



# Free food for everyone: artificial feeding of brown bears provides food for many non-target species

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## Abstract

Artificial feeding of wildlife is a widely used tool for a range of conservation and management goals. While the effects of artificial feeding on target species have been studied rather extensively, little is known about its effects on non-target species. We used automatic video surveillance to monitor the vertebrate species using artificial feeding sites ( $n = 20$ ) established primarily for brown bears (*Ursus arctos*) in Dinaric Mountains, Slovenia. We also studied how type of artificial food (only plant-based food vs. mixed food including carrion) affects the species diversity and assemblage at the feeding sites. In total, we analyzed 117,566 recordings and identified 23 vertebrate taxa, including the brown bear, using the feeding sites. Brown bear, European badger (*Meles meles*), and red fox (*Vulpes vulpes*) were the most frequently recorded species. Birds represented a substantial part (46%) of vertebrate community using the feeding sites, including species of a high conservation importance. Feeding sites were regularly used also by species for which intentional artificial feeding is forbidden in study area (e.g., roe deer *Capreolus capreolus*). Species diversity at the feeding sites was highest in spring while species composition varied both seasonally and according to the type of artificial food (with or without carrion). Our study indicates that artificial feeding affects numerous non-target species, which could have several ecological and management-relevant effects, including potentially undesired consequences. Artificial feeding of wildlife should be carefully planned and we provide recommendations on how to mitigate the side effects on non-target species.

**Keywords** Anthropogenic food · Wildlife feeding · Non-target species · Brown bear · *Ursus arctos* · Camera traps

## Introduction

Artificial feeding of wildlife is practiced in many regions throughout the world for various goals and species (Orams 2002; Robb et al. 2008; Putman et al. 2011; Ewen et al. 2015; Felton et al. 2017). Food is typically placed at feeding sites to attract certain target species for conservation, recreational, and/or management aims. Artificial feeding encompasses baiting, diversionary, supplemental, recreational, commercial, research, and unintentional feeding (Garshelis et al. 2017). Supplementary feeding is used to improve nutrition and increase population density of target species (Boutin

1990; Milner et al. 2014; Steyaert et al. 2014). For example, Iberian lynx (*Lynx pardinus*) responded positively to supplementary feeding and consumed most of the food provided (López-Bao et al. 2008), and the practice was recognized as an important long-term conservation measure for the endangered Swedish arctic fox (*Alopex lagopus*) population (Angerbjörn et al. 2002). Diversionary feeding aims to divert animals from the areas where they could cause conflicts with people (Kavčič et al. 2015; Garshelis et al. 2017), and baiting is used to attract the species for viewing, photography, harvesting, or trapping (Dunkley and Cattet 2003; Selva et al. 2014; Bowman et al. 2015; Penteriani et al. 2017).

Artificial feeding may be used simultaneously for several purposes. For example, supplementary and diversionary feeding can help decrease damage in forests and agriculture (Putman and Staines 2004; Ziegltrum 2009), improve body condition and trophy quality (Putman and Staines 2004), reduce human-wildlife conflicts (Steyaert et al. 2014), and traffic collisions (Andreassen et al. 2005). Even if the purpose of feeding is clearly defined, its actual effects cannot be always strictly controlled, and may yield both positive and negative side effects for either wildlife or

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people. For example, traditional backyard bird feeding has been recognized to have a high sociological and educational value and raises interest in nature, which may help species conservation programs (Robb et al. 2008), and diversionary feeding sites of brown bears (*Ursus arctos*) can create additional opportunities for bear monitoring, hunting, and eco-tourism (Kavčič et al. 2013; Garshelis et al. 2017; Penteriani et al. 2017). On the other hand, artificial feeding can have negative implications for the target species, which can undercut the purpose of the feeding practice (Garshelis et al. 2017; Penteriani et al. 2018). For example, supplementary feeding of red deer (*Cervus elaphus*) can deteriorate body condition and increase the risk of pathogen transmission at feeding sites (Sorensen et al. 2013; Milner et al. 2014). Moreover, artificial feeding of brown bear with corn affected bear denning behavior (Krofel et al. 2017), and increased the levels of kleptoparasitism on Eurasian lynx (*Lynx lynx*; Krofel and Jerina 2016). Also, diversionary feeding of brown bears with carrion does not reduce livestock depredation as intended (Kavčič et al. 2013; Morehouse and Boyce 2017). Consequently, artificial feeding is often recognized as controversial, and special attention to the mitigation of the possible negative side effects for the target species is advised.

Besides recognizing the side effects that artificial feeding may bring for the target species, possible impacts for non-target species and on entire ecosystems have been suggested lately (e.g., Selva et al. 2014, 2017; Krofel and Jerina 2016). Impacts of supplemental feeding on non-target species depend on the feeding regimes, the way in which the food is provided (manually or using various types of feeders), and the type of food provided, among others. Feeding sites targeting ungulates are often supplied with grains and hay. Unintentionally, this food may attract other species from local vertebrate communities. For example, baiting sites for white-tailed deer in North America attracted more than 20 non-target species (Bowman et al. 2015), while ungulate feeding sites in Eastern Europe were visited by 13 different taxa (Selva et al. 2014). Moreover, intraspecific and interspecific interactions may occur at the feeding site (Popova and Zlatanova 2017), and presence of feeding sites in the environment may alter movement ecology of non-target species (Selva et al. 2017). Finally, local concentration of vertebrate taxa, including omnivorous predators, may have several ecological consequences. For example, depredation of nests in the vicinity of ungulate and vulture feeding sites increased, resulting in a local reduction in the breeding success of ground nesting birds, including protected species (Cooper and Ginnett 2000; Cortés-Avizanda et al. 2009; Selva et al. 2014).

