Received: 15 May 2025 | Accepted: 16 April 2026
DOI: 10.1002/2688-8319.70275

RESEARCH ARTICLE

BRITISH ECOLOGICAL SOCIETY Ecological Solutions and Evidence

A spatial analysis workflow to derive landscape-scale conservation management information from GPS-monitored grazing livestock

Tom Major[1] | Antonio Uzal[2] | Ross A. Hill[1] | Anita Diaz[1]

[1]School of Life and Environmental Sciences, Bournemouth University, Poole, UK

[2]School of Animal, Rural and Environmental Science, Brackenhurst Campus, Nottingham Trent University, Southwell, UK

Correspondence
Tom Major
Email: tmajor@bournemouth.ac.uk

Funding information
Bournemouth University

Handling Editor: Caryne Braga

Abstract

1. The use of domestic livestock in naturalistic grazing is increasingly common in habitat conservation management, restoration and rewilding initiatives. The goal is to enable natural herd behaviours so that livestock support landscape-scale ecological processes and fulfil ecosystem functions such as increasing connectivity and habitat diversity. However, despite the increasing availability of satellite telemetry equipment to monitor livestock locations, users are often limited in their ability to analyse the resulting data to better understand herd movements and thereby inform management decisions.
2. Here, we provide a spatial analysis workflow for researchers and land managers seeking to use satellite telemetry data (e.g. GPS) to answer the following key questions about the behaviour of their grazing animals: (i) how far do they move, and does this vary with season; and (ii) which habitats do they prefer when grazing, and does either patch size or isolation influence selection?
3. We demonstrate this workflow by presenting a case study using 'Digitanimal GPS collars' on a herd of cattle on the Purbeck Heaths National Nature Reserve in Dorset, UK. Our workflow shows how we addressed each of these questions using a combination of movement models, step-selection functions and resource-selection functions. For each stage in the workflow, we provide guidance and resources for users to analyse their own data.
4. We illustrate how, in our case study, the analyses showed that cattle range more widely in late summer than in early summer. Further, their habitat preferences shift between the early summer and the drier late summer. Cattle sought out even small patches of suitable habitat but were less likely to use very isolated patches.
5. *Practical implications*. Our case study demonstrates how spatial data collected with telemetry devices can enable users to gain and share key insights into the landscape-scale seasonal habitat preferences and movement behaviours of livestock. The suite of analytical approaches presented in our workflow is broadly

applicable to any type of GPS-tracked livestock and offers researchers and land managers a practical tool for understanding herd behaviour and informing conservation grazing management decisions.

KEYWORDS
cattle, ecology, space use, step-selection, tracking

1 | INTRODUCTION

Biodiversity conservation needs landscape-scale, dynamic, well-connected habitat mosaics to be successful (Bengtsson et al., 2021; Lawton, 2011). One solution that is being widely applied in conservation management is the use of more free-ranging domestic herbivores to produce conservation benefits as they graze across landscapes (Gorghiu et al., 2024; Lovász et al., 2024; Troiano et al., 2021). Free-ranging livestock are intended to restore biodiversity by enhancing dispersal of propagules and vegetation structural heterogeneity through processes such as selective defoliation, treading of land and cycling of nutrients (Hart et al., 2023; Köhler et al., 2023; Rook & Tallowin, 2003; Stewart & Pullin, 2008). However, grazing animals face complex environments where their decision-making is influenced by numerous biotic and abiotic factors (Lovász et al., 2024; Soder et al., 2009). Understanding how free-ranging livestock respond to their environment is key to being able to plan their use as effective landscape-scale nature conservation tools. Tracking animals with collars that use signals from satellites to determine location (e.g. GPS) has long been used by scientists to investigate the behaviour of free-ranging livestock (de Weerd et al., 2015; Tofastrud et al., 2019; Versluijs et al., 2024), and the growing availability of more affordable hardware has enabled many conservation managers to adopt satellite tracking of livestock to locate them for welfare purposes (Herlin et al., 2021). In the United Kingdom alone, at least 26 projects are tracking conservation grazing cattle using satellite collars. Understanding how far livestock are moving, the extent of the area they inhabit, their habitat preferences and how factors such as habitat type and landscape configuration influence their movements is essential for using them as effective management tools in conservation. However, rapid advancements in spatial ecology make it challenging to stay updated and access the latest tools, often hindering effective data analysis. To improve monitoring of how livestock are responding to their environments and to facilitate the sharing of effective conservation practices, telemetry data analysis should be more accessible.

Here, we present a spatial analysis workflow to demonstrate how to process data from telemetry equipment to understand the spatial ecology of free-ranging livestock. Using a case study, we present a developed workflow that utilises freely available tools and software within the R environment (R Core Team, 2022). We provide our workflow and the results from our case study in our Supporting Information to contextualise the use of this workflow. We demonstrate how to analyse data to obtain answers to key questions that govern the efficacy of any free-ranging large herbivores as conservation tools in any system. (1) How far do free-ranging large herbivores move, and does this vary with season? (2) Which habitats do the cattle prefer when grazing, and does patch size and isolation influence selection by cattle? These analyses were chosen because movement and habitat selection underpin the ecological impacts of grazers. Land managers can use the space estimate to understand the area over which their animals range, helping to evaluate the scale of grazing influence. The habitat selection analyses inform which habitats receive grazing pressure and when. By quantifying these patterns, our workflow provides conservation managers with insight into where and when grazing occurs, allowing them to evaluate whether livestock are interacting with habitats which are relevant to their desired conservation outcomes, and whether this interaction varies seasonally.

2 | MATERIALS AND METHODS

2.1 | The workflow

Our workflow takes the user through all the necessary steps to accomplish space and habitat-related analyses. Portions of the R code that vary between sites are annotated, and prompts are given to change them. Data requirements are a .csv file containing animal tracking data and a .tiff raster detailing the spatial distribution of habitat variables of interest. R works on Linux, Windows and Mac, and these analyses take little computing power to run for most animal tracking datasets. However, processing power and task run time will increase with larger datasets. The workflow is visualised in Figure 1. An annotated guidance document is provided in the Supporting Information for use within the R environment. This workflow includes removing duplicated rows from the tracking data, although the removal of other errant points must be performed by the user prior to using the workflow.

2.2 | The case study

We conducted our case study within The Purbeck Heaths National Nature Reserve (NNR) in Purbeck, Dorset, southern England

BRITISH ECOLOGICAL SOCIETY Ecological Solutions and Evidence

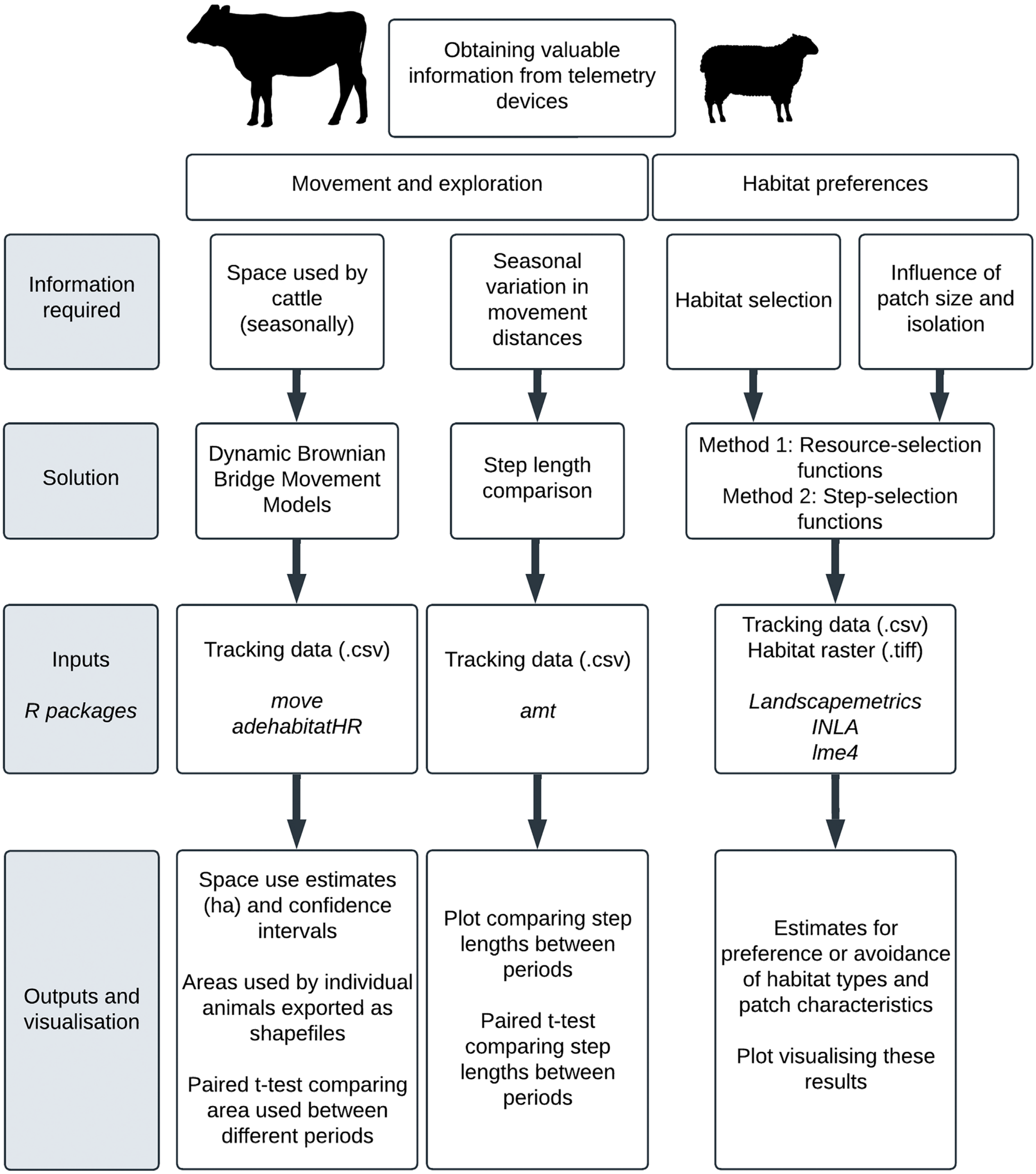

FIGURE 1 Flow chart demonstrating the desired information to be extracted from livestock movement data, showing the solutions and outputs resulting from the provided workflow.

(between −2.062° and −2.037° north latitude and 50.675° and 50.695° east longitude). This NNR is the UK's second largest nature reserve, encompassing 3331 ha of mixed habitats, including wet heathland (plant community dominated by *Erica tetralix*), dry heathland (dominated by *Calluna vulgaris*, *Erica cinerea* and *Ulex* spp), mires (dominated by *Sphagnum* spp. and *Molinia caerulea*) and acid grassland (dominated by *Agrostis capillaris*). In common with most European heathlands, this anthropogenic plagioclimax landscape was created through initial deforestation by post-glacial hunter-gathers and then maintained by centuries of human use as a source of fuel (peat and heather turves and scrub kindling) and rough grazing for livestock (Webb, 1998). Grazing with domestic livestock declined after the mid-20th century but has been reinstated in recent years as the key heathland management tool used on the NNR, supplemented with some heather cutting and gorse flailing (Chatters, 2021).

The cattle (*Bos taurus*) monitored in this study are part of a conservation grazing herd of Red Devon cattle. The herd includes around 65 cows, the vast majority of which have calves, plus approximately 25 yearlings and five bulls. The cattle roam within a 1280 ha fenced area of the NNR (Figure 2). The cattle are released into this fenced part of the reserve between May and October and allowed to roam freely, except for 2 weeks in July when they are brought in for welfare checks.

Tracking data were collected by Wessex Grazing Ltd. for animal welfare monitoring purposes and were made available for this study with appropriate permissions. Digitanimal GPS Tracker collars (Digitanimal, Madrid, Spain) were attached to 20 cattle from late May to September 2022. We attached the collars to adult female cattle because most of the herd is female and selected cattle pseudo-randomly during husbandry by the grazier. The GPS collars generally obtained locations every 30 min. All analyses on the derived GPS data were conducted using R version 4.2.1 (R Core Team, 2022). Within the R environment, data organisation and manipulation activities were performed using the *dplyr* package version 1.0.10 (Wickham et al., 2022).

2.3 | Workflow question one: How far do free-ranging large herbivores move, and does this vary with season?

The workflow first addressed movement and exploration. We determined the size of the area that each individual animal has inhabited. We analysed this using dynamic Brownian Bridge Movement Models (dBBMMs). These models considered the path between animal locations, as well as the time between them, to model the likely path that the animal took and provide accurate estimates of space use (Kranstauber et al., 2012; Silva et al., 2020). This method enabled the estimation of space use based on predictions of where the animal may have been between locations (Silva et al., 2018). To assess the seasonality of cattle behaviour, our workflow divided the data into customisable time periods. In this example, we split the tracking duration into two periods, separated by a 2-week data gap in July when the cattle were brought back in from the reserve. The first period, termed 'early summer,' spanned from May 29 to July 5, coinciding with the peak of fresh grass growth. The second period, 'late summer,' ran from July 15 to August 28, overlapping with a time of significantly reduced grass growth due to a severe drought in our survey year. To compare the estimates of space use between these periods, we conducted a paired *t*-test on cattle tracked for at least 14 unique days in each period. This number of days was chosen to provide a representative sample of

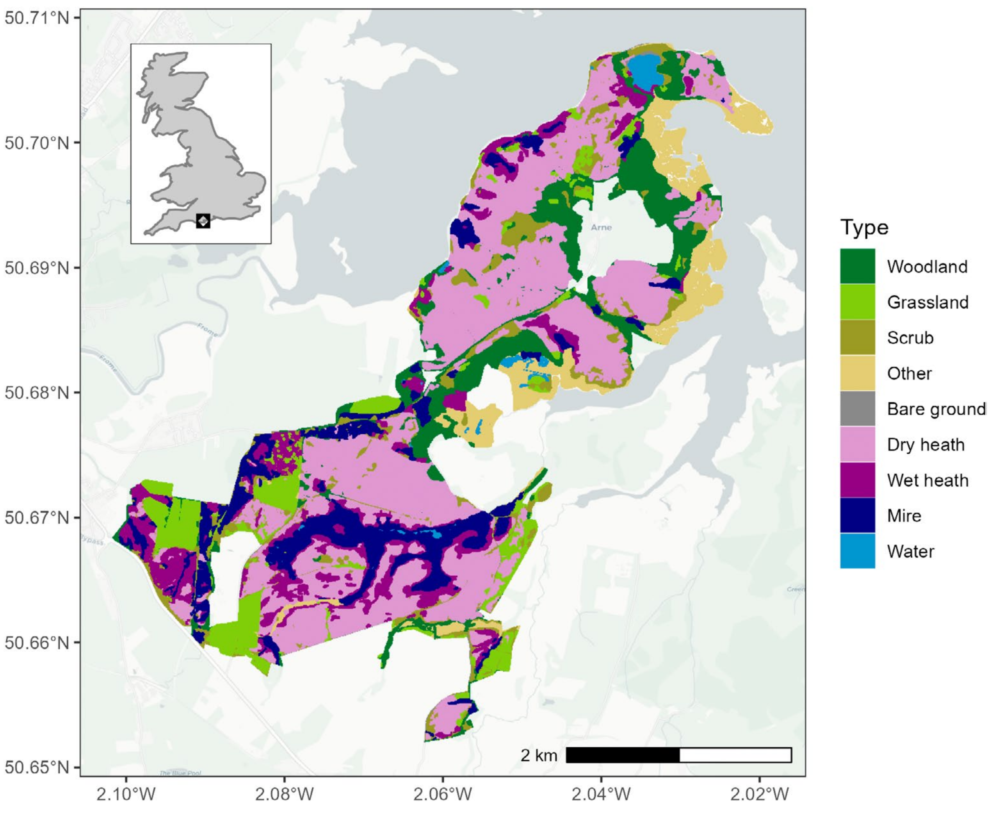

FIGURE 2 Purbeck Heaths Super National Nature Reserve common grazing unit showing the habitat types used in the analysis. Inset map shows the location of the reserve in the context of Great Britain. Basemap copyright OpenStreetMap, available under the Open Database Licence www.openstreetmap.org/copyright.

BRITISH ECOLOGICAL SOCIETY Ecological Solutions and Evidence

individual behaviour during each period. Due to incomplete tracking data, these were not the same 14 days for all individuals. Note that space use differs from home range, because home range is the entire area the animal will require for foraging and mating during its lifetime and cannot be split into discrete periods; therefore, dBBMMs do not extrapolate to the home range but rather measure the space used during a determined period (Kranstauber et al., 2012; Kranstauber et al., 2014; Silva et al., 2020). To reduce the effect of time periods where location data were missing from a collar due to hardware malfunction or insufficient satellite connection, we removed time lags greater than a user-customisable number of minutes (180 in our example) from our dBBMMs to avoid over-inflation of space use caused by a long period of simulated movement between known locations.

The dBBMMS are calculated using the package *adehabitat* version 0.4.20 (Calenge, 2006), while *amt* version 0.1.7 (Signer et al., 2019) and *move* version 4.1.10 (Kranstauber et al., 2022) were used for the calculation of step lengths and the manipulation of tracking data.

Next, our workflow examined the activity of the animals using step length distances (i.e. the Euclidean distance between successive locations of the animal, as recorded by the telemetry devices). To examine whether the step length distributions differ between early summer and late summer, indicating a difference in movement distances, we used a paired *t*-test.

2.4 | Workflow question two: Which habitats do the cattle prefer when grazing, and does patch size and isolation influence selection?

We wanted to determine the habitats that cattle selected while grazing, rather than roaming in general. To ensure this, we first fitted a Hidden Markov Model (HMM) to our animal location data using the *MomentuHMM* package version 1.5.7 (McClintock & Michelot, 2018). We used a two-state model to separate grazing behaviour from travelling behaviour based on step length and turn angle metrics, allowing only movements which were likely to be grazing behaviour to be used for habitat selection analyses.

These analyses require a raster showing the habitat type that is present in that area. Free habitat rasters can be obtained for the United Kingdom from https://www.ceh.ac.uk/data/ukceh-land-cover-maps (Morton et al., 2021). The annually updated 10-m raster data are suitable for local studies and show land cover as UK Biodiversity Action Plan (BAP) Broad Habitats. However, as part of a long-term monitoring project we digitised a habitat raster of our study area in 2022 using QGIS 3.24.3 (QGIS Development Team, 2023) to ensure that the data were as current as possible and of high spatial resolution. This raster was based on information from both site visits and aerial imagery from Google Earth.

Our habitat map was originally digitised as National Vegetation Classification (NVC) communities, but we condensed these into eight relevant classes: bare ground, dry heath, grassland, mire, scrub, water, wet heath and woodland (Figure 2). Other habitats that did not fit into these categories were not included in the analyses, including buildings, sand dunes, rush pasture, reedbeds, fen meadows and saltmarsh. These categories totalled a small area 95.75 ha (8.56%) of the study site and were rarely visited by the cattle. To determine the size and isolation of each patch, we rasterised our habitat shapefile using *terra* version 1.7–39 (Hijmans et al., 2023). We used a resolution of 7-m pixels as this avoided narrow strips of bare ground bisecting large habitat patches. We limited the analysis to patches >0.5 ha to remove numerous small patches of limited ecological relevance that would skew our results.

Using the habitat raster, the workflow provides two distinct modelling approaches to assess cattle habitat selection, step-selection functions (SSFs) and resource-selection functions (RSFs) (Figure 1). These two analyses represent two different ways of determining habitat preference, one which compares used animal locations to simulated locations based on animal movement, and one which selects unused locations randomly from within the area they inhabit. RSFs focus solely on the selection of habitat or resources, while SSFs model movement and selection simultaneously. Our workflow provides both methods to reflect their current use in the scientific literature. SSFs are a movement-based analysis where location data are transformed into 'steps', with each step representing two consecutive GPS fixes for each animal. For every real step, a custom number of simulated steps is generated. Habitat use in these simulated steps is then compared with real movement data in a logistic regression: if a habitat appears more frequently in simulated steps, it suggests cattle are less likely to use it when moving; if it is overrepresented in real steps, it indicates preference (Muff et al., 2019). In contrast, resource-selection functions (RSFs) are used to compare randomly generated points across the study area with the actual cattle locations. RSFs have been a widely used approach for over 20 years to assess animal habitat selection (Johnson et al., 2006; Millspaugh et al., 2006). They are typically based on a Generalised Linear Model (GLM), where used locations are compared to random locations within the study area. By incorporating animal ID as a random factor, RSFs account for intra-population variation (Muff et al., 2019).

2.5 | Step-selection function analysis

Modifying code from Smith et al. (2021) and Muff et al. (2019), our workflow uses mixed conditional Poisson regression models essentially functioning as population-level integrated step-selection functions (population-level ISSFs) on the cattle tracking data. ISSFs (Muff et al., 2019) are one of a variety of selection functions that are used to determine habitat selection by animals. They use tracking data to generate random 'available' steps, with the distributions of turn angle and step length used for random steps coming from the animal tracking data. Covariates are then compared to determine which predicts the observed locations most accurately versus the available, unused locations. In our workflow, we use habitat types as covariates. These ISSFs evaluate used against unused locations on a single-step basis.

For our case study analysis, we ran our population level ISSF to ascertain either association or low affinity of eight habitat classes (excluding other), using the *INLA* package version 22.05.07 (Rue et al., 2009). The positional accuracy of the GPS collars was approximately 10 m, so we removed cattle movements (relocations) of less than 10 m as they may have been caused by GPS error. We then created 10 random relocations or 'steps' for each relocation by the animal, using Gamma and Von Mises distributions for step length and turn angle, respectively (Hodges et al., 2022; Smith et al., 2021). We constructed one single-factor model per habitat type for a total of eight habitat classes. The interaction of turn angle and step length was incorporated in all models. The stratum-specific random effect of the step was set to 0.0001 (Muff et al., 2019). For the individual random slopes (random effects that allow the effect of a predictor variable to vary between individuals in the population), we used a Penalised Complexity prior, PC (1, 0.05), and for fixed effects, we used uninformative normal priors. These Bayesian models were fitted using integrated nested Laplace approximations as per (Rue et al., 2009). For both habitat selection analyses, we set a customisable resample rate denoting the desired time between successive locations and enforced this with a tolerance value. This effectively removed periods of missing data and ensured only realistic movement steps were included in the analysis.

2.6 | Resource-selection function analysis

To fit resource selection functions for our case study, we first generated 100,000 random locations within our study area using sampleRandom from the *raster* package version 3.6.3 (Hijmans et al., 2015). We then recorded the habitat types of these random locations. We compared these random locations with locations that our cattle selected using logistic regression in a generalised linear mixed-effects model (GLMM) from the *lme4* package version 1.1.30, (Bates et al., 2015), with individual animal as a random effect. Resource-selection functions output log-odds values, where positive values denote a preference for a particular habitat feature or type, and negative values indicate low affinity.

Our case study area consists of a mosaic of habitat patches through which the animals move. We wanted to determine whether the size of these patches influence how likely the animals are to be found in them and whether patch isolation (distance from another patch of the same type) affects habitat patch use. To assess this, our workflow incorporates habitat patch size and isolation into the step-selection and resource-selection functions. The package *landscapemetrics* version 1.7.7 (Hesselbarth et al., 2019) is used to extract patch area and isolation. Through this process, we measure the area of each patch of habitat in hectares and calculate isolation as the nearest neighbour distance in metres to another patch of the same type. This enables us to assess whether cattle preferentially selected isolated habitat patches or showed a preference for larger or smaller patches. We conducted this analysis for both early and late summer.

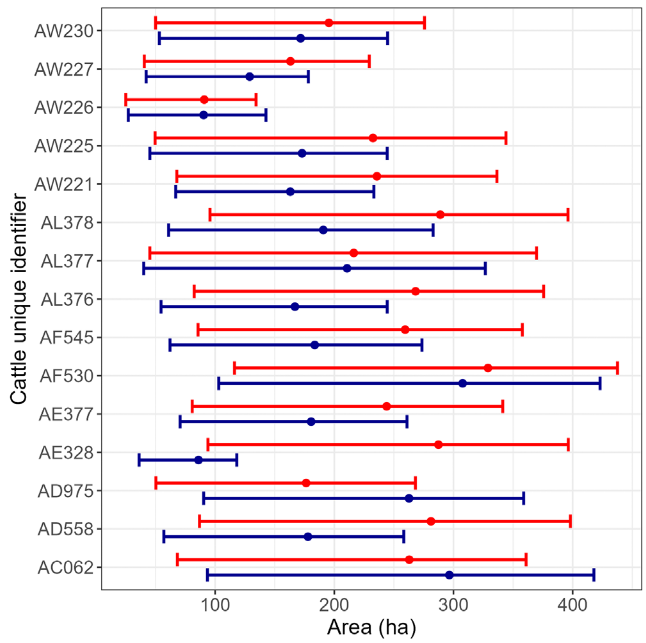

FIGURE 3 Space use for individual Red Devon cattle estimated using dynamic Brownian Bridge Movement Models. Dark blue denotes the early summer period while red denotes late summer. Points represent the 90% space use estimate, and error bars indicate 70% (low) and 95% (high) estimates. Only cattle tracked for a minimum of 14 days in each period are shown.

3 | RESULTS

3.1 | Workflow question one: How far do free-ranging large herbivores move and does this vary with season?

The workflow enables estimation of movement ranges and seasonal comparisons using dynamic Brownian Bridge Movement Models. Using our case study dataset, the workflow outputted values for seasonal data use with 95% confidence intervals and visualisations comparing movement extents between periods (Figure 3). Users can therefore identify whether animals tend to expand or contract their ranging area between seasons, and examine corresponding differences in step lengths (Figure S1).

3.2 | Workflow question two: Which habitats do the cattle prefer when grazing, and does patch size and isolation influence selection?

The Hidden Markov Model successfully isolated grazing points according to their step lengths and turn angles (see online Supporting Information for details). The workflow provides functions for summarising habitat use and generating visual outputs showing proportional use of each habitat type (Table 1, Figure 4). Through the workflow, users can test hypotheses about habitat preference and

BRITISH ECOLOGICAL SOCIETY Ecological Solutions and Evidence

TABLE 1 Summary of habitat types and their use by cattle during the study. Counts are the raw counts of cattle locations in each habitat type from GPS tracking data.

Habitat class	Total area (hectares)	Cattle locations during early summer	Cattle locations during late summer
Grassland	145.8 (11.3%)	4565 (44.2%)	1880 (15.3%)
Dry Heath	526.8 (41%)	1674 (16.2%)	2643 (21.4%)
Mire	184 (14.3%)	922 (8.9%)	2265 (18.4%)
Scrub	130 (10%)	754 (7.3%)	1182 (9.6%)
Wet Heath	182 (14.2%)	1654 (16%)	2569 (20.9%)
Woodland	117.9 (9.2%)	376 (3.7%)	1011 (8.2%)

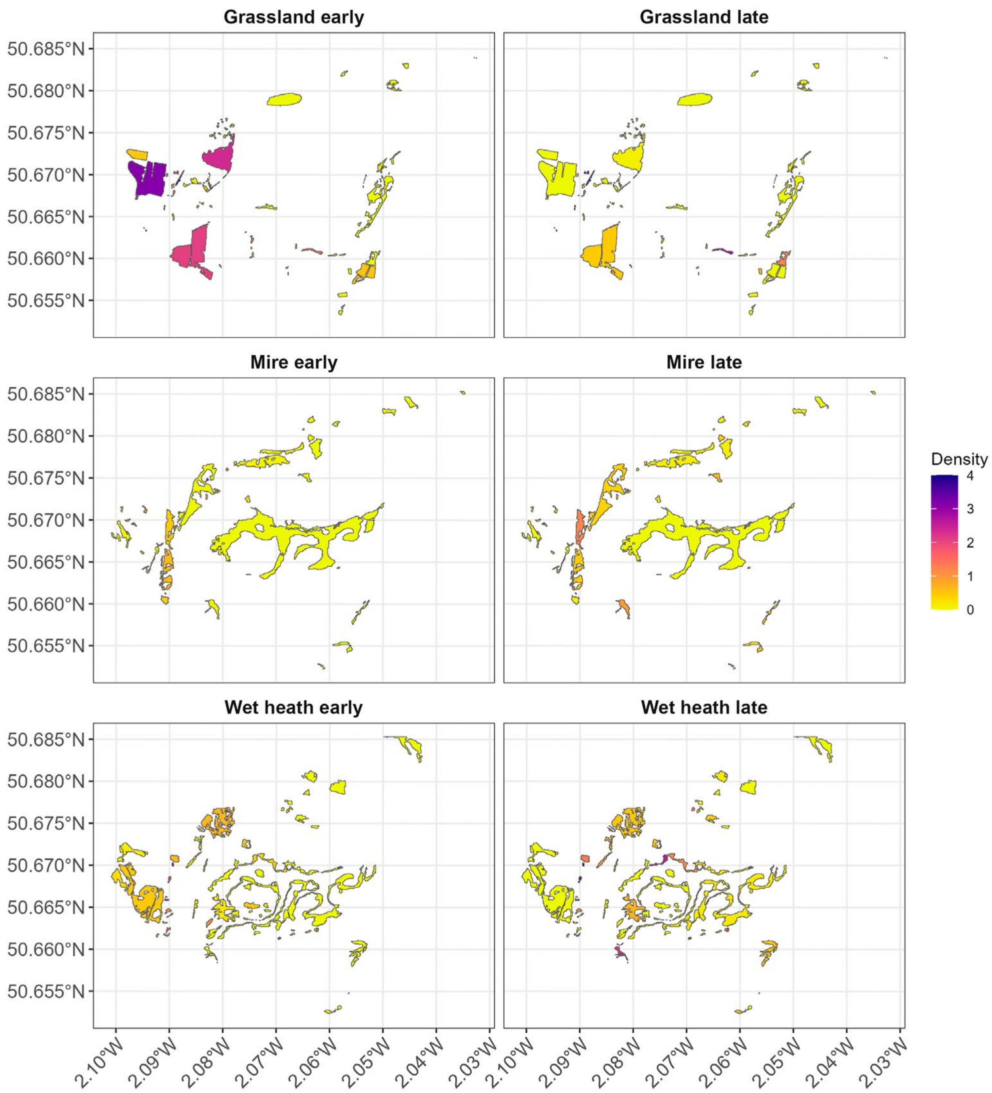

FIGURE 4 Density plot showing the use of habitat patches by cattle in the study site, with higher values denoting greater density of use by cattle, for three selected habitats. Density values were area-corrected to avoid bias from patch size. Each habitat type is represented by two seasonal plots. Because of the wide range of the data, values were scaled to a mean of zero and a standard deviation of one. The scale is truncated to a maximum of four (max value 11.13) to facilitate visualisation; 14 total patches (1.02% of patches) had a scaled density above this threshold.

investigate how spatial characteristics (e.g. patch size, isolation) influence habitat selection across seasons.

Preferred and avoided habitat types and the effects of patch characteristics were quantified in terms of their relative attraction to livestock using both step-selection functions (Figure 5) and resource-selection functions (Figure 6). By splitting the data into discrete time periods, it also identifies how preferences change between time periods.

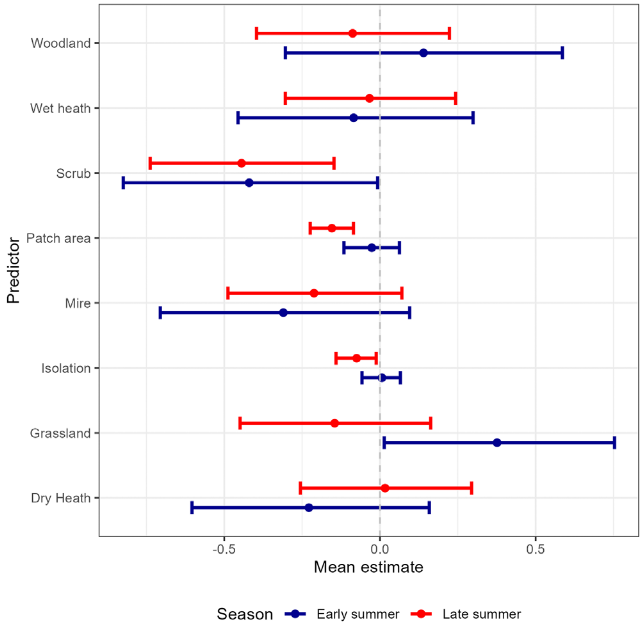

FIGURE 5 Results of the step-selection function analysis showing estimates for preference or low affinity by cattle. Habitats that have estimates and 95% confidence intervals above zero demonstrate preference for a habitat type, while values below zero suggest low affinity for a habitat. For habitat patch characteristics 'patch area' and 'isolation', lower values denote selection for smaller and less isolated patches.

4 | DISCUSSION

Cattle and other livestock often range over large areas, and understanding their decision-making within a landscape would require managers to have detailed information. This level of detail is difficult to accomplish through direct observation (which can potentially interfere with normal behaviours), while the growing use of GPS technology can bring major benefits if data can be analysed effectively (Löttker et al., 2009). Our workflow provides scientific rigour to spatial ecology data collected from free-ranging livestock. We present a structured workflow to assist conservation managers in visualising and extracting critical information about grazing animals, and we demonstrate its effectiveness using data from free-ranging cattle. Our analysis highlights significant seasonal variation in the spatial movement and habitat use of a conservation grazing herd. These findings offer valuable insights that can guide the effective management and strategic deployment of grazing animals for conservation purposes.

4.1 | Workflow question one: How far do free-ranging large herbivores move and does this vary with season?

Understanding space use can prevent overgrazing in sensitive areas and ensure that underutilised areas receive adequate grazing. Knowing where livestock spend their time can guide interventions such as relocating salt licks, water sources or fencing to direct grazing pressure. The dBBMM analysis in our case study revealed that in late summer from mid-July onwards, the space used by individual cattle increased. Despite larger areas being used overall, the distance between consecutive cattle locations was generally shorter during the late summer. This provides an example of how analysis from the workflow may provide a manager with new insights into processes governing the welfare of cattle and/or their value as habitat management tools. In our case study, cattle may have been moving shorter distances to keep cool, or this may represent energy conservatism resulting from reduced food availability.

Visualising accurate estimates of space used gives managers the opportunity to see where livestock have been spending their time and adding a seasonal dynamic to this allows for the determination of the most effective periods to put livestock on the land to accomplish different objectives. For example, cattle in Mediterranean grassland paddocks spent less time grazing during August when food was scarcer than in spring and early summer (Henkin et al., 2012). Grazing became more uniform across the area as herbage mass decreased. Indeed, both cattle and sheep (*Ovis aries*) have been shown to graze larger areas during periods in the late dry season when forage is scarce compared with the early wet season (Launchbaugh & Howery, 2005). This may be due to increased food scarcity during the hotter months of the summer. This may force cattle to graze less favoured habitats and so enhance their benefits as grazing management tools for these habitats. While we were unable to weigh the cattle, the grazier reported that the herd generally appeared to lose weight during the late summer. Analysis from our workflow enables the monitoring of underlying shifts in behaviour of cattle and allows the herd manager to identify where grazing has been focussed. This informs decisions on conservation grazing benefits versus welfare concerns.

4.2 | Workflow question two: Which habitats do the cattle prefer when grazing, and does patch size and isolation influence selection?

Resource availability, distribution and quantity all affect the behaviour of keystone herbivores (Fuhlendorf et al., 2018). Our workflow allows land managers to track whether livestock are using target habitats that are essential for conservation objectives (e.g. species-rich grasslands or wetlands). Using our workflow to determine these preferences in individual herds provides land managers with quantitative data to communicate with stakeholders (e.g. conservation organisations, farmers, or the public) about how conservation grazing is achieving ecological benefits. It helps to plan for changing conditions by monitoring how livestock respond to seasonal or climatic shifts in habitat availability and forage quality.

In our case study, the results of our resource-selection functions (RSF) suggested that during the early summer, cattle strongly selected for grassland, demonstrating a reliance on this resource as food. This model also suggested that in the late summer (which

BRITISH ECOLOGICAL SOCIETY Ecological Solutions and Evidence

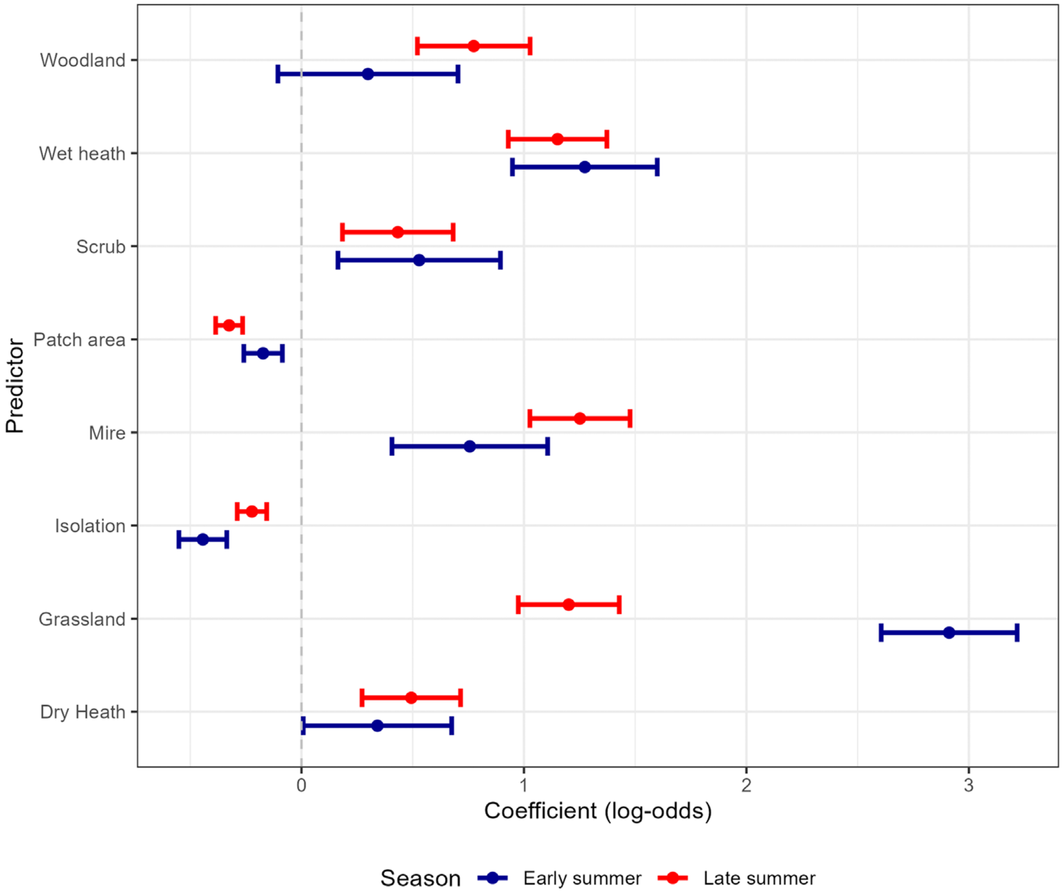

FIGURE 6 Results of the resource-selection function comparing cattle locations from observed data with locations simulated randomly throughout the study area. A positive log-odds value suggests that the habitat type is positively associated with selection, while negative log odds values suggest low affinity. For habitat patch characteristics 'patch area' and 'isolation', lower values denote selection for smaller and less isolated patches. Model intercept values: Early summer: Estimate = −6.13 (95% CI −6.78, −5.47) and −5.25 (95% CI −5.79, −4.72).

was very hot and dry), cattle were seeking wet heathland, behaviour likely related to foraging and keeping cool. Cattle are known to consume twigs from trees when other forage is less abundant (Cromsigt et al., 2018), an increase in space use in late summer likely reflects the cattle seeking new sources of food when the grass had become dry. This resource use pattern is in-keeping with Asturiana de los Valles cattle from Spain, which reduced their use of improved grasslands when the availability of pasture was lower during the late summer (Ferreira et al., 2013). The RSF results also suggested that mire and grassland were preferred by cattle during the latter part of the summer whereas the step-selection function (SSF) results did not. The difference between the results of the two approaches likely reflects the fact that the SSF models movement based on a per-step basis, compared to the random locations used by the RSF. The SSF is therefore likely to be more nuanced, as it provides insight into fine-scale spatial and temporal animal movements, while the RSF provides a coarser view of habitat preferences. Together, these complementary approaches offer a more complete understanding of how cattle respond to seasonal changes in resource availability.

Our analyses can be employed by land managers to determine which habitats are being used by grazing livestock in their system and how this might change with the type of livestock or season. Managers may select breeds of livestock that comply with traditional practices, but biodiversity outcomes may be better with other breeds (Rook & Tallowin, 2003). Similarly, the dietary choices of livestock will change over time (Rivero et al., 2021) and by using outputs from our workflow to refine the periods during which the landscape is grazed according to animal behaviour, managers can increase the likelihood that grazing animals are successful in bringing about conservation management outcomes.

Every landscape contains a different mosaic of habitats, and this configuration will impact the ability and willingness of cattle to utilise certain features of the habitat. Our workflow allows managers to determine how these influence selection by livestock and decide whether some landscape-scale habitat management intervention, for example removal of features such as woodland, is likely to help increase ranging movement by removing a barrier (Wolański et al., 2021), or decrease it by removing shade (De-Sousa et al., 2023). In our case study, there was consistent selection for smaller patches of desired habitat by cattle across both seasons examined which indicates the importance of specific habitat type in driving movements compared to the availability of large areas of less desired habitat.

Our workflow provides a way for managers to assess how patch characteristics influence selection in their system. Both step-selection and resource-selection models indicated that cattle showed preference for patches, which were less isolated. This demonstrated that cattle in our case study showed a general unwillingness to travel to isolated patches when less isolated patches of the same habitat are available. This is in keeping with cattle behaving in an energy efficient manner, maximising access to resources while reducing the time spent travelling and thus energy expenditure (Bailey et al., 1996). According to the resource-selection function, cattle were more willing to use isolated patches during the late summer. This is the period during which they were seeking a wider variety of habitats to meet their nutritional needs and were searching further afield.

5 | CONCLUSIONS

The growing use of conservation grazing herds as management strategies for natural areas, combined with the increasing affordability of telemetry devices, has heightened interest in livestock behaviour under these regimes. By using our workflow, we demonstrated that cattle in our case study altered their habitat preferences and movement behaviour seasonally within a dynamic landscape matrix. Our spatial analysis workflow provides land managers and researchers with key insights into space use and habitat selection based on remotely collected data.

AUTHOR CONTRIBUTIONS

All authors conceived ideas, contributed critically to drafts and gave final approval for publication; Tom Major designed the method and led the writing of the manuscript. Data were processed and analysed in conjunction with Antonio Uzal.

ACKNOWLEDGEMENTS

We thank David Brown at the National Trust for funding the GPS collars, and Jake and Chrissy Hancock of Wessex Grazing for deploying them on their cattle.

FUNDING INFORMATION

Funding was provided by Bournemouth University.

CONFLICT OF INTEREST STATEMENT

There are no conflicts of interest.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1002/2688-8319.70275.

DATA AVAILABILITY STATEMENT

All data and code are available from https://figshare.com/s/263e9b1bfdd351d833bf (Major & Uzal, 2026).

ORCID

Tom Major https://orcid.org/0000-0002-0351-6593
Anita Diaz https://orcid.org/0000-0002-2368-0630

REFERENCES

Bailey, D. W., Gross, J. E., Laca, E. A., Rittenhouse, L. R., Coughenour, M. B., Swift, D. M., & Sims, P. L. (1996). Mechanisms that result in large herbivore grazing distribution patterns. *Journal of Range Management*, *49*, 386. https://doi.org/10.2307/4002919

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*, 1–48. https://doi.org/10.18637/jss.v067.i01

Bengtsson, J., Angelstam, P., Elmqvist, T., Emanuelsson, U., Folke, C., Ihse, M., Moberg, F., & Nyström, M. (2021). Reserves, resilience and dynamic landscapes 20 years later. *Ambio*, *50*, 962–966. https://doi.org/10.1007/s13280-020-01477-8

Calenge, C. (2006). The package "adehabitat" for the R software: A tool for the analysis of space and habitat use by animals. *Ecological Modelling*, *197*, 516–519. https://doi.org/10.1016/j.ecolmodel.2006.03.017

Chatters, C. (2021). *Heathland*. Bloomsbury Publishing.

Cromsigt, J. P. G. M., Kemp, Y. J. M., Rodriguez, E., & Kivit, H. (2018). Rewilding Europe's large grazer community: How functionally diverse are the diets of European bison, cattle, and horses? *Restoration Ecology*, *26*, 891–899. https://doi.org/10.1111/rec.12661

de Weerd, N., van Langevelde, F., van Oeveren, H., Nolet, B. A., Kölzsch, A., Prins, H. H. T., & de Boer, W. F. (2015). Deriving animal behaviour from high-frequency GPS: Tracking cows in open and forested habitat. *PLoS One*, *10*, e0129030. https://doi.org/10.1371/journal.pone.0129030

De-Sousa, K. T., Deniz, M., Hill, J. A. G., Dittrich, J. R., & Hötzel, M. J. (2023). Tree arrangements for silvopastoral system: Livestock advisors' knowledge and attitudes. *Agroforestry Systems*, *97*, 1143–1156. https://doi.org/10.1007/s10457-023-00853-z

Ferreira, L. M. M., Celaya, R., Benavides, R., Jáuregui, B. M., García, U., Sofia Santos, A., Rosa García, R., Rodrigues, M. A. M., & Osoro, K. (2013). Foraging behaviour of domestic herbivore species grazing on heathlands associated with improved pasture areas. *Livestock Science*, *155*, 373–383. https://doi.org/10.1016/j.livsci.2013.05.007

Fuhlendorf, S. D., Davis, C. A., Elmore, R. D., Goodman, L. E., & Hamilton, R. G. (2018). Perspectives on grassland conservation efforts: Should we rewild to the past or conserve for the future? *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *373*, 20170438. https://doi.org/10.1098/rstb.2017.0438

Gorghiu, G., Bîzoi, M., Gorghiu, L. M., Buruleanu, C. L., & Suduc, A.-M. (2024). Rewilding as a multifaceted concept and emerging approach: The Romanian experience. *Sustainability*, *16*, 1645. https://doi.org/10.3390/su16041645

Hart, E. E., Haigh, A., & Ciuti, S. (2023). A scoping review of the scientific evidence base for rewilding in Europe. *Biological Conservation*, *285*, 110243. https://doi.org/10.1016/j.biocon.2023.110243

Henkin, Z., Ungar, E. D., & Dolev, A. (2012). Foraging behaviour of beef cattle in the hilly terrain of a Mediterranean grassland. *The Rangeland Journal*, *34*, 163–172. https://doi.org/10.1071/RJ11096

Herlin, A., Brunberg, E., Hultgren, J., Högberg, N., Rydberg, A., & Skarin, A. (2021). Animal welfare implications of digital tools for monitoring and Management of Cattle and Sheep on pasture. *Animals*, *11*, 829. https://doi.org/10.3390/ani11030829

Hesselbarth, M. H. K., Sciaini, M., With, K. A., Wiegand, K., & Nowosad, J. (2019). Landscapemetrics: An open-source R tool to calculate landscape metrics. *Ecography*, *42*, 1648–1657. https://doi.org/10.1111/ecog.04617

Hijmans, R. J., Bivand, R., Edzer, P., & Sumner, M. D. (2023). Package 'terra.'.

Hijmans, R. J., Van Etten, J., Cheng, J., Mattiuzzi, M., Sumner, M., Greenberg, J. A., Lamigueiro, O. P., Bevan, A., Racine, E. B., & Shortridge, A. (2015). Package 'raster.'. R package 734:473.

Hodges, C. W., Marshall, B. M., JGH, I., & Strine, C. T. (2022). Malayan kraits (*Bungarus candidus*) show affinity to anthropogenic structures in a human dominated landscape. *Scientific Reports*, *12*, 7139.

Johnson, C. J., Nielsen, S. E., Merrill, E. H., Mcdonald, T. L., & Boyce, M. S. (2006). Resource selection functions based on use–availability data: Theoretical motivation and evaluation methods. *Journal of Wildlife Management*, *70*, 347–357. https://doi.org/10.2193/0022-541X(2006)70[347:RSFBOU]2.0.CO;2

Köhler, M., Schmidt, A., Hölzel, N., Baasch, A., & Tischew, S. (2023). Positive long-term effects of year-round horse grazing in orchid-rich dry calcareous grasslands–results of a 12-year study. *Frontiers in Ecology and Evolution*, *11*, 1107987. https://doi.org/10.3389/fevo.2023.1107987

Kranstauber, B., Kays, R., LaPoint, S. D., Wikelski, M., & Safi, K. (2012). A dynamic Brownian bridge movement model to estimate utilization distributions for heterogeneous animal movement. *Journal of Animal Ecology*, *81*, 738–746. https://doi.org/10.1111/j.1365-2656.2012.01955.x

Kranstauber, B., Safi, K., & Bartumeus, F. (2014). Bivariate gaussian bridges: Directional factorization of diffusion in Brownian bridge models. *Movement Ecology*, *2*, 5. https://doi.org/10.1186/2051-3933-2-5

Kranstauber, B., Smolla, M., & Scharf, A. K. (2022). move: Visualizing and Analyzing Animal Track Data.

