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Food plots as a habitat management tool: forage production and ungulate browsing in adjacent forest

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A key challenge for wildlife management is to handle competing goals. High ungulate densities may be desirable from hunting and recreational perspectives, but may come in conflict with needs to limit or reduce browsing damage. Since browsing intensity is negatively related to forage availability it may be possible to mitigate damage on forest by increasing forage availability within the landscape. A commonly used method to increase the attractiveness of a localized part of the landscape is to establish food plots. In a multiyear setup using enclosures, wildlife observations, field surveys, and controlled biomass removal, we studied food plots to document forage production, utilization by ungulates, and browsing on adjacent forests in southern Sweden. The fenced parts of the food plots produced on average 2230 to 5810 kg ha^{-1} marrow-stem kale, second-year clover mix or early-sown rapeseed. The biomass of target crops was generally higher within ungrazed (exclosures) compared to grazed (controls) quadrats on the food plots, which demonstrates that the crops were used as forage by ungulates. Browsing on deciduous trees in the adjacent forest was higher within 70–135 m from the food plots compared to areas further away. For wildlife management, our study shows that establishment of food plots provides substantial amounts of forage both during growing season and at the onset of the dormant season, and that a large share of this food is consumed. Finally, our study documents that forage availability for ungulates at the onset of the often-limiting dormant season can be increased by fencing food plots throughout the growing season.

Multiple and contradicting goals between ungulate management and human land use are common features worldwide, and often a source of conflict among different interest groups (Gill 1992, Putman et al. 2011). Particularly, foraging ungulates may cause extensive economic loss. In forestry, intensive browsing may reduce tree growth and lower timber quality (Aldous 1952, Miquelle 1983, Gill 1992). A straightforward measure for mitigating the negative effects of high browsing pressure on forest is population control (Brown et al. 2000, Côté et al. 2004, Miller et al. 2009). High ungulate densities may however be desirable from hunting and recreational perspectives (Gordon et al. 2004, Sharp and Wollscheid 2009), which then come in conflict with population control to reduce e.g. browsing impact. Wildlife management often involve groups of stakeholders with competing interests (foresters, farmers and hunters), but may also involve single landowners aiming for high yields of both timber and game (Gordon et al. 2004, Mysterud 2006, 2010, Redpath et al. 2013). It is therefore urgent to develop effective ungulate and forest management methods which can help reducing such conflicts.

Higher yield of ungulates can be achieved by increasing forage abundance through a wide spectrum of possible measures, such as supplemental feeding (e.g. providing silage or hay at feeding stations; Smith 2001, Gundersen et al. 2004, Cooper et al. 2006, Sahlsten et al. 2010), ungulate-adapted silviculture (Heikkilä and Härkönen 2000, Månsson et al. 2010, Edenius et al. 2014), fertilization (Ball et al. 2000, Månsson et al. 2009) or establishment of food plots, i.e. crops on arable fields providing forage for game species (Hehman and Fulbright 1997, Edwards et al. 2004, Smith el al. 2007). In addition to increasing the availability of high quality forage, these measures may contribute to redistributing ungulates and their browsing within the landscape. Provision of supplementary forage may lead to disproportionally increased use of forest areas in close vicinity of the attracting food source, with associated risks for locally amplified forest damage (van Beest et al. 2010). However, since browsing intensity is negatively related to forage availability for a given ungulate density (Månsson 2009), it should also be possible to mitigate damage on forest by increasing forage availability within the landscape while controlling ungulate populations. By providing attractive forage in strategic locations it may be possible to reinforce the effect of increased forage by diverting the animals away from economically valuable forest stands sensitive to browsing (Gundersen et al. 2004, Sahlsten et al. 2010). This implies that the added forage should be available during time periods when the risk of damage is high, i.e. when trees play a major role in the herbivores' diet. In most temperate forest systems this time period coincides with the dormant season when herbs and grasses are unavailable and the field layer may be covered by snow (Cederlund et al. 1980, Baskin and Danell 2003). However, damage on trees can also be substantial during summer; for deciduous trees it can occasionally be more severe during summer than winter (Moore et al. 2000, Bergqvist et al. 2013).

In several regions worldwide, food plots ('game fields'; Putman and Staines 2004) are used to improve forage availability for ungulates (Keegan et al. 1989, Hehman and Fulbright 1997, Smith et al. 2007). However, we do not know of any published studies about ungulate forage production on food plots in northern Europe. By tradition, food plots have been used in wildlife management as one form of supplemental feeding to attract and to enhance survival and reproduction of ungulates (Leopold 1933, Ozoga and Verme 1982, Putman and Staines 2004). Dependent of crop type and management actions (e.g. fencing), food plots can provide supplemental forage both during the vegetation growth and dormant periods. Therefore, increasing forage availability through food plot management may potentially be used to alleviate damage on economically valuable crops and forests (Smith et al. 2007). However, as the food plots attract ungulates, they may not only decrease the overall browsing pressure in the landscape, but also increase the risk of damage in adjacent forests (sensu Gundersen et al. 2004, Sahlsten et al. 2010). This issue is crucial to spatial planning in forestry and game management.

