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HOW 'GREEN' IS YOUR GRASS? MANAGEMENT AND CONSERVATION VALUE OF WARWICKSHIRE ARABLE GRASSLAND GREEN INFRASTRUCTURE

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DECLARATION

I can confirm that this research project is within the prescribed word limit. 12,000

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Abstract

Grasslands in humid temperate biomes require regular cutting, or grazing, to prevent succession to scrub and woodland. European traditional management creates highly biodiverse semi-natural habitat, such as hay meadow, though currently rare, highly fragmented and degraded. Core remnants, at the base of food-webs, provide ecosystem services and resilience to climatic change essential for future sustainable food production. Maintenance of cores requires network connectivity. In agricultural landscapes Grassland Green Infrastructure (GGI) has potential to fulfil this function. This study focused on GGI in two low intensity vegetable farms in Warwickshire, UK, aiming to establish if management influenced conservation value of GGI composition. Methodology: secondary data provided ecological landscape context, and primary data including land manager interviews and fieldwork standardized plant surveying techniques, investigated species richness and abundance of three cutting frequencies (n = 10). Data analysis included National Vegetation Classification (NVC) floristic tables, mean floral structure values, and mean floral function using Ellenberg Indicator Values. NVC Mesotrophic Grassland MG5 dominated, possibly transitioning from MG6 in historical sown swards, with MG1b in long established semi-abandoned sward. Management closest to that of hay meadow recorded significantly highest species richness and diversity in MG5. Other factors influencing composition were proposed, including Replicate historical management, topography, and surrounding habitat. Influence of crop bed arable weed species was inconclusive. Replicate habitat compared favourably with local nature reserves, with 8 red listed species found. Management recommendations to enhance and restore GGI conservation value were proposed. Replicates contribute towards a heterogenous agricultural matrix, with potential as ecological ‘stepping-stones’.

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1. Introduction

European humid temperate grasslands support globally important high vascular plant species richness and diversity. An estimated 18.1 % of endemic plant species are reliant on the habitat. This biodiversity exists despite Pleistocene glaciations leaving the northern region with relatively low species and genetic diversity (Habel *et al.* 2013). Natural grassland occurred in the Holocene through herbivory by native fauna, curtailing post glacial primary ecological succession to woodland climax communities. Subsequently from around 7000 BP semi-natural grassland was created by traditional agricultural management through regular livestock grazing of permanent pasture or cutting of hay meadow (Fuller, 1987; Habel *et al.* 2013; Manton and Angelstam, 2018).

1.1 Semi-natural grassland habitat ecosystem services

Measures of biodiversity in semi-natural grassland correlate with natural productivity and effectiveness of ecosystem services (Horrocks *et al.* 2016; JNCC, 2021; Smith *et al.* 2017). The habitat is critical at the foundation of terrestrial food chains, with evidence of cross-taxa congruence (Habel *et al.* 2013; Kimberley *et al.* 2021). It provides forage, breeding and hibernating habitat for birds, mammals and, primarily, invertebrates, such as insect pollinators and predators of crop pests that support higher crop yields (Badenhausser *et al.* 2020; Feng *et al.* 2021; Holland *et al.* 2017; Isbell *et al.* 2011; Li *et al.* 2020). Balancing ecosystem priorities, such as biodiversity, carbon storage, water and soil provision and cultural and societal enhancement (for example, traditional practices (Hawkes *et al.* 2021) and the aesthetics of wildflower meadows (Plantlife, 2022)) is often a trade-off. However, the habitat offers an option to deliver multiple benefits (Bardgett *et al.* 2021; Holland *et al.* 2017; Jiang *et al.* 2013; Kövendi-Jakó *et al.* 2019; Norton *et al*. 2019), not least of which is ecosystem resilience to climate change (Nichols *et al.* 2022) essential for sustainable human food production (Bardgett *et al.* 2021; Berg *et al.* 2010).

1.2 Agricultural legislation and policy: influence on conservation value

Since the 1700s however, by drainage and ploughing, and 20th century maximum yield agriculture, fuelled by legislation such as the UK Agricultural Act 1947 (Millennium Ecosystem Assessment, 2022; Winn *et al.* 2011), this indispensable major European habitat has become increasingly rare (Habel *et al.* 2013; Ridding *et al.* 2020). For example, a 97 % loss is estimated in Britain since the 1930s (Fuller, 1987) primarily through artificially improving sward productivity with synthetic fertilization and replacing semi-natural species ('improved' grassland ploughed and re-seeded with *Lolium* spp. (Ryegrass spp.) and *Trifolium repens* (White Clover)) (Critchley *et al.* 2003; Fuller, 1987). Though assessed as critical for national food security after the Second World War, and since to feed an increasing human population, the legacy of such policy has undermined the protection of ecosystem processes and conservation value of remnant semi-natural habitat.

Currently, species associated with intensive agricultural landscapes are amongst the most threatened globally (Maxwell *et al.* 2016). Close to half of habitable land is agricultural (71 % of total area in UK (DEFRA, 2022)) of which one-quarter is each used for producing crops and grazing (Bardgett *et al.* 2021; Ritchie and Roser, 2019). In recent decades, legislation has refocused to reverse trends of habitat and biodiversity loss (Foley *et al.* 2012). Global targets set out to manage 30 % land for nature by 2030 (30 by 30), have sustainable agricultural practices central to their aims (UN Environment Programme, 2023). However, global policy targets to halt biodiversity loss have not been met (Sutherland *et al*. 2022) and agricultural policy is criticised as environmentally ineffective (Hautier *et al*., 2018; Isbell *et al*. 2011; Resch *et al*. 2021; Scotton and Rossetti, 2021; Tscharntke *et al*. 2021). Post Brexit, the future of UK agricultural environmental legislative guidance and incentives are uncertain (Coe and Finley, 2020; Debonne *et al*. 2022; Natural England Framework, 2022; UK Government Legislation, 2022) though are aligning around concepts of sustainable farming (GOV.UK, 2023).

1.3 Ecological connectivity

Habitat loss is the main threat to semi-natural grassland plant species. Fragmentation and isolation of remnant conservation value habitat equates to loss of connectivity in ecological networks (Fuller, 1987; Hambler *et al.* 2011; Hooftman *et al*. 2021; Manton and Angelstam, 2018; Maxwell *et al.* 2016; Vié *et al.* 2009). Long-term effects of this degradation are not yet fully understood however it is known to negatively impact the whole ecosystem (Chase *et al.* 2020; Hadded *et al.* 2015; Hooftman *et al*. 2021; Manton and Angelstam, 2018). Effective landscape connectivity requires species rich core patches (often conservation reserves) connected by network corridors or 'stepping-stones' (series of small patches connecting cores with similar composition) to maintain habitat species richness for native plants and animals (Prugh *et al.* 2008). For example, connectivity is essential for restoring and extending plant species ranges through dispersal, re-colonisation, and maintaining gene-flow and genetic diversity. This in turn increases species and community resilience to environmental fluctuation (Comins and Hamilton, 1980; Damschen *et al.* 2006; Hooftman *et al.* 2021; Plue *et al.* 2022). The importance of connectivity is amplified within intensive agricultural landscapes (matrices) (Hambler and Canney, 2013) such as exist in Britain.

1.4 Species richness in semi-natural grassland remnants

Only 1 - 2 % of semi-natural grassland in Britain is estimated as conservation priority core habitat (Blackstock *et al.* 1999; Fuller, 1987; Hambler and Canney, 2013; Hooftman and Bullock, 2012). Cores are refugia for grassland specialist species. Specialists are defined as requiring specific environmental conditions, sensitive to environmental change, with naturally low abundance and dispersal capacity (fewer seeds) (Hooftman *et al.* 2021; Kimberley *et al*. 2021; Manton and Angelstam, 2018; Plue *et al.* 2022; Sarr, 2012). However, remnant traditionally managed habitat is less species rich today than pre-industrialisation. Trends towards species homogenisation are seen since the middle of the last century, the balancing influence of specialist re-colonisations unable to offset the influx of generalist species where connectivity is lost (Bartelheimer and Poschlod, 2016; Baum *et al.* 2004). Generalists are defined as able to establish in a range of habitats through competitive dispersal strategies. Additionally, where generalists and 'improved' grassland dominate matrices (Resch *et al.* 2021), core spatial isolation over long time periods increases specialist species vulnerability to local extinction. This process of slow erosion of quality is known as extinction debt (Aavik *et al*. 2020; Cousins, 2006; Kimberley *et al.* 2021; Le Provost *et al*. 2020).

1.5 Grassland Green Infrastructure (GGI)

To offset trends of ecosