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Article

Using Activity Measures and GPS Data from a Virtual Fencing System to Assess Habitat Preference and Habitat Utilisation Patterns in Cattle

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Simple Summary: Developing sustainable livestock management requires knowledge and monitoring of which habitats within an enclosure, the livestock prefers to stay in, and in what way they utilise the available habitats. The technology of virtual fencing provides the ability to both monitor and adapt enclosures with little extra cost or work for farmers and livestock managers. To this end, the possibilities this new technology offers need to be explored, and methods developed. In this paper we explore the monitoring capabilities of virtual fencing technology on a herd of cattle in a coastal dune landscape. We explore to what extent a herd of cattle prefers some habitats over others, and in what way they utilise each of the available habitats. We find clear differences in the amount of time the herd spends in each habitat and in the ways they utilise each habitat. The herd spend a disproportionately large amount of time in a salt meadow, and likely spend most of their time there resting and ruminating. We conclude that the method for monitoring of cattle applied in this study, using existing virtual fencing technology, is a relatively precise and cost-free method useful in year-round monitoring, with room for improvement.

Abstract: There has been an increased focus on new technologies to monitor habitat use and behaviour of cattle, to develop a more sustainable livestock grazing system, without compromising animal welfare. The currently most used method for monitoring cattle behaviour is tri-axial accelerometer data from systems such as virtual fencing technology or bespoke monitoring technology. This method requires high frequency data, and as such, quickly drains contemporary systems of power making it unsuitable for long-term monitoring. In this paper, we explore the possibility of determining habitat preference and habitat utilisation patterns in cattle, using low frequency activity and location data. We do this by (1) calculating habitat selection ratios, (2) determining daily activity patterns and based on those, (3) inferring grazing and resting sites in a group of cattle wearing virtual fencing collars in a coastal setting with grey, wooded and decalcified dunes, humid dune slacks and salt meadows. We found that GPS data, and a measure of activity, combined with accurate mapping of habitats can be an effective tool in assessing habitat preference. The animals preferred salt meadows over the other habitats, with wooded dunes and humid dune slacks being the least preferred. We were able to identify daily patterns in activity. By comparing general trends in activity levels to existing literature, it was possible to somewhat infer resting and grazing behaviour in the different habitats. According to our inference of behaviour the herd predominantly used the salt meadows for resting and ruminating. The approach used in this study allowed us to use GPS location data for measuring the activity and combine it with accurate habitat mapping in a cheap and effective way, which can be an important tool for guiding management decisions.

Keywords: animals; virtual fencing; grazing management; Nofence©; cattle; habitat preference; habitat utilisation

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1. Introduction

Recent advances in precision livestock farming technologies, such as GPS-based virtual fencing, allow for greater control of grazing pastures and easier monitoring of animals, providing potential benefits for both production, nature conservation and animal welfare [1–3]. This is especially true in areas with sloped and hilly terrain where traditional physical fencing can be challenging and labour intensive [4,5]. In the last few decades, there has been an increased focus on monitoring livestock in both production and nature conservation settings to make better and more informed management decisions [6–9]. Especially the habitat use and behaviour of cattle in regards to environmental concerns and animal welfare are of high interest [7,9–11]. Understanding habitat preferences of grazing livestock and their use of the grazing areas, is important to help develop a more sustainable livestock grazing system with minimal negative impact on the environment [11]. Multiple studies have investigated the habitat use by free-ranging livestock to make better management decisions and promote resource conservation [12–15]. Cattle are generally less selective in their feed preferences compared to other grazing livestock such as sheep and goats [16]. They prefer habitats with a high biomass production such as meadows and grasslands but are also used in nature conservation on salt meadows and heathland with lower biomass production [15,17]. However, because grazing resources are often spatially and temporally heterogeneously distributed, animals need to visit different habitats to satisfy all their nutritional needs [13]. In addition, terrain characteristics such as the steepness of slopes and the distance to drinking water also affect the habitat selection of cattle [13–15]. The habitat distribution of cattle is furthermore affected by temperature, protection from pests, and shelter from the elements [18]. GPS-based systems with built-in accelerometers can be used to monitor both spatial distribution of animals and their movement, which can potentially allow monitoring of animal behaviour and activity [19]. The collected data can be used to monitor variations in daily animal activity and help characterise typical behavioural patterns which make it feasible to detect deviations when they occur, thereby making it possible to detect potential disease and/or welfare concerns remotely [11,20].

The currently most used method for monitoring activity and classifying behaviour of livestock in recent years has been tri-axial accelerometer data [19,21,22]. An example of this can be found in a recent paper by Versluijs et al. [19], where accelerometer data from a virtual fencing system was used to accurately classify the behaviour of beef cattle in a natural setting. This method, although displaying high fidelity in classifying behaviour in shorter time frames, quickly drains the system of power and is therefore not usable when considering constant long-term monitoring. This limits research to short consecutive periods [19]. To enable longer term studies with continuous data, and constant year-round monitoring, a method needs to be developed based on far simpler, and less power-consuming data. In this paper, we explore the possibility of determining habitat preference and habitat utilisation patterns using low frequency location data and a coarse measure of activity. Habitat preference is defined by Matthiopoulos et al. [23] as: The ratio of habitat usage over its availability. Habitat utilisation patterns is loosely defined by us as: At what time of day and in which way do the animals use each habitat, e.g. do the animals use a habitat mainly for grazing or for resting. We do this by (1) calculating habitat selection ratios, (2) determining daily activity patterns and based on those, (3) inferring grazing and resting sites in a group of grazing cattle wearing virtual fencing collars. All three of these criteria must be met for the method to be considered successful.

2. Materials and Method

All data in this study was provided by 'Projekt Virtuelt Hegn, Fanø' www.virtuelthegn.dk. The management of the enclosure and the animals was carried out entirely by the farmer at 'Projekt Virtuelt Hegn, Fanø' for this study.

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2.1. Animals and Location

This study took place on the western coast of the Danish island of Fanø, located in the southwestern part of Denmark in the Wadden Sea (Figure 1). The size of the study area was 163.5 hectares, and the area consisted of a mosaic of different coastal habitats. The initial mapping of habitats was carried out by downloading existing mapping by the Danish "National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environment (NOVANA)" from www.arealdata.miljoeportal.dk (Kortlægning af naturtyper - flader). The most recent mapping done by the NOVANA program in the area is based on in-field observations and assessments by trained field biologists in the years 2016-2018. The mapping of habitats by the NOVANA program was supplemented and lightly modified by us using elevation models and aerial photographs (Dataforsyningen.dk, (Forårsbilleder Ortofoto - GeoDanmark), orthophotos from spring 2022). The modifications were: merging of different habitat subtypes with similar vegetation compositions; mapping of wooded areas as these were not covered by the NOVANA program; and minor alterations to the existing NOVANA mapping due to observed differences in mapping and actual conditions. Observed differences were likely due to the age of mapping, as some areas were last visited by the NOVANA program in 2016. The mapped habitats in the enclosure, with characteristic vegetation as reported by the NOVANA program, area and percentage of total area is listed in Table 1, and the geographic extent shown in Figure 1.

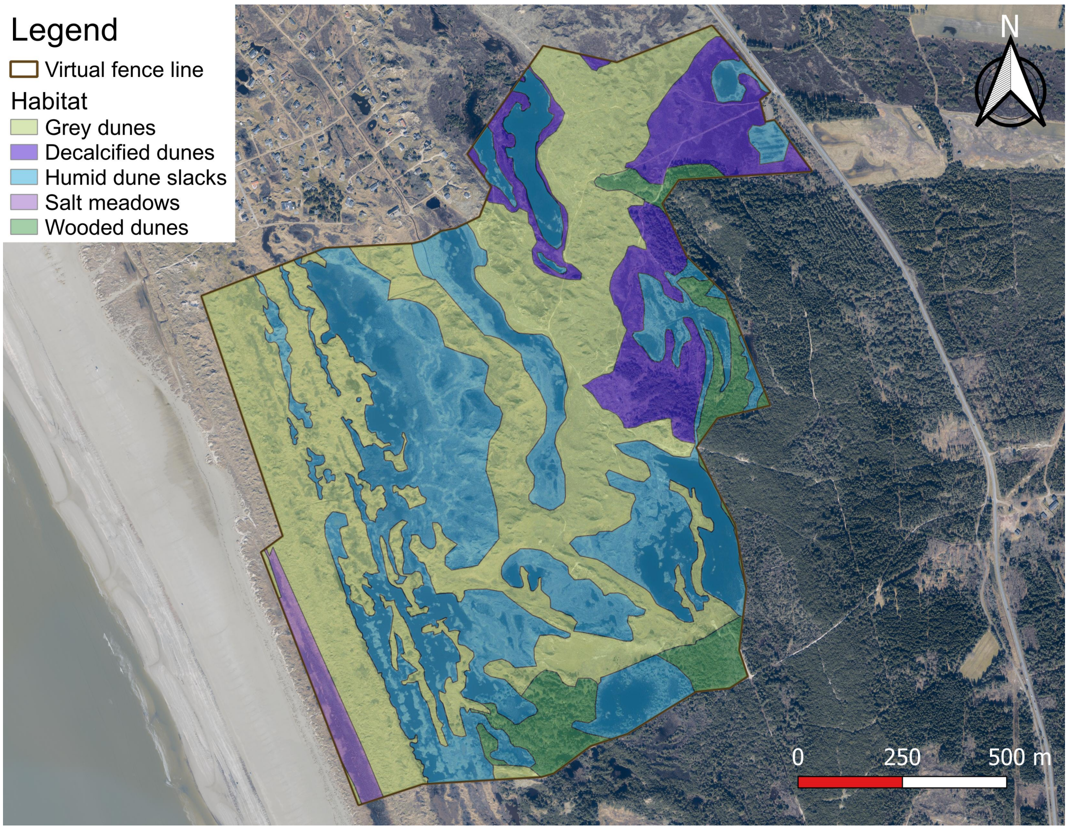

Figure 1. The study area and mapped habitats, each colour represents a different habitat, with the brown line outlining the virtual fence line in the study period (July 11, 2023 to October 2, 2023. Contains data from The Danish Agency for Data Supply and Infrastructure, Forårsbilleder Ortofoto - GeoDanmark, December 2023. https://datafordeler.dk/vejledning/brugervilkaar/sdfi-geografiske-data/

The study animals were 17 Angus beef cattle (*Bos taurus*), of which 16 were heifers and 1 was an older cow. All animals had been at the study location and within the virtual enclosure for at least two months before data collection for this study began. The cattle were enclosed using a virtual fencing system developed by Nofence©. Each animal was fitted with a GPS collar capable of logging location and activity of the animal, as described by Aaser et al. [24]. The size of the enclosure had gradually

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increased over two months from the initial introduction of the animals to the study area, but was kept constant at 163.5 hectares from July 11 onwards. To ensure that no changes in the size or extent of the enclosure occurred during the period analysed, only data from July 11 until the time of download of data on October 2, was included in this study. The data used in this study was downloaded from the database provided to us by Projekt Virtuelt Hegn, Fanø.

Table 1. Overview of the habitats available in the enclosure. For each habitat the characteristic species found in the area are listed, as well as the available area of the habitat and the percentage of the overall area covered by that habitat.

Habitat	Characteristic species	Area (ha)	% of total area
Salt meadow	*Phragmites australis, Carex extensa, Carex distans, Plantago maritima, Triglochin maritima, Agrostis stolonifera*	2.9	1.8%
Wooded dunes	*Pinus mugo, Pinus sylvestris, Pinus contorta, Picea sitchensis, Carex arenaria, Calluna vulgaris*	9.7	5.9%
Decalcified dunes	*Calluna vulgaris, Empetrum nigrum, Carex arenaria, Avenella flexuosa, Polypodium vulgare*	16.6	10.2%
Humid dune slacks	*Salix repens var. argentea, Equisetum fluviatile, Eriophorum angustifolium, Drosera intermedia, Gentiana pneumonanthe*	62.8	38.4%
Grey dunes	*Ammophila arenaria, Corynephorus canescens, Carex arenaria, Calluna vulgaris, Festuca ovina, Jasione montana, Potentilla erecta, Cladina sp.*	71.5	43.7%

2.2. Data and Statistical Analysis

The collars sent two separate types of data points. One type contained just the position of the animal and was sent every 15 minutes. The other type was sent every 30 minutes and contained a measure of activity, as well as the position of the animal at the time of sending. Activity was given as a converted measure of movement as registered by the built-in accelerometer. The collars did contain a tri-axial accelerometer, as they were the same model as the ones used by Versluijs et al. [19], but with a slightly different data output. Access to the raw tri-axial accelerometer data requires custom-made firmware, which was unavailable for this study. As such, the obtained activity value from the collars was a sum of the registered movement since the last activity data point was sent, that is every activity measure described the movement of the animal in the 30 minutes leading up to the sending. The exact method of converting the raw accelerometer data to activity measure has not been disclosed by Nofence©. The values were not capped, and as such could vary from zero to an indefinite number. Since the software converting the raw accelerometer data to a measure of activity was originally developed for sheep, the measure was given as a unit-less number with no biological meaning.

All recorded data points were assigned a habitat based on their position within the virtual enclosure (see Figure 1). Points that fell outside the virtual enclosure, either due to GPS inaccuracy, or the animal having momentarily escaping the enclosure, were excluded from the data. Activity measures were inspected visually and determined to display clear bi-modality. This bi-modality stems from the daily activity pattern of cattle, with distinct periods of high activity behaviours such as grazing, separated by periods of low activity, usually due to resting [25–27]. Therefore, all activity measures were classified as either High or Low activity (Figure 2). This was done using a Gaussian Mixture Model on the log-transformed measures of activity. Before log-transformation, 1 was added to all measures of activity to avoid the problem of log-transforming activity measures of zero.