In addition to ungulates, an important group of target species regularly provided with artificial food in many parts of the world are bears, especially the brown bear and the American black bear (*Ursus americanus*; Kavčič et al. 2013; Garshelis et al. 2017). Besides plant-based foods, bear feeding sites can also be supplied with carrion, which could make them attractive for a range of carnivore and scavenger species. The effect

of artificial feeding on bears and their interspecific interactions have been extensively studied (Krofel et al. 2012, 2017; Kavčič et al. 2013, 2015; Steyaert et al. 2014; Reding 2015; Krofel and Jerina 2016; Garshelis et al. 2017), but there is lack of information on how artificial feeding of bears might affect other species (Kirby et al. 2017). Moreover, the difference in the species assemblages using feeding sites with different types of artificial food has, to our knowledge, not yet been evaluated. However, such evaluation could be important given the changes in the artificial feeding regulations during the past few decades (e.g., ban on feeding of bears with livestock carrion in the European Union; Kavčič et al. 2013).

In order to fill this knowledge gap, we studied vertebrate species using artificial feeding sites for bears in Dinaric Mountains in Slovenia. To evaluate wildlife use of the feeding sites, we studied (i) species richness, (ii) species diversity, (iii) dissimilarity in species composition, and (iv) indicator species. We studied how the type of artificial food (only plant-based food vs. combination of carrion and plant-based food) provided for the bears affects the use of feeding sites. We were also interested if other potential ecologically important environmental factors, i.e., distance to forest edge, altitude, and season, could influence the use of feeding sites. We predicted (1) high dissimilarity in species composition between feeding sites with different food types, and between seasons; (2) higher species richness and diversity at the feeding sites where also carrion was provided, since it would make them attractive for scavengers; and (3) scavengers to appear as indicator species for these feeding sites.

## Material and methods

### Study area

The study was carried out in 2016 in an area covering a large part of the Core Bear Protected Area (CBPA; approximately 4000 km<sup>2</sup>) in the Dinaric mountains in Slovenia (45° 25'–45° 47' N, 14° 15'–14° 50' E). The area is characterized by high vertebrate diversity, including large, meso- and small carnivores, ungulates, and a rich avian community. The estimated population densities only exist for red deer, roe deer (*Capreolus capreolus*), and brown bears: 13 bears/100 km<sup>2</sup> (Jerina et al. 2013), 6.7 red deer/km<sup>2</sup>, and 1.7 roe deer /km<sup>2</sup> (Adamič and Jerina 2010). The area is mainly covered with forests, dominated by silver fir (*Abies alba*) and common beech (*Fagus sylvatica*) associations, but also includes cultivated land and smaller settlements. The climate is a mix of influences from the Alps, the Mediterranean sea, and the Pannonia basin, with average annual temperature of 7 °C, ranging from an average monthly maximum of 18 °C to an average monthly minimum of –2 °C, and average annual precipitation of 1700 mm. Snow cover lasts from 50 days at lower altitudes and up to several months at higher elevations. The vegetative growth period lasts from late April to late October.

## Artificial feeding

Artificial feeding of bears in Slovenia is used simultaneously for several purposes, including diversionary feeding to divert bears from human settlements and baiting for hunting, eco-tourism, and monitoring purposes. The same feeding sites are also sometimes used simultaneously for several wildlife species (e.g., brown bear, wild boar *Sus scrofa*, red deer), mainly for hunting and damage prevention purposes. The feeding sites are supplied with corn, grains, fruits, and in some cases, also with carrion from wild ungulates (mostly road-kills and unused parts of shot animals). The current legislation permits feeding with carrion under certain restrictions (e.g., only carrion from wild ungulates is allowed since 2004; Kavčič et al. 2013). Artificial feeding is intensive with high energy food, especially corn, available to animals year-round and in high quantities (on average, 12,500 kg/100 km<sup>2</sup> annually) at a dense network of feeding sites (on average one artificial feeding site per every 2.7 km<sup>2</sup>) (Krofel and Jerina 2016). The provision of carrion is opportunistic and varies between the seasons and regions as carrion availability is mainly related to the intensity of hunting (Mohorović et al. 2015). Additionally, supplementary and diversionary feeding sites for ungulates, particularly red deer and wild boar, are widely distributed across the entire country (Jerina 2012; Stergar and Jerina 2017). They are mostly supplied with corn, hay, sugar beets, and apples. Artificial feeding of roe deer or chamois (*Rupicapra rupicapra*) is forbidden in order to prevent health problems; however, usually, no measures to prevent these species to use the feeding sites are implemented (Adamič and Jerina 2010).