Launchbaugh, K. L., & Howery, L. D. (2005). Understanding landscape use patterns of livestock as a consequence of foraging behavior. *Rangeland Ecology & Management*, *58*, 99–108. https://doi.org/10.2111/03-146.1

Lawton, J. (2011). Making space for nature. *Environmental Law Review*, *13*, 1.

Löttker, P., Rummel, A., Traube, M., Stache, A., Šustr, P., Müller, J., & Heurich, M. (2009). New possibilities of observing animal behaviour from a distance using activity sensors in Gps-collars: An attempt to calibrate remotely collected activity data with direct Behavioural observations in Red Deer *Cervus elaphus*. *Wildlife Biology*, *15*, 425–434. https://doi.org/10.2981/08-014

Lovász, L., Korner-Nievergelt, F., & Amrhein, V. (2024). Natural grazing by horses and cattle promotes bird diversity in a restored European alluvial grassland. *PeerJ*, *12*, e17777. https://doi.org/10.7717/peerj.17777

Major, T., & Uzal, A. (2026). Cattle spatial ecology workflow. https://doi.org/10.6084/m9.figshare.29072666.v1

McClintock, B. T., & Michelot, T. (2018). momentuHMM: R package for generalized hidden Markov models of animal movement. *Methods in Ecology and Evolution*, *9*, 1518–1530. https://doi.org/10.1111/2041-210X.12995

Millspaugh, J. J., Nielson, R. M., McDONALD, L., Marzluff, J. M., Gitzen, R. A., Rittenhouse, C. D., Hubbard, M. W., & Sheriff, S. L. (2006). Analysis of resource selection using utilization distributions. *Journal of Wildlife Management*, *70*, 384–395. https://doi.org/10.2193/0022-541X(2006)70[384:AORSUU]2.0.CO;2

Morton, R. D., Marston, C. G., O'Neil, A. W., & Rowland, C. S. (2021). Land Cover Map 2020 (land parcels, GB). EIDC.

Muff, S., Signer, J., & Fieberg, J. (2019). Accounting for individual-specific variation in habitat-selection studies: Efficient estimation of mixed-effects models using Bayesian or frequentist computation. *Journal of Animal Ecology*, *89*, 80–92. https://doi.org/10.1111/1365-2656.13087

QGIS Development Team. (2023). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

R Core Team. (2022). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Rivero, M. J., Grau-Campanario, P., Mullan, S., Held, S. D. E., Stokes, J. E., Lee, M. R. F., & Cardenas, L. M. (2021). Factors affecting site use preference of grazing cattle studied from 2000 to 2020 through GPS tracking: A review. *Sensors*, *21*, 2696. https://doi.org/10.3390/s21082696

Rook, A. J., & Tallowin, J. R. B. (2003). Grazing and pasture management for biodiversity benefit. *Animal Research*, *52*, 181–189. https://doi.org/10.1051/animres:2003014

Rue, H., Martino, S., & Chopin, N. (2009). Approximate Bayesian inference for latent gaussian models by using integrated nested Laplace approximations. *Journal of the Royal Statistical Society, Series B: Statistical Methodology*, *71*, 319–392. https://doi.org/10.1111/j.1467-9868.2008.00700.x

Signer, J., Fieberg, J., & Avgar, T. (2019). Animal movement tools (amt): R package for managing tracking data and conducting habitat selection analyses. *Ecology and Evolution*, *9*, 880–890. https://doi.org/10.1002/ece3.4823

Silva, I., Crane, M., Marshall, B. M., & Strine, C. T. (2020). Reptiles on the wrong track? Moving beyond traditional estimators with dynamic Brownian bridge movement models. *Movement Ecology*, *8*, 1–13. https://doi.org/10.1186/s40462-020-00229-3

Silva, I., Crane, M., Suwanwaree, P., Strine, C., & Goode, M. (2018). Using dynamic brownian bridge movement models to identify home range size and movement patterns in king cobras. *PLoS One*, *13*, 1–20. https://doi.org/10.1371/journal.pone.0203449

Smith, S. N., Jones, M. D., Marshall, B. M., Waengsothorn, S., Gale, G. A., & Strine, C. T. (2021). Native Burmese pythons exhibit site fidelity and preference for aquatic habitats in an agricultural mosaic. *Scientific Reports*, *11*, 1–13. https://doi.org/10.1038/s41598-021-86640-1

Soder, K. J., Gregorini, P., Scaglia, G., & Rook, A. J. (2009). Dietary selection by domestic grazing ruminants in temperate pastures: Current state of knowledge, methodologies, and future direction. *Rangeland Ecology & Management*, *62*, 389–398. https://doi.org/10.2111/08-068.1

Stewart, G. B., & Pullin, A. S. (2008). The relative importance of grazing stock type and grazing intensity for conservation of mesotrophic 'old meadow' pasture. *Journal for Nature Conservation*, *16*, 175–185. https://doi.org/10.1016/j.jnc.2008.09.005

Tofastrud, M., Devineau, O., & Zimmermann, B. (2019). Habitat selection of free-ranging cattle in productive coniferous forests of south-eastern Norway. *Forest Ecology and Management*, *437*, 1–9. https://doi.org/10.1016/j.foreco.2019.01.014

Troiano, C., Buglione, M., Petrelli, S., Belardinelli, S., De Natale, A., Svenning, J.-C., & Fulgione, D. (2021). Traditional free-ranging livestock farming as a management strategy for biological and cultural landscape diversity: A case from the southern Apennines. *Land*, *10*, 957. https://doi.org/10.3390/land10090957

Versluijs, E., Tofastrud, M., Hessle, A., Serrouya, R., Scasta, D., Wabakken, P., & Zimmermann, B. (2024). Virtual fencing in remote boreal forests: Performance of commercially available GPS collars for free-ranging cattle. *Animal Biotelemetry*, *12*, 33. https://doi.org/10.1186/s40317-024-00389-8

Webb, N. r. (1998). The traditional management of European heathlands. *Journal of Applied Ecology*, *35*, 987–990. https://doi.org/10.1111/j.1365-2664.1998.tb00020.x

Wickham, H., François, R., Henry, L., Müller, K., & Davis, V. (2022). dplyr: A Grammar of Data Manipulation.

Wolański, P., Bobiec, A., Ortyl, B., Makuch-Pietraś, I., Czarnota, P., Ziobro, J., Korol, M., Havryliuk, S., Paderewski, J., & Kirby, K. (2021). The importance of livestock grazing at woodland-grassland interface in the conservation of rich oakwood plant communities in temperate Europe. *Biodiversity and Conservation*, *30*, 741–760. https://doi.org/10.1007/s10531-021-02115-9

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Figure S1. Frequency density plot of cattle step lengths, with logarithmic scale. Step length represents the Euclidean distance between two successive cattle locations. Step lengths were on average significantly longer during the early summer.

Table S1. Results of the step-selection functions applied to cattle movement data during early and late summer.

Table S2. Results of the resource-selection functions on cattle location data during both early and late summer.

How to cite this article: Major, T., Uzal, A., Hill, R. A., & Diaz, A. (2026). A spatial analysis workflow to derive landscape-scale conservation management information from GPS-monitored grazing livestock. *Ecological Solutions and Evidence*, *7*, e70275. https://doi.org/10.1002/2688-8319.70275