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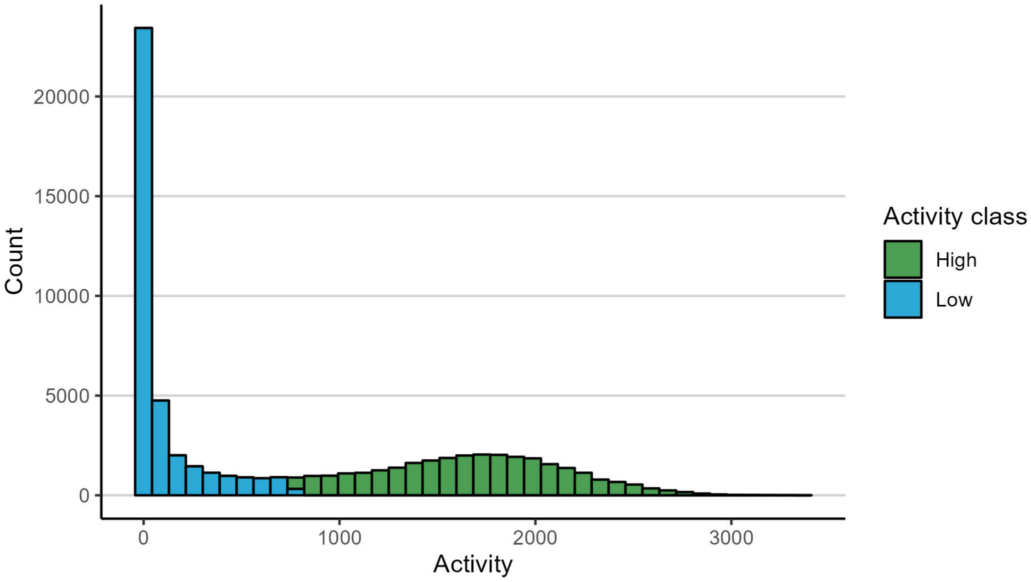

Figure 2. The activity measures displaying clear bi-modality. The bars are coloured based on classification as either High or Low activity.

Habitat preference was analysed using the position-only data points, while the analysis of behaviour and activity patterns was based on activity data. The analysis of habitat preference consisted of calculating habitat selection ratios for each individual cow [28]. The habitat selection ratio is defined as the proportion of time an animal spends in a habitat relative to the availability of that habitat [28,29]. The selection ratio (SR) is calculated as:

$$SR = \frac{\frac{n_{i,x}}{N_i}}{\frac{a_x}{A}}$$

Where n_i is the number of position-only data points logged by cow i in habitat x, N_i is the the total number of position-only data points logged by cow i, a_x is the area of habitat x, and A is the total area of the enclosure. In this way, a selection ratio above 1 indicates a preference for that habitat, while a selection ratio below 1 indicates preference against the habitat. To test whether the observed preference for or against each habitat deviates significantly from a null hypothesis of no habitat preference, a χ^2 test is used. The χ^2 statistic is calculated for each combination of individual cow and habitat, and then added together by habitat. The sum of the 17 χ^2 statistics for each habitat is used for the χ^2 test (with 16 degrees of freedom), as recommended by Manly et al. [28] and White & Garrott [30] in Calenge & Dufour [31]. Additionally, possible differences in selection ratios between habitats are tested using pairwise Mann-Whitney U-tests. The analysis of activity and habitat utilisation patterns was done primarily qualitatively, by visual inspection of logged activity data, with all data pooled irrespective of individual.

Mapping of habitats was done in QGIS version 3.26 [32] and all statistical analysis were done in R version 4.3.0 [33].

3. Results

3.1. Habitat Preference

All habitats were found to be significantly selected for or against, using χ^2-tests. All χ^2-tests yielded a $p < 0.001$ at 16 degrees of freedom, with the χ^2 statistic ranging from 3,055 to 1,558,201. Pairwise

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Mann-Whitney U-tests on habitat selection rations, showed that animals preferred salt meadows significantly more than all other habitats ($p < 0.001$). As such, the selection ratio for salt meadows was 6.78±0.36 (reported as median±median absolute deviance (MAD)). There was a significant difference in habitat selection ratios between all habitats except between wooded dunes and humid dune slacks (Figure 3).