In 2016, we initiated monitoring of wildlife at selected bear feeding sites with the use of automatic cameras (see below for details on camera trapping). Feeding sites were distributed over a gradient of altitude (485–1186 m) and in different distances from forest edge (341–7996 m). Ten feeding sites were supplied only with plant-based food, i.e., corn, cereals, and fruits, and ten sites with mixed food, i.e., combination of plant-based food and carrion. Feeding regime of the monitored feeding sites was randomly determined prior to the start of the monitoring and remained the same during the entire monitoring period. Feeding sites were regularly supplied with food throughout the year and food was placed at the feeding sites either using automatic corn feeders with a built-in timer or manually by local hunting managers. Carrion used originated from animals killed in vehicle collisions, left-overs from animals shot by hunters, or carcasses of animals that died due to natural causes. Most carrion was from local wild ungulates (red deer and roe deer) (Mohorović et al. 2015).

## Camera trapping

The selected feeding sites ( $n = 20$ ) were monitored with automatic photo/video cameras (UOVision IR PLUS BF HD UV 565) between February 24 and December 3 in 2016, 24 h per day. Due to technical issues or unexpected events which hampered the

functioning of some cameras (e.g., cameras being stolen or damaged by people or wildlife), not all of the cameras were continuously operational for the entire study period. We controlled for the differences in camera performance with appropriate data pooling (see below). Cameras were set with the help of local hunters, who were also responsible for regular camera maintenance, data retrieving, and artificial food provisioning according to pre-determined regime. One camera per feeding site was used to monitor wildlife visitation. Cameras were passive-triggered with PIR motion sensors and programmed to take one photo and a 20-s video and record the time and date. During the night, recording were made with the use of “black IR” flash with 940 nm wavelength designed for not disturbing the animals. When an animal stayed at the feeding site for a longer period, camera was set at trigger interval of 5 min (i.e., recordings were made every 5 min if sensor triggered continuously).

Each camera was set to point directly towards the place where the artificial food was placed, at a distance of 5–8 m from the food, framing the entire feeding site. The setup and settings were aimed at registering medium- and large-sized mammals and birds, which were the focus of our research. Therefore, detection of the smallest vertebrates, such as rodents and small birds, was likely not complete.

## Data analysis

We manually checked all photos and identified the species appearing on each photo. When not clear from the photo, video recordings were used to aid species identification. Smaller animals that were recorded but were not the focus of our research, such as passerine birds, were not identified to the species level but grouped to higher categories. All bird species smaller than blackbird were assigned to the “small birds” category, while the category “medium birds” included unidentified bird species larger than blackbird but smaller than pigeons (Columbidae). Similarly, “small mammals” included mammals that generally weigh less than 1 kg. Due to difficult identification, we also grouped all species of pigeons (wood pigeon, turtle dove, stock dove) and the two species of martens, i.e., the beech marten (*Martes foina*) and pine marten (*M. martes*). We considered these taxa equal to single species for the description of species richness but excluded them from the analysis of dissimilarity in species composition because they might hold considerable species variation. Recordings with unidentified taxa (0.4% of all recordings) were removed from the analysis.

When an animal was present at the feeding site for > 5 min and recorded on several photos/videos, we counted the visit as a single event and used date and time of the first recording. We defined seasons in respect to changes in availability of major natural food sources: spring from March to May, summer from June to August, fall from September to November, and winter from December to February. Because cameras were not operational during most of the winter, we excluded winter data from further analysis.

The total number of species appearing at feeding sites was a measure of species richness. We summed up the daily presence-absence data for each species per feeding site per month and used it as a proxy for species relative abundance. Using this data, we calculated Shannon diversity index for each month in order to estimate temporal change in species diversity. The effect of food type on species diversity was analyzed with generalized linear mixed model (GLMM). Local bear density, altitude, and distance to forest edge were scaled before added to the model together with season as fixed effects and correlation tests confirmed that the fixed effects were not correlated. Sampling effort (number of camera trapping days per month per feeding site) was nested in feeding site ID and included in the model as random effect. When terms were not significant, model was simplified through AICc-based, backward removal procedure to obtain the final, most parsimonious model (Arnold 2010).

We summed up the data per feeding site per season to create a matrix for the analysis of the abundance-based dissimilarity (Baselga 2013). We also excluded the records that were not identified to the species level (small birds, medium birds, small mammals, and pigeons) from the dataset. In this analysis, we focused on the differences in species composition between feeding sites with or without carrion and among seasons. For the calculation of abundance-based species dissimilarity, we used Bray-Curtis index and used balanced variation in relative abundance and abundance gradients (Baselga 2013). The balanced variation in relative abundance shows balanced changes in species relative abundance, i.e., the degree how individuals of one species at one site are substituted by individuals of different species in another site and is analogous to species turnover in incidence-based patterns. Abundance gradient shows the total incline or decline of species relative abundance and is analogous to species nestedness in incidence-based patterns. Bray-Curtis index accounts for total abundance-based dissimilarity. We tested the dissimilarities with a permutational MANOVA (PERMANOVA) (Anderson 2001) using 999 mutations. In order to visualize the differences in species composition, we performed non-metric multidimensional scaling (NMDS, Minchin 1987). Finally, we identified the indicator species for selected conditions with the indicator value analysis (IndVal) proposed by Duf re and Legendre (1997). Data was analyzed in R program version 3.5.0 (R Core Team 2018), using *lme4* (Bates et al. 2015), *MuMIn* (Barto n 2018), *vegan* (Oksanen et al. 2018), *betapart* (Baselga et al. 2018), and *indicspecies* (De Caceres and Legendre 2009) packages.

