Habitat use of beech martens *Martes foina* in relation to meadowbird conservation practices in the Netherlands

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Abstract

Meadowbird populations are declining across Europe, partly due to increased predation rates. To combat this decline, conservationists and farmers have implemented varying conservation measures within the agricultural landscape. This created a 'mosaic landscape' of parcels with varying levels of accommodation for breeding birds. The effects of these 'mosaic landscapes' have been studied from the perspective of meadowbirds, but not from the perspective of predators. In this study, three beech martens *Martes foina* are followed through GPS-tracking during the meadowbird breeding season in order to study their habitat preference in relation to prey availability. It was found that vole densities were highest in more conventionally managed fields and very low in the most accommodating fields. The number of meadowbird nests, on the other hand, was low in conventionally managed fields and higher in more accommodating ones. During the study period, martens showed a preference for more accommodating fields, rather than vole-rich conventional fields, with two out of three martens selecting strongly for the most accommodating category. Furthermore, martens began spending even more time in the most accommodating fields towards the end of the season, when fields of intermediate accommodation were being mowed. Through studying ditch crossings, this study also calls into question whether wide ditches are an effective means of excluding beech martens from parcels. The results of this study may help towards a better understanding of the factor of predation in relation to meadowbird conservation.

Introduction

Meadowbirds, iconic bird species of the European agricultural landscape, have drastically declined in numbers due to the intensification of European agriculture (Donald et al., 2001; Plard et al., 2019; Teunissen & Soldaat, 2006). Meadowbirds suffer from low reproductive output and mortality through modern farming practices and associated habitat degradation (Kentie et al., 2013; Plard et al., 2019; Roodbergen et al., 2012; Schekkerman et al., 2009). In an effort to curb the decline of meadowbirds, measures were implemented to improve the quality of the agricultural landscape for these species. Initial measures focused on postponing mowing dates to reduce nest losses due to mowing. However, these measures alone proved insufficient and thus efforts were made to also improve habitat quality by creating herb-rich meadows and wet grassland habitats (in Dutch "plasdras") through raising water tables or inundation. The implementation of these different management types throughout the landscape has created a 'mosaic' of different types of grassland management (from no measures to measures accommodating meadow birds).

Studies suggest that accommodating measures are valuable for meadowbirds (Kleijn & Van Zuijlen, 2004; Wiggers et al., 2015; Visser et al., 2017). Wet parcels, whether through increased water tables or inundation, seem particularly attractive (Kleijn & Van Zuijlen, 2004; Visser et al., 2017; Weterings et al., 2014). However, whether these accommodating habitats correspond to higher reproduction and survival is disputed (Melman et al., 2020), and the overall effect of these conservation efforts on the populations of meadow birds is disappointing (Plard et al., 2019; Teunissen et al., 2006).

Increased predation is often pointed out as one of the main factors limiting the recovery of meadowbirds in the agricultural landscape (Roodbergen et al., 2012; Schekkerman et al., 2009; Teunissen et al., 2006), partly due to the population recovery of many predatory species (Melman et al., 2020; Schekkerman & Teunissen, 2009). Studies suggest that predation rates within managed meadows are high. Meadow bird eggs and chicks are subject to predation by many different species of predators (Praus et al., 2014; Schekkerman & Teunissen, 2009; Teunissen et al., 2008). Studies find that mammalian predators appear to the primary predators of eggs, whereas avian predators are responsible for the majority of chick predation (Schekkerman & Teunissen, 2009; Teunissen et al., 2008). However, nearly all research on the topic of meadowbird predation has been performed from the perspective of the meadow birds themselves, with a focus on identifying the predators involved (Melman et al., 2020; Teunissen et al., 2008). Little research has been performed focused on the ecology of the predators themselves. As predation has been found to be a major factor within the field of meadowbird conservation, proper research into the ecology of predators is crucial to ultimately develop effective management strategies. To gain a complete understanding of the relation between meadowbirds and their predators, we must understand how predators behave in agricultural landscapes.

Therefore, in this explorative study, I studied the land use of three beech martens *Martes foina* in a meadow bird breeding area in northern Groningen, The Netherlands. Local managers have found beech martens to be a major predator of both eggs and chicks in this area, and believe them to be a leading cause of the poor reproduction of meadow birds in the area. I combine GPS tracking with field measurements to study the habitat preferences of beech martens in relation to different management types. I do this by first collecting data on the characteristics of the differently managed parcels by measuring vegetation, water level and prey availability over an 8-week period. Second, I use GPS tracking to determine which of these habitat characteristics are preferred by martens. Furthermore I conduct a specific study on how the martens deal with waterways that form barriers throughout the landscape, which is a specific topic of interest in this landscape.