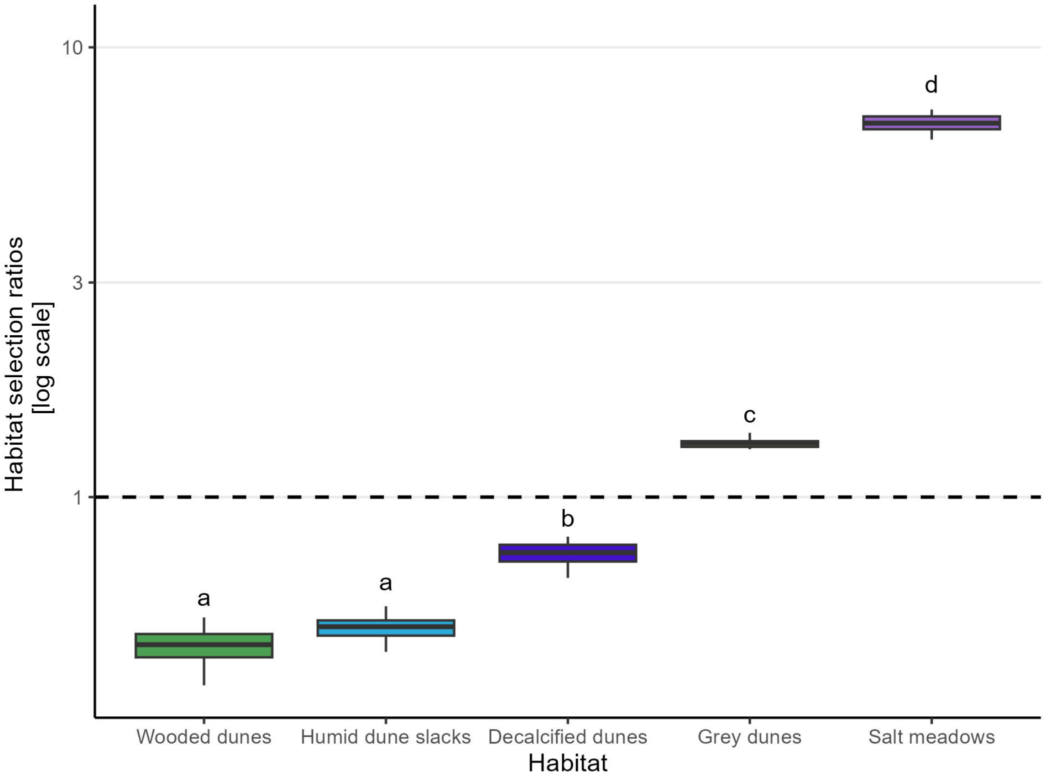

Figure 3. Habitat selection ratios calculated as proportion of recorded position-only points in a habitat divided by the availability of the habitat. The dotted line indicates a proportion of time spent in a habitat equal to its availability, i.e. random use relative to availability. Therefore, values above the dotted line indicate that the cattle actively select for the habitat, while values below indicate that the cattle actively select against the habitat. The y-scale has been log base 10 transformed. Different letters indicate statistical significant difference with pairwise Mann-Whitney U-test after Bonferroni correction, $p_{bonf} < 0.01$.

Out of the five habitats in the enclosure, two were selected for, and three were selected against (Figure 3). The habitats that were selected for were: Salt meadows 6.78±0.36 (median±MAD) and grey dunes 1.32±0.04 (median±MAD). The three habitats selected against were: Decalcified dunes 0.75±0.05 (median±MAD), humid dune slacks 0.52±0.03 (median±MAD) and wooded dunes 0.47±0.04 (median±MAD) (Figure 3).

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Table 2. Median selection ratio and median absolute deviance (MAD) for each habitat.

Habitat	Median Selection Ratio	MAD
Salt Meadow	6.78	0.36
Grey dunes	1.32	0.04
Decalficied dunes	0.75	0.05
Humid dune slacks	0.52	0.03
Wooded dunes	0.47	0.04

3.2. Daily Activity Patterns and Behaviour Classification

Activity of the animals was found to display a clear daily rhythm, with median activity being far higher in the early morning and late afternoon/evening, than during midday and night hours (Figure 4A). The same pattern was found in the proportion between high and low activity measures throughout the day, with high activity measures being far more prevalent around dawn and dusk, and low activity measures dominating around midday and during the night (Figure 4B). Overall, the animals spent significantly more time at low activity levels (median of 13 hours/day), than at high activity levels (median of 10.5 hours/day). The two medians don't quite add up to 24 hours. This is likely due to the first and last day of the study period not being complete days, and slight inconsistencies in the collars, meaning sometimes only 47 (and not the expected 48) daily activity measurements would be recorded. These inconsistencies seemed to be irrespective of collar and to occur randomly.