## Results

We analyzed 117,566 recordings from a total of 3964 days of camera trapping at 20 brown bear feeding sites. We documented 67,722 recordings with animal visitations, among which 51,455 (76%) showed non-target taxa. Three thousand seven hundred eighty-four (6%) recordings showed more than one

taxa simultaneously present at the feeding site. We identified animals from 24 taxa, including 13 species of mammals from 5 genera and 11 species birds from 4 genera (Table 3). We could not identify animals on 278 (0.4%) recordings, so we excluded this data from the further analysis.

In total, on feeding sites with and without carrion, we recorded on average 3650 and 3118 recordings of animals per feeding site (17.8 and 16.7 recordings per camera-trap day), respectively. Each species was recorded on average 0.7-times per camera-trap day per feeding site (mean = 0.67 and SE = 0.24 for feeding sites with carrion, mean = 0.75 and SE = 0.24 for feeding sites without carrion). In total, 23 taxa were observed at the feeding sites with mixed food (plant-based food and carrion) and 18 taxa at the feeding sites with plant-based food only, among which 17 taxa were using both types of feeding sites.

We observed considerable variation in the number of recordings among different species (Table 1). Brown bear, European badger (*Meles meles*), and red fox (*Vulpes vulpes*) were the most frequently present mammals visiting the feeding sites, and Eurasian jay (*Garrulus glandarius*), pigeons (Columbiformes), and common raven (*Corvus corax*) were the most frequently observed birds. Thirteen (57%) taxa were recorded less than 100 times. Several raptors (golden eagle *Aquila chrysaetos*, white-tailed eagle *Haliaeetus albicilla*, Northern goshawk *Accipiter gentilis*, red kite *Milvus milvus*, and Eurasian sparrowhawk *Accipiter nisus*) only visited the feeding sites with carrion (Table 3).

Our final best model included season as the only variable affecting species diversity at the feeding sites, with higher species diversity in spring (Est = 1.46, SD = 0.072,  $t = 3.079$ ,  $p = 0.003$ ), compared to fall (Fig. 1). Food type and other environmental factors showed no predictive value. Dissimilarity between the species assemblages at the feeding sites with different type of supplemental food was highly significant ( $F = 5.12$ ,  $R^2 = 0.081$ ,  $p = 0.001$ ) and so was the dissimilarity between seasons ( $F = 2.61$ ,  $R^2 = 0.084$ ,  $p = 0.004$ ) (Fig. 2). The total dissimilarity was strongly influenced by variation in relative abundance (Table 2), but not changes in abundance gradients. The species associated with the feeding sites without carrion were red deer and wild boar and species indicative for feeding sites with mixed foods were common buzzard (*Buteo buteo*), common raven, and red fox (Table 4). Red deer was strongly indicative for species assemblage in fall, while jay and brown bear were indicator species for summer assemblages (Table 4).

## Discussion

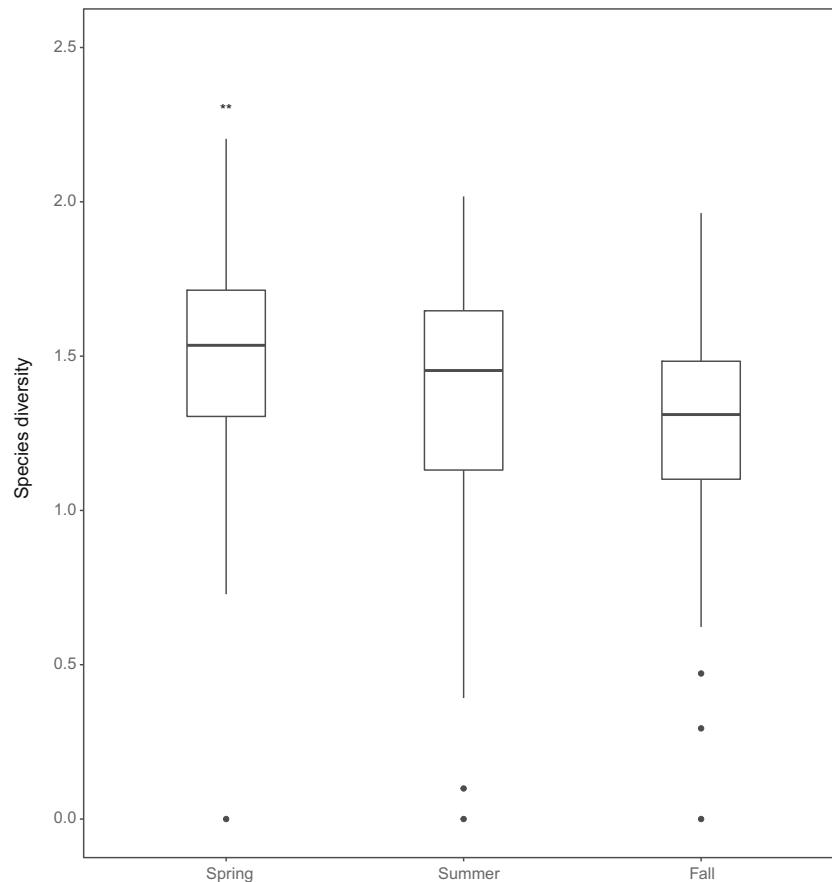
We found that, regardless of the type of food provided, the artificial feeding sites were regularly visited by a large number of non-target species (at least 12 species of mammals and 11 species of birds) in numbers and frequency that far surpass the target species (the brown bear). This suggests that effects of