Dietary studies find that small mammals and birds are the two preferred prey types of the beech marten (Goszczyński, 1986; Lanszki et al., 2020; Rysava-novakova & Koubek, 2009). Fruits also constitute a significant portion of marten diet in natural habitats (Goszczyński, 1986; Vilella et al., 2020), but are sparce during the spring and early summer. It is also suggested that beech martens are more carnivorous when not occurring sympatric with the larger pine marten (Gazzola & Balestrieri, 2020). For these reasons, fruit was disregarded as a significant source of food in this study. In terms of small mammals, the common vole *Microtus arvalis* and field vole *Microtus agrestis* are the most common species in European agricultural grassland (Hein & Jacob, 2019; Heroldová et al., 2007; Janova & Heroldova, 2016). The population densities of voles follows a highly cyclical 'boom and bust' pattern, with population peaks once every 3-4 years followed by crashes (Hein & Jacob, 2019; Wymenga et al., 2015). Prey population crashes are a well-documented phenomenon, and equally well documented is the tendency of predators to switch to alternative prey when population of their main food sources are low (Korpimäki, 1992; Spencer et al., 2017; Yip et al., 2015). Indeed, American martens *Martes americana* in Alaska primarily hunt voles in most years, but switch to salmon carcasses during times of low vole abundance (Ben-David et al., 1997). It has already been documented that years of low vole abundance correspond to increased predation on birds in agricultural settings in Europe (Angelstam & Widen, 1984; Beintema & Muskens, 1987; Dunn, 1977). It can therefore be expected that martens may prey more actively on birds when vole densities are low.

Voles, however, are not uniformly distributed across the landscape, and can therefore be a factor for meadow bird predators even within a year. Voles prefer well drained soils with higher vegetation and appear to thrive in more intensively managed grasslands (Fischer & Schröder, 2014; Prieur & Swihart, 2020; T. Smink, M. Koopmans, 2018), which is in contrast to the wet, extensively managed fields generally preferred by meadow birds (Kleijn & Van Zuijlen, 2004; Weterings et al., 2014). Voles are generally found to be the food source most preferred by beech martens (Goszczyński, 1986; Lanszki et al., 2020; Rysava-novakova & Koubek, 2009), and yet beech martens are found to be a dominant predator of meadow birds in my study area. As voles and meadow birds thrive under different types of management, it is interesting to study how the land use of beech martens is influenced by these different management types. In order to understand the relative importance of the abundance of alternative prey on the predation of meadowbirds, I studied, in addition to habitat selection and characterization, vole abundance in the differently managed grasslands.

If voles indeed are the favoured prey of martens, it could be expected that beech martens display habitat selection for the type of well drained, intensively managed parcels that support high vole densities, rather than fields that are managed for nesting meadowbirds. If martens are focused on preying on voles it could also be expected that they show a preference recently mowed parcels, as many vole-predators do as voles are easier to capture after mowing (Schlaich et al., 2015; Wymenga et al., 2015). If, alternatively, martens prefer meadow birds eggs and chicks, it would be expected that the animals show a preference for fields with meadowbird management measures in place.

In this study, I explore which habitat types are preferred by martens during the meadowbird breeding season in relation to the characteristics of these habitats: vegetation, wetness, bird nests and vole abundance. As a side study I also explore how martens cross water filled ditches of different widths that run between parcels, as a possible way of blocking off access to areas of high conservation value. It is expected that beech martens, though capable of swimming, will be less inclined to cross wider ditches to reach parcels. Though explorative, the results of this study may inspire further research into the dynamics between beech martens, different prey species and meadowbird conservation practices in the agricultural landscape.

Materials and methods

Study Site

The study was conducted in an agricultural area north of the city of Groningen, the Netherlands, which consists mostly of permanent grassland for dairy farming. Measures for meadow birds are taken by farmers that lease land from the nature conservation organization Het Groninger Landschap (GL) or by farmers that are connected to the WeidevogelCollectief Groningen-West (WCG). WCG coordinates the implementation of meadow bird farming schemes, in which farmers are financially compensated for the measures they take. Agreements on management are made between farmers and GL/WCG in terms of rest periods, water levels and other requirements for meadow bird conservation. Management agreements are implemented at the scale of parcels, creating a mosaic of differently managed grasslands throughout the study area (figure 1). For my analyses, I divided the different management types into three main categories, based on the level of measurements taken to accommodate for breeding meadowbird species. These categories will be referred to from this point on as "Accommodation Scores", or AS. Parcels are assigned an accommodation score by the following criteria:

AS 1: Conventional mowing/grazing regimes. Accommodation for birds only in terms of nest protection: Barriers are placed to prevent trampling by cattle and nests are avoided while mowing (81 fields)

AS 2: Mowing/grazing regime adapted to accommodate for nesting birds. Includes: Delayed mowing, Herb-rich grassland parcels. (24 fields)

AS 3: Adapted mowing/grazing regime plus creation of wet habitats through raised water tables or water added to the surface. Includes: Plasdras, Moist grassland (Groninger Landschap) (23 fields)

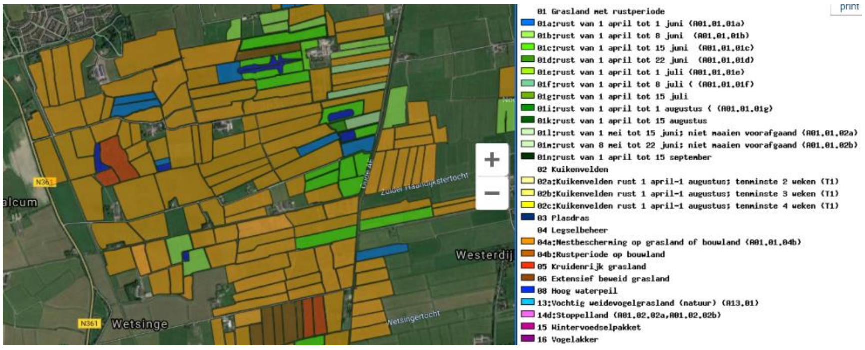

Figure 1. Map showing the eastern section of the study area, Winsumermeeden, illustrating the large variety of different management types used in the area.

Beech marten tracking

Three male beech martens were trapped in March and April. These individuals will be referred to as Freerk, Anne-Jan and Eddie. Martens were fitted with accelerometer-informed GPS tracking collars (E-OBS, model 1C). As beech martens are predominantly nocturnal and mostly inactive during the day (Herr, 2008; Vilella et al., 2020), the collars were set to automatically shut down 1 hour after sunrise and reactivate 1 hour before sunset to save battery. When active, tracking collars were programmed to log the animal's position in strings of 5 datapoints every five minutes. This data was later reduced to one datapoint every 5 minutes. All three martens also went through a period of 1 or 2 nights of intensive tracking.

During these nights collars were set to log one location once per minute. This was done to determine the paths that the martens take with greater precision.

Field measurements

Within the home range of each marten (see below how this home range was calculated), ten fields were selected as focal fields (thirty fields in total). Within focal fields, habitat and vole abundance measurements were taken once per week in week 17 - 24. Care was taken to select fields of each Accommodation Score in each of the home ranges. The following measurements were taken each week within each focal field:

Vegetation Height/Water level: Vegetation height was measured by sticking a tape measure onto the ground and measuring the maximum length of the vegetation at this spot. The vegetation (mainly grass) was held up straight for this. Measurements were taken in the 2nd, 4th, 6th, and 8th vole plot (see below). Water level was determined by measuring the difference between the ground level of the parcel and the water level in the ditches. This measurement was taken on four sides of the parcel, at the same locations every week. *Fresh vole signs*: A 100x100cm square plot was used to search for signs of recent vole activity. The plot would be placed on the edge of the field, and 10 plots were searched for each parcel, each time approximately 5 meters further towards the center of the parcel. As the starting point would be different every week, a comprehensive view of the entire parcel was obtained at the end of the study. Vole signs that were counted were amount of burrow entrances, amount of runways, signs of feeding, and vole droppings based on the methods developed by Altenburg and Wymenga (T. Smink, M. Koopmans, 2018). Burrow and runway counts were ultimately disregarded as these grasslands are seldomly plowed and the high clay content of the soil allows these features to be preserved for a long time period, which means they are not good indicators of current vole density. Vole droppings and grass clippings were taken as the most reliable indicators of short-term vole activity based on Gervais (2010). The level of presence of indicators was standardized (table 1). The average of both indicators was used to calculate a Vole Sign Index (VSI) for every count. Normally, VSI is based on the presence/absence of vole signs within a larger number of smaller plots (e.g. 20x20 cm). After consultation with experts, we opted for larger plots and more accurate counts of vole signs (actual counts instead of determining presence/absence) as counting a large number of plots was believed to take too much time, which would potentially disturb the meadow birds breeding on the parcel.