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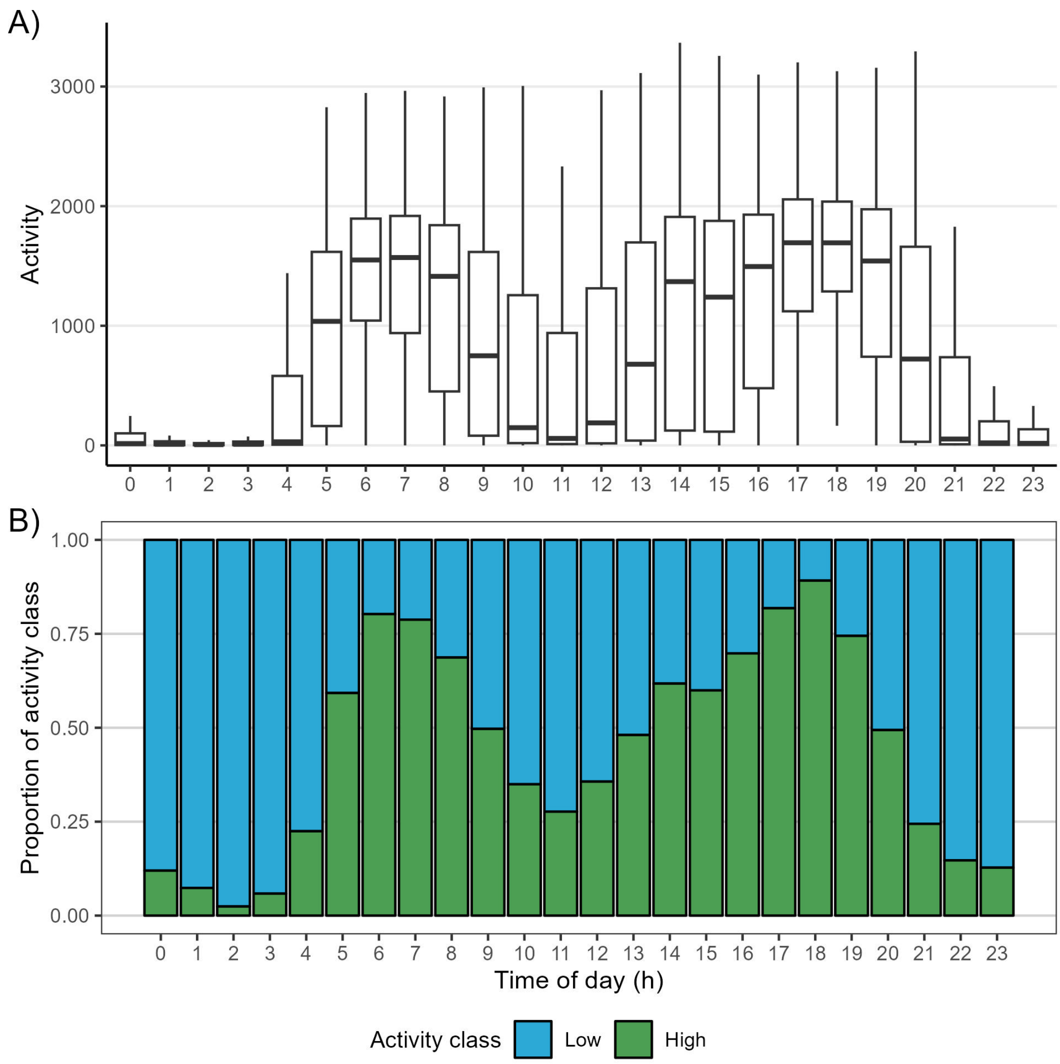

Figure 4. Daily activity patterns, with (A) showing the distribution of all recorded activity measures for every hour of the day. Outliers are not shown to improve legibility. (B) shows the proportion of low and high activity measures for every hour of the day.

Actual quantification of habitat utilisation was not possible with the methodology used in this study. Therefore, analysis of habitat utilisation was limited to inferring grazing and resting sites from the activity patterns in Figure 4A & 4B compared with a qualitative visual inspection of habitat preference by time of day (Figure 5).

In decalcified dunes there were relatively more points recorded during low activity hours, especially at night, than at high activity hours (Figure 5, Decalcified dunes). In grey dunes, there were more recorded points during the daytime than at night, where the activity is lower (Figure 5, Grey dunes). In humid dune slacks there was a clear pattern of more recorded points during periods of high activity in the morning hours, late afternoon and early evening. Consequently, humid dune slacks had clear dips in the number of points recorded during low activity hours at night and around noon (Figure 5, Humid dune slacks). Salt meadows likewise showed a clear, but opposite, pattern. The number of recorded points in salt meadows was higher during periods of lower activity, with more points recorded during the night and around noon, and fewer around periods of high activity, such as in the morning, late afternoon and early evening (Figure 5, Salt meadows). Not a lot of time was spent in wooded dunes, but there was a clear pattern of more recorded points during the night in periods with the lowest activity (Figure 5, Wooded dunes).