**Table 1** The percentage of camera trapping days when given taxon was recorded at the artificial feeding sites for brown bears and the average number of recordings of taxon per day. Data are shown separately for the feeding sites with mixed food (plant-based and carrion) and the feeding sites with only plant-based food (without carrion). Only taxa recorded > 100 times are presented. For a full range of documented taxa at the feeding sites, see Table 4

Taxon		% of days with animal presence		No. of recordings/day	
		Without carrion (n = 1934)	With carrion (n = 2030)	Without carrion (n = 1934)	With carrion (n = 2030)
Wild boar	<i>Sus scrofa</i>	42.6	14.8	1.7	4.6
Brown bear	<i>Ursus arctos</i>	41	53.8	2.9	5.3
Eurasian jay	<i>Garrulus glandarius</i>	34.8	34.2	1.7	2
European badger	<i>Meles meles</i>	34.2	31.8	1	1.1
Pigeons	Columbidae	31.9	26.2	1	1.2
Red deer	<i>Cervus elaphus</i>	29.7	15	2	0.9
Red Fox	<i>Vulpes vulpes</i>	25	36.8	0.6	1.6
Roe deer	<i>Capreolus capreolus</i>	20.3	21.8	1.6	1.3
Common raven	<i>Corvus corax</i>	13.8	22.3	0.4	1.8
Small-sized birds		9	12.5	0.2	0.5
Medium-sized birds		5.9	7.9	0.1	0.2
Marten	<i>Martes sp.</i>	1.4	4.1	< 0.1	0.1
Common Buzzard	<i>Buteo buteo</i>	0.9	13.1	< 0.1	0.3

bear feeding sites are not limited to the target species, but have potential to affect large part of the local vertebrate community. This adds to the existing knowledge about the possible side

effects of artificial feeding on wildlife (Lambert and Demarais 2001; Campbell et al. 2013; Selva et al. 2014; Bowman et al. 2015; Krofel and Jerina 2016; Penteriani et al. 2017).



**Fig. 1** Seasonal variation in species diversity of vertebrates visiting the artificial feeding sites in Dinaric mountains, Slovenia. Shannon diversity index was used as a measure of species diversity





**Table 2** Species assemblage dissimilarity at the feeding sites with or without carrion (food type) and between spring, summer, and fall (season). Bray-Curtis index reflects total dissimilarity, while balanced variation in abundance and abundance gradient indicate substitution of different species and loss of some species abundance, respectively. Significance ( $\alpha < 0.05$ ) is italicized

	Site	<i>F</i>	<i>R</i> <sup>2</sup>	<i>p</i>
Bray-Curtis index	Food type	<i>5.12</i>	<i>0.08</i>	<i>0.001</i>
	Season	<i>2.61</i>	<i>0.08</i>	<i>0.004</i>
Balanced variation in abundance	Food type	<i>9.20</i>	<i>0.14</i>	<i>0.001</i>
	Season	<i>3.29</i>	<i>0.10</i>	<i>0.003</i>
Abundance gradient	Food type	-5.55	-0.11	1.000
	Season	1.68	0.07	0.301

densities of species like wild boar and others that may cause human-wildlife conflicts might outweigh the benefits of artificial baiting for hunting and diversionary feeding. Moreover, several species that we frequently observed at feeding sites, i.e., wild boar, brown bear, European badger, martens, red fox, Eurasian jay, and common raven, are known as potential nest predators (Cortés-Avizanda et al. 2009; Selva et al. 2014), so their increased abundance may affect the local bird community (Lima 2009). Increased local abundance of predator species may also cause direct or indirect effects on lower trophic levels, potentially resulting in trophic cascades (Schmitz et al. 2000; Ripple et al. 2014). However, some carnivorous species (e.g., wildcat *Felis silvestris* and raptors) may not only respond to the food provided at the artificial feeding sites, but also to a higher concentration of their prey (rodents and small birds) that are attracted by the artificial food. For example, we observed hunting by wildcat on rodents at a feeding site with corn. In this respect, it is important for future studies to explore whether the feeding sites only redistribute the predator abundance (i.e., increase it around the feeding site and decrease it elsewhere) or increase the overall densities.

An important aspect of artificial feeding is the type of food provided at the feeding sites. While most taxa (17 out of 23) used both types of feeding sites, we recorded more species at feeding sites where also carrion was provided. This is in line with our predictions since presence of carrion made these feeding sites attractive also to carnivorous species, like the red kite, northern goshawk, and golden and white-tailed eagle. Highest species diversity was observed in spring, regardless of the food type provided. Species diversity in this time of the year may increase due to a higher food intake of the adult individuals, especially birds, due to rearing of offspring. Moreover, species diversity at feeding sites may have dropped in fall because of the high availability of a natural nutrient rich food, the beech nuts. The year 2016 was a good masting year for European beech (*Fagus sylvatica*), and summer was not particularly dry (Agencija Republike Slovenije za okolje 2018). These conditions undoubtedly influenced the amount of natural plant-based food available in the forest, as beechnuts are a major

food source for many herbivore and omnivore species in this ecosystem, which could affect the species use of the artificial feeding sites. The dissimilarity in species assemblages and no changes in relative abundance gradients between feeding sites with or without carrion and among seasons showed that no species were “lost” from the community but that number of observations of some species was substituted by the same number of observations of different species.

In contrast to a common belief among local hunters (e.g., Štrumbelj 2006), our results showed that the main target species, the brown bear, did not select for any type of food provided, but preferred using feeding sites in summer. This supports the previous findings of Kavčič et al. (2013), reporting that a ban on carrion feeding did not decrease bear visitation rates of the artificial feeding sites. However, for definitive answers on the effects of carrion feeding on brown bear, additional studies are required, which should include artificial food manipulation at the same feeding sites, i.e., in 1 year only plant-based food and in another also carrion should be available. Red deer and wild boar showed a strong preference for the feeding sites with only plant-based food. Since corn and forage (i.e., fresh grass) was available to animals on all feeding sites, this may suggest avoidance of prey species either due to actual increased presence of predators or their potential increase indicated by the smell of killed conspecifics (Gonçalves and Biro 2018).

Surprisingly, we found that birds represented a large part of the identified taxa visiting the bear feeding sites (46%). This could have several effects on the bird community and their interactions, which warrants further research. Notable is the considerable number of recordings of facultative avian scavengers feeding at the feeding sites with carrion. Many raptors supplement their diet with carrion, including both indicator species for carrion feeding sites (common buzzard and common raven), for which animal carcasses represent a significant part of their diet in Dinaric forests (Tome et al. 2009; Krofel 2011). While ravens nest throughout this ecosystem (Atlas ptic 2018) and move around in larger groups containing non-breeding individuals that may gather at the abundant food sources (Loretto et al. 2016), buzzard occurs in lower densities in Dinaric forests compared to the surrounding lowlands (Atlas ptic 2018). While the common buzzard is a relatively widespread species in the study area, only four breeding pairs of golden eagle (Atlas ptic 2018) and three pair of white-tailed eagle have been confirmed in the region (Vrezec et al. 2009). It has been assumed that carrion placed in the forests may be important for local population of white-tailed eagles at least in part of the year, due to the shortage of large wetlands and other suitable feeding habitats in the region (Vrezec et al. 2009). This could indicate potential conservation implications of supplementary feeding for eagles, similar to vulture restaurants (San-Blas and Gowen 2008). It seems that carrion sites attract great diversity of raptors, including some regionally rare species, like a red kite, which had no prior records within study area (Bordjan 2017).

Eurasian jays and pigeons, indicator taxonomic groups for feeding sites without carrion, are both widespread and common (Atlas ptic 2018). There are several species of pigeons present in the area but only wood pigeon (*Columba palumbus*) is common and widespread (Atlas ptic 2018). For Eurasian jay and wood pigeon, grains are important part of their diet and both tend to move around in flocks in non-breeding period (BirdLife International 2018), albeit jays move in smaller mostly family parties (Patteson et al. 1991). Their presence at feeding sites from late spring to early autumn may indicate the movement from highly dispersed breeding sites in the forest to more localized and constantly present sources of food. High aggregations of birds at the bear artificial feeding sites may cause similar side effects as noticed for the backyard bird feeding, including changing the species' spatial distribution and abundance, increasing risk of disease transmission, and affecting breeding success (Robb et al. 2008), and thus again warrant further research.

We also documented regular use of the feeding sites by the roe deer. Artificial feeding of this species is forbidden in Slovenia (Adamič and Jerina 2010; Slovenia Forest Service 2010), as ingesting fodder with high levels of carbohydrates, e.g., corn and root crops, can change deer browsing behavior (Timmons et al. 2010) and may lead to potentially fatal metabolic diseases in winter (Petan 2016; Ritz et al. 2013). However, recordings from the bear feeding sites showed that lack of measures to prevent ingestion of such fodder by roe deer regularly exposes animals to this risk.

Due to the limitations of camera trapping, reported diversity of the vertebrate community is likely an underestimation of the true vertebrate diversity at the feeding sites. The cameras were set to capture medium to large animals (the focus of our research) and smaller vertebrate species were likely missed in many cases. Alternative methods, such as mist net trapping (Dunn and Ralph 2004), snap trapping (Weihong et al. 1999), or different location of cameras (i.e., closer to the food), should be applied to better evaluate the use of artificial feeding sites by smaller fauna, such as several species of rodents and small birds. We also recommend future studies investigating the effects of artificial feeding on vertebrate diversity with manipulations of the feeding regime in time at the same feeding site. Although the monitored feeding sites were located homogeneously over the study area, considerable differences in respect to local fauna may have been present among the feeding sites. Since there may be considerable inter-annual variability in certain factors influencing visitation rate (e.g., population size, climate factors, availability of natural food), we recommend future research to stretch over several years to account for this variability.

## Management implications

Our study showed that bear feeding sites are used by a large number of non-target species. This creates a potential for several

unexpected side effects of this management measure and supports the necessity to reconsider artificial feeding practices and implement measures to minimize these side effects (Selva et al. 2014, 2017; Kavčič et al. 2015; Krofel and Jerina 2016; Krofel et al. 2017; Penteriani et al. 2017, 2018). Limiting the amount of food provided and the time period when artificial feeding is practiced could reduce some of the unwanted side effects. For example, density of artificial feeding sites was observed to correlate with the proportion of artificial food in bear diet (Kavčič et al. 2015) and ban of artificial feeding of bears during winter was suggested to reduce side effect on bear denning behavior (Krofel et al. 2017). Side effects on the non-target species could be further decreased by adjusting schedule of artificial feeding to the circadian activity patterns of the target species. For example, using automatic feeders that release fodder at the start of bear activity peaks (i.e., in the evening) could limit the use of artificial food by diurnal species. Placing food in boxes with heavy lids or/and on raised platforms could further prevent birds or ungulates, respectively, to access the artificial food but not constrain bears from obtaining food. Using specific type of food that specifically attracts target species could be used to limit the range of species affected, e.g., using hay to feed wild ungulates to limit effects for the bear (Krofel et al. 2017; Selva et al. 2017). Also, spatial arrangement and abundance of feeding sites could be adjusted to the distribution of certain species (Krofel et al. 2017) or to a conservation and management priorities in a particular area, such as national parks and other protected areas, intensive hunting grounds, or forest plantations (Stergar and Jerina 2017).

Our study contributes to the knowledge about the side effects of artificial feeding on wildlife, particularly the diversity of non-target species that can be affected by this measure, which is often neglected by the managers. However, further studies are needed to better understand the effects of artificial feeding on the ecology of non-target species and the wider impacts on ecosystem functioning and wildlife management. We advise management authorities to recognize the importance of side effects of artificial feeding on non-target species and incorporate the knowledge in the future management and planning.

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## Appendix

**Table 3** List of resident large and mid-sized mammals (> 1 kg in body mass) and nesting birds (> 30 cm in length) present in the Dinaric forest ecosystem in the study area, their relative abundance (abundant, common, uncommon, rare) and distribution (widespread, scattered, local), and number of bear feeding sites ( $n = 20$ ) at which they were recorded in this

study. Vagrant species are not included in the list, except for the one (red kite), which was recorded during the study. Number of visited feeding sites is presented separately for feeding sites without and with carrion. Data sources: Atlas ptic 2018; Kryštufek 1991, authors' pers. obs

Class	Order	Species	Status in the study area	No. of feeding sites visited (without; with carrion)		
Mammalia	Artiodactyla	Wild boar	<i>Sus scrofa</i>	Common, widespread	9; 9	
		Red deer	<i>Cervus elaphus</i>	Abundant, widespread	10; 8	
		Roe deer	<i>Capreolus capreolus</i>	Abundant, widespread	10; 8	
	Carnivora	Alpine chamois	<i>Rupicapra rupicapra</i>	Uncommon, local	0; 1	
		Brown bear	<i>Ursus arctos</i>	Common, widespread	10; 10	
		Gray wolf	<i>Canis lupus</i>	Uncommon, widespread	4; 6	
		Golden jackal	<i>Canis aureus</i>	Uncommon, local	1; 2	
		Raccoon dog	<i>Nyctereutes procyonoides</i>	Rare, local	0	
		Red fox	<i>Vulpes vulpes</i>	Abundant, widespread	10; 10	
		European badger	<i>Meles meles</i>	Abundant, widespread	10; 9	
		Marten	<i>Martes sp.</i>	Abundant, widespread	6; 6	
		Eurasian otter	<i>Lutra lutra</i>	Uncommon, scattered	0	
		Wild cat	<i>Felis silvestris</i>	Common, widespread	1; 0	
		Eurasian lynx	<i>Lynx lynx</i>	Rare, scattered	0	
		Lagomorpha	Brown hare	<i>Lepus europaeus</i>	Common, widespread	2; 1
			Ciconiiformes	Black stork	<i>Ciconia nigra</i>	Rare, local
		Accipitriformes		Honey buzzard	<i>Pernis apivorus</i>	Uncommon, widespread
			Red kite	<i>Milvus milvus</i>	Vagrant	0; 1
		Aves	White-tailed eagle		<i>Haliaeetus albicilla</i>	Rare, local
Griffon vulture	<i>Gyps fulvus</i>			Rare, local	0	
Short-toed eagle	<i>Circus gallicus</i>		Rare, local	0		
Marsh harrier	<i>Circus aeruginosus</i>		Rare, local	0		
Northern goshawk	<i>Accipiter gentilis</i>		Uncommon, widespread	0; 2		
Sparrowhawk	<i>Accipiter nisus</i>		Common, widespread	0		
Common buzzard	<i>Buteo buteo</i>		Common, widespread	6; 9		
Golden eagle	<i>Aquila chrysaetos</i>		Uncommon, scattered	0; 4		
Common kestrel	<i>Falco tinnunculus</i>		Uncommon, scattered	0		
Hobby	<i>Falco subbuteo</i>		Uncommon, scattered	0		
Peregrine falcon	<i>Falco peregrinus</i>		Uncommon, scattered	0		
Galliformes	Capercaillie		<i>Tetrao urogallus</i>	Rare, local	0	
	Hazel grouse		<i>Tetrao bonasia</i>	Uncommon, scattered	0	
Columbiformes	Pigeons		<i>Columbidae</i>	Abundant, widespread	9; 10	
Cuculiformes	Common cuckoo		<i>Cuculus canorus</i>	Common, widespread	0	
Strigiformes	Tawny owl		<i>Strix aluco</i>	Uncommon, widespread	0	
	Ural owl		<i>Strix uralensis</i>	Uncommon, widespread	0	
	Eagle owl		<i>Bubo bubo</i>	Rare, scattered	0	
Piciformes	Long-eared owl		<i>Asio otus</i>	Rare, scattered	0	
	Black woodpecker		<i>Dryocopus martius</i>	Common, widespread	0	
	Green woodpecker		<i>Picus viridis</i>	Common, widespread	0	
Passeriformes	Gray-headed woodpecker		<i>Picus canus</i>	Common, widespread	0	
	Magpie		<i>Pica pica</i>	Rare, local	0	
	Common raven		<i>Corvus corax</i>	Common, widespread	10; 10	
	Eurasian jay		<i>Garrulus glandarius</i>	Abundant, widespread	10; 10	
	Spotted nutcracker		<i>Nucifraga caryocatactes</i>	Uncommon, scattered	0	
Hooded crow	<i>Corvus cornix</i>		Uncommon, scattered	0		

**Table 4** Indicator species for site groups, i.e., feeding sites with or without carrion and different seasons (spring, summer, fall). “A” is the positive predicting value of the species abundance as indicator of the site group (specificity). “B” is the probability of finding the species in sites belonging to the site group (fidelity). Significant indicator values (alpha < 0.05) are italicized

	With carrion		Without carrion		stat	p	Fall		Spring		Summer		stat	p
	A	B	A	B			A	B	A	B	A	B		
Alpine chamois	1.00	0.03	0.00	0.00	0.19	1.00	0.00	0.00	1.00	0.05	0.00	0.00	0.23	1.00
Brown bear	0.64	1.00	0.36	1.00	0.80	0.07	0.23	1.00	0.23	1.00	<i>0.55</i>	<i>1.00</i>	<i>0.74</i>	<i>0.01</i>
Brown hare	0.08	0.03	0.92	0.11	0.32	0.23	0.00	0.00	0.35	0.11	0.65	0.11	0.26	0.59
Common buzzard	<i>0.96</i>	<i>0.79</i>	0.04	0.37	<i>0.87</i>	<i>0.01</i>	0.43	0.56	0.41	0.58	0.16	0.63	0.49	0.89
Common raven	<i>0.82</i>	<i>0.86</i>	0.18	0.85	<i>0.84</i>	<i>0.02</i>	0.54	0.89	0.18	0.79	0.28	0.89	0.69	0.11
Eurasian jay	0.53	0.90	0.47	1.00	0.69	0.97	0.09	0.83	0.25	1.00	<i>0.66</i>	<i>1.00</i>	<i>0.81</i>	<i>0.02</i>
European badger	0.52	0.86	0.48	0.96	0.68	0.88	0.37	0.89	0.35	0.95	0.27	0.89	0.58	0.86
Golden eagle	0.04	0.07	0.96	0.11	0.33	0.26	0.12	0.06	0.32	0.16	0.56	0.05	0.22	0.91
Golden jackal	1.00	0.14	0.00	0.00	0.37	0.13	0.33	0.06	0.67	0.16	0.00	0.00	0.33	0.26
Gray wolf	0.63	0.24	0.37	0.19	0.39	0.53	0.63	0.28	0.22	0.16	0.16	0.21	0.42	0.26
Marten	0.76	0.34	0.24	0.33	0.51	0.46	0.57	0.33	0.27	0.37	0.16	0.32	0.44	0.73
Northern goshawk	1.00	0.07	0.00	0.00	0.26	0.50	0.00	0.00	1.00	0.11	0.00	0.00	0.32	0.34
Red deer	0.29	0.72	<i>0.71</i>	<i>0.93</i>	<i>0.81</i>	<i>0.01</i>	0.58	<i>0.89</i>	<i>0.23</i>	0.74	0.19	0.84	<i>0.72</i>	<i>0.02</i>
Red fox	<i>0.71</i>	<i>1.00</i>	0.29	0.93	<i>0.84</i>	<i>0.02</i>	0.33	0.94	0.31	1.00	0.36	0.95	0.59	0.94
Red kite	1.00	0.03	0.00	0.00	0.19	1.00	1.00	0.06	0.00	0.00	0.00	0.00	0.24	0.28
Roe deer	0.42	0.66	0.58	0.89	0.72	0.20	0.54	0.83	0.30	0.68	0.16	0.79	0.67	0.08
Sparrowhawk	1.00	0.03	0.00	0.00	0.19	1.00	0.00	0.00	0.00	0.00	1.00	0.05	0.23	1.00
White-tailed eagle	1.00	0.10	0.00	0.00	0.32	0.27	0.90	0.11	0.00	0.00	0.10	0.05	0.32	0.17
Wild boar	0.26	0.62	<i>0.74</i>	<i>0.81</i>	<i>0.78</i>	<i>0.02</i>	0.19	0.61	0.31	0.74	0.49	0.79	0.62	0.15
Wild cat	0.00	0.00	1.00	0.04	0.19	0.55	0.00	0.00	1.00	0.05	0.00	0.00	0.23	1.00

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