The aim of this study was threefold: 1) to quantify the forage biomass available in food plots during summer and at the onset of the dormant season for the three commonly sown crops marrow-stem kale *Brassica oleracea* var. *medullosa*, rapeseed *Brassica napus* and clover *Trifolium* spp. mix; 2) to compare forage availability between food plots grazed by ungulates during the growing season and ungrazed parts of the food plots (fenced exclosures); 3) to assess the impact of food plots on browsing pressure in adjacent forests. We hypothesized that 1) food plots can provide ungulates with substantial amounts of supplemental forage, 2) fencing of food plots should increase forage biomass availability at the end of the growing season, and 3) the degree of ungulate browsing on adjacent forest would be stronger at short distances from the food plots compared to areas further away.

Study area

We performed the study from May to November 2008–2010 in an area (43 km² in size), located in the hemiboreal zone of southeastern Sweden (57°27′N, 16°32′E). The study area consists of 81% forest land, 10% rocky outcrops, 4% mires, 2% pastures and the 3% other (e.g. arable land and water bodies). The mean patch size for terrestrial land cover types (e.g. forest stands, pastures, mires) is 2.1 hectare. The period of vegetative growth (mean temperature > 5°C) extends from mid-April to the end of October (Wastenson et al. 1990). Forests in this area are intensively managed for timber and pulp production through even-aged forestry, whereby mature stands are harvested by clear-cutting and reforested by planting or natural regeneration. The forests consist of a mosaic of coniferous, deciduous and mixed (coniferous–deciduous) forest stands. The dominating tree species are Scots pine *Pinus sylvestris*, Norway spruce *Picea abies*, silver birch *Betula pendula*, downy birch *B. pubescens* and pedunculate oak *Quercus robur.* Also rowan *Sorbus aucuparia*, aspen *Populus tremula*, willows *Salix* spp. and alder buckthorn *Frangula alnus* are relatively common.

Five ungulate species occur in the area: moose *Alces alces*, roe deer *Capreolus capreolus*, red deer *Cervus elaphus*, fallow deer *Dama dama* and wild boar *Sus scrofa*. European hare *Lepus europaeus* and mountain hare *Lepus timidus* also occur in the area. Aerial moose surveys (methods as in Rönnegård et al. 2008) performed in February 2007 over an area including the actual study area showed a mean density of 0.9 ± 0.13 (SE) moose km^{-2} (Månsson et al. unpubl.). Pellet group counts in April 2008 (uncleaned plots; methods as in Mayle et al. 1999, Månsson et al. 2011) within the study area yielded density estimates of 0.4 ± 0.1 red deer km^{-2} and 14.1 ± 2.3 roe deer or fallow deer km^{-2} (Edenius et al. unpubl.). The pellet groups were not separated for the two species as they are difficult to distinguish in field. Note that density estimates based on pellet group counts only provide indices. Hence, the densities provided above should not be interpreted as precise figures, but rather as rough indications of deer abundance in the study area.

Methods

Food plots and their management

We used 20 individual food plots in the size range 0.2–2.2 ha (Table 1) where we studied grazing on marrow-stem kale (nine fields in 2008), clover mix (eight fields in 2009) and rapeseed (nine fields in 2010). Marrow-stem kale *Brassica oleracea* var. *medullosa* and rapeseed *Brassica napus* were sown as one-species crops, whereas the 'clover mix' consisted of a mixture of 20% red fescue *Festuca rubra*, 13% white mustard *Sinapis alba*, 13% meadow fescue *Festuca pratensis*, 12% timothy-grass *Phleum pratense*, 10% ryegrass *Lolium* spp., 10% phacelia *Phacelia tanacetifolia*, 8% alfalfa *Medicago sativa*, 5% red clover *Trifolium pratense*, 5% white clover *Trifolium repens*, and 4% chicory *Cichorium intybus*. We re-used six of the 20 food plots over the years for studies involving different crop types (five over two years and one over all three years). The food plots were sown in May–June and fertilized with 200 kg ha^{-1} N-P-K fertilizer (nutrient ratios 21–10–3) soon after sowing. In addition, all food plots used in 2008 were also fertilized with manure (3 tons ha^{-1}) before sowing. Three food plots in 2008 and four food plots in 2010 were excluded from the N-P-K fertilization due to substantial growth of non-targeted plants and late sowing, respectively.

Table 1. Management and description of the field work conducted on the food plots.

	Food plots (n)	Plot area (range, ha)	Exclosures (n)	Sowing period	Cutting period 1	Cutting period 2	Cutting period 3
Marrow stem kale (2008)	9	0.20–2.20	30	May	Sept.	Nov.	–
Clover, sown 2008	5	0.22–1.10	20	May	June	Aug.–Sept.	Nov.
Clover, sown 2009	3	0.17–0.68	14	June	Nov.	–	–
Rapeseed, sown early (2010)	5	0.29–2.68	23	May	Sept.	–	–
Rapeseed, sown late (2010)	4	0.28–1.14	12	June	Sept.	–	–