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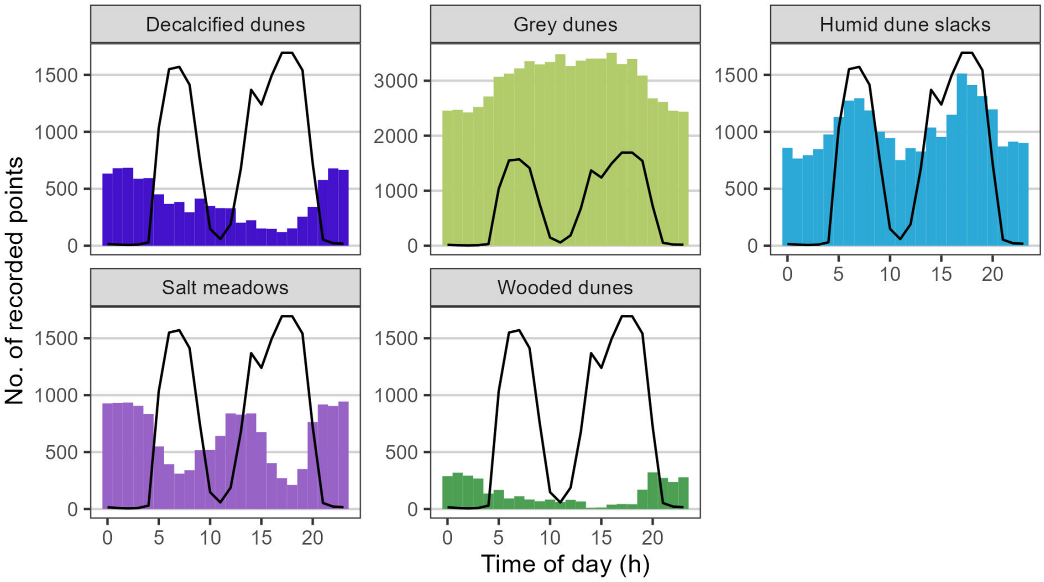

Figure 5. Habitat use by time of day, visualised as the number of location-only points recorded in each habitat for every hour of a day. The black line indicates the median activity for the corresponding time of day. Note that the y-axis for grey dunes is expanded to fit all points.

4. Discussion

By combining GPS data from a group of cattle wearing virtual fencing collars, and mapping of habitats from publicly available field data and aerial photos, we successfully mapped habitat preference of the herd of cattle within the virtual enclosure. This method has previously been shown to be an effective way of assessing habitat preference and as an estimate of grazing pressure [34]. In this study, the herd showed a clear preference for salt meadows, as evidenced by the significantly higher selection ratio for this habitat 6.78±0.36 (median±MAD) compared to all other habitats 1.32±0.04 (median±MAD) to 0.47±0.04 (median±MAD). This preference for salt meadows is not immediately logical according to existing literature, as cattle generally prefer grazing on drier habitats, as these tend to have vegetation with higher crude protein and lower fibre content than wet habitats [11,35], although one study has found cattle to preferentially graze wet areas [36]. In a previous study in a mosaic landscape of sand-dunes and lowland habitats, somewhat comparable to this area, cattle also preferred grazing in the lowland habitats [37]. This seemingly counter-intuitive preference could be a result of what other habitats are available. Across several studies, the least preferred vegetation for grazing by cattle is half-shrubs, such as heather (*Calluna vulgaris*), irrespective of cattle breed and season [34,38,39]. This would explain the preference of salt meadows over both decalcified dunes and grey dunes, which are usually characterised by heather [40]. Likewise, humid dune slacks are generally dominated by sedges, which cattle also tend to avoid when other options are available [35,40]. Another explanation for the preference of salt meadows over other habitats is the productivity of the habitat. Studies suggest that cattle prefer habitats characterised by high biomass production [15,34,39], and of the five classified habitats in the study area, salt meadows have the highest biomass production and highest nutritional value for cattle [17,41]. The least preferred habitat in this study was wooded dunes with a selection ratio of 0.47±0.04 (median±MAD). This is in line with previous studies, that have found cattle to avoid wooded areas and have higher occupancy of open grassland in both extensive and intensive grazing conditions [12,42,43].

Despite not being able to directly quantify habitat utilisation in this study, we were able to identify some general trends based on patterns in activity and differences in habitat selection ratios. Quantifying habitat utilisation would require classification of behaviours as done by others, such as Ungar et al. [6] and Versluijs et al. [19]. This would necessitate higher frequency of data collection and in-field

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observations for training a classification model. In accordance with existing literature, we found that cattle spend a majority of the day at low activity levels (median of 13 hours/day) [27,44], and that cattle exhibit periods of high activity during early morning and late afternoon, with periods of low activity in between (Figure 4) [26]. The high level of variation in activity during daytime hours, is most likely due to combined effects of weather and season (Figure 4) [25–27]. Effect of season is especially pertinent in this study, as the length of the day has been shown to significantly affect the activity and behaviour of cattle [25–27]. The period of data collection was characterised by a shortening of the day from around 17 hours of daylight to 10.5 hours (Source: WorldData.info, retrieved on 19/12/2023). Based on previous studies, we can infer that a low activity level likely covers behaviours such as resting and ruminating, while high activity is a sign of grazing and/or walking [6,27,44,45]. These inferences indicate, that while the herd of cattle preferentially stayed on the salt meadows, they might have predominantly used the area for resting and ruminating rather than grazing, as most of the time spent on salt meadows was during periods of generally low activity (Figure 5, Salt meadows). Previous studies have shown cattle to prefer resting and ruminating near water sources and on nutrient-rich vegetation [11,46]. However, cattle also seem to prefer grazing near water sources[11,36], which could explain why the most presences in humid dune slacks were recorded during high activity periods (Figure 5, Humid dune slacks). Humid dune slacks were one of the least preferred habitats (23.1$\pm$1.49 points/ha), and the majority of grazing has likely not taken place there. The relative preferential use of decalcified dunes and wooded dunes during night hours, and grey dunes during hours of daylight, is likely due to the weather patterns of the study site. Climate and weather plays a major role in explaining animal behaviour and habitat use [11]. Due to the location, topography and vegetation of the different habitats at this particular study site, decalcified dunes and wooded dunes would have provided the most cover against the prevailing winds at the study site, with grey dunes providing the least amount of cover. Wooded dunes would also have provided natural shelter against precipitation [11]. It is highly unlikely that much grazing has happened in the decalcified and wooded dunes, as the majority of the time spent there by the cattle was at low activity levels, and during night hours when cattle have been shown to avoid grazing (Figure 5) [35].

Our results showed that GPS data and a coarse measure of activity, combined with accurate mapping of habitats can be an effective tool in assessing habitat preference and general trends in habitat utilisation. Additionally, by utilising existing technology integrated in virtual fencing systems, this is a cheap and effective method of monitoring cattle in extensive settings, without the need for additional sensors [11]. There are, however, some apparent drawbacks to using the data from virtual fencing systems, as quantification of habitat utilisation was not possible. One potential easy improvement to the method of this study, is to include the distance the animal has travelled between two activity recordings. This simple addition would likely allow for more accurate behaviour classification, as done by Ungar et al. [6] and Ganskopp et al. [47]. Another potential improvement is recording activity counts in two-dimensions (fore-aft and left-right). This also allows for greater fidelity in behaviour classification and is a widespread method [6,9,45]. The downside to this method is that it usually requires purpose made equipment and a higher frequency of data collection [9]. Alternatively, using tri-axial accelerometer data provides the highest fidelity in classifying behaviour but also requires the highest frequency of data collection [19]. This method is possible using the same virtual fencing system as used in this study, but requires purpose made firmware and quickly drains the system of power [19]. We believe that although the method used in this study does not allow for fine detail analysis, it does provide some general insights into habitat use and preference of cattle, that can be useful for management decisions. Although this study was limited to around three months of data collection, our method allows for year-round studies. This is important, as habitat use of cattle has been shown to be season dependent [11,13].

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5. Conclusions

The method in this study was successfully used to map habitat preference and general trends in activity patterns of a herd of cattle in a mosaic dune landscape. Although we were unable to quantify habitat utilisation, comparing general trends in activity levels to existing literature, we were able to somewhat infer grazing and resting sites in different habitats and at different times of day. In this study, the herd of cattle had a significant preference for salt meadows, while wooded dunes and humid dune slacks were the least preferred habitats. The herd had a clear diurnal activity pattern with two distinct periods of high activity. One period in the early morning and one in the late afternoon. According to our inference of habitat utilisation, the herd predominantly used the salt meadows for resting and ruminating, rather than grazing. The differential preference of the habitats present in the study area, could likely be explained by differences in vegetation cover, topography and moisture. Although our developed method was not completely successful at achieving the set goals, we believe the use of GPS location data and a coarse measure of activity combined with accurate mapping of habitats, is a cheap and effective tool for guiding management decisions. By utilising existing technology and data from already implemented virtual fencing technology, and only needing relatively infrequent data collection, this allows for long term year round studies without the need for purpose made systems.

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