Table 1. Table explaining methods used to quantify varying levels of presence of fresh vole activity signs. Used to calculate VSI.

score	Droppings	Clippings
1	1 or several loose fresh droppings (droppings retain some green color/no fungus growth)	1 clear clipped patch or sporadic grass clippings (either short-grazed stems or small piles of clipped stems)
2	1 clear latrine with at least 10 fresh droppings in a small area	Several clearly clipped patches or piles of grass clippings
3	More than 1 clear latrine	Clear feeding signs throughout at least three quarters of the plot.

Other measurements: Each week I noted which fields had recently been mowed. If I did not observe the exact moment of mowing, I estimated the date on which the mowing had most likely occurred based on length and color of the grass. Professionals and volunteers from GL and WCG regularly monitored the area and kept a database on meadow bird nests. This database was used to determine the amount of active meadowbird nests per parcel per week.

Analysis

Analyses were primarily in R version 3.6.3. Maps and other visualizations were created using QGIS.

Field data: VSI, vegetation height and nests data were transformed using a cube root, square root and log transformation, respectively, to meet model assumptions. Relationships between the different measurements, and how they varies over time, were analysed by using general linear modelling. Vegetation height was treated in the analysis as a time dependent variable, while no trend in VSI and water level was found and thus one average value was calculated per field. To determine how these measurements varied between Accommodation Scores, a two-way ANOVA was performed. ANOVA results were subjected to a Tukey's honest significance test to determine statistical differences between the three AS groups.

Tracking data: From the tracking dataset the information on Subject (individual), Date, Time, Longitude, Latitude and Night of fix were extracted. As an extra variable, the nearest distance to a daytime roost was calculated for each point. To calculate this variable, first all potential marten resting sites were determined by isolating the first and last point of each night. These 'potential roosting points' were inspected in QGIS. Any landscape feature on the map that contained at least 10 'potential roosting points' was considered a daytime roost. Total home range and core home range sizes were calculated using the package adehabitatHR (Calenge, 2015). For this analysis, coordinates were transformed to UTM, EPSG:32632. Total home range was defined as the area in which martens spent 95% of their time and core home range as the area where they spent 50% of their time. The relationship between home range size and date was analyzed using a general linear mixed model. In this model, 'week' was a fixed factor and 'individual' a random factor. Home ranges were exported as spatial polygons to QGIS for visualization.

Habitat selection analyses were conducted using the package adehabitatHS (Calenge, 2011). To visualize selection of different habitat types, the IVLEV selection index was calculated for the different Accommodation Scores. The same approach was used to determine whether the individuals preferred parcels where the grass had recently been mown. For this analysis, grasslands were divided into the categories 'unmown', 'mown the same week', or 'mown during the previous week'.

A generalized linear mixed model was used to determine which factors best explain variation in time spent in different parcels. The number of GPS-datapoints within a parcel was taken as a measure of the time spent in these parcels. VSI, amount of meadow bird nests, vegetation height and distance from the nearest roost were taken as explanatory variables, while individual and week were included as random effects.

Data from the nights of intensive tracking were plotted over a satellite map in QGIS, and the function 'PointstoPath' was used to visualize the paths that the martens had taken during these nights. To determine how ditches influence the movement of martens, each path was followed on QGIS maps and each crossing of a ditch was noted. At each crossing, the width of the crossed ditch was measured in triplicate using the basic 'measure line' function. If the line between two points was drawn over or near a bridge, dyke, bar or other object, it was assumed that the marten crossed the ditch using this feature. These crossings were marked as "assisted crossings". If no such landscape feature was near, it was assumed that the marten had either jumped or swam across the ditch and the crossing was marked as an "unassisted crossing". A generalized linear binomial model was used to determine the relationship between ditch width and the likelihood of an unassisted crossing.

Results

Water table depth differed between Accommodation Scores ($P<0.01$). Means of AS1 and AS2 did not differ significantly ($P>0.05$), but the water table depth of AS3 was significantly lower than the levels of AS1 ($P<0.01$) and AS2 ($P<0.01$). Vegetation height also differed between Accommodation Scores, with the mean average vegetation height of AS2 being higher than that of AS1 ($P<0.01$) and AS3 ($P<0.01$). AS1 and AS3 did not differ significantly in vegetation height ($p>0.05$).

Both VSI ($P<0.05$) and the total number of bird nests per field ($P<0.05$) were positively correlated with average vegetation height. Of all monitored species, godwit nests correlated most strongly with vegetation height ($P<0.01$). VSI was positively correlated with water table depth ($P<0.01$), being very low in fields with higher water tables as well as inundated 'plasdras' fields. Bird nests showed an inverse relationship with water and the amount of bird nests in a field was strongly negatively correlated with water table depth ($p<0.01$).

Both VSI ($P<0.05$) and the amount of bird nests per field ($P<0.05$) differed significantly between Accommodation Scores. Mean VSI did not differ between AS1 and AS2 (figure 2), but VSI in AS3 was significantly lower compared to the other two groups ($P<0.01$). The mean amount of bird nests per field was lowest in AS1, differing highly significantly from AS2 ($P<0.01$) and AS3 ($P<0.01$) (figure 3). The mean amount of bird nests did not differ significantly between AS2 and AS3 ($P>0.05$).

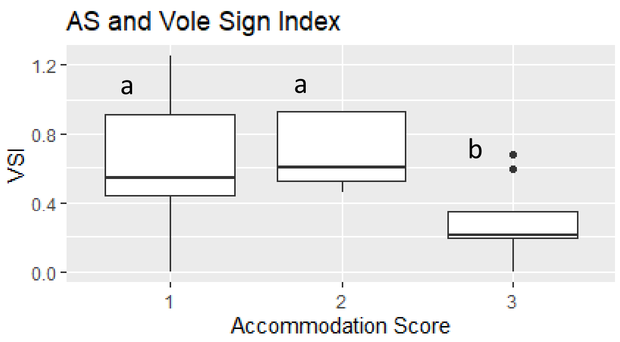

Figure 2. Boxplot of Vole Sign Index per Accommodation score. Letters denote significant differences (P<0.05) based on a Tukey's honest significance test. N=30

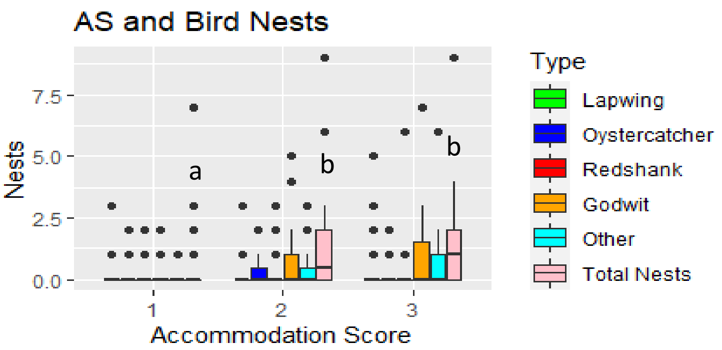

Figure 3. Boxplot of the number of meadowbird nests per Accommodation score, showing differences between bird species. Letters denote significant differences (P<0.05) based on a Tukey's honest significance test. N=128

Home range (95%) size of the three individuals Eddie, Anne-Jan and Freerk over the entire study period were 97 ha, 234 ha and 155 ha, respectively. Core ranges (50%) of these animals were 25 ha, 50 ha and 39 ha. The home ranges of Anne-Jan and Freerk overlapped across an area of 50 ha. The results of the mixed model analysis on the relationship between home range size and time showed that home range size increased significantly over the 8-week study period ($P<0.01$).

The habitat selection analysis showed that, on average, the three beech martens selected most strongly for AS2, followed by AS3, and preference was lowest for AS1. When this analysis was performed separately for each week, it was found that the order of preference was variable, where the most preferred habitat type was one of the managed habitats (AS2 or AS3) in all 8 weeks. By plotting the IVLEV-index per individual per week, it was likewise found that AS2 and AS3 were used more often than expected based on the area available, with AS2 being selected for most strongly. AS1 was used less than expected. The same analysis revealed that two out of the three martens strongly selected for AS3 over the 8-week period, while one individual selected strongly for AS2 while mostly ignoring AS3 (figure 4). None of the individuals selected for AS1.

Over the first 5 weeks, habitat selection was more or less constant with preference for AS2 and AS3 (figure 5). From week 22 onwards, selection for AS2 decreased, while selection for AS3 increased. No change was observed in the selection index for AS1 (figure 5).

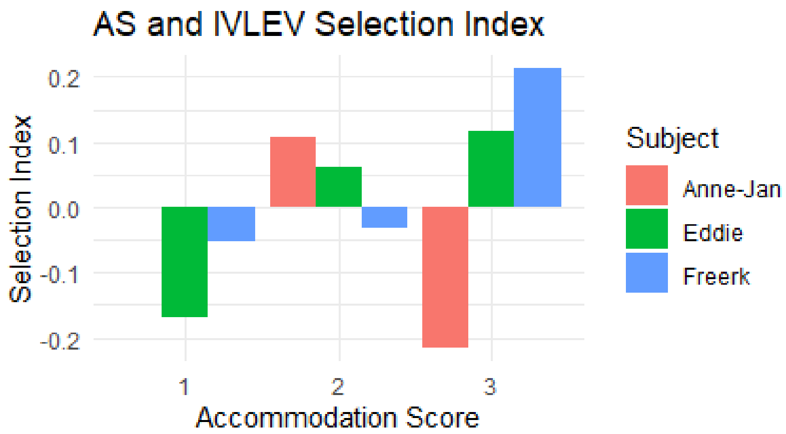

Figure 4. Bar plot of the IVLEV selection index for Accommodation Scores per individual marten. Plot shows average selection indexes for habitat types over the 8-week study period. N=3 individuals.

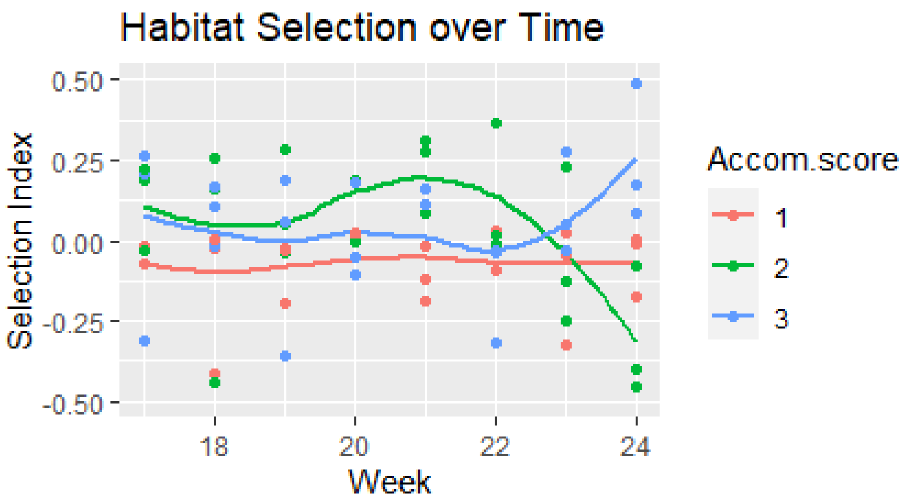

Figure 5. IVLEV habitat selection Index plotted over time during the 8-week study period. Each dot represents the selection index of an individual marten calculated per week. N=3 (individuals).

The number of ditch crossings decreased with ditch width for all martens (figure 6). The likelihood of an unassisted crossing decreased significantly with increasing ditch width ($P<0.01$). The widest recorded unassisted was the crossing of a ditch with a width of 7.29 m.

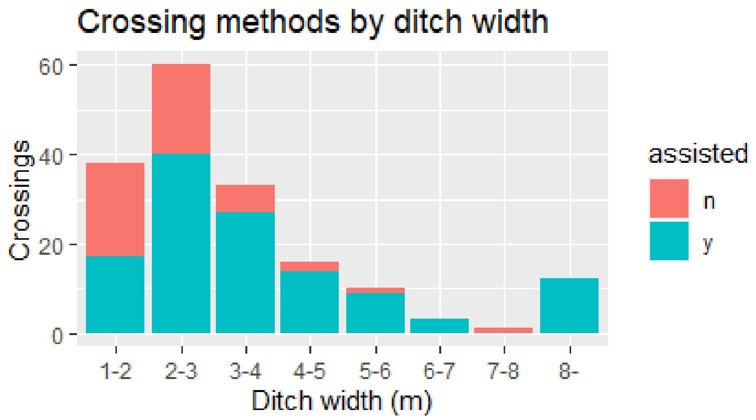

Figure 6. Bar plot of ditch crossings per ditch width range. Crossings were logged during the period of intensive tracking. Colors denote whether a crossing was assisted or unassisted. N=3

Discussion and conclusions

The results from my field study first of all granted insight into the effect of the different types of management of grasslands in this dairy farming system on the habitat selection of meadow birds. Parcels were divided into three different "Accommodation Scores", with AS1 being the least and AS3 being the most accommodating for meadow birds. Measures taken for the protection of meadow birds do, as expected, result in increased breeding densities (figure 3). Meadow birds were found to prefer higher vegetation height and higher ground water levels. The preferences of different species varied, with black-tailed godwits showing a particularly strong preference for longer vegetation for example. It is inferred that due to these two factors, the mean number of bird nests was higher in both AS2-parcels (with highest average vegetation) and AS3-parcels (with highest water levels). These results are consistent with existing knowledge on the habitat preferences of the focal meadow bird species (Eglington et al., 2010; Groen et al., 2012; Johansson, 2001).

Vole populations appear to respond differently to the different types of management of the fields. Consistent with earlier studies (Fischer & Schröder, 2014; Prieur & Swihart, 2020; Wymenga et al., 2015), it was found that vole densities were positively correlated with higher vegetation and lower water levels. Longer vegetation corresponds to both food and increased cover from predators, whereas high water tables impede the ability of voles to dig intricate burrow networks. Another reason why AS3 parcels are less suitable is that grass production is low as little manure is applied. This combination of wet soil and lowered grass production creates an unsuitable environment for voles. Consequently, we found that vole populations were much lower in AS3 compared to the other two categories (figure 2).

In terms of prey availability it can be concluded that, generally speaking, the conventionally managed parcels of the AS1 category are characterized by higher vole densities and low amounts of bird nests. The wet parcels of the AS3 category, conversely, are characterized by higher amounts of bird nests and very low vole densities (figure 2, figure 3). AS2 represents a middle ground with both voles and bird nests both present in relatively high numbers.

Based on dietary studies which show that small mammals are a primary food source for beech marten (Goszczyński, 1986; Lanszki et al., 2020) it would be expected that the beech martens tracked in this study would select for parcels with a lower Accommodation Score (AS1 and AS2), as these offer the highest vole densities. However, the results of the habitat selection analysis suggest otherwise. Two out of three martens showed a general preference for AS3 parcels, spending more time in these wet fields than would be expected based on their availability within their home ranges (figure 4). One individual (Anne-Jan) spent relatively little time in AS3 parcels, though this might partially be explained by the fact that two of the AS3 parcels available to this individual lie within the home range of another tracked beech marten (Freerk). As male beech martens rarely tolerate other adult males within their territory (Genovesi et al., 1997), it is possible that these parcels were avoided not on basis of prey availability but due to intraspecific competition. Individual Anne-Jan instead showed a preference for AS2 fields. None of the three martens tracked in this study showed a consistent preference for AS1 parcels (figure 4), even though these parcels are relatively rich in voles and abundant in the study area.

A preference for AS2-parcels was to be expected as these parcels were found to have relatively high abundances of both voles and meadow bird nests. However, the lack of preference for AS1 and the strong selection of two out of three martens for AS3 suggests that abundance of voles was not the most important driver for habitat selection during this period. What is yet more interesting is the fact that from week 22 (may 25th to may 31st) onwards, preference for AS2 dropped rapidly for all three martens, and all three individuals increased the selection for bird-rich AS3-parcels rather than the vole-rich AS1-parcels(figure 3). The 1st of June is the date on which farmers are allowed to mow the AS2-parcels for the first time, and from this day forward the majority of these fields was mown. The reduction in time spent by the three martens in AS2 thus coincides directly with this mowing. This was unexpected, as other (avian) predators are known to be attracted to recently mown fields due to the increased availability of voles (Schlaich et al., 2015; Wymenga et al., 2015). It is possible that due to differences in hunting strategies, increased visibility due to mowing may be less important for beech martens than it is to avian and diurnal predators. The steep decrease in time spent in AS2 fields in favour of vole-poor but bird-rich AS3 fields suggests that the habitat selection of beech martens is more shaped by bird abundance than vole abundance.

The diet of the beech marten is seasonal (Ben-David et al., 1997; Helldin, 2000; Vilella et al., 2020), and it is known that martens supplement their diets with bird eggs when these are available (Herr, 2008). Though small mammals may generally be the preferred prey of martens (Goszczyński, 1986; Lanszki et al., 2020), this does not exclude the possibility that martens prefer eggs and young of meadowbirds during the short period of the year when these are available. The caching of food items for later use is a well-documented behavior within the genus *Martes* (Helldin & Lindstrom, 1995; Twining et al., 2018). It has been documented that cached bird eggs, taken during the summer, are used as a food source by pine martens during the winter (Helldin, 2000; Pulliainen & Ollinmäki, 1996) as eggs may remain edible for over six months. If the same is true for beech martens, then this could partly explain why this species is such a dominant predator of meadowbird eggs in the Dutch countryside (Roodbergen et al., 2012; Teunissen et al., 2006, 2008).

If martens were mostly predators of eggs, rather than chicks (Teunissen et al., 2008), one would not expect two out of three martens in this study to strongly prefer AS3 over AS2 (figure 4), as the mean number of nests did not differ between these two categories (figure 3). Also note the fact that all three martens showed increased selection for AS3 around the beginning of June (figure 5), a period in which AS2 fields are mown because the majority of eggs is assumed to have hatched. Most meadowbird species are precocial breeders, and do not necessarily raise their chicks in the same parcels they lay their eggs in (Dreitz, 2009; Redfern, 1982; Wiltermuth et al., 2015). Wet and inundated grasslands, which are given Accommodation Score 3 in this study, are the habitat type most meadowbirds prefer for chick rearing (Kleijn & Van Zuijlen, 2004; Visser et al., 2017; Weterings et al., 2014). Wet parcels provide higher amounts of available insects and worms, thus creating suitable circumstances for meadowbird families to forage (Melman et al., 2020; Visser et al., 2017). The increased interest in AS3 by martens towards the end of the season suggests a greater focus on chicks than was previously expected (Teunissen et al., 2006, 2008).

Whether the increased selection for AS3 was directly driven by the abundance of meadow birds in these areas is impossible to determine from the current results. As martens show a preference for areas with higher vegetation cover (Puig-Gironès & Pons, 2020), an alternative explanation would be that martens are attracted to AS3 field near the end of the study period because this is the only habitat that had not been mown at the time. Clearly, the switch to AS3 fields cannot be explained from a preference for voles, as vole densities were very low in AS3.

Regardless of causality, the increased interest of the three martens in AS3 coincides with a period in which meadowbird families are raising their chicks in these wet fields. Though parcels with accommodating management are known to attract meadow birds and their chicks during the breeding season (Kleijn & Van Zuijlen, 2004; Weterings et al., 2014), the efficiency of this management is debated. Studies show that relatively few chicks survive until fledging age, in part due to high predation rates (Melman et al., 2020; Schekkerman et al., 2008). Some farmers practice nest protection by identifying and avoiding nests while mowing, leaving small 'islands' of taller vegetation untouched. Research suggests that these nests saved from mowing suffer from increased predation as they are easily located by predators (Kentie et al., 2015). The results of this study suggest beech martens may respond similarly to the mosaic management practiced on a larger scale. Within their home ranges, which consist largely of conventionally managed grasslands, parcels with management types designed to accommodate for meadowbirds stand out in a way similar to ‘nest islands’. The martens easily find these isolated wet habitat patches to which they are heavily attracted.

As predation is a significant factor for the conservation of meadow birds (Plard et al., 2019; Roodbergen et al., 2012; Schekkerman et al., 2009), more research from the perspective of predators is needed to better understand this factor. The results of this explorative study may serve as an encouragement to further research on the relationship between predators and methods of meadow bird management in the Dutch countryside. My results suggest that beech martens spend a disproportionately large amount of time in parcels meant to accommodate for breeding birds, and managers of such areas will be interested in methods to reduce this behaviour. For this reason I additionally studied the willingness/probability to cross ditches of different widths. The results show that beech martens may less readily cross ditches of greater width, even though crossings of ditches over seven meters in width were documented (figure 6). This suggests that though martens may be discouraged by wider ditches, they cannot fully exclude crossings by martens. Given the fact that (wide) ditches seem to form a barrier for beech martens to some extent, it would be interesting to study this at a larger scale, specifically whether wide ditches without crossing points would reduce predation rates on meadow bird nests and young. Such research could also include experiments in which crossing points are blocked or removed.

Another unknown factor is the effect of yearly variation in vole densities on the habitat selection and land use of beech martens. Meadow bird breeding success increases in years of high vole abundance (Angelstam & Widen, 1984; Beintema & Muskens, 1987), suggesting that the habitat selection of predators like the beech martens may change in relation to vole abundance. It is unknown, however, how different predators respond to the variation in vole abundance. Though some species may disregard meadow bird nests and chicks when sufficient voles are available, as predicted by classic predator/prey dynamics models, others may continue to prey on birds even during vole peak years. Martens, for example may be incentivized to raid nests due to their habit of caching eggs for the winter months (Helldin, 2000; Pulliainen & Ollinmäki, 1996). To further understand predation rates through prey choice and habitat selection in relation to variation in vole abundance, studies should be conducted on multiple predator species and during multiple years (at least one whole vole cycle). Further studies would benefit from standardization of methods, making results comparable between studies. This holds true particularly for estimates of vole densities, as several different vole sign indices are currently used (Gervais, 2010). Furthermore, as meadowbirds are precocial breeders, further studies should include observations on bird families, rather than just nests, to gain a more complete picture of predation on eggs and chicks. With increased knowledge on the underlying dynamics, it may be possible to come up with meadow bird management strategies that are more robust to predation, which may help to secure a future for iconic meadowbird species in our landscape.

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