Forage biomass estimation

To estimate the forage biomass available on grazed and ungrazed parts of the food plots, we used exclosures (1.6 × 1.6 m; height 1.4 m) made of metal wire of 25 × 25 mm mesh size that we distributed randomly in the food plots (Table 1). The number of exclosures per food plot was proportional to plot size and varied from 1 to 14. In a random direction and 5 m away from each exclosure, we delineated one unfenced sampling quadrat (control; 1.6 × 1.6 m). At different times of the year from June to November (depending on crop type; cf. Table 1), we cut all aboveground parts of the plants in the exclosures and controls (unfenced quadrats) and weighed them to the nearest gram (fresh weight). We treated target (sown crop) and non-target (common weeds on arable land) plants separately for these biomass estimations. To calculate the dry weight, we estimated the dry matter ratio (dry/fresh weight) by drying random samples (>150 g fresh weight, occasionally less when not available) to constant weight. Assessment of forage availability during the fall provides an estimate of the amount of forage available just before the onset of the dormant season. For marrow-stem kale, we cut and weighed the plants on one-half of the quadrats' area in September and the other half in November. Between September and November in 2008 two exclosures were destroyed, resulting in a total sample size of 28 exclosures in that year. Clover was harvested three times within a year – in June, September and November. For rapeseed, we estimated the biomass only once, in September (Table 1).

Browsing in adjacent forests

We surveyed browsing pressure on deciduous trees in the forest surrounding the food plots in the end of September of each of the three study years, i.e. after the summer but before leaf abscission. We used circular survey plots of 20 m² (hereafter 'browsing survey circles') distributed along lines stretching in each of the four cardinal directions from the food plots. We located the first browsing survey circle so that its border was tangential to the edge of the food plot. We distributed the subsequent survey circles at distances of 50, 100, 200, 300, 400 and 500 m from the field (i.e. in total four samples per distance for each field) along the transect. At each distance, we surveyed two circles: one on the transect and another 20 m to the left. We only surveyed forested areas, excluding survey circles in wetlands or lakes. We also excluded circles located <500 m from other food plots. In the event where a survey circle did not encompass any deciduous tree, we moved the circle (maximum 20 m) to include the closest tree. In each circle, we counted the total number of deciduous trees and the number of trees with occurrence of fresh (i.e. from current summer) bites or stripped leaves. We included silver birch, downy birch, rowan, aspen, pedunculate oak and willows with leaves available within the browsing height interval 0.5–2.5 m.

Counts of utilizing species by direct observations

We counted ungulates at the food plots during the study period to obtain data about species utilizing the fields. We watched activity in all food plots from concealed places during dawn and dusk. In total we observed the food plots during 2 h per plot for marrow-stem kale, 7.5 h per plot for clover and 6.5 h per plot for rapeseed. The aim of these observations was not to formally compare utilization rates by different ungulate species, but rather to obtain preliminary knowledge about which species foraged in the food plots.

Statistical analyses

To compare forage availability inside and outside the exclosures, we fitted linear mixed models with dry biomass as a response, fencing status (i.e. exclosure or not) as a fixed factor, and field-ID as a random factor to account for the spatially aggregated sampling design (package *lme4*; <www.r-project.org>). We fitted separate models for the three crop types and for target and non-target plants.

To assess patterns in browsing pressure in forest at various distances from the food plots, we fitted logistic models with browsing pressure (i.e. number of browsed and unbrowsed trees) as a response variable and distance from the food plot as a predictor. We combined data by using the sum from the four samples (corresponding to the four transects) at each distance for each food plot. To test the hypothesis that browsing pressure would be stronger at shorter distances from the field and fade out at longer distances, we fitted segmented models (package *Segmented*; < www.r-project.org >) with a single breakpoint. The segmented function requires that the user specifies a starting value for the breakpoint iterations. We chose 250 m (i.e. one-half of the total sampled distance) as a starting value for all models. Then, to verify the robustness of the results to the selection of starting values, we reran the analyses with the following starting values: 25, 75, 150, 350 and 450 m. The final breakpoint values obtained with these starting values were all within ± 1 m from the breakpoint obtained for a starting value of 250 m, which confirmed that the estimated breakpoints were not contingent on the selection of specific starting values.

Results

Biomass estimations

The dry biomass of targeted crops produced in the food plots during the growing season and available upon the onset of the dormant season in the fall varied between 6 and 581 g m^{-2} within exclosures (i.e. ungrazed quadrats) and between 1 and 102 g m^{-2} in unfenced quadrats, depending on crop type and cutting date (Fig. 1). The corresponding figures for non-target plants were 13–89 g m^{-2} and 18–115 g m^{-2} within exclosures and unfenced quadrats, respectively.

The mean dry biomass of marrow-stem kale within exclosures was 222 (± 80 SE) g m^{-2} in September and increased with 74% from September to November (300 ± 67 g m^{-2}; Fig. 1A). Marrow-stem kale biomass in unfenced quadrats amounted to 11% (September) and 10% (November) of the biomass in exclosures (Fig. 1A). The proportion of non-targeted plants decreased from 42% of the total biomass in September to 4% in November in the exclosures (compare Fig. 1A and 2A). The dry matter quota was on average 14% and 17% for marrow-stem kale and 19% and 18% for non-target plants in September and November, respectively.

