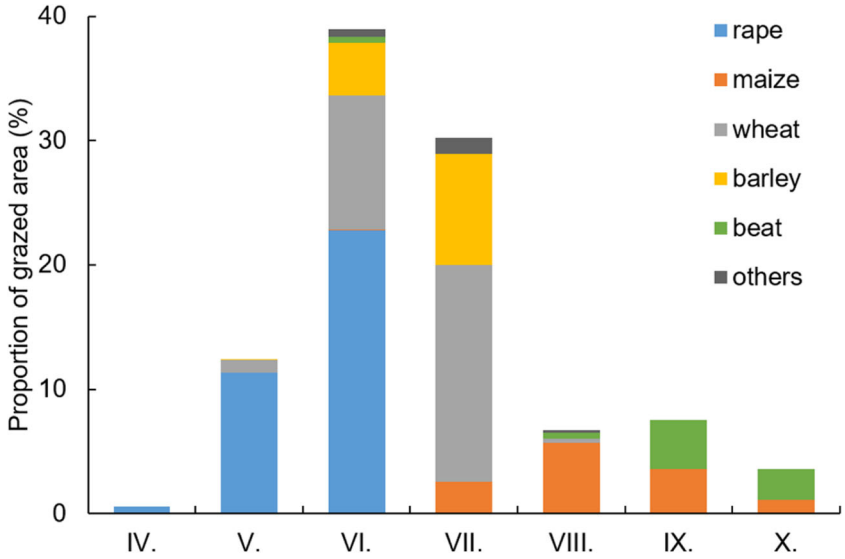

Fig. 4 Percentage area of crops grazed by beavers in individual months (pooled data from 2 years; others = sunflower, rye, oats)

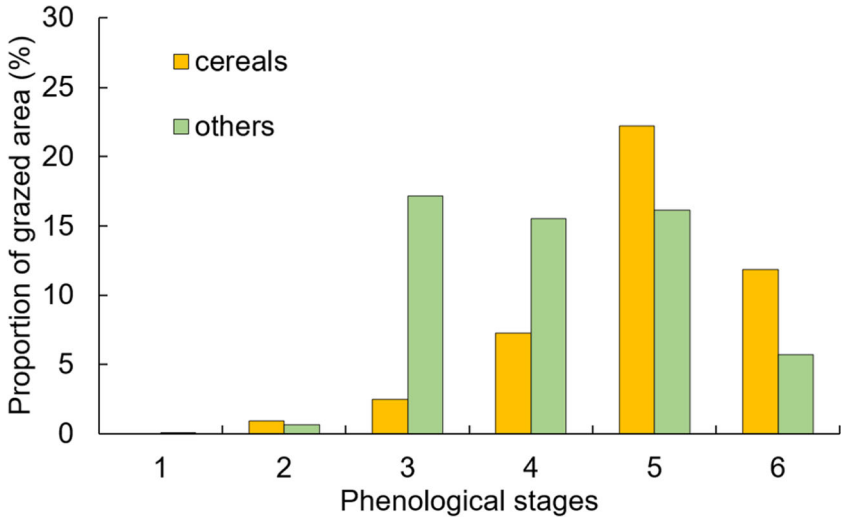

Fig. 5 Percentage area of cereal and other crops grazed in different phenological stages

Conditions for beavers in agricultural landscapes are generally unfavourable; thus, population densities are generally low in such areas and local damage to crops is unlikely to be high, with annual damage to individual farmers probably no more than tens of Euros.

Discussion

During the growing season, European beavers tend to prefer herbaceous vegetation to the bark of woody plants as it contains more nutrients and is usually within easy reach (Bryant et al. 1981; Belovsky 1984), while intensively farmed field crops usually have an even higher nutritional value than wild plants (Merta et al. 2014). The results of this study confirm that, as in other countries, field crops represent an attractive food source for beavers. The beavers in this study grazed on all crop types close to the river, with oilseed rape at the height of its vegetative growth clearly a preferred crop. During this period, cereals are at still at the stem extension and heading stage, and they appear to be less attractive to beavers, possibly due to their higher fibre content. After rape finishes flowering, the stems rapidly become woody, and the beavers shift their attention to the ripening cereals. When beavers in a particular site had the choice, they tended to prefer wheat kernels to barley or rye; however, when there was no choice, they also grazed on barley and rye. Indeed, wheat appeared to be highly attractive to beavers, and they grazed on it from the milk ripe stage right up to the harvest, after which they continued to search for loose wheat ears scattered in the fields following the harvest up until the fields were ploughed. In this particular study, maize kernels were only of average importance as beaver food; however, observations from sites outside the study area suggest that maize can be a very important food source for beavers and that they can graze on it from the milk ripe kernel stage right up until winter (unpublished data). At our

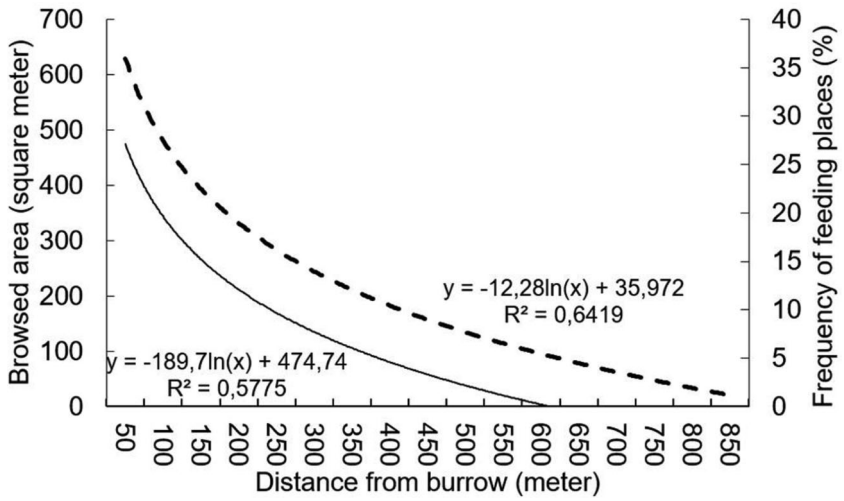

Fig. 6 The relationship between size of field area grazed by beavers (accumulated values) and distance from the burrow (thin line), and between number of feeding sites (accumulated values) and their distance from the burrow (thick dashed line)

sites, beavers could no longer consume maize after the milk ripe stage as the crop was harvested at this point for silage. As regards the other crops, there was too little data to assess the overall importance of sugar beet as food. In one instance, beet was grown around 800 m from the burrow, right on the edge of the beaver's site and there was no evidence that the beaver grazed on it. Where beet was grown close to a beaver's burrow, however, it was commonly eaten, though the total area taken was the smallest of all field crops taken. Sunflowers appeared unattractive to beavers as they only grazed on it at the beginning of the vegetation stage rarely, and only when it was grown alongside maize and wheat in the immediate proximity of a burrow when it was ripe. It appears unlikely that beavers would consume sunflowers if there were no other cultivated plants nearby.

As beavers are closely attached to the aquatic environment, they tend to stay close to water when they move to land to find food (Kostkan and Lehky 1997; Haarberg and Rosell 2006), mainly concentrating on food resources in close proximity to their burrows (Hartman and Axelsson 2004). Such behaviour was also confirmed in our own study. To find food in fields, beavers covered shorter distance than in forests. According to Margaletić et al. (2006), beavers tend to feed most intensively within 10 m of the river; however, when food resources are limited, they may extend their search for food for distances up to 50 m. As field crops provide equally abundant food over the whole field, the distance travelled by beavers will depended primarily on the width of bank vegetation separating the field from the river's edge. In our five study territories, beavers chose to cross up to 12 m of vegetated bankside to access the fields. While it is possible that they could have crossed even greater distances, we were unable to assess this with our sites. If grazing at distances of tens of metres, the beaver would usually transport the grazed crop straight back to the burrow to eat; however, when grazing at distances of hundreds of metres from the burrow, the even into the water, but not to the burrow. The beavers tended to travel larger distances to obtain food in April and August. In April, they actively sought for oilseed rape at the stage of high vegetation growth, and tended to avoid other, closer, crops; while in August, beavers were often forced to concentrate on less preferred crops, even when some distance from the burrow, as the greater part of the available crops had been harvested already.

While the actual area of crops grazed by beavers was not large in terms of economic damage to farmers, it provided an important proportion of the beaver's nutritional requirements during the growing season. Based on the area grazed, the final crop yield and the estimated number of beavers, we calculated that an individual consumed approximately 0.79 kg of green matter (0.14 kg of dry matter) and 0.16 kg of kernels (0.14 kg of dry matter) per day from May to October. By way of contrast, the beaver's usual diet comprises green branches, which represent 1–2 kg of fresh biomass or 0.6 kg of dry matter per day (Warren 1940; Stegman 1954; Nolet 1992; Dyck and MacArthur 1993; Baker and Cade 1995). Moreover, analysis of beaver scat (faeces) collected from the study area also indicated that field crops were an important food resource for beavers. In two samples collected in May 2016, for example, oilseed rape accounted for 60% of the food volume, and in three samples collected in September 2017, maize kernels accounted for 82% of food volume (Homolka unpublished). In the same area, beavers also grazed on fully grown rape during a mild and snowless winter (Homolka unpublished), though no winter grazing on winter cereal has yet been recorded.

The crop composition along the banks in our study area corresponds with that found in most beet and maize growing areas and, as such, the results of this study are likely to represent damage levels under the same geographical conditions in other parts of the Czech Republic, as well as other sites within the temperate zone.

While beavers have been known to forage on field crops throughout their natural range, damage levels tend to be mentioned in general terms only, with no specific data provided on the extent of damage (e.g. see Schwab and Schmidbauer 2003 for Germany; Gaywood et al. 2008 for England; or Rouland 1991 for France). The content of field crops in the beaver stomachs mentions Bełżecki et al. (2018) for Poland, Krojerová-Prokešová et al. (2010) for Czech Republic. Likewise, Baker and Hill (2003); Hammerson (1994); McKinstry and Anderson (1999) have also reported on crop damage by North American beavers. The specific damage is described by Campbell et al. (2012) for Scotland, where 90 m^2 of rape and only 1.5 m^2 of cereals were damaged. These latter authors also noted that overall damage to field crops was negligible in comparison to the damage caused to trees, flooding and damage to dams, hydraulic structures and roads. Our study concurs with these findings, i.e. that overall crop damage caused by beavers in the fertile Moravian lowlands appears to be negligible. This is not to say that field crops are not attractive to beavers, they are; it is more that the majority of beavers in this region are confined to forested areas and have no access to crops. Furthermore, watercourses running through agricultural land tend to provide less suitable living conditions for beavers (Havens et al. 2013) than in the forests and, consequently, beaver population density is low (John and Kostkan 2009; Vorel et al. 2008; Mikulka unpublished) reducing their capacity to cause any extensive damage. It is obvious that forest habitats have mostly been colonized, where beavers find a sufficient supply of preferred food and agricultural crops make up a negligible share in the growing period. Conversely, in the nongrowing period, beavers are dependent on woody plants, of which there are fewer in agricultural areas. Damage to field crops depends on the different nature of the landscape in the regions. Damage and crop selection will be significantly affected by other components of

the available food (woody plants, herbs). In our opinion, damage to field crops is unlikely to increase to any great degree, even if the total number of beavers in the Czech Republic continues to grow.

Conclusion

The results of this study confirm that some agricultural field crops can be a highly attractive food resource for European beavers. Crop preference depended on kind of crop the phenological stage of the crop and on the distance between the crop and the beaver's burrow. From an economic point of view, beavers pose no serious problems to farmers as the numbers in open agricultural landscapes remain low. The total financial loss is extremely low, and it considered negligible in comparison to crop damage from other rodents or game species. Overall, our results provide new insights into beaver dietary ecology in agricultural landscapes in general, and the first specific data on the extent of damage to agricultural production in the fertile lowlands of Central Europe.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10344-020-01442-6.

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