

Stakeholder preferences for breeding wader conservation in the Somerset Levels

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2024-11-08

Summary

This report presents the outputs from stakeholder workshops that aimed to explore where lowland wader conservation would preferably be carried out within four landscapes (Norfolk Broads, North Kent, Essex and the Somerset Levels). For each landscape, we held a workshop with a varied group of local stakeholders that were broadly divided into three groups: conservationists, public bodies and land managers. During the workshops each stakeholder group created a series of guidelines that could be used to identify areas within the landscape where wader conservation would be preferentially targeted or avoided. As part of the workshops we also introduced participants to three key components of the “Lawton principles of nature restoration” ([Lawton et al. 2010](#)), i.e. improving the quality of current wildlife sites by better management ('better'), increasing the size of current wildlife sites ('bigger'), and creating new wildlife sites ('more'). This was to allow stakeholders to make their guidelines specific to different principles, thereby trying to transition from theory to practical conservation. Using the guidelines generated in each workshop we generated spatial graded layers that were then combined to rank land in order of preference for each landscape and (where possible) each stakeholder group. These heat maps indicate where wader conservation would be most preferred within each landscape under each of the three Lawton principles.

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Introduction

Many areas across England have been heavily modified by humans and contain a mixture of land uses and semi-natural habitats ([Song et al. 2018](#)). Modified landscapes often harbor important biodiversity, but ongoing intensification of land management threatens what biodiversity remains ([Raven and Wagner 2021](#); [Donald, Green, and Heath 2001](#)). Due to a variety of different land uses in modified landscapes, restoration of biodiversity must compete with numerous other objectives such as, food and timber production, energy production, water resource management and urbanization ([Chazdon et al. 2016](#)). Restoring biodiversity at larger scales must therefore carefully balance multiple objectives and working alongside the people living and working in the landscape is an integral part of this process. Involving local stakeholders from the start of ecological restoration and adapting the process along the way with ongoing engagement can help lead to higher levels of mutual understanding as well enhancing mutual benefits ([Gamborg, Morsing, and Raulund-Rasmussen 2019](#)).

Lowland breeding waders across Europe (order *Charadriiformes*) declined during the 20th century ([Roodbergen, Werf, and Hötker 2011](#)) due to loss and degradation of their preferred habitat, floodplain and coastal grasslands. Habitat was lost due land use change and remaining areas became degraded due to drainage (reduced prey availability, ([Eglington et al. 2010](#))); increased stocking and earlier more frequent mowing (nest and brood destruction, ([Sabatier, Doyen, and Tichit 2010](#))); and increased meso-predator density (eggs and chick predation, ([Roos et al. 2018](#))). Across much of Europe efforts to restore populations have taken two main avenues:

1. creation of Protected Areas (PA) through statutory protection (e.g. Sites of Special Scientific Interest, SSSI) and nature reserves. On nature reserves specifically, high-quality breeding habitat is often created through rewetting ([Eglington et al. 2010](#)), appropriate grazing management ([Verhulst et al. 2011](#)) and predator exclusion with fences ([Malpas et al. 2013](#)). Statutory protection (specifically SSIs) on its own provides weaker benefits to breeding waders ([Smart et al. 2014](#)) Hawkes et al in press.
2. use of agri-environment schemes on farmed land where payments support bespoke wader-focused measures like that of reserves, but generally lacking predator fences. This produces lesser quality habitat ([Smart et al. 2014](#)) but it is cheaper to create and maintain and often fits in with the existing land user operations (e.g. beef cattle farming and hay/silage cutting).

Despite widespread uptake of AES and reserve/PA creation, populations of lowland breeding waders have still declined across Europe ([Franks et al. 2018](#)). Suggesting improvements in efficacy or further increases in scale are needed to prevent further population declines. The ‘Making Space for Nature’ report ([Lawton et al. 2010](#))

set out a spatial targeting approach for landscape-scale restoration that was distilled down to four words, ‘better, bigger, more and joined’. Based off the summation of a substantial body of scientific work this report recommended these actions in order of priority: (1) improving the quality of existing habitat, (2) increasing the size and (3) number of sites, and (4) enhancing connectivity among sites for conservation. This provides a starting framework but there are important trade-offs between strategies imposed by limited resources, land, and surrounding context (e.g. wider land-uses, levels of fragmentation and biogeographic context). We focused on the first three principles during workshops as wading birds can likely readily disperse between the existing habitat patches within our landscapes of interest ([Jackson 1994](#)).

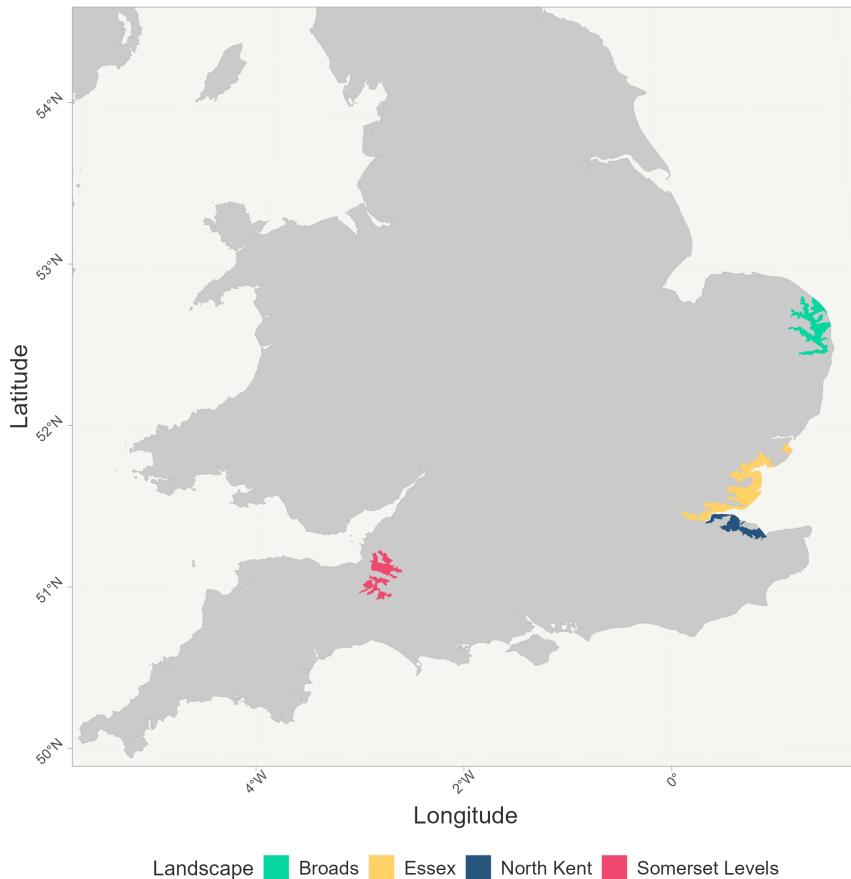


Figure 1: Map of the four case-study landscapes from this study. Essex and North Kent were formerly part of the same “priority landscape” but split due to differing characteristics and geographic separation.

We ran stakeholder workshops across four different landscapes to understand where it is possible to deploy these strategies according to people who live and work in the area, thereby trying to link theory to real world situations and landscapes. We focus on three



different ‘priority landscapes’ (formerly known as Environmentally Sensitive Areas, ([Natural England 2024](#))): Somerset Levels; Norfolk Broads (hereafter Broads); and Greater Thames (see Figure 1). We subsequently split the Greater Thames landscape up into North Kent and Essex owing to differing land uses and geographic separation. We chose these landscapes as they hold important populations of breeding waders in a national context ([Wilson et al. 2005](#)) but also have different characteristics (e.g. soil types, land use compositions, wading bird assemblages, uptake of AES and lowland wet grassland distribution, see Table 1 for landscape specific details). For North Kent, Essex and the Broads we focus on Lapwing *Vanellus vanellus* and Redshank *Tringa totanus* during the workshops and for the Somerset Levels we focused on Lapwing and Snipe *Gallinago gallinago*. We focused on these species as they were the predominant breeding wader species in each landscape. Curlews are a key part of the breeding wader assemblage in the Somerset Levels but there were too few survey records to build a model that predicted abundance, which was a key aspect of the wider project.

Extensive breeding wader surveys were conducted in each landscape in 2021-22 as part of the national breeding wader of wet meadows survey. Up to three visits during the breeding season were made to lowland wet grassland fields (areas below 200m altitude subject to freshwater flooding and water logging) with wading bird abundance and habitat characteristics recorded. An optional fourth ‘dusk’ visit was also undertaken where Snipe breeding was suspected. As part of the wider project, the four selected landscapes also received further visits in 2023 to survey areas that were missed in 2021-22.

Methods

Workshop Aim

To create a map of future opportunity for wader conservation for each stakeholder group within each landscape.

This can consist of preferences of where wader conservation could occur as well as defining areas where wader conservation should be avoided. These preferences can also be linked to specific nature restoration strategies (better, bigger, more) and where arable land could be reverted back to lowland wet grassland so that the map of future opportunity can vary depending on the strategy.



Table 1: Characteristics for each of the four case study landscapes. The breeding pairs for each landscapes were estimated from the breeding waders of wet meadows survey. The total hectarage for AES excludes reserves that also have AES agreements.

	Broads	Essex	North Kent	Somerset
Total Area (ha)	43,138	72,342	22,798	30,905
Reserve LWG area (ha)	1,151	1,636	2,151	1,204
AES only LWG area (ha)	5,068	1,279	1,976 ha	3,078
LWG type	Floodplain	Coastal	Coastal	Floodplain
Land use	Mixed arable & grassland	Mainly arable, some grassland	Mainly grassland, some arable	Mainly grassland
Soil Type	Mixed mineral & organic	Mainly mineral	Mainly mineral	Mainly organic, some mineral
Breeding Pairs	775	825	1575	225
Predominant Species	Lapwing/ Redshank	Lapwing/ Redshank	Lapwing/ Redshank	Snipe

Workshop Attendees

We ran four regional workshops and we aimed to have three different stakeholder groups attend each workshop. The three different groups (and organisations invited) were:

- Conservationists (RSPB, Wildlife Trust, Wildfowl and wetland trust and Private nature reserves)
- Public bodies (Natural England, Environment Agency, Internal drainage board, Local Authorities, Ministry of Defense, regional Farming and Wildlife Advisory Group rep)
- Land managers (land owners, farmers, tenant farmers)

These groups were created to align participants in terms of background. This helped to drive more productive group discussions and made it more likely that a consensus would be reached during group activities. The people invited to the workshops were largely already known to regional RSPB members of staff. This may slightly bias the group of people that attended towards those with more of an understanding and preference for conservation. This could have particularly affected the land managers group, for example some tenant farmers rent RSPB land for cattle grazing or carry out wader friendly management on their own farm. This could result in outputs are not fully representative of the wider stakeholder group. Overall, we felt that this bias



Table 2: Workshop attendance for the three different stakeholder groups across the four priority landscapes. Note if only one member of a stakeholder group attended a workshop then this individual was generally moved into one of the other groups. Number of attendees for each group is shown in brackets.

Landscape	Conservationists	Public Bodies	Land Managers
Broads	Y (5)	Y (7)	
Kent	Y (5)		Y (7)
Essex	Y (7)		Y (7)
Somerset	Y (7)	Y (6)	Y (8)

was tolerable and that a group of more like minded participants would lead to more productive conversations and ultimately result in more usable outputs.

In the end it was not possible to run all three group of stakeholders in each priority landscape, apart from the Somerset Levels. We were only able to run the activities with two groups in three of the landscapes, see Table 2 for a breakdown of group attendance.

Workshop Activities

In each workshop we gave an introductory presentation followed by three stakeholder-led activities. The introductory presentation was in two parts. Initially we presented the results from the 2021/22 breeding waders of wet meadow survey, including the influence of habitat and land management on breeding populations and the distribution of populations within the landscape. Maps were also provided to participants to show the distribution of breeding wader populations and the layout of different land uses within the priority landscape. Throughout all activities, we told participants to focus on land within the priority landscape; that the conservation of Lapwing and Redshank was a priority (Lapwing and Snipe in the Somerset Levels); and to imagine what could be possible in the year 2050.

After the presentation we ran three activities. We show below how each task was presented to participants during the workshops.

- Activity 1
 - For each wader habitat intervention card discuss the challenges and opportunities. These can be associated with certain areas, land-uses, farming practices, costs/funding or practicalities. Mediators will record your discussion on the back of each card.



- After the cards provided record any other interventions on the blank cards provided and discuss their challenges/opportunities.
 - The cards depicted the following interventions or management strategies for breeding waders: keeping standing water throughout spring; foot drain/scrape creation for wet surface features; grazing to create a varied sward; rush control; delayed cutting on hay/silage fields; predator exclusion using fences; and predator control.
- Activity 2
 - Discuss any goals for breeding waders. For example, how many waders, in the landscape and which species?
 - Are there existing landscape plans that could influence breeding waders?
 - Choose conservation strategies and rank them (better, bigger, more and arable reversion). If you can't rank strategies choose priority ones.
 - Activity 3
 - Create guidelines for where each strategy can (preference) and can't (avoidance) be used.
 - Mention any data sources that could be used to create the guidelines. Are there specific cut-off points associated with any of the guidelines?

Activity 1 was designed as a primer activity and while we recorded the main points of discussions within stakeholder groups there were no main outputs from this activity. This activity was designed to initiate conversations about wader conservation and the challenges and opportunities in its implementation. This activity helped spark ideas for further activities as it identified where management for breeding waders would be the easiest or hardest to implement (see activity 3).

Activity 2 was designed as another primer activity but we planned that some of these tasks would feed into other aspects of this project (i.e. scenario modelling). Participants discussed goals for breeding waders and identified existing plans that these discussion fed into the scenario modelling part of the project. Participants also discussed and ranked conservation strategies which was used as a primer for the final task so stakeholders could discuss where their priorities lay between the following conservation strategies: 1) improving existing breeding wader sites (better); 2) expanding existing wader sites (bigger); 3) creating new sites for breeding wader (more); and 4) converting arable land to lowland wet grassland for breeding waders. Although arable reversion is not a Lawton principle, it was defined as a separate option here because stakeholder preferences for wet grassland creation could markedly differ between existing unsuitable grassland and arable land, i.e. preferring reversion of arable land on peaty soils or specific crop types.

Activity 3 generated the main outputs presented in this report and stakeholder generally spent more time on this task than on the other two activities combined. The



purpose of this task was for stakeholders to create preferences or avoidance guidelines for where breeding wader conservation could or could not occur within the landscape. Preferences were guidelines that could essentially grade the land into areas of differing favorability, e.g. prefer breeding wader conservation on lower lying land. Avoidance rules mapped out where wader conservation would not be carried out, e.g. avoiding areas of priority habitat lowland fen. Preferences could also be linked to one, multiple or all the conservation strategies outlined in activity 2 (i.e. better, bigger, more, arable reversion). For example, preferring conservation efforts in the smallest existing breeding populations first was linked to the improving existing wader strategy (better), whereas preferring conservation efforts on lower lying land was often associated with all of the conservation strategies. All avoidance guidelines created applied to all the conservation strategies. During stakeholder discussions there was filtering of guidelines by the facilitator to remove any guidelines that we would not be able to map out spatially. If there was any doubt, then the guideline was recorded and if it could not be used then a full explanation is provided in the appendix.

Compiling Preferences

For each landscape and stakeholder group combination we produced heat maps for the main conservation strategies, better, bigger and more. We also produced heat maps for the bigger and more strategies being realized through arable reversion which involved combining the guidelines for arable reversion and bigger or more. In total, for any stakeholder group this meant the creation of 5 different heat maps.

Each guideline was mapped out onto a 25m x 25m base raster. Each preference guideline became a continuous raster with pixels given a value between 0 (least preferred) and 1 (most preferred) and avoidance rules became a binary raster of 0 (no avoidance) and 1 (avoid). Next, for each 25m x 25m cell, preference rules were subsequently aggregated (summed) to produce an overall preference score. Note, for simplicity, individual preference rules were treated as equal with no form of weighting applied. Last, any cells that were classified as 1 for any of the avoidance rules were excluded from the opportunity area, irrespective of their preference score. A 25m x 25m pixel size was chosen as this is the resolution of the UKCEH land cover maps ([Marston et al. 2022](#)) that was used to identify areas of suitable grassland and arable land for lowland wetland creation (see following section). For the creation of each graded raster including the manipulation, processing and analysis we used the packages *sf* ([Pebesma 2018](#)) and *terra* ([Hijmans 2024](#)) in the programming language R ([R Core Team 2023](#)).



Defining Conservation Strategy Extent

For each conservation strategy there were only certain areas within the landscapes where the strategy could be realized. For all strategies, creation of lowland wet grassland for breeding waders had to be carried out on land where this habitat could feasibly be created. Areas were often unsuitable due to topography, land use or soil type. For better, bigger and more strategies this land had to currently be some form of grassland. When any of these strategies were realized using arable reversion then the starting land use had to be arable. In addition, for the strategy to improve existing wader sites (better) we had to define where existing wader sites were within the landscape. Any areas outside of defined wader sites could be used to expand existing sites (bigger) or create more sites (more). We go into detail of how we define land that has the right characteristics to be lowland wet grassland; current arable land; and breeding wader sites below.

Defining candidate lowland wet grassland for restoration

We defined current grassland that has the right characteristics, i.e. elevation and soil type, to be areas where high quality lowland wet grassland could be created, regardless of its current condition. Therefore, this included current high-quality lowland wet grassland as well as dry grassland with drainage. This mapping exercise was done using a base raster with a resolution of 25 meters. Potential lowland wet grassland pixels included fields considered for survey from the 2021/2022 BWWM survey Hawkes et al in press. These fields were historically defined as periodically water-logged permanent grassland below 200 meters above sea level, including grazing marshes, flood meadows, man-made washlands, and water meadows. We supplemented this with areas of semi-natural grassland habitats (Coastal and floodplain grazing marsh; Good quality semi-improved grassland; Lowland meadows; and Purple moor grass and rush pastures) from the Natural England's priority habitat index ([Natural England 2022](#)). These supplementary areas also had to overlap with peaty or seasonally wet soils from the NATMAP soil vector data (see Table 3 for a full list of acceptable soil types ([NSRI 2022](#))) and be at an elevation below the 99.5th quantile of all elevation values within field included in the 2021/2022 BWWM survey (Hawkes et al in press). These criteria prevented fields at high elevations being included. Since both data sets were created more before the year of the study we masked out any pixels classified as non-grassland habitats from any of the UKCEH landcover datasets from 2021 ([Marston et al. 2022](#)), 2022 ([Marston et al. 2024](#)), or 2023 ([Morton et al. 2024](#)). Finally, we visually checked every map to remove obvious arable land, woodland, salt marsh, and golf courses.

In the Somerset Levels and Norfolk Broads in particular, small pockets of trees were not detected in the UKCEH land cover data sets. To remove all trees, we created a canopy model by subtracting the digital terrain model ([Environment Agency 2023a](#))



Table 3: List of soil types from the NATMAP vector of soil types that were to be seasonally wet or peaty soils

Soil types
Fen peat soils
Lime-rich loamy and clayey soils with impeded drainage
Loamy and clayey floodplain soils with naturally high groundwater
Loamy and clayey soils of coastal flats with naturally high groundwater
Loamy and sandy soils with naturally high groundwater and a peaty surface
Loamy soils with naturally high groundwater
Naturally wet very acid sandy and loamy soils
Raised bog peat soils
Slightly acid loamy and clayey soils with impeded drainage
Slowly permeable seasonally wet acid loamy and clayey soils
Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils

from the first pass digital surface model ([Environment Agency 2023b](#)) from the Environment Agency National Lidar Programme dataset. This canopy model had a resolution of 1 meter, which we transformed to our base resolution using nearest neighbor interpolation. We then used this layer to mask out any pixels with a canopy height greater than 2 meters.

Defining candidate arable land for restoration

To identify arable land that could be reverted to high quality lowland wet grassland we used a similar method to above. We first identified any land that overlapped with peaty or seasonally wet soils from the NATMAP soil vector data ([NSRI 2022](#)). This land also had to be at an elevation below the 99.5th quantile of all elevation values within field included in the 2021/2022 BWWM survey (Hawkes et al in press). We then identified arable pixels as any that were identified as arable in at least two of the UKCEH landcover datasets from 2021 ([Marston et al. 2022](#)), 2022 ([Marston et al. 2024](#)), or 2023 ([Morton et al. 2024](#)). Finally, we visually checked every map to remove obvious woodland, salt marsh, and golf courses and for the Somerset Levels and Norfolk Broads we used the same tree mask as described above.

Defining existing wader sites

There is no set definition of what an existing site for nature is, and it could be quantified using habitat type, habitat quality or the current distribution of species.



We took the approach that existing sites for breeding wader were the areas already occupied by breeding waders. We used field-level data from the breeding waders of wet meadows survey in 2021/22 and further gap filling surveys in 2023 to define breeding wader sites. A field was defined as occupied if the number of estimated breeding pairs of Lapwing, Redshank or Snipe in a field was greater than 1 (see ([Smart et al. 2014](#)) for pair estimation methods). We then created polygons around clusters of occupied fields and defined these as breeding wader sites. This clustering approach was used, instead of just using the occupied field centroids, as it allowed us to capture suitable fields recorded as unoccupied due to imperfect detection or factors other than habitat quality. For example, some large reserves have large areas of suitable habitat but not every single parcel is occupied by breeding waders. As we did not carry out breeding surveys over the entire landscapes, this approach could have missed some small breeding populations. However, for all four landscapes, all sites with known wader populations were surveyed unless access was denied. We consulted with regional conservationist and recording bodies to confirm that the surveys did not miss any previously known breeding populations. The full details of are clustering approach are detailed below.

We used the centroids of all occupied fields to run a K-means clustering analysis to identify distinct clusters of breeding wader fields within each of the four landscapes ([Figure 2](#)). This essentially creates k number of clusters while minimizing the within cluster sum of squares. We explored a range of different values for k between 2 and 25 and chose the one at the elbow of the relationship between within cluster sum of squares and k. For all regions we selected a value of 6 or 7 for k. This analysis was done using the *kmeans* function in the R package stats ([R Core Team 2023](#)). For each of the identified clusters we then create a kernel density estimate using the field centroids in each cluster. We created 95% kernel density estimate boundaries using the *hr_kde* in the R package amt ([Signer, Fieberg, and Avgar 2019](#)) and set the bandwidth parameter to the median field width for each landscape. The median field width ranged from 155.7m in the Somerset Levels to 233.4m in Essex. Any overlapping boundaries between clusters were combined at this stage. This step allowed smoothed polygons to be created around clusters and was preferable to using minimum convex polygons as often single occupied fields, far from cluster centers, expended cluster polygons into unsuitable habitat. With these smoothed polygons we classified individual land parcels as within ‘wader sites’ if they were more than 50% covered and that the habitat was been previously identified as suitable for lowland wet grassland. Finally, we removed any small sites that contained very few land parcels or had a very small population of waders that were too small to be a viable population. Therefore, we removed clusters that contained three or less land parcels or three or less pairs of breeding waders ([Figure 3](#)).

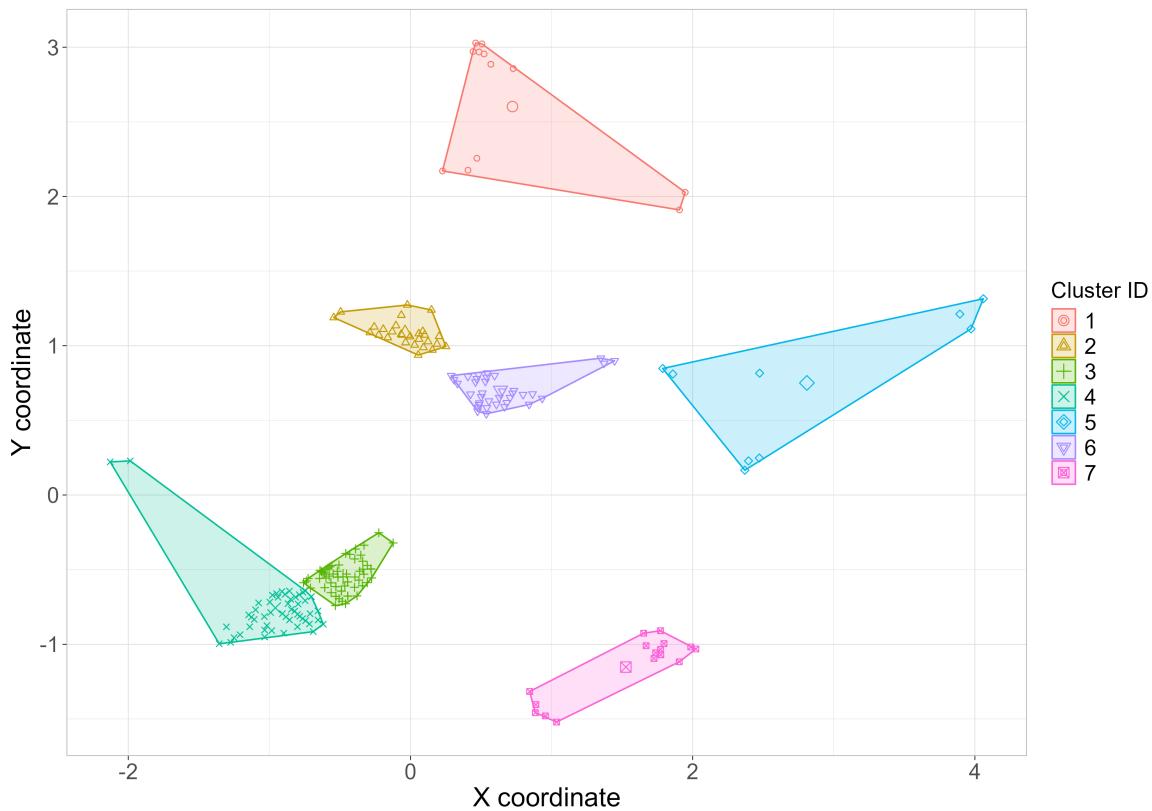


Figure 2: Results of k-mean clustering of field centroids for land parcels occupied by breeding wader in the Somerset Levels. A value of 7 for k was chosen based off the elbow point of the relationship between within cluster sum of squares and k

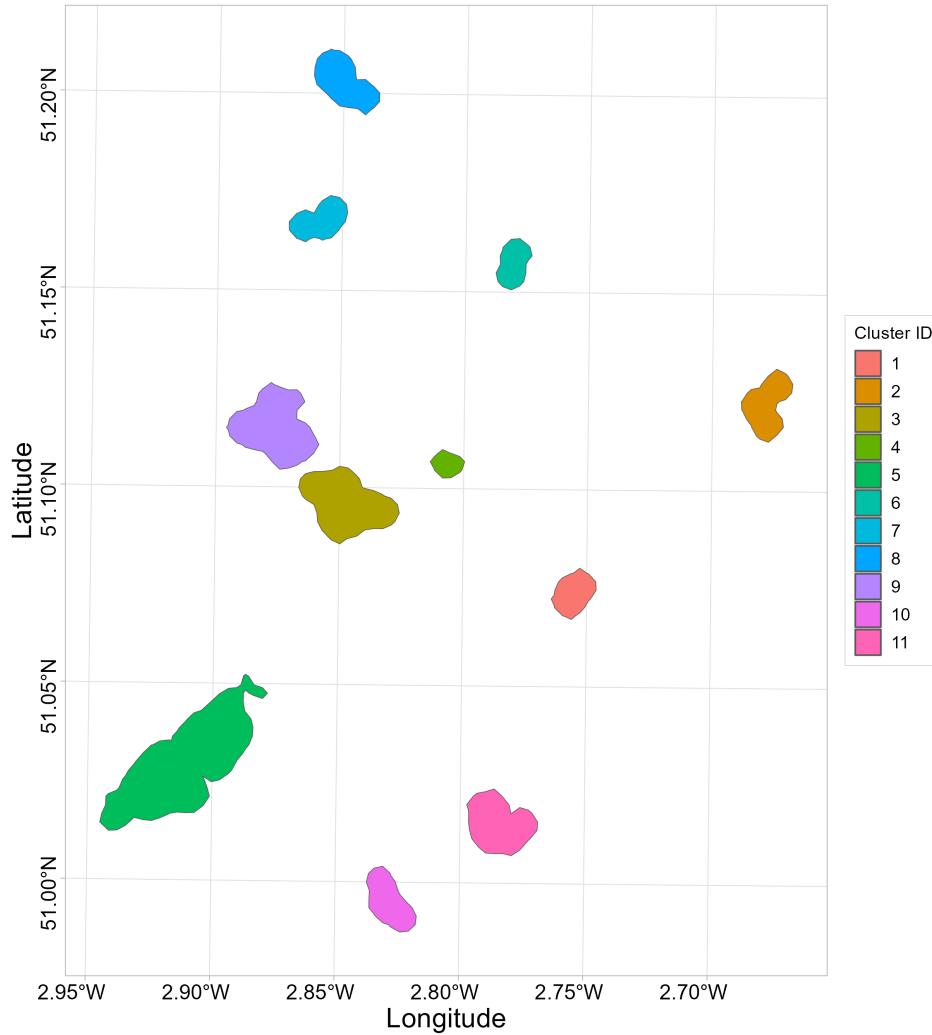


Figure 3: Final retained 95% kernel density estimate polygons of breeding wader clusters for the Somerset Levels. Each cluster was treated as a separate site

Linking this work to the wider project

As part of the wider project we created different scenarios for wading bird conservation in each landscape. These scenarios test which set of conservation decisions lead to the most cost effective use of funding. It tests the influence of the type of habitat management (AES vs reserves), the quality of the management, whether a single large or several small habitat patches are created, and where we create habitat in relation to existing populations (i.e. the ‘Lawton principles’). Using the findings from this analysis and the maps provided below we hope that it is possible to work out the



best conservation strategy for each landscape and then using the heat maps identify priority areas for habitat creation or restoration under the chosen strategy.

Results

Somerset Levels Results

For the Somerset Levels we had three different stakeholder groups. Group 1 (G1) was a group of conservationists, group 2 was a group of various body representatives tasked with wider objectives than the preservation of biodiversity (e.g. Natural England, Internal drainage board, Environment Agency and South West FWAG) group 3 was a group of landowners and farmers. The stakeholder guidelines that were generated during the workshops and how these were converted into a graded map can be found in Table S1 for group 1, Table S2 for group 2 and Table S3 for group 3. The fields identified as grassland or arable land that have the right characteristics to be lowland wet grassland, regardless of their current condition, can be seen in Figure 4 and existing wader sites can be seen in Figure 5.

Somerset Levels: Opportunity Habitat

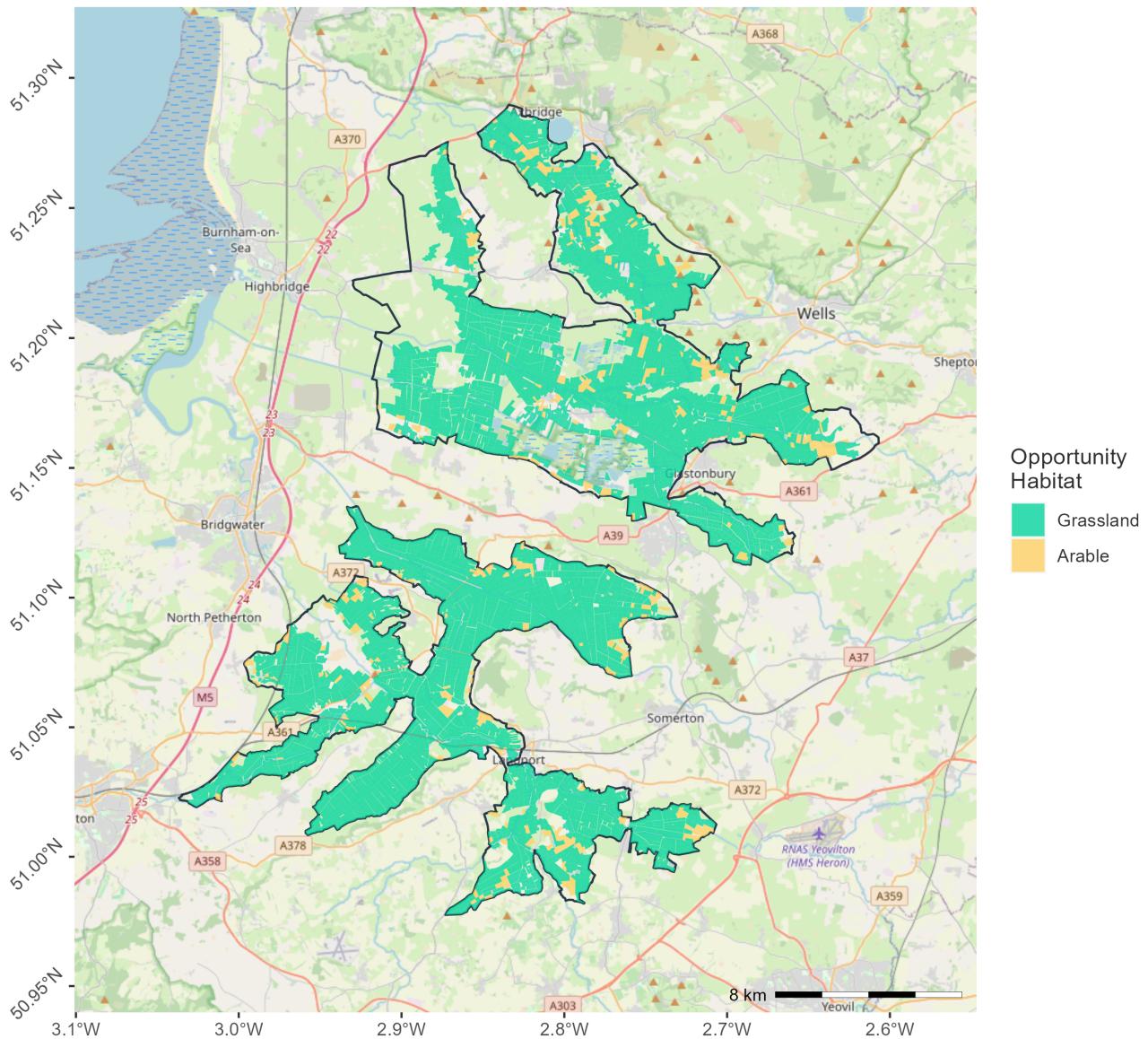


Figure 4: Parcels in the Somerset Levels that were identified as having the right soil type and elevation to become lowland wet grassland, regardless of current condition. An OS map is used as the background.

Somerset Levels: Targetting Strategy

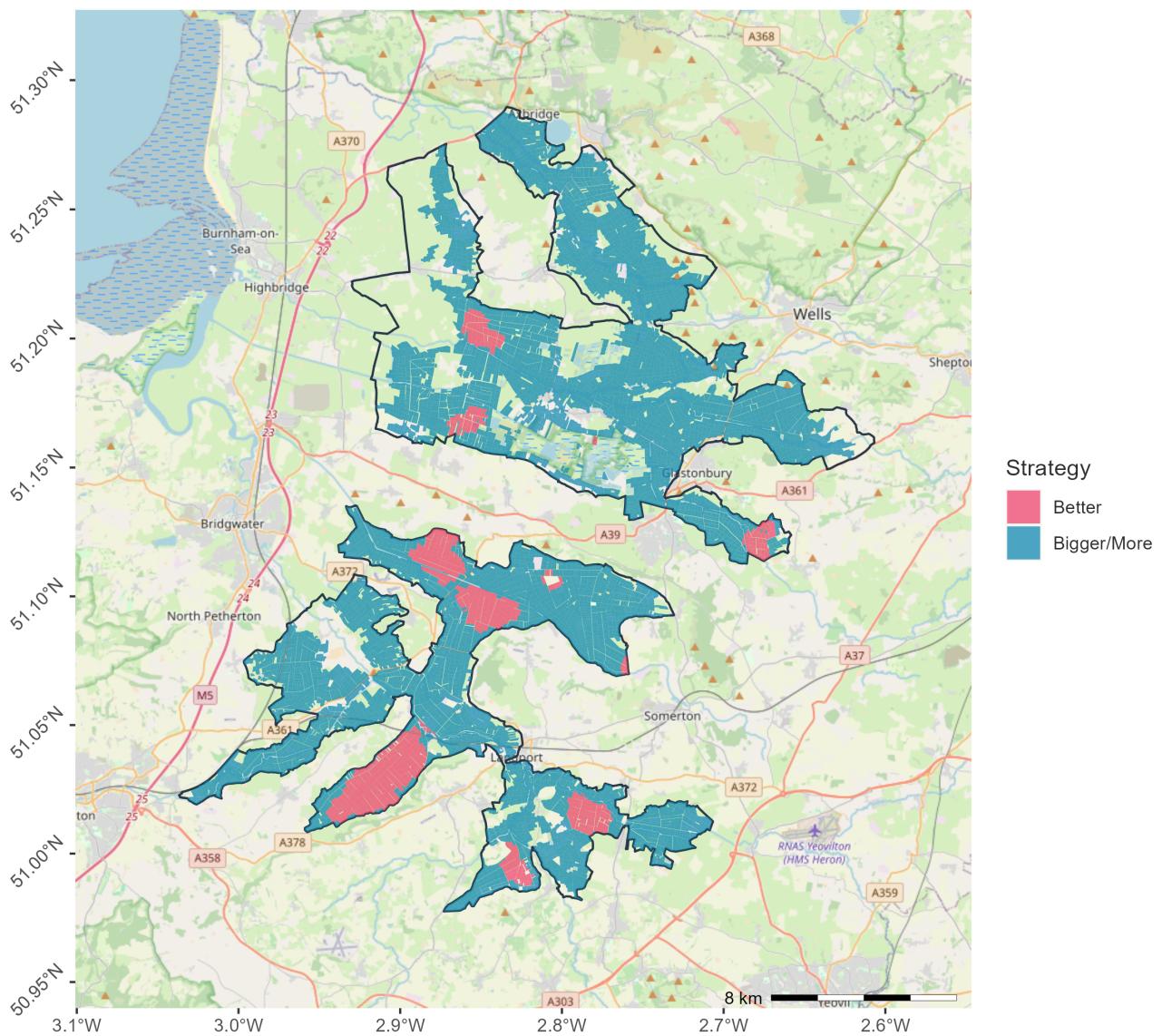


Figure 5: Parcels in the Somerset Levels that were identified as being part of lowland breeding wader clusters. These clusters were identified using the breeding waders of wet meadows survey data from 2021-23.

Somerset Levels: Better

The stakeholder preferences for the better principle of nature restoration for group 1, group 2 and group 3 can be visualized in (Figure 6), (Figure 7) and (Figure 8) respectively.

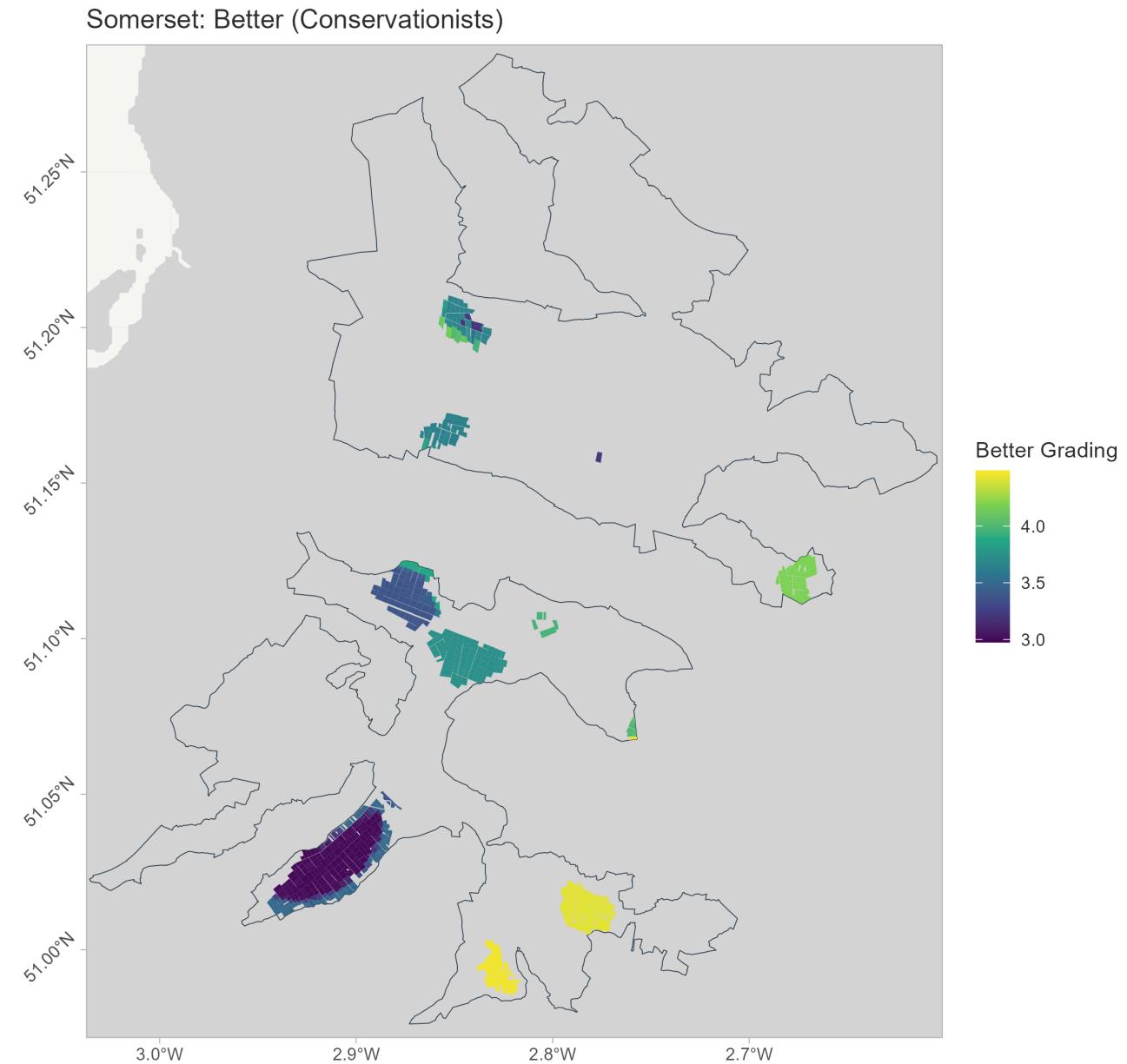


Figure 6: Stakeholder gradings for group 1 in the Somerset Levels for the better principle of nature restoration

Somerset: Better (Public Bodies)

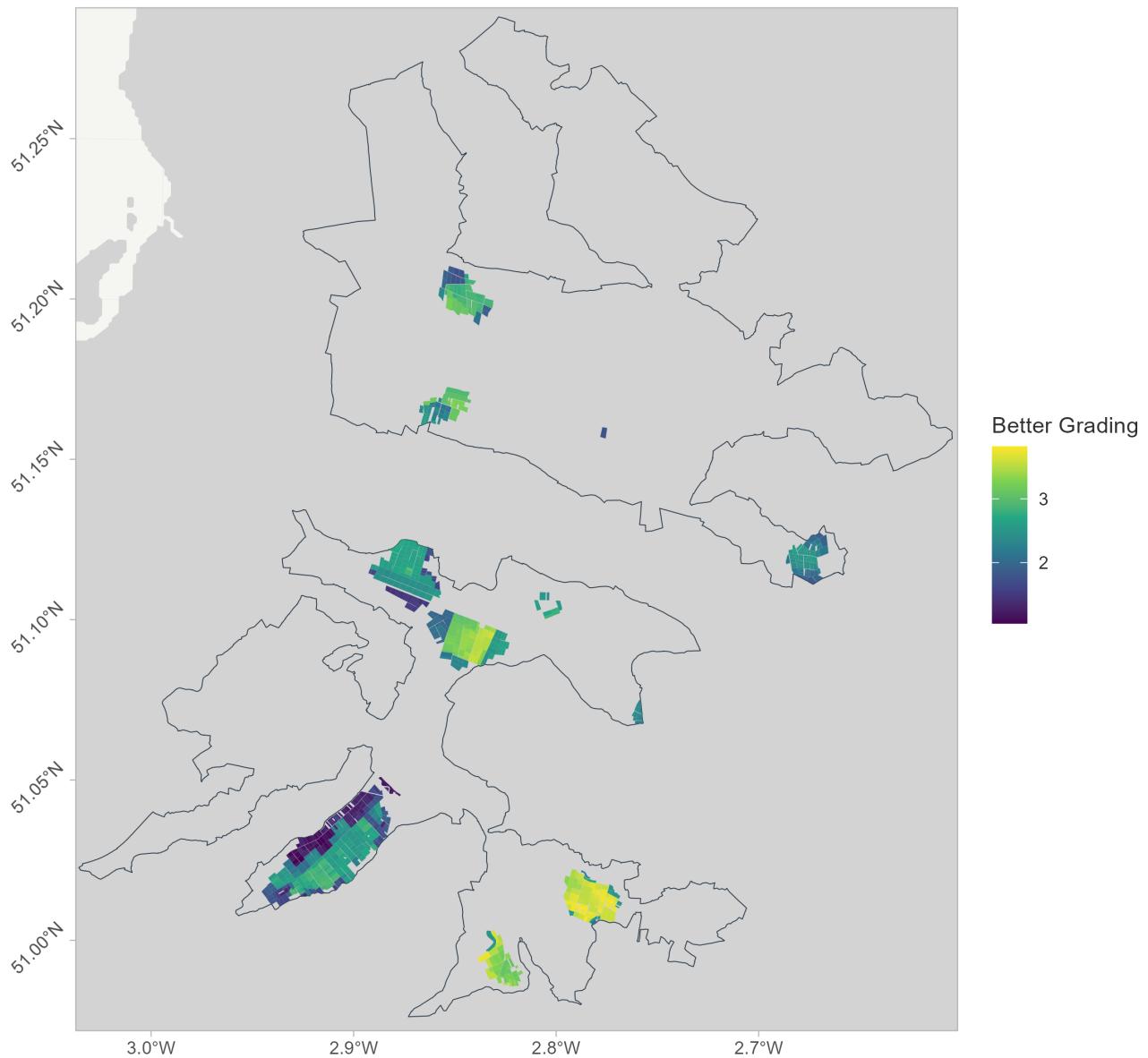


Figure 7: Stakeholder gradings for group 2 in the Somerset Levels for the better principle of nature restoration

Somerset: Better (Land managers)

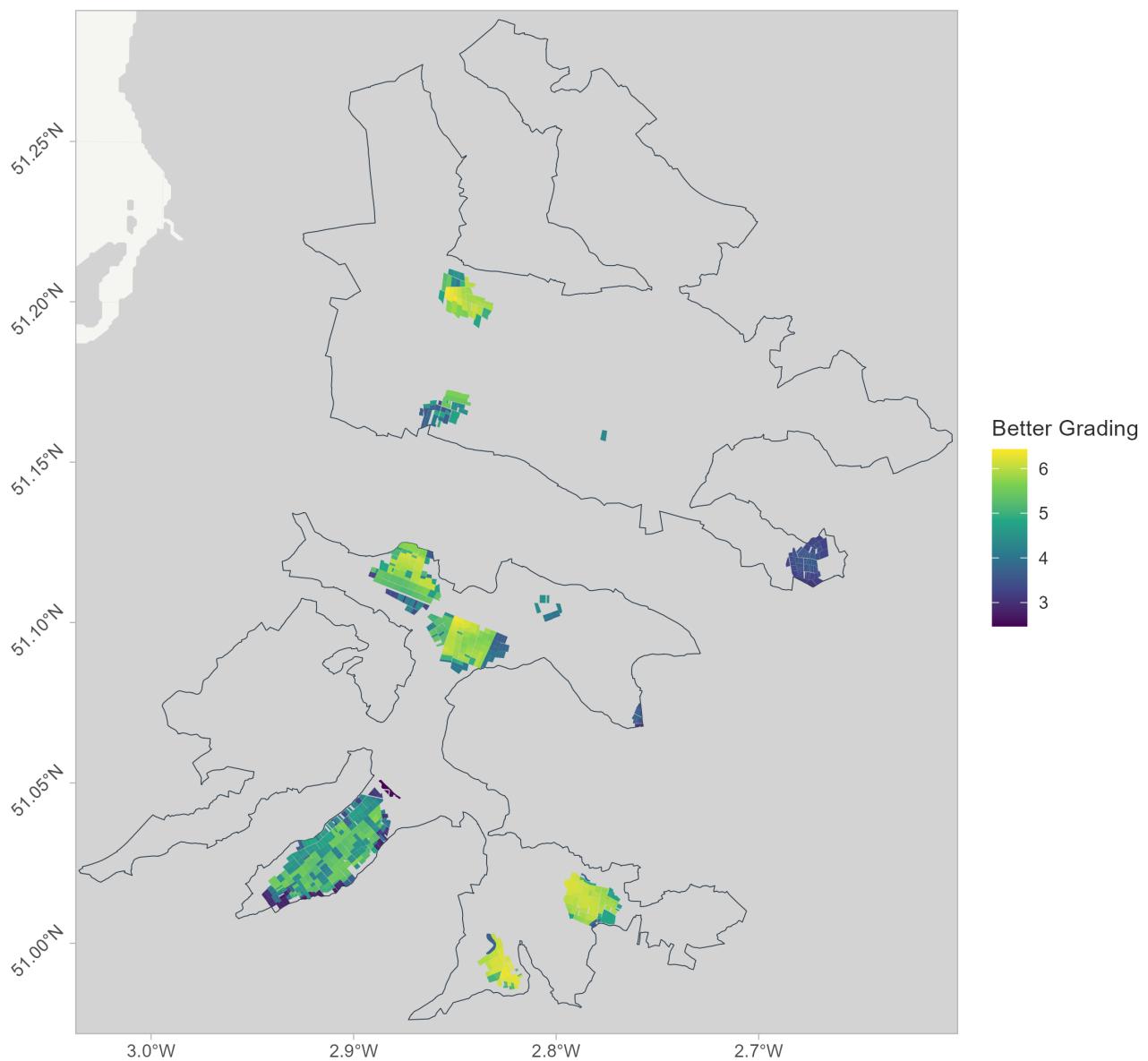


Figure 8: Stakeholder gradings for group 3 in the Somerset Levels for the better principle of nature restoration

Somerset Levels: Bigger

The stakeholder preferences for the bigger principle of nature restoration for group 1 (Figure 9), group 2 (Figure 10) and group 3 (Figure 11).

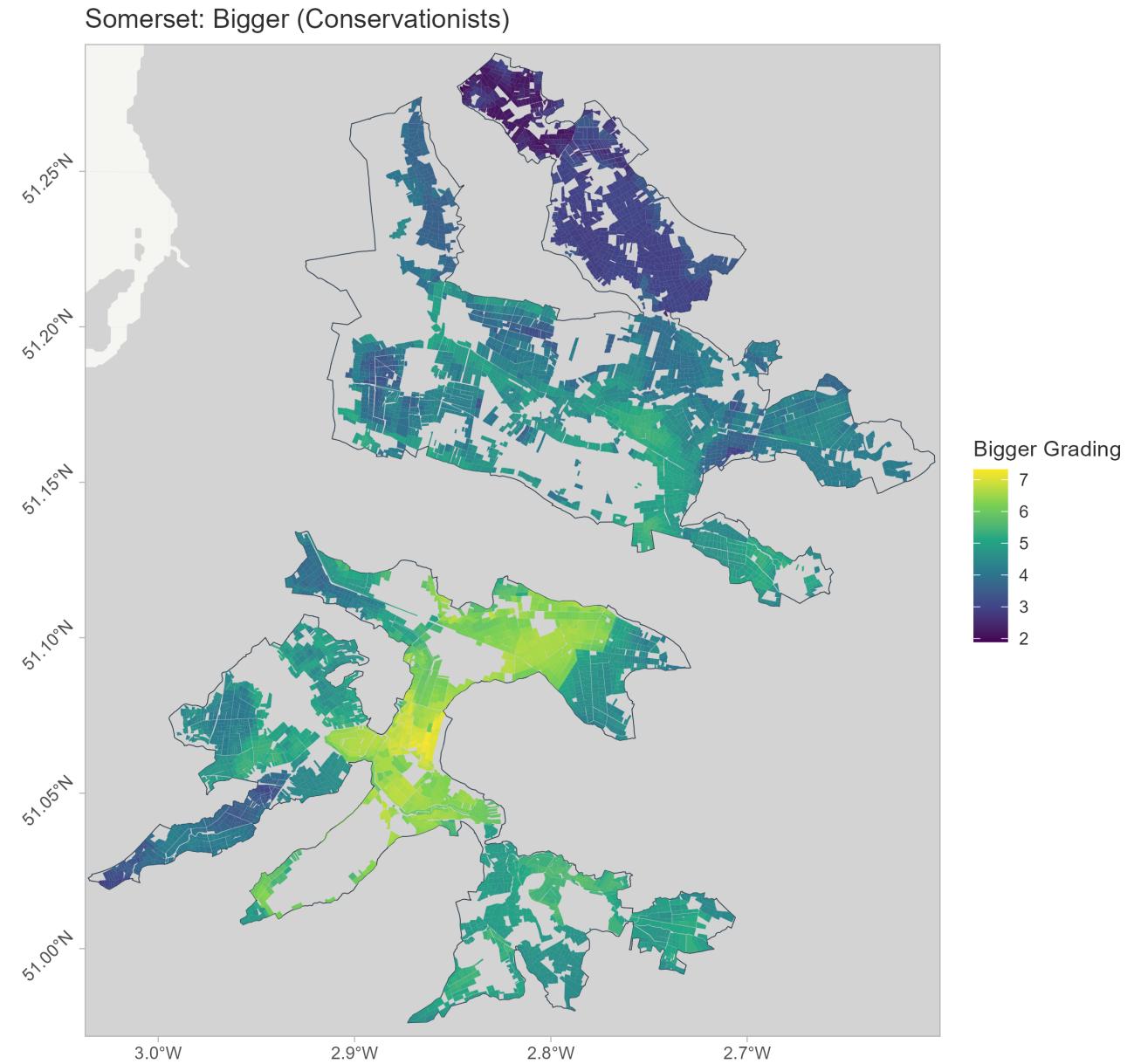


Figure 9: Stakeholder gradings for group 1 in the Somerset Levels for the bigger principle of nature restoration

Somerset: Bigger (Public Bodies)

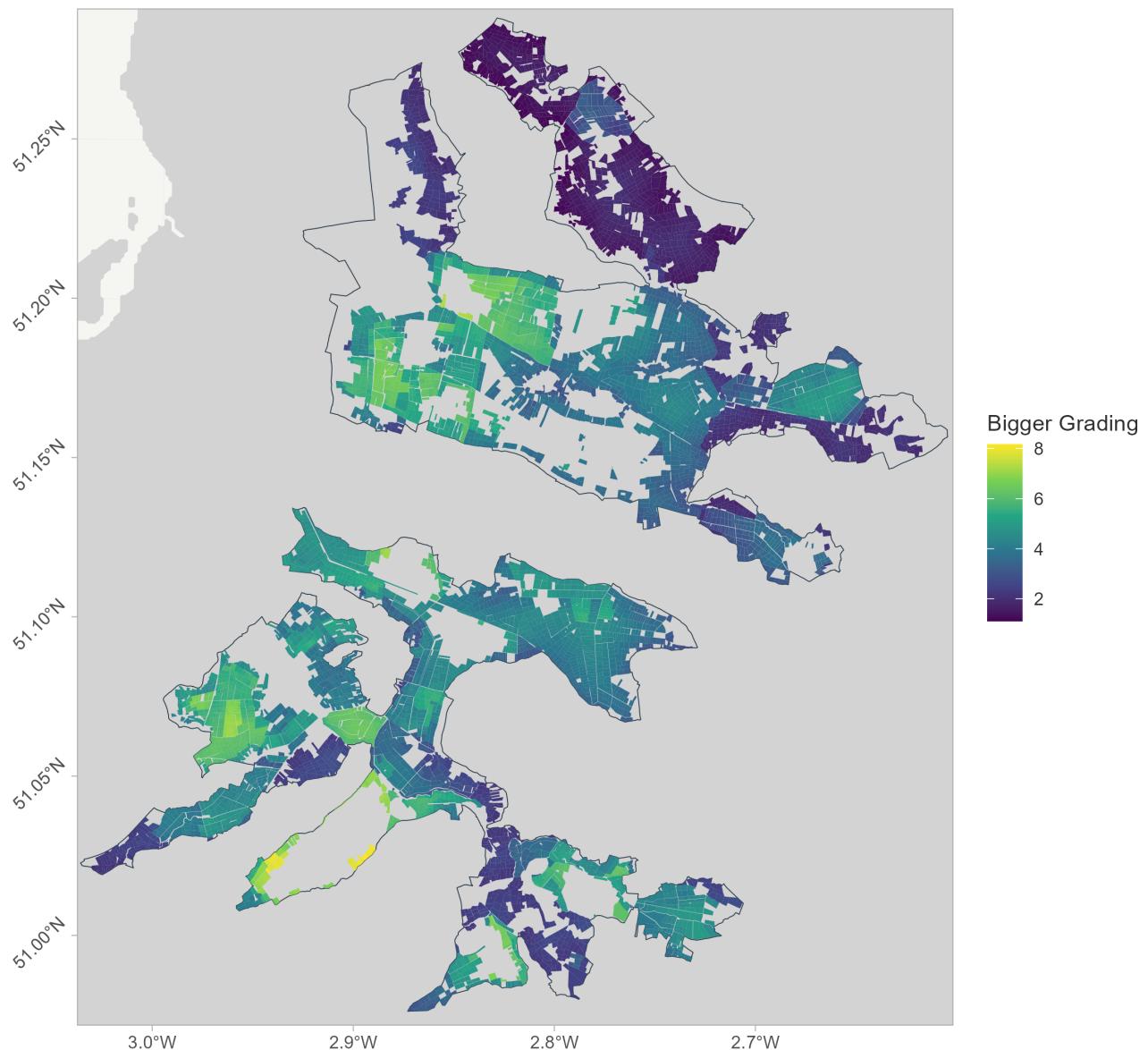


Figure 10: Stakeholder gradings for group 2 in the Somerset Levels for the bigger principle of nature restoration

Somerset: Bigger (Land managers)

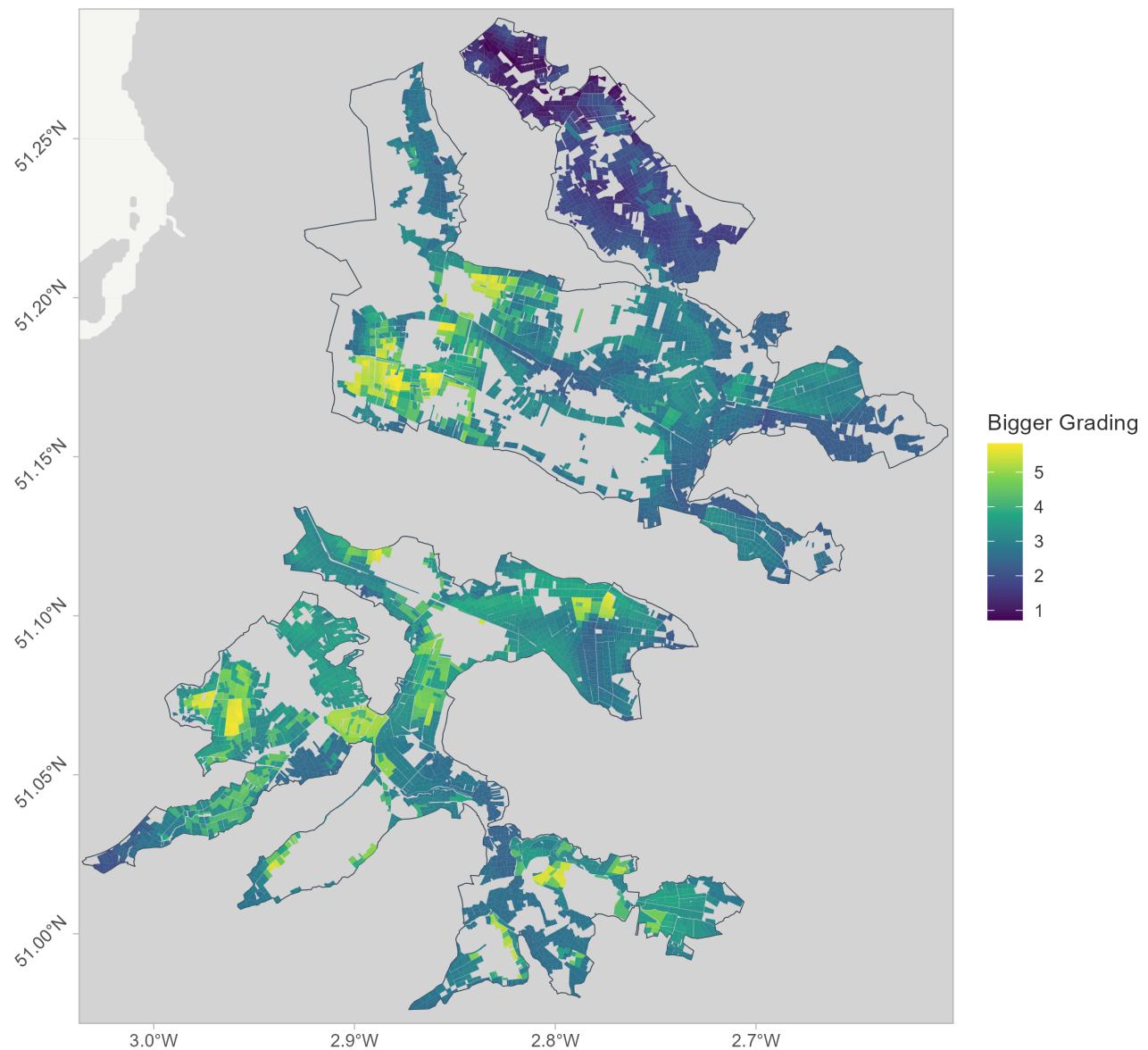


Figure 11: Stakeholder gradings for group 3 in the Somerset Levels for the bigger principle of nature restoration

Somerset Levels: More

The stakeholder preferences for the more principle of nature restoration for group 1 (Figure 12), group 2 (Figure 13) and group 3 (Figure 14).

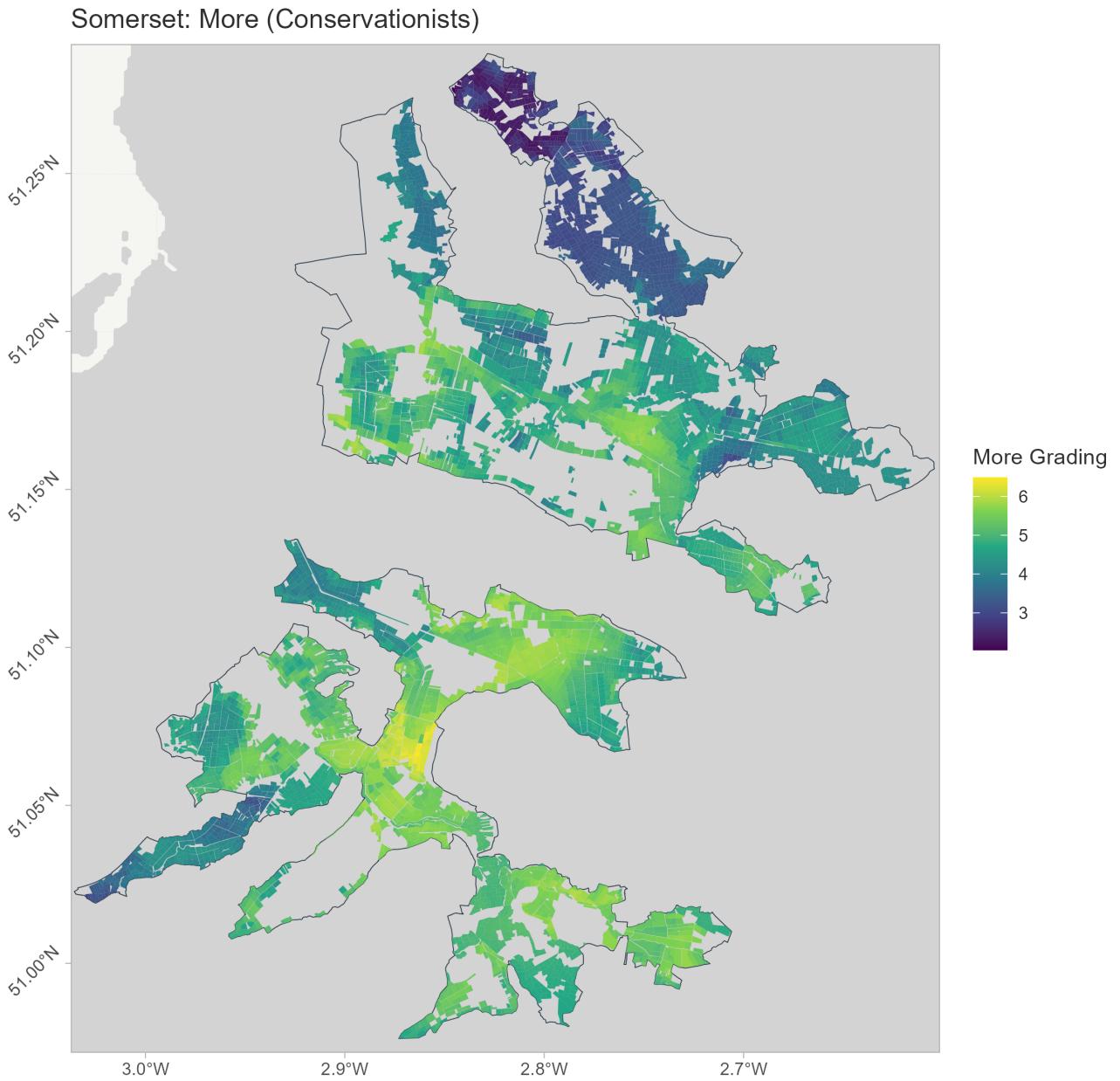


Figure 12: Stakeholder gradings for group 1 in the Somerset Levels for the more principle of nature restoration

Somerset: More (Public Bodies)

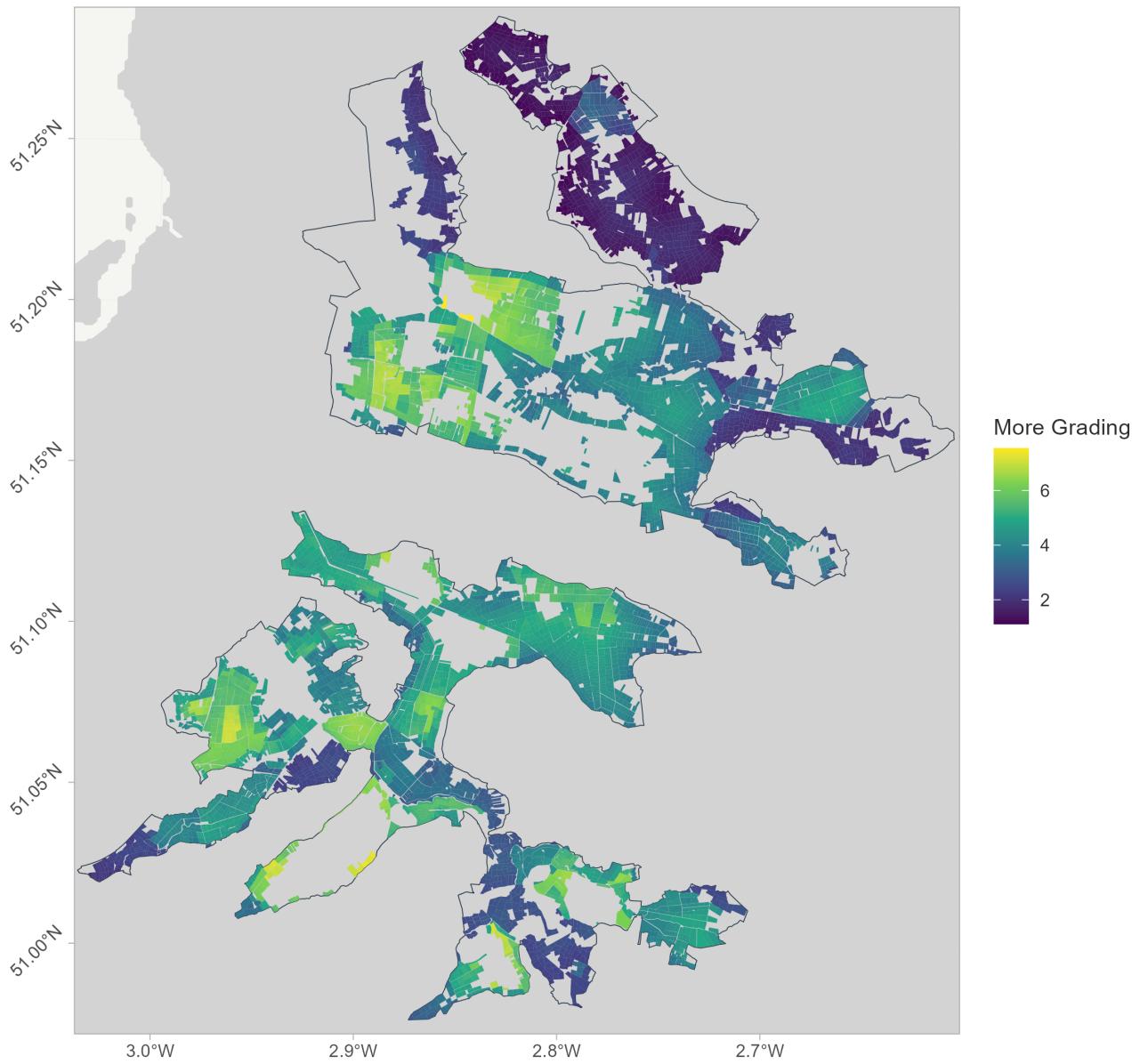


Figure 13: Stakeholder gradings for group 2 in the Somerset Levels for the more principle of nature restoration

Somerset: More (Land managers)

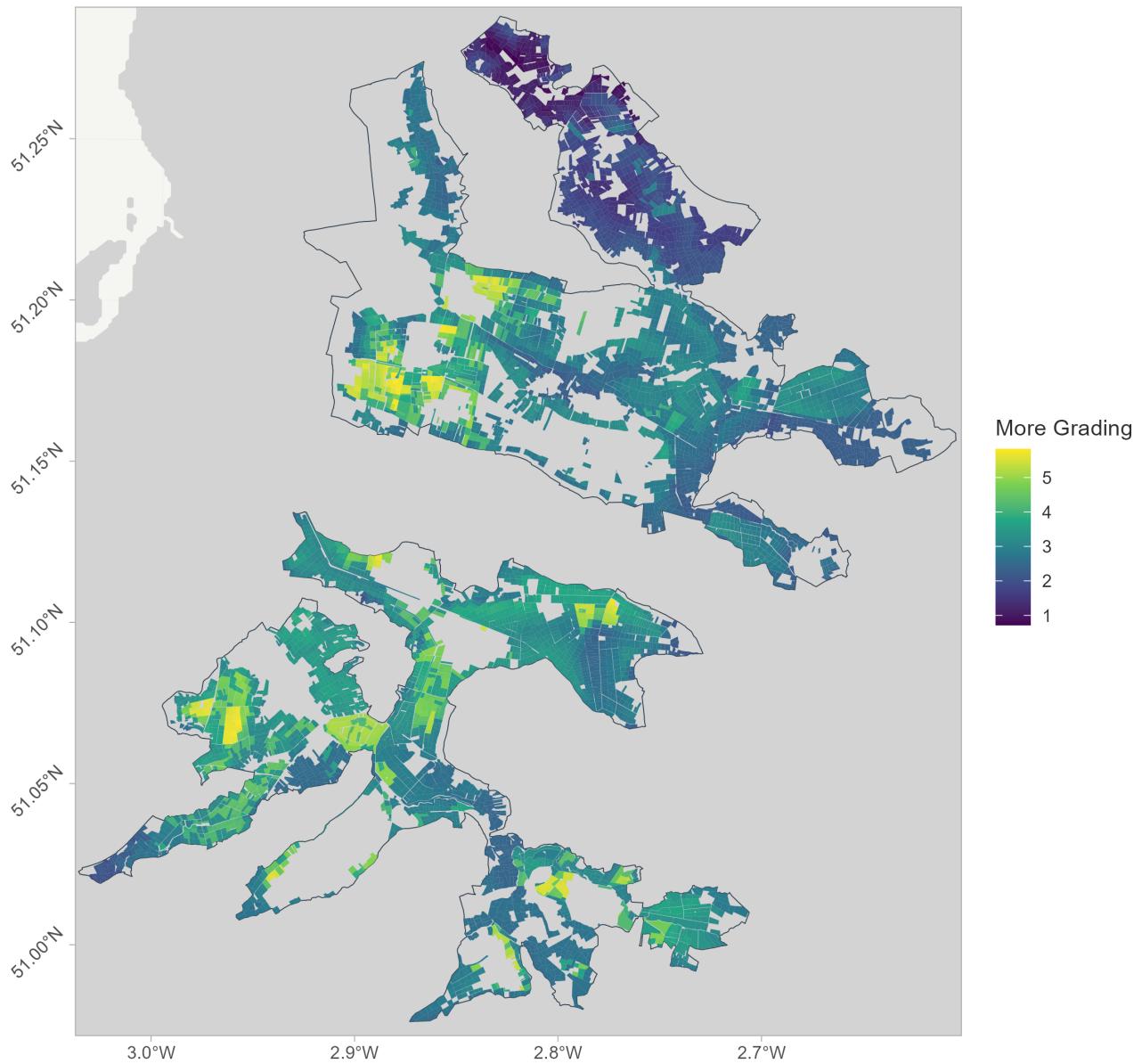


Figure 14: Stakeholder gradings for group 3 in the Somerset Levels for the more principle of nature restoration

Somerset Levels: Arable Reversion for Bigger

Stakeholder preferences for reversion of arable land to lowland wet grassland under the bigger principle of nature restoration for group 1 (Figure 15), group 2 (Figure 16) and group 3 (Figure 17).

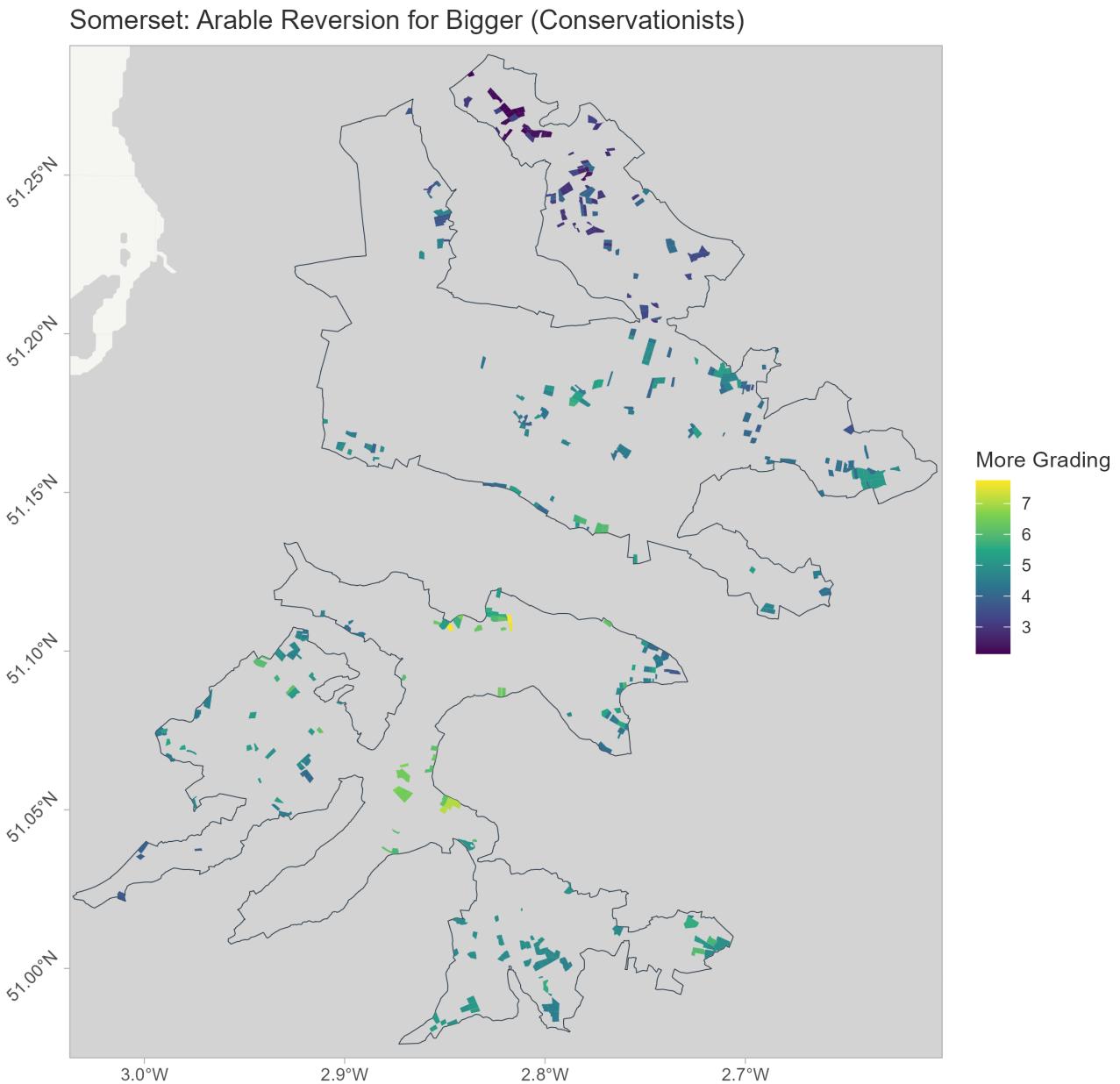


Figure 15: Stakeholder gradings for group 1 in Somerset for the reversion of arable land to lowland wet grassland under the bigger principle of nature restoration

Somerset: Arable Reversion for Bigger (Public Bodies)

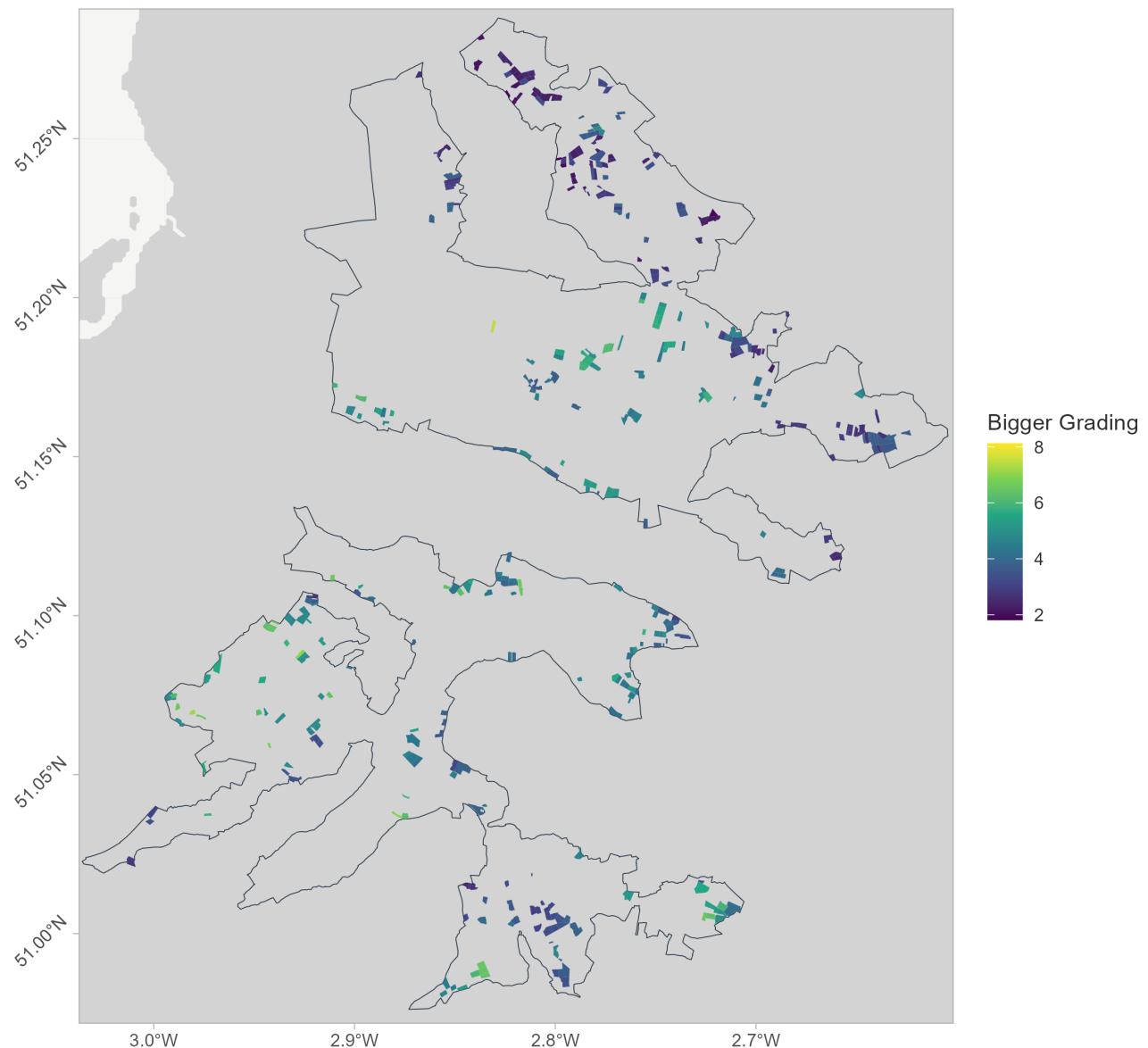


Figure 16: Stakeholder gradings for group 2 in Somerset for the reversion of arable land to lowland wet grassland under the bigger principle of nature restoration

Somerset: Arable Reversion for Bigger (Land managers)

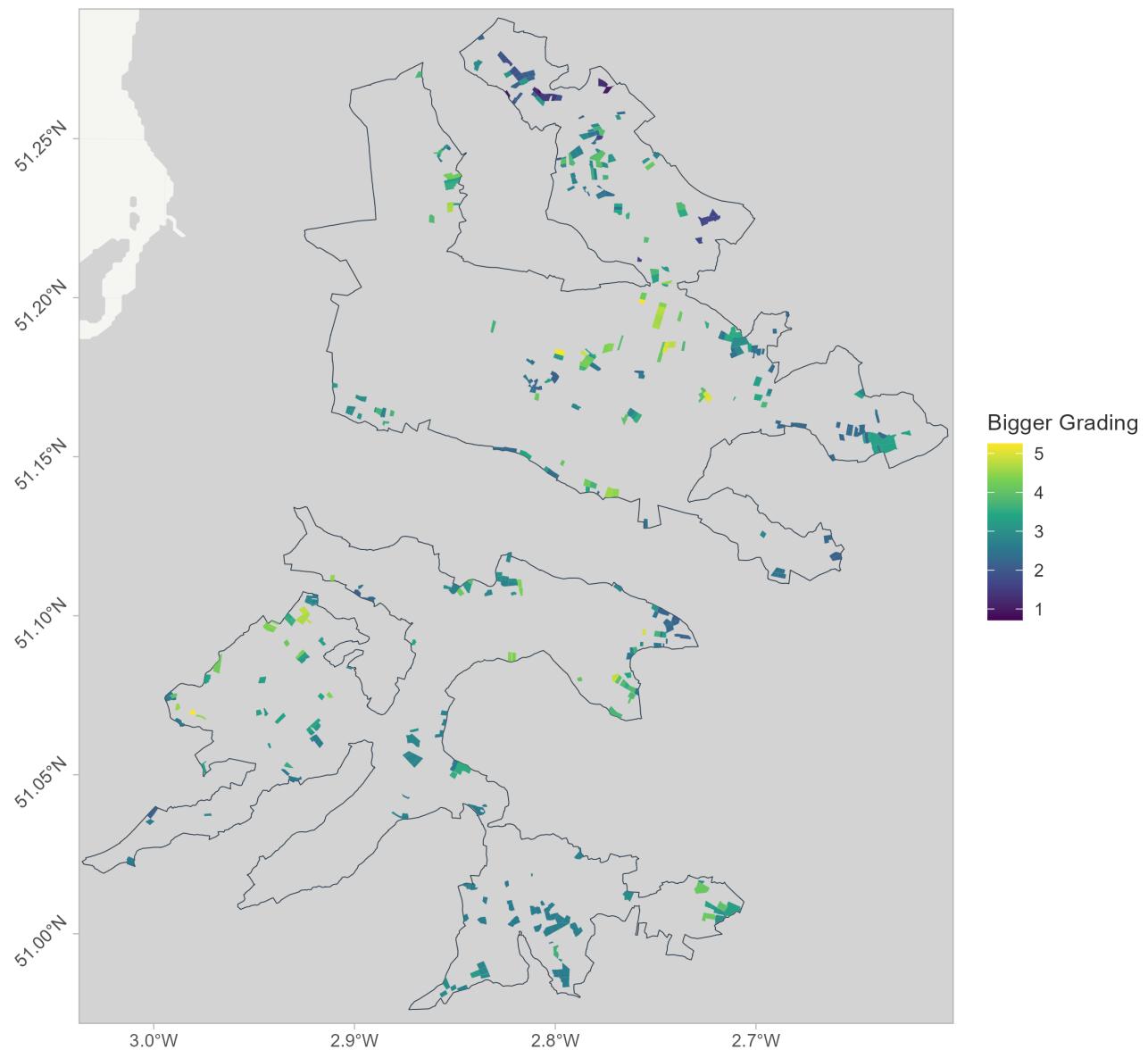


Figure 17: Stakeholder gradings for group 3 in Somerset for the the reversion of arable land to lowland wet grassland under bigger principle of nature restoration

Somerset Levels: Arable Reversion for More

Stakeholder preferences for reversion of arable land to lowland wet grassland under the more principle of nature restoration for group 1 (Figure 18), group 2 (Figure 19) and group 3 (Figure 20).

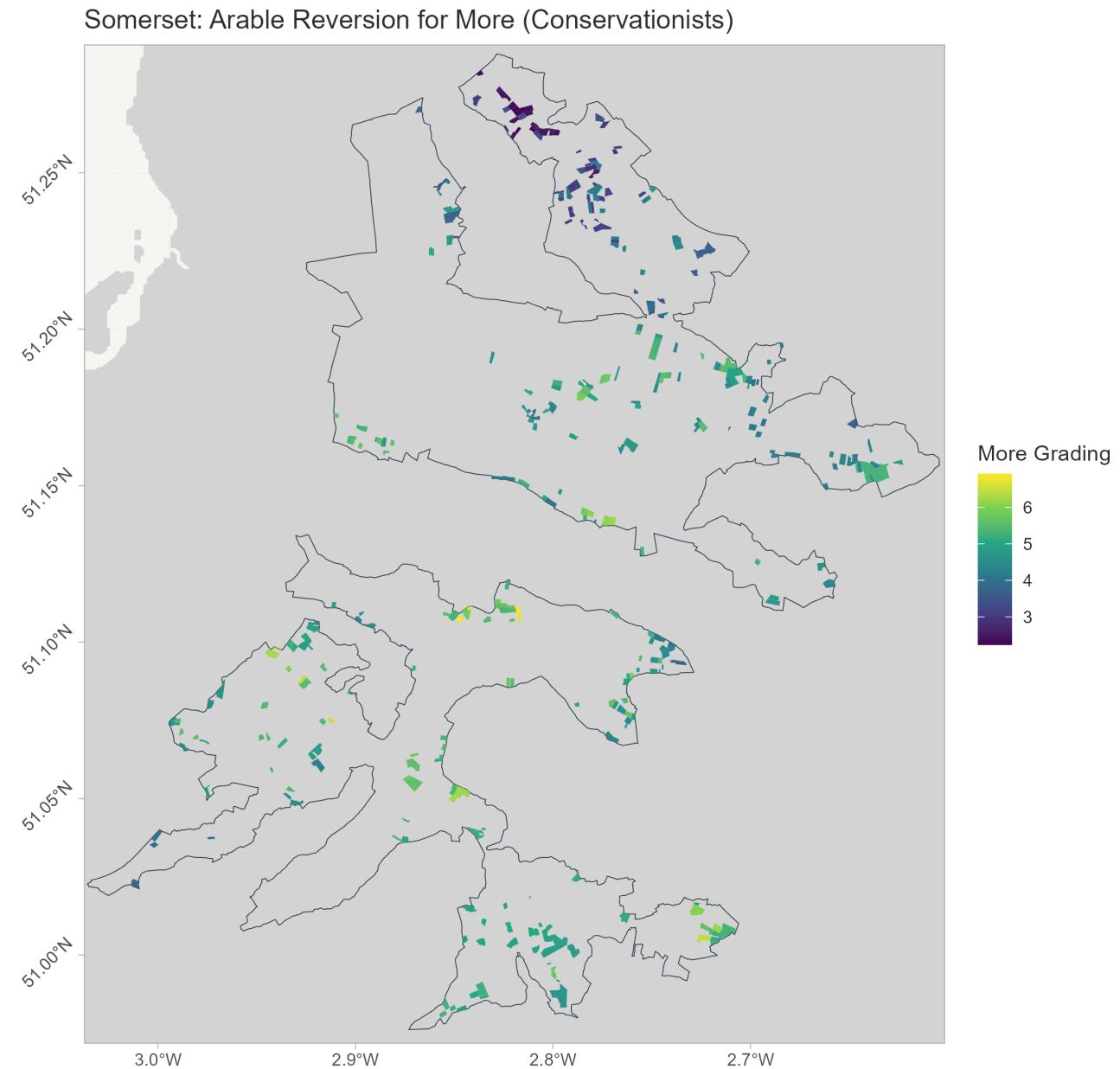


Figure 18: Stakeholder gradings for group 1 in Somerset for the reversion of arable land to lowland wet grassland under the bigger principle of nature restoration

Somerset: Arable Reversion for More (Public Bodies)

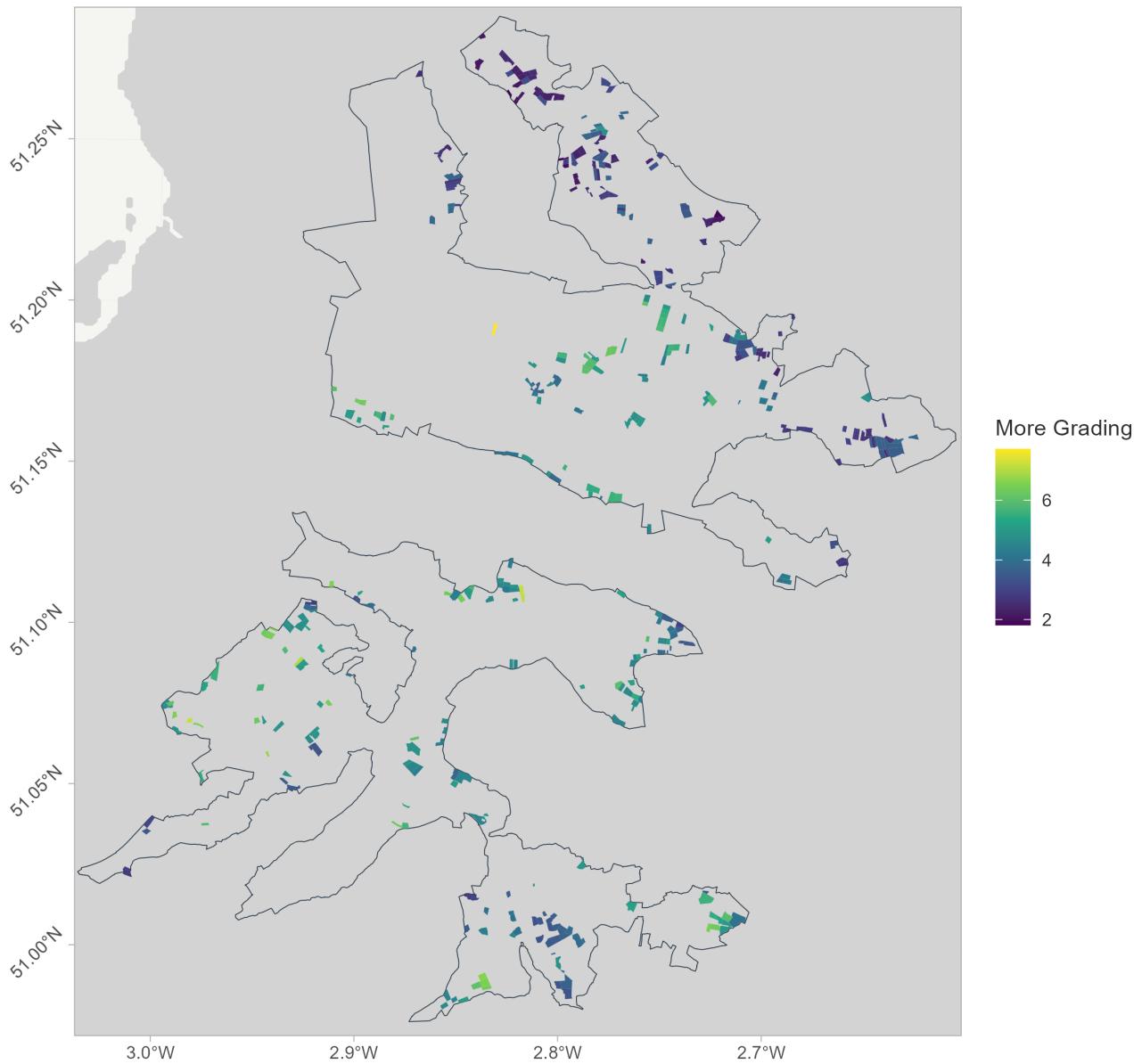


Figure 19: Stakeholder gradings for group 2 in Somerset for the reversion of arable land to lowland wet grassland under the bigger principle of nature restoration

Somerset: Arable Reversion for More (Land managers)

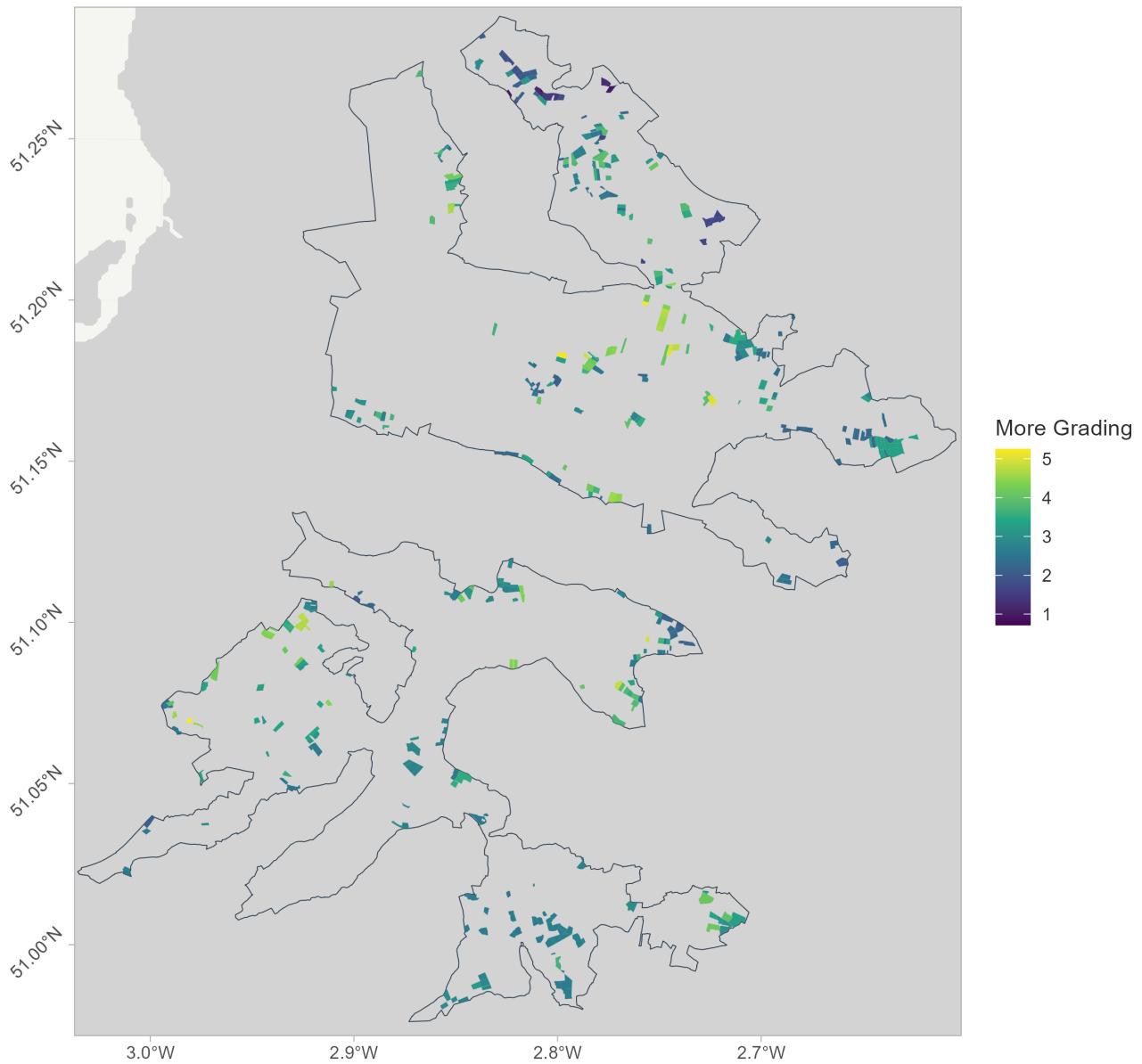


Figure 20: Stakeholder gradings for group 3 in Somerset for the reversion of arable land to lowland wet grassland under the bigger principle of nature restoration



Acknowledgements

We thank all the workshop attendees, and a specific thanks to Damon Bridge, Kieran Alexander, Will Tofts, Ian Robinson, Alan Johnson and Mark Smart for helping to organise these workshops. We also thank Malcolm Ausden and the wider lowland wader scenario steering group team for input into the project. We also need to thank NE for funding.



Bibliography

- Chazdon, R. L., P. H. S. Brancalion, D. Lamb, L. Laestadius, M. Calmon, and C. Kumar. 2016. "A Policy-Driven Knowledge Agenda for Global Forest and Landscape Restoration." *Conservation Letters* 10 (1): 125–32. <https://doi.org/10.1111/conl.12220>.
- Donald, P. F., R. E. Green, and M. F. Heath. 2001. "Agricultural Intensification and the Collapse of Europe's Farmland Bird Populations." *Proceedings of the Royal Society of London. Series B: Biological Sciences* 268 (1462): 25–29. <https://doi.org/10.1098/rspb.2000.1325>.
- Eglington, S. M., M. Bolton, M. A. Smart, W. J. Sutherland, A. R. Watkinson, and J. A. Gill. 2010. "Managing Water Levels on Wet Grasslands to Improve Foraging Conditions for Breeding Northern Lapwing *Vanellus Vanellus*." *Journal of Applied Ecology* 47 (2): 451–58. <https://doi.org/10.1111/j.1365-2664.2010.01783.x>.
- Environment Agency. 2023a. *LIDAR Composite Digital Terrain Model (DTM)* - 1m. <https://environment.data.gov.uk/dataset/13787b9a-26a4-4775-8523-806d13af58fc>.
- . 2023b. *LIDAR Composite First Return Digital Surface Model (FZ_DSM)* - 1m. <https://environment.data.gov.uk/dataset/df4e3ec3-315e-48aa-aaaf-b5ae74d7b2bb>.
- Franks, S. E., M. Roodbergen, W. Teunissen, Carrington. C. A., and J. W. Pearce-Higgins. 2018. "Evaluating the Effectiveness of Conservation Measures for European Grassland-Breeding Waders." *Ecology and Evolution* 8 (21): 10555–68. <https://doi.org/10.1002/ece3.4532>.
- Gamborg, C., J. Morsing, and K. Raulund-Rasmussen. 2019. "Adjustive Ecological Restoration Through Stakeholder Involvement: A Case of Riparian Landscape Restoration on Privately Owned Land with Public Access." *Restoration Ecology* 27 (5): 1073–83. <https://doi.org/10.1111/rec.12955>.
- Hijmans, R. J. 2024. *Terra: Spatial Data Analysis*. <https://CRAN.R-project.org/package=terra>.
- Jackson, D. B. 1994. "Breeding Dispersal and Site-Fidelity in Three Monogamous Wader Species in the Western Isles, U.K." *Ibis* 136 (4): 463–73. <https://doi.org/10.1111/j.1474-919x.1994.tb01123.x>.
- Lawton, J. H., P. N. M. Brotherton, V. K. Brown, C. Elphick, A. H. Fitter, J. Forshaw, R. W. Haddow, et al. 2010. "Making Space for Nature: A Review of England's Wildlife Sites and Ecological Network. Report to Defra."
- Malpas, L. R., R. J. Kennerley, Graham J. M. Hirons, R. D. Sheldon, M. Ausden, J. C. Gilbert, and J. Smart. 2013. "The Use of Predator-Exclusion Fencing as a Management Tool Improves the Breeding Success of Waders on Lowland Wet Grassland." *Journal for Nature Conservation* 21 (1): 37–47. <https://doi.org/10.1016/j.jnc.2012.09.002>.
- Marston, C. G., R. D. Morton, A. W. O'Neil, and C. S. Rowland. 2024. "Land Cover



- Map 2022 (25m Rasterised Land Parcels, GB)." NERC EDS Environmental Information Data Centre. <https://doi.org/10.5285/C9449BF5-B8F6-4A1C-B3EB-0D70575CBA39>.
- Marston, C. G., C. S. Rowland, A. W. O'Neil, and R. D. Morton. 2022. "Land Cover Map 2021 (25m Rasterised Land Parcels, GB)." NERC EDS Environmental Information Data Centre. <https://doi.org/10.5285/A1F85307-CAD7-4E32-A445-84410EFDFEA70>.
- Morton, R. D., C. G. Marston, A. W. O'Neil, and C. S. Rowland. 2024. "Land Cover Map 2023 (25m Rasterised Land Parcels, GB)." NERC EDS Environmental Information Data Centre. <https://doi.org/10.5285/AB10EA4A-1788-4D25-A6DF-F1AFF829DFFF>.
- Natural England. 2022. *Priority Habitats Inventory (England)*. <https://www.data.gov.uk/dataset/4b6ddab7-6c0f-4407-946e-d6499f19fcde/priority-habitats-inventory-england>.
- . 2024. *Environmentally Sensitive Areas (England)*. <https://www.data.gov.uk/dataset/a5b0ccc4-a144-4027-91fa-49084ff07da2/environmentally-sensitive-areas-england>.
- NSRI. 2022. *National Soil Map of England and Wales - NATMAP Vector, 1:250000 Soil Association Map*. <https://www.landis.org.uk/data/natmap.cfm>.
- Pebesma, E. 2018. "Simple Features for R: Standardized Support for Spatial Vector Data." *The R Journal* 10 (1): 439–46. <https://doi.org/10.32614/RJ-2018-009>.
- R Core Team. 2023. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>.
- Raven, P. H., and D. L. Wagner. 2021. "Agricultural Intensification and Climate Change Are Rapidly Decreasing Insect Biodiversity." *Proceedings of the National Academy of Sciences* 118 (2). <https://doi.org/10.1073/pnas.2002548117>.
- Roodbergen, M., B. van der Werf, and H. Hötker. 2011. "Revealing the Contributions of Reproduction and Survival to the Europe-Wide Decline in Meadow Birds: Review and Meta-Analysis." *Journal of Ornithology* 153 (1): 53–74. <https://doi.org/10.1007/s10336-011-0733-y>.
- Roos, St.n, J. Smart, D. W. Gibbons, and J. D. Wilson. 2018. "A Review of Predation as a Limiting Factor for Bird Populations in Mesopredator-Rich Landscapes: A Case Study of the UK." *Biological Reviews* 93 (4): 1915–37. <https://doi.org/10.1111/brv.12426>.
- Sabatier, R., L. Doyen, and M. Tichit. 2010. "Modelling Trade-Offs Between Livestock Grazing and Wader Conservation in a Grassland Agroecosystem." *Ecological Modelling* 221 (9): 1292–1300. <https://doi.org/10.1016/j.ecolmodel.2010.02.003>.
- Signer, J., J. Fieberg, and T. Avgar. 2019. "Animal Movement Tools (Amt): R Package for Managing Tracking Data and Conducting Habitat Selection Analyses." *Ecology and Evolution* 9 (2): 880–90. <https://doi.org/10.1002/ece3.4823>.
- Smart, J., S. R. Wotton, I. A. Dillon, A. I. Cooke, I. Diack, A. L. Drewitt, P. V. Grice, and R. D. Gregory. 2014. "Synergies Between Site Protection and Agri-



- Environment Schemes for the Conservation of Waders on Lowland Wet Grasslands.” *Ibis* 156 (3): 576–90. <https://doi.org/10.1111/ibi.12153>.
- Song, X., M. C. Hansen, S. V. Stehman, P. V. Potapov, A. Tyukavina, E. F. Vermote, and J. R. Townshend. 2018. “Global Land Change from 1982 to 2016.” *Nature* 560 (7720): 639–43. <https://doi.org/10.1038/s41586-018-0411-9>.
- Verhulst, J., D. Kleijn, W. Loonen, F. Berendse, and C. Smit. 2011. “Seasonal Distribution of Meadow Birds in Relation to in-Field Heterogeneity and Management.” *Agriculture, Ecosystems & Environment* 142 (3-4): 161–66. <https://doi.org/10.1016/j.agee.2011.04.016>.
- Wilson, A. M., J. A. Vickery, A. Brown, R. H. W. Langston, D. Smallshire, S. Wotton, and D. Vanhinsbergh. 2005. “Changes in the Numbers of Breeding Waders on Lowland Wet Grasslands in England and Wales Between 1982 and 2002.” *Bird Study* 52 (1): 55–69. <https://doi.org/10.1080/00063650509461374>.



Appendix

Table S1: Stakeholder rules generated during a workshop for Somerset Levels group 1 (conservationists). See Table S4 for full citation of each reference

Strategies	Guideline	Reference	Implementation
better	Target smallest existing populations	New data set	Within identified wader clusters all breeding pairs of lapwing, redshank and snipe are summed. The population sizes are then scaled so that clusters with lowest total population receives a score of 1 and the highest population a score of 0.
bigger	Target areas within the Greater Sedgemoor landscape recovery block	New data set	Pixels that are within or overlap with the landscape recovery block are given a ranking of 1 and those outside a value of 0
bigger	Target hydrological units more gradually sloping boundaries	(Environment Agency 2022a)	**NOT USED** I calculated this metric for each hydro unit by dividing the 3D surface area by the 2D surface area. There is very little variation between units in this metric. Most of the variation comes from the small undulations from rivers and ditches within units which is not why this rule was created. This rule was not used as most units are the same in terms of boundary elevation.
more	Target sites that historically had breeding waders	(Round 1978)	Use breeding wader abundance counts from Round (1978) that were aggregated for each Moor. The Moor-level values are then interpolated onto a raster using ordinary kriging. Areas with higher historic abundance are given higher gradings.
bigger/more	Target areas that link existing wader sites	New data set	Least cost path analysis was used for this rule. The resistance surface had the following values based upon land use: opportunity lowland grassland = 5; opportunity arable = 3; and all other habitats 1). This surface is used to calculate the least costs paths between the centroid of all wader sites in the landscape. Next, I calculate the number of least costs paths that pass through a 2km resolution raster of the priority landscape and scale pixel values. Therefore, the pixels with the greatest number of paths have a value of 1. Finally, this 2km raster is converted back to a 25m raster using smoothing.
bigger/more	Target fields with lower public footfall	(Day & Smith 2018)	Disturbance index is calculated by multiplying the inverse scaled distance to a path (constrained within 500m of a path so >500m = 0 and 0m=1) by the total visitors to the path. If multiple paths have overlapping 500m extents, then the values for the closest path are taken. Pixels greater than 500m from a path have a grading of 1 and pixels along the path with the largest number of visitors have a grading of 0.
bigger/more	Target mid height land within hydrological units	(Environment Agency 2022a)	For each hydrological unit all elevation values were extracted and the and the quantile value for each pixel calculated. The pixels with an elevation at the 50th quantile receive a grading of 1 and the highest and lowest quantile pixels in each hydrological unit are graded 0. All pixels not in a hydro unit are given a value of 0.
arable conversion	Target arable conversion on land where maize is grown	(UKCEH 2021)	All pixels that more than 50% overlap a maize polygon from the UKCEH landcover plus crops map are assigned a grading of 1 as they will be targeted first for reversion.
all	Target hydrological units with more water in the future	(Environment Agency 2022b)	For each EA catchment zone there is a rough percentage of time that water is available for abstraction. These catchments are polygons that are then rasterized. The largest percentage of time that water is available for abstraction is graded 1 and the lowest percentage time is graded 0.



(continued)

Strategies	Guideline	Reference	Implementation
all	Target silty areas for Lapwing management	(NSRI 2022)	All wet loamy or clay soils are defined as silty (mainly excluding well drained, sandy, and organic peaty soils). Silty Soils given a grading of 1 and all others a grading of 0. Finally, these gradings are halved as this guideline only relates to Lapwing.
all	Target areas not part of floodplain restoration area on Curry moor	(Somerset Drainage Board Consortium 2011)	If a pixel is more than 50% within the digitised Curry moor hydrological unit then it is given a value of 0 and all other values are given a value of 1.
all	Target areas away from priority habitat expansion areas	(Natural England 2020a); (Natural England 2020b); (Natural England 2020c)	I used the Natural England habitat network maps for Reedbed, Lowland raised bog and lowland fen. Any pixels more than 50% overlapping a "Fragmentation Action Zone" or "Habitat Restoration-Creation" area were given a value of 0 and any areas overlapping a Network Enhancement Zone 1 given a value of 0.5. All other areas were given a score of 1.
all	Avoid priority habitats	(Natural England 2024a)	All pixels that overlap a non-lowland wet grassland priority habitat polygon by more than 50% are assigned as a masked pixel. This includes priority habitat woodland, raised bog, dry grasslands, heathland, reedbed and fen.
all	Avoid peat extraction areas	New data set	All pixels that overlap digitised peat extraction sites from aerial images by more than 50% are masked.
all	Avoid lowest land that will become Fen	NA	**NOT USED**- not used as overlaps with preference above: "Target mid height land within hydro units"
all	Avoid scheduled monuments	(Historic England 2024)	All pixels that overlap a scheduled monument polygon (+ 20m buffer) by more than 50% are masked out. This buffer is based on recommendations from Natural Heritage.
all	Mask urban areas	(Marston et al. 2022)	All pixels in the UKCEH habitat data that are assigned as urban/suburban, or a coastal habitat are turned into masks. As the UKCEH 25m raster is the base for all masks this is simply selecting certain pixels.



Table S2: Stakeholder rules generated during a workshop for Somerset Levels group 2 (public bodies). See Table S4 for full citation of each reference

Strategies	Guideline	Reference	Implementation
better	Target smallest existing populations	New data set	Within identified wader clusters all breeding pairs of lapwing, redshank and snipe are summed. The population sizes are then scaled so that clusters with lowest total population receives a score of 1 and the highest population a score of 0.
bigger	Target sites with more breeding waders for expansion	New data set	Only consider areas within 2km of breeding wader sites. For any pixels within 2km of a site, calculate the distance to the nearest site multiplied by the population size of the nearest site. If a pixel is within 2km of two clusters then take the max value from the previous calculation. Pixels within or immediately on the border of the cluster with the largest population get a value of 1 and pixels 1km from the mean sized population get a value of 0.5.
more	Target areas that link existing wader sites	New data set	Least cost path analysis was used for this rule. The resistance surface had the following values based upon land use: opportunity lowland grassland = 5; opportunity arable = 3; and all other habitats 1). This surface is used to calculate the least costs paths between the centroid of all wader sites in the landscape. Next, I calculate the number of least costs paths that pass through a 2km resolution raster of the priority landscape and scale pixel values. Therefore, the pixels with the greatest number of paths have a value of 1. Finally, this 2km raster is converted back to a 25m raster using smoothing.
more	Target creation of larger patches under more strategy	NA	**NOT USED**- This is an aspect that we have tested using our scenario modelling approach, i.e. the influence of creating larger cluster of suitable habitat.
bigger/ more	Target areas with existing moorland associations	New data set	Using the farming clusters provided by FWAG southwest (current and proposed future clusters). All pixels within a farming cluster are assigned a value of 1 and all areas outside assigned a value of 0.
bigger/ more	Target areas further away from urban areas	(Marston et al. 2022)	Using the UKCEH landcover 25m raster identify all pixels classified as urban or suburban. Calculate the distance of all none-urban pixels to the nearest urban pixels. Scale distance to urban pixels to between 1 and 0. Largest distance to urban = 1, urban pixels = 0.
bigger/ more	Target areas further from flood storage reservoirs	(Somerset Drainage Board Consortium 2011)	If a pixel is more than 50% within the digitised Curry moor hydrological unit then it is given a value of 0 and all other values are given a value of 1. This was the only designated flood storage area we could identify within the priority landscape.
bigger/ more	Target sites that historically had breeding waders	(Round 1978)	Use breeding wader abundance counts from Round (1978) that were aggregated for each Moor. The Moor-level values are then interpolated onto a raster using ordinary kriging. Areas with higher historic abundance are given higher gradings.
bigger/ more	Target hydrological units that have few landowners	(Rural Payments Agency 2024)	Using the RPA anonymised customer data set I calculate the number of unique customers within each hydrological unit. Then the density of landowners within hydro unit was calculated. Finally, I inversely scaled the density values so that the unit with the lowest density of landowners is given a value of 1.
bigger/ more	Target SSSI area	(Natural England 2024b)	Any pixels that are within a SSSI are classified as 1. All other areas are given a value of 0.
bigger/ more	Target areas that are not paludiculture expansion areas	NA	**NOT USED**- only small paludiculture trial in the Somerset Levels and we are not sure where future paludiculture will be done.

(continued)

Strategies	Guideline	Reference	Implementation
better/ bigger/ more	Target raised water level areas	New data set	All pixels within a raised water level area (provided by the internal drainage board) are given a grading of 1 and all areas outside are given a grading of 0. Not used for arable conversion as a very similar arable conversion only guideline exists and this would essentially be a duplicate of that rule.
arable conversion	Target arable reversion near to raised water level areas	New data set	Calculate the distance to a raised water level for all pixels within 1km of raised water level. All pixels within or immediately on the boundary with a raised level area have a grading of 1 and all pixels > 1km from a raised water level area = 0.
arable conversion	Target arable reversion in isolated patches within grassland	New data set (see methods)	This guideline used a raster of lowland wet grassland that was created using BWWM fields and NE priority habitat inventory. Using this raster, I calculated the proportion of lowland wet grassland surrounding each pixel within a 1.025km buffer. Higher values are given to pixels that are surrounded by more lowland wet grassland. Final gradings halved as very similar to targeting arable adjacent to grassland.
arable conversion	Target arable conversion on land where maize is grown	(UKCEH 2021)	All pixels that more than 50% overlap a maize polygon from the UKCEH landcover plus crops map are assigned a grading of 1 as they will be targeted first for reversion.
arable conversion	Target arable conversion on areas adjacent to wet grassland	New data set (see methods)	Calculate the distance to a raised water level for all pixels within 1km of lowland wet grassland. All pixels within or immediately next to lowland wet grassland received a grading of 1 and all pixels > 1km from a lowland wet grassland pixel a grading of 0. Final gradings halved as very similar to targeting arable isolated in larger patches of grassland.
all	Target hydrological units with more water in the future	(Environment Agency 2022b)	For each EA catchment zone there is a rough percentage of time that water is available for abstraction. These catchments are polygons that are then rasterized. The largest percentage of time that water is available for abstraction is graded 1 and the lowest percentage time is graded 0.
all	Target mid height land within hydrological units	(Environment Agency 2022a)	For each hydrological unit all elevation values were extracted and the and the quantile value for each pixel calculated. The pixels with an elevation at the 50th quantile receive a grading of 1 and the highest and lowest quantile pixels in each hydrological unit are graded 0. All pixels not in a hydro unit are given a value of 0.
all	Avoid scheduled monuments	(Historic England 2024)	All pixels that overlap a scheduled monument polygon (+ 20m buffer) by more than 50% are masked out. This buffer is based on recommendations from Natural Heritage.
all	Mask urban areas	(Marston et al. 2022)	All pixels in the UKCEH habitat data that are assigned as urban/suburban, or a coastal habitat are turned into masks. As the UKCEH 25m raster is the base for all masks this is simply selecting certain pixels.
all	Avoid priority habitats	(Natural England 2024a)	All pixels that overlap a non-lowland wet grassland priority habitat polygon by more than 50% are assigned as a masked pixel. This includes priority habitat woodland, raised bog, dry grasslands, heathland, reedbed and fen.

Table S3: Stakeholder rules generated during a workshop for Somerset Levels group 3 (landowners and famers). See Table S4 for full citation of each reference

Strategies	Guideline	Reference	Implementation
more	Target small scattered clusters across landscape under more strategy	NA	**NOT USED**- We are testing the effects of small vs large clusters in the scenario modelling and can't really include it as spatial grading here.
bigger/more	Target sites that historically had breeding waders	(Round 1978)	Use breeding wader abundance counts from Round (1978) that were aggregated for each Moor. The Moor-level values are then interpolated onto a raster using ordinary kriging. Areas with higher historic abundance are given higher gradings.
arable conversion	Target arable conversion on land where maize is grown	(UKCEH 2021)	All pixels that more than 50% overlap a maize polygon from the UKCEH landcover plus crops map are assigned a grading of 1 as they will be targeted first for reversion.
arable conversion	Target arable reversion on any peat soils first	(NSRI 2022)	Used the NATMAP vector to extract peaty soils in Somerset. I filter out the same soil types that I have classified as Peaty in all scripts. Any pixel covered by peaty soil = 1 and none-peaty soils = 0
all	Target areas that already had wader CS schemes	(Natural England 2024c); (Rural Payments Agency 2024)	I identified land parcels that had either wader specific CSS or ESS and then rasterized these. The codes used as "wader specific" are consistent with wider project. AES field value = 1; all other areas = 0
all	Target hydrological units with more water in the future	(Environment Agency 2022b)	For each EA catchment zone there is a rough percentage of time that water is available for abstraction. These catchments are polygons that are then rasterized. The largest percentage of time that water is available for abstraction is graded 1 and the lowest percentage time is graded 0.
all	Target raised water level areas for Snipe management	New data set	All pixels within a raised water level area (provided by the internal drainage board) are given a grading of 1 and all areas outside are given a grading of 0.
all	Target Lapwing management in lowest lying areas	(Environment Agency 2022a)	For each hydrological unit all elevation values were extracted and the value at the quantile of each elevation value calculated for each unit. The pixels with an elevation at the lowest quantile receive a grading of 1 and the highest quantile in each hydrological unit are graded 0. All pixels not in a hydro unit are given a value of 0.
all	Target fields with lower public footfall	(Day & Smith 2018)	Disturbance index is calculated by multiplying the inverse scaled distance to a path (constrained within 500m of a path so >500m = 0 and 0m=1) by the total visitors to the path. If multiple paths have overlapping 500m extents, then the values for the closest path are taken. Pixels greater than 500m from a path have a grading of 1 and pixels along the path with the largest number of visitors have a grading of 0.
all	Target silty sites for lapwing/redshank management	(NSRI 2022)	All wet loamy or clay soils are defined as silty (mainly excluding well drained, sandy, and organic peaty soils). Silty Soils given a grading of 1 and all others a grading of 0. Finally, these gradings are halved as this guideline only relates to Lapwing.
all	Target edge or periphery of peat areas	(NSRI 2022)	For any pixels that were classified as peaty soils I calculate the distance to the nearest non-peaty soil pixel. Any pixels that are right on the border between peaty and none-peaty soils were then given a grading of 1 and the peaty pixels furthest from non-peaty soils given a grading of 0.
all	Avoid scheduled monuments	(Historic England 2024)	All pixels that overlap a scheduled monument polygon (+ 20m buffer) by more than 50% are masked out. This buffer is based on recommendations from Natural Heritage.
all	Mask urban areas	(Marston et al. 2022)	All pixels in the UKCEH habitat data that are assigned as urban/suburban, or a coastal habitat are turned into masks. As the UKCEH 25m raster is the base for all masks this is simply selecting certain pixels.



(continued)

Strategies	Guideline	Reference	Implementation
all	Avoid priority habitats	(Natural England 2024a)	All pixels that overlap a non-lowland wet grassland priority habitat polygon by more than 50% are assigned as a masked pixel. This includes priority habitat woodland, raised bog, dry grasslands, heathland, reedbed and fen.



Table S4: A full list of citations that were used to turn the stakeholder guidelines into realy world spatially graded layers

Reference	Dataset References
(Borrelli et al. 2017)	Borrelli, P., Lugato, E., Montanarella, L., & Panagos, P. (2017). A New Assessment of Soil Loss Due to Wind Erosion in European Agricultural Soils Using a Quantitative Spatially Distributed Modelling Approach. <i>Land Degradation & Development</i> , 28: 335–344, DOI: 10.1002/lde.2588, DOI: 10.1002/lde.2588
(Day & Smith 2018)	Day, B., & Smith, G. S. (2018). The Outdoor Recreation Valuation (ORVal) tool: Technical report, January 2018. Report to the Department of Food and Rural Affairs.
(Environment Agency 2013a)	Environmental Agency. (2013). North Kent & Swale Abstraction Licensing Strategy February 2013. Date Accessed: 01-07-2024. URL: https://www.gov.uk/government/publications/north-kent-and-swale-catchment-abstraction-licensing-strategy
(Environment Agency 2013b)	Environmental Agency. (2013). Medway Abstraction licensing strategy February 2013. Date Accessed: 01-07-2024. URL: https://www.gov.uk/government/publications/medway-catchment-abstraction-licensing-strategy
(Environment Agency 2013c)	Environmental Agency. (2013). Essex abstraction licensing strategy. Date Accessed: 01-07-2024. URL: https://www.gov.uk/government/publications/cams-essex-abstraction-licensing-strategy
(Environment Agency 2022a)	Environment Agancy. (2022). LiDAR Composite Digital Terrain Model (DTM) 2m. Date Accessed: 01-06-2024. URL: https://environment.data.gov.uk/dataset/09ea3b37-df3a-4e8b-ac69-fb0842227b04
(Environment Agency 2022b)	Environment Agancy. (2022). South and West Somerset abstraction licensing strategy. Date Accessed: 29-08-2024. URL: https://www.gov.uk/government/publications/south-and-west-somerset-abstraction-licensing-strategy/south-and-west-somerset-abstraction-licensing-strategy
(Environment Agency 2024a)	Environmental Agency. (2024). Water Resource Availability and Abstraction Reliability Cycle 2. Date Accessed: 01-07-2024. URL: https://environment.data.gov.uk/dataset/62514eb5-e9d5-4d96-8b73-a40c5b702d43
(Environment Agency 2024b)	Environment Agency. (2024). Permitted Waste Sites - Authorised Landfill Site Boundaries. Date Accessed: 01-07-2024. URL: https://www.data.gov.uk/dataset/ad695596-d71d-4cbb-8e32-99108371c0ee/permitted-waste-sites-authorised-landfill-site-boundaries
(Fuller et al. 2022)	Fuller, R.M.; Smith, G.M.; Sanderson J.M.; Hill, R.A.; Thomson, A.G; Cox, R.; Brown, N.J.; Clarke, R.T; Rothery, P.; Gerard, F.F. (2002). Land Cover Map 2000 (25m raster, GB). NERC Environmental Information Data Centre. https://doi.org/10.5285/f802edfc-86b7-4ab9-b8fa-87e9135237c9
(Historic England 2024)	Historic England. (2024). Scheduled Monuments. Date Accessed: 28-08-2024. URL: https://opendata-historicengland.hub.arcgis.com/datasets/historicengland::national-heritage-list-for-england-nhle/explore?layer=6
(Holm & Laursen 2009)	Holm, T.E. and Laursen, K. (2009). Experimental disturbance by walkers affects behaviour and territory size of nesting Black-tailed Godwit <i>Limosia limosa</i> . <i>Ibis</i> , 151(1), pp.77–87. doi: https://doi.org/10.1111/j.1474-919X.2008.00889.x .
(Lislevand et al. 2009)	Lislevand, T., Byrkjedal, I. and Grønstøl, G. B. (2009) “Dispersal and age at first breeding in Norwegian Northern Lapwings (<i>Vanellus vanellus</i>)”, <i>Ornis Fennica</i> , 86(1), pp. 11–17. Available at: https://ornisfennica.journal.fi/article/view/133716
(Marston et al. 2022)	Marston, C.; Rowland, C.S.; O’Neil, A.W.; Morton, R.D. (2022). Land Cover Map 2021 (25m rasterised land parcels, GB). NERC EDS Environmental Information Data Centre. https://doi.org/10.5285/a1f85307-cad7-4e32-a445-84410efdfa70
(Morton et al. 2014)	Morton, R.D.; Rowland, C.S.; Wood, C.M.; Meek, L.; Marston, C.G.; Smith, G.M. (2014). Land Cover Map 2007 (25m raster, GB) v1.2. NERC Environmental Information Data Centre. https://doi.org/10.5285/a1f88807-4826-44bc-994d-a902da5119c2
(Natural England 2019)	Natural England. (2019). Provisional agricultural land classification (ALC) natural England, United Kingdom. Date Accessed: 27-08-2024. URL: https://naturalen gland-defra.opendata.arcgis.com/datasets/5d2477d8d04b41d4bbc9a8742f858f4d_0
(Natural England 2020a)	Natural England. (2020). Habitat Networks (England) - Lowland Fen. Date Accessed: 28-08-2024. URL: https://environment.data.gov.uk/dataset/1c85a398-653a-4a21-9923-f5d09adfea3a
(Natural England 2020b)	Natural England. (2020). Habitat Networks (England) - Reedbed. Date Accessed: 28-08-2024. URL: https://environment.data.gov.uk/dataset/4b93c91b-3c7f-4ad2-9fe7-ad93e920b1ad
(Natural England 2020c)	Natural England. (2020). Habitat Networks (England) - Lowland Raised Bog. Date Accessed: 28/08-2024. URL: https://environment.data.gov.uk/dataset/c8244a2d-6e53-499a-8419-b41aae88a90e
(Natural England 2024a)	Natural England. (2024). Priority Habitats Inventory (England). Date Accessed: 28-08-2024. URL: https://naturalengland-defra.opendata.arcgis.com/datasets/Defra::priority-habitats-inventory-england/about
(Natural England 2024b)	Natural England. (2024). Sites of Special Scientific Interest (England). Date Accessed: 28-08-2024. URL: https://naturalengland-defra.opendata.arcgis.com/datasets/f10ccb4425154bfda349ccf493487a80_0/about



(continued)

Reference	Dataset References
(Natural England 2024c)	Natural England. (2024). Countryside Stewardship Scheme Options (England). Date Accessed: 01-05-2024. URL: https://naturalengland-defra.opendata.arcgis.com/datasets/Defra::countryside-stewardship-scheme-options-england/about
(Natural England 2024d)	Natural England. (2024). King Charles III England Coast Path Route. Date Accessed: 25-07-2024. URL: https://naturalengland-defra.opendata.arcgis.com/datasets/a1488f928832407fdb267feb6802bed6_0/about
(NSRI 2022)	NSRI (2022) National soil map of England and Wales - NATMAP Vector, 1:250000 Soil Association Map. Date Accessed: 01-02-2024. URL: https://www.landis.org.uk/data/natmap.cfm .
(Ordnance Survey 2024)	Ordnance Survey. (2024). OS Open Rivers. Date Accessed: 01-06-2024. URL: https://www.data.gov.uk/dataset/dc29160b-b163-4c6e-8817-f313229bcc23/os-open-rivers
(Panagos et al. 2015)	Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., Alewell, .C. (2015). The new assessment of soil loss by water erosion in Europe. Environmental Science & Policy. 54: 438-447. DOI: 10.1016/j.envsci.2015.08.012
(Round 1978)	Round, P. D. (1978) An ornithological survey of the Somerset Levels 1976-77. A joint Wessex Water Authority and Royal Society for the Protection of Birds project.
(Rowland et al. 2020)	Rowland, C.S.; Marston, C.G.; Morton, R.D.; O'Neil, A.W. (2020). Land Cover Map 1990 (25m raster, GB) v2. NERC Environmental Information Data Centre. https://doi.org/10.5285/1be1912a-916e-42c0-98cc-16460fac00e8
(RSPB 2018)	RSPB. (2018). Sustainable Shores habitat creation opportunities WFS. Date Accessed: 01-07-2024. URL: https://opendata-rspb.opendata.arcgis.com/maps/24944d24920a445cb82b724c69715b59/about
(Rural Payments Agency 2024)	Rural Payments Agency. (2024). RPA Parcel Points (England). Date Accessed: 29-08-2024. URL: https://environment.data.gov.uk/dataset/93a2433d-054a-484c-aec4-4e2ce9d7f2a9 ; Anonymised customer ID available on request to RPA (open.data@rpa.gov.uk).
(Somerset Drainage Board Consortium 2011)	Somerset Drainage Board Consortium. (2011). Curry Moor Water Level Management Plan. Date Accessed: 29-08-2024. URL: https://somersetdrainageboards.gov.uk/environment/wlmps/
(UKCEH 2021)	Based upon UKCEH Land Cover® Plus: Crops © 2021. UKCEH. © RSAC. © Crown Copyright 2007, Licence number 100017572