Second-year clover-mix food plots produced 296 (± 35) g m^{-2} (dry weight) of forage (all plant species included) in the exclosures during the growing season (calculated as the sum of the biomass values upon crop harvest in June, September and November; Fig. 1B). The biomass produced in first-year clover-mix food plots was only estimated in November and amounted to 17 (± 1) g m^{-2} in the exclosures. The total forage biomass available in unfenced quadrats in the clover-mix food plots constituted 43% (second-year fields) and 6% (first-year fields) of the biomass in the exclosures (Fig. 1B). The dry matter quota was on average 27%, 32% and 26% for second year clover fields in June, August and November, respectively, and 16% for first year fields in November.

The mean dry biomass of rapeseed in exclosures was 581 (± 102) g m^{-2} and 172 (± 55) g m^{-2} in September for food plots sown early (May) and late (June), respectively. The proportion of non-target plants constituted 15% (early) and 36% (late) of the dry biomass in the exclosures (Fig. 2B). The available biomass of rapeseed in unfenced quadrats constituted 18% (early) and 2% (late) of the biomass in the exclosures (Fig. 1C). The dry matter quota was on average 20% for rapeseed (early and late combined) and 24% for non-target plants.

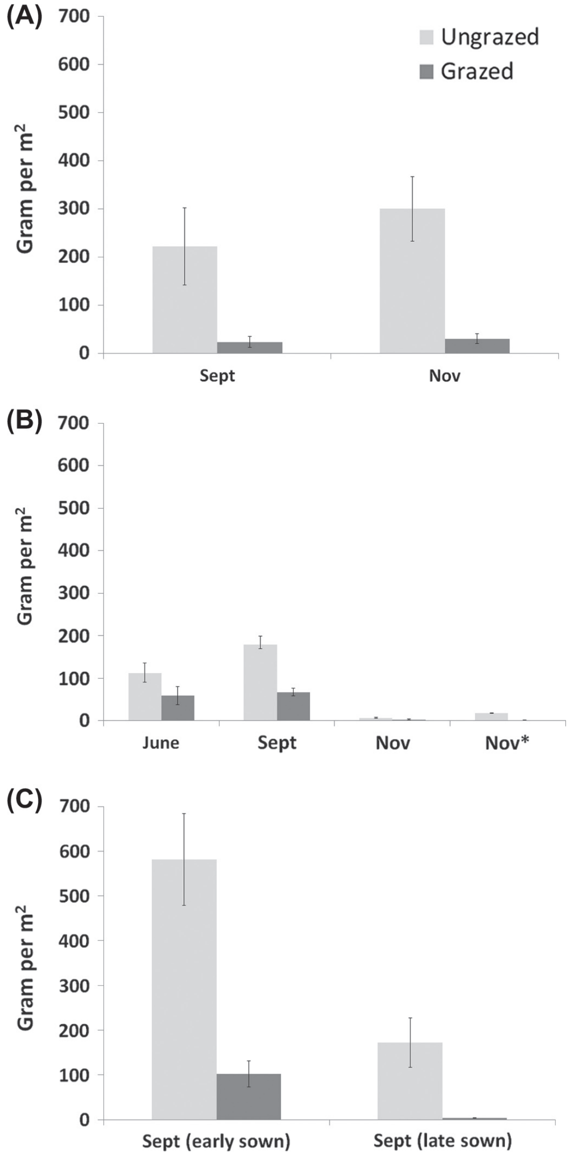

Figure 1. Available biomass (mean ± SE, dry weight) of target crops in food plots in ungrazed (exclosures) and grazed plots (control) for (A) marrow-stem kale, (B) clover mix (first* and second year fields) and (C) rapeseed established in May (early) and June (late).

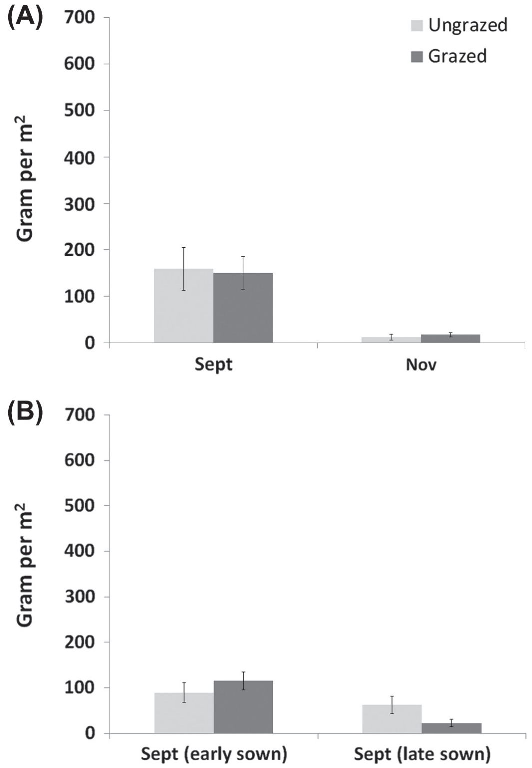

Figure 2. Available biomass (mean and SE, dry weight) of non-target plants in food plots in ungrazed (exclosures) and grazed quadrats (control) on (A) marrow-stem kale food plots and (B) rapeseed food plots established in May (early) and June (late).

Table 2. Summaries of linear mixed models comparing the biomass of the target crops and other plant species inside the exclosures and in unfenced quadrats. The identity of the study field was included as a random factor in all models. Significant differences between exclosures and unfenced quadrats are highlighted in bold.

						Intercept			Effect of exclosure		
Crop	Plant	Cutting month	n[a]	n[b]	DF	Coefficient (SE)	t	p-value	Coefficient (SE)	t	p-value
Marrow-stem kale											
	Kale	September	30	9	56	2.28 (0.27)	8.49	< 0.001	2.19 (0.38)	5.76	**< 0.001**
		November	28	9	52	1.40 (0.26)	5.40	< 0.001	3.85 (0.37)	10.48	**< 0.001**
	Others	September	30	9	56	4.73 (0.29)	16.13	< 0.001	–0.19 (0.20)	–0.96	0.34
		November	28	9	52	2.39 (0.33)	7.25	< 0.001	0.32 (0.26)	1.23	0.22
Second-year clover mix											
	All	June	20	5	36	6.14 (0.08)	77.73	< 0.001	0.21 (0.11)	1.87	0.067
		August–Sept.	20	5	36	6.36 (0.08)	83.78	< 0.001	–0.01 (0.06)	–0.10	0.92
		November	20	5	36	4.16 (0.35)	12.02	< 0.001	0.25 (0.11)	2.15	**0.038**
First-year clover mix											
	All	November	14	3	24	2.86 (0.16)	17.90	< 0.001	2.22 (0.19)	11.51	**< 0.001**
Rapeseed, sown early											
	Rapeseed	September	23	5	42	4.19 (0.48)	8.73	< 0.001	1.64 (0.22)	7.64	**< 0.001**
	Others	September	23	5	42	4.54 (0.28)	16.06	< 0.001	–0.27 (0.18)	–1.47	0.15
Rapeseed, sown late											
	Rapeseed	September	12	4	20	1.40 (0.53)	2.62	0.029	2.22 (0.61)	3.61	**0.002**
	Others	September	12	4	20	2.72 (0.39)	6.92	0.001	1.07 (0.29)	3.64	**0.001**

[a] number of pairs (exclosure and grazed quadrat)
[b] number of food plots

Grazing effects and utilizing species

The available biomass of target crops was significantly higher within the exclosures compared to unfenced quadrats for all crops (independent of date for biomass estimation; $p \leq 0.002$ for all cases) except for second-year clover mix in June and August ($p = 0.067$ and $p = 0.92$, respectively; Table 2). However, for non-target plants a significant difference between the exclosures and unfenced quadrats was only observed for late-sown rapeseed food plots ($p = 0.001$), while there was no significant difference for non-target plants on other types of food plots ($p \geq 0.15$ in all cases), independent of the date for biomass estimation.

Roe deer was the most frequently observed ungulate on the food plots ($n = 128$ animal observations) followed by wild boar ($n = 73$), moose ($n = 50$), fallow deer ($n = 23$) and red deer ($n = 14$).

Browsing in adjacent forests

The general relationship between browsing pressure and distance to the food plot was characterized by a steep decrease in browsing over a short distance, followed by a non-significant relationship at greater distances from the food plots. For marrow-stem kale, there was a strong decrease in browsing pressure from the food plot edge up to a breakpoint located approximately 135 m into the forest, followed by a lack of significant relationship at greater distances (Table 3, Fig. 3A). For the clover mix, the pattern was similar to marrow-stem kale, with a strong decrease in browsing pressure up to a breakpoint located at approximately 112 m, followed by a lack of significant relationship at greater distances (Table 3, Fig. 3B). For rapeseed, there was a strong decrease in browsing pressure up to approximately 68 m, followed by a weaker but still highly significant decrease over greater distances (Table 3, Fig. 3C). For all three crop types combined, the mean values of browsing pressure (i.e. percent browsed trees) were 83% (± 3% SE) at the food plot's edges (i.e. distance of 0 m), 73% (± 4%) at 50 m, 62% (± 5%) at 100 m, 60% (± 5%) at 200 m, 61% (± 4%) at 300 m, 53% (± 5%) at 400 m and 56% (± 5%) at 500 m from the food plots.

Discussion

This study shows that food plots contributed with substantial amounts of forage for ungulates during summer and at the onset of the dormant season. The non-grazed crops produced on average 2230 to 5810 kg ha^{-1} biomass during the growing season (marrow stem kale, second-year clover mix and early-sown rape seed within exclosures). This is in the upper range of what has been shown in earlier studies where biomass produced in food plots varied between 545 and 5860 kg ha^{-1} over a season (Keegan et al. 1989, Hehman and Fulbright 1997, Edwards et al. 2004; all in southeastern

Table 3. Segmented logistic models for the relationship between distance to the food plots and browsing pressure on deciduous trees. Slope 1 and slope 2 depict the model coefficients for the sections to the left and right of the breakpoint, respectively.

Crop	Breakpoint location (m) [95% confidence interval]	Slope 1	Slope 2
Marrow-stem kale	135 [89–181]	–0.00763***	0.00025 [ns]
Clover mix	112 [93–132]	–0.01934***	0.00959 [ns]
Rapeseed	68 [39–98]	–0.01374***	–0.00201***

***$p < 0.001$, [ns] $p \geq 0.05$

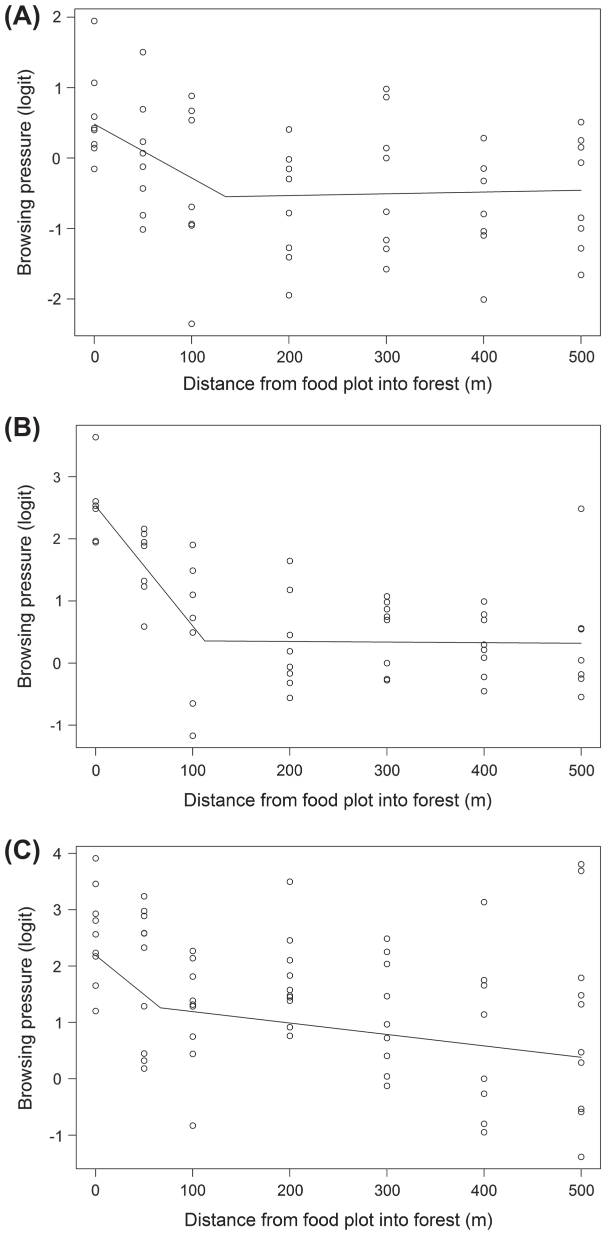

Figure 3. Relationship between browsing pressure in forest and distance from the food plots. The lines depict the segmented models with a single breakpoint for (A) marrow-stem kale, (B) clover mix and (C) rapeseed. For visual clarity, the y-axis is drawn on the logit scale. See Table 3 for model details.

USA). Furthermore, the biomass produced per unit area in our study also seems to be larger than what has been reported through other measures used for forage improvement in forest-dominated landscapes, such as burning and fertilization (leaf biomass 435 kg ha^{-1}; Edwards et al. 2004 in southeastern USA), ungulate-adapted slash treatment at final felling of forest stands (271 kg ha^{-1} winter forage, Edenius et al. 2014 in Sweden), felling of seed trees (1200 kg ha^{-1} winter forage, Månsson et al. 2010 in south–central Sweden) and establishment of willow plantations for bioenergy purposes (128–1222 kg ha^{-1} summer forage, Bergström and Guillet 2002 in south–central Sweden). The biomass is also larger than the amounts of forage generally available in young Scots pine dominated forests in Scandinavia (200–2000 kg ha^{-1} moose winter forage, Kalén and Bergquist 2004). However, compared to measures conducted in forests, the areas used as food plots used in our study were almost solely dedicated to forage production, i.e. they did not result in the production of additional goods such as timber or conventional crop yield.

Our results show that fencing of the fields during the growing season may be a measure to substantially increase the biomass available at the end of the growing season, as also has been suggested elsewhere (Edwards et al. 2004). For all target crops except second-year clover mix, there was a significant difference in plant biomass between unfenced quadrats and exclosures. However, from these observations we cannot conclude how much biomass actually was consumed by ungulates, as grazing may have affected the establishment and growth of crops and that also other herbivores such as hares may have consumed parts of the biomass. Still, our observations of ungulates (288 animal observations over 140 h i.e. ~ 2 animal observations per hour) clearly indicate a utilization by ungulates of the food plots. Although we did not make systematic notes of the behavior of the animals observed on the food plots, the vast majority were seen feeding actively on the plots. However, the difference between grazed and ungrazed plots is of course dependent of grazing intensity and may therefore vary among areas. The effects of grazing on non-target plants were less clear (only significant effect on fields with late-sown rapeseed). We suggest three possible underlying mechanisms for this difference in patterns between target and non-target plants: 1) ungulates did not forage on non-target plants to the same extent as target plants (i.e. they were less preferred), 2) the non-target plants were grazed but their subsequent re-growth was not affected to the same extent as target crops, 3) non-target grazed plants were replaced by other non-target plants that were not utilized by the ungulates (i.e. an effect hidden by the fact that we did not distinguish the different species when estimating biomass of non-target plants).

As hypothesised, we found that summer browsing intensity on deciduous trees in forests was higher in the proximity of the food plots (i.e. within approximately 70–135 m depending on crop type) than further away. This suggests a potential negative side-effect of food plots. Similar patterns have been observed for supplemental feeding, where winter browsing intensity has been found to increase close to feeding stations. Gundersen et al. (2004) and van Beest et al. (2010) showed that moose concentrated their activity pattern close to supplemental feeding stations. Further, the spatial redistribution of moose in the landscape led to lower browsing pressure on sensitive young Scots pine stands on the landscape scale (Gundersen et al. 2004) but not on local scale. An increased winter browsing on the vegetation close to the feeding stations (< 200 m) was evident (van Beest et al. 2010). During winter the ungulates browse on twigs and shoots to a higher extent than during summer when herbs and leaves constitute a larger part of the diet, which implies a higher risk for damage to trees during winter. However, our study show that over 80% of the trees were affected by summer browsing in the forest area directly adjacent to the food plots' edges, which indicates that also summer browsing can potentially have a significant impact on trees and forestry, as also supported by earlier studies (coniferous: Bergqvist et al. 2013; deciduous: Moore et al. 2000).

We conclude that ungulates use the food plots for foraging and that browsing intensity on trees in forest is higher in the vicinity of the food plots than further away. We can envisage two potential mechanisms for this with support from earlier studies: 1) concentration of animals near the food plots due to locally increased forage availability on these plots possibly as a consequence of animals using the food plots as a central place affecting the browsing pattern according to the central place foraging theory (cf. Gundersen et al. 2004, Cooper et al. 2006, Mathisen et al. 2014), and 2) general attraction of ungulates to productive and/or protective edge zones between open land and forest (cf. Welch et al. 1990, Ruzicka et al 2010, Torres et al. 2011). We suggest that the observed patterns are the result of a combination of both factors. We conclude that more research is needed to unravel the relative importance on food plots per se and edge effects in general.

Our results highlight the need for careful spatial planning when deciding on the placement of food plots in forested landscapes: one should avoid establishing food plots close to economically valuable and damage-prone young forest stands. The large biomass production in the food plots, the high level of utilization of the crops and the increased browsing intensity in nearby forest areas suggest that food plots may have the potential to redistribute ungulates by concentrating ungulates to specific areas, and thereby decrease browsing intensity in other parts of the landscapes. However, our study setup does not allow us to draw conclusions about browsing effects across whole landscapes (Gundersen et al. 2004) or about possible long-term effects of food plots (Mathisen et al. 2014). We therefore call for further studies addressing the effects of food plots on the movements of ungulates and on browsing effects over larger spatial and temporal (years and different seasons) scales. There is also a need for future studies designed to assess the effect of food plot size on utilization by ungulates and browsing in adjacent forest.

This study shows that establishment of food plots has the potential to provide ungulates with substantial amounts of forage both during the dormant and growing season even at relatively high latitudes such as in Scandinavia. Food plots therefore have the potential for increasing the yield of ungulates but may also decrease the total browsing pressure on forest in the landscape, provided that ungulate density is controlled. Finally, we recommend fencing food plots throughout the growing season if the aim is to provide large amounts of forage during the often-limiting dormant season.

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References

Aldous, S. E. 1952. Deer browse clipping study in the Lake states region. – J. Wildl. Manage. 16: 401–409.

Ball, J. P. et al. 2000. Response of a herbivore community to increased food quality and quantity: an experiment with nitrogen fertilizer in a boreal forest. – J. Appl. Ecol. 37: 247–255.

Baskin, L. and Danell, K. 2003. Ecology of ungulates: a handbook of species in eastern Europe and northern and central Asia. – Springer.

Bergström, R. and Guillet, C. 2002. Summer browsing by large herbivores in short-rotation willow plantations. – Biomass Bioenerg. 23: 27–32.

Bergqvist, G. et al. 2013. Summer browsing by moose on Scots pine. – Scand. J. For. Res. 28: 110–116.

Brown, T. L. et al. 2000. The future of hunting as a mechanism to control white-tailed deer populations. – Wildl. Soc. Bull. 28: 797–807.

Cederlund, G. et al. 1980. Foods of moose and roe deer at Grimsö in central Sweden – results of rumen content analyses. – Swe. Wildl. Res. 11: 169–247.

Cooper, S. M. et al. 2006. Effect of supplemental feeding on spatial distribution and browse utilization by white-tailed deer in semi-arid rangeland. – J. Arid Environ. 66: 716–726.

Côté, S. D. et al. 2004. Ecological impacts of deer overabundance. – Annu. Rev. Ecol. Evol. Syst. 35: 113–147.

Edenius, L. et al. 2014. Ungulate-adapted forest management: effects of slash treatment at harvest on forage availability and use. – Eur. J. For. Res. 133: 191–198.

Edwards, S. L et al. 2004. White-tailed deer forage production in managed and unmanaged pine stands and summer food plots in Mississippi. – Wildl. Soc. Bull. 32: 739–745.

Gill, R. M. A. 1992. A review of damage by mammals in north temperate forests. 3. Impact on trees and forests. – Forestry 65: 363–388.

Gordon, I. J. et al. 2004. The management of wild large herbivores to meet economic, conservation and environmental objectives. – J. Appl. Ecol. 41: 1021–1031.

Gundersen, H. et al. 2004. Supplemental feeding of migratory moose *Alces alces*: forest damage at two spatial scales. – Wildl. Biol. 10: 213–223.

Hehman, M. W. and Fulbright, T. E. 1997. Use of warm-season food plots by white-tailed deer. – J. Wildl. Manage. 61: 1108–1115.

Heikkilä, R. and Härkönen, S. 2000. Thinning residues as a source of browse for moose in managed forests in Finland. – Alces 36: 85–92.

Kalén, C. and Bergquist, J. 2004. Forage availability for moose of young silver birch and Scots pine. – For. Ecol. Manage. 187: 149–158.

Keegan, T. W. et al. 1989. American jointvetch improves summer range for white-tailed deer. – J. Range Manage. 42: 128–134.

Leopold, A. 1933. Game management. Charles Scribner's Sons. Reprint 1986. – Univ. of Wisconsin Press.

Mathisen, K. M. et al. 2014. Long-term effects of supplementary feeding of moose on browsing impact at a landscape scale. – For. Ecol. Manage. 314: 104–111.

Mayle, B. A. et al. 1999. How many deer? A field guide to estimating deer population size, Field book 18. – Forestry commission, Edinburgh, UK.

Miller, B. F. et al. 2009. White-tailed deer herbivory and timber harvesting rates: implications for regeneration success. – For. Ecol. Manage. 258: 1067–1072.

Miquelle, D. G. 1983. Browse regrowth and consumption following summer defoliation by moose. – J. Wildl. Manage. 47: 17–24.

Moore, N. P. et al. 2000. Browsing by fallow deer (*Dama dama*) in young broadleaved plantations: seasonality, and the effects of previous browsing and bud eruption. – Forestry 73: 437–445.

Mysterud, A. 2006. The concept of overgrazing and its role in management of large herbivores. – Wildl. Biol. 12: 129–141.

Mysterud, A. 2010. Still walking on the wild side? Management actions as steps towards 'semi-domestication' of hunted ungulates. – J. Appl. Ecol. 47: 920–925.

Månsson, J. 2009. Environmental variation and moose *Alces alces* density as determinants of spatio-temporal heterogeneity in browsing. – Ecography 32: 601–612.

Månsson, J. et al. 2009. Fertilization – effects on deciduous tree growth and browsing by moose. – For. Ecol. Manage. 258: 2450–2455.

Månsson, J. et al. 2010. Felled Scots pine (*Pinus sylvestris*) as supplemental forage for moose (*Alces alces*): browse availability and utilization. – Scand. J. For. Res. 25: 21–31.

Månsson, J. et al. 2011. Can pellet counts be used to accurately describe winter habitat selection by moose *Alces alces*? – Eur. J. Wildl. Res. 57: 1017–1023.

Ozoga J. J. and Verme, L. J.1982. Physical and reproductive characteristics of a supplementally-fed white tailed deer herd. – J. Wildl. Manage. 46: 281–301.

Putman, R. et al. 2011. Ungulate management in Europe: problems and practices. – Cambridge Univ. Press.

Putman, R. J. and Staines, B. W. 2004. Supplementary feeding of wild red deer *Cervus elaphus* in Europe and North America: justifications, feeding practice and effectiveness. – Mammal Rev. 34: 285–306.

Redpath, S. M. et al. 2013. Understanding and managing conservation conflicts. – Trends Ecol. Evol. 28: 100–109.

Ruzicka, K. J. et al. 2010. Deer browsing, forest edge effects, and vegetation dynamics following bottomland forest restoration. – Restor. Ecol. 18: 702–710.

Rönnegård, L. et al. 2008. Evaluation of four methods used to estimate population density of moose *Alces alces*. – Wildl. Biol. 14: 358–371.

Sahlsten, J. et al. 2010. Can supplementary feeding be used to redistribute moose *Alces alces*? – Wildl. Biol. 16: 85–92.

Sharp, R. and Wollscheid, K.-U. 2009. An overview of recreational hunting in North America, Europe and Australia. – In: Dickson, B. et al. (eds), Recreational hunting, conservation and rural livelihoods: science and practice. Blackwell, pp. 233–251.

Smith, B. L. 2001. Winter feeding of elk in western North America. – J. Wildl. Manage. 65: 173–190.

Smith, J. R. et al. 2007. Diets, movements, and consequences of providing wildlife food plots for white-tailed deer in central North Dakota. – J. Wildl. Manage. 71: 2719–2726.

Torres, T. et al. 2011. Comparative use of forest habitats by roe deer and moose in a human-modified landscape in southeastern Norway during winter. – Ecol. Res. 26: 781–789.

van Beest, F. M. et al. 2010 Long-term browsing impact around diversionary feeding stations for moose in southern Norway. – For. Ecol. Manage. 259: 1900–1911.

Wastenson, L. et al. 1990. Skogen. Svensk National Atlas. Bokförlaget Bra Böcker. (in Swedish).

Welch, D. et al. 1990. Habitat usage by red (*Cervus elaphus*) and roe (*Capreolus capreolus*) deer in a Scottish Sitka spruce plantation. – J. Zool. 221: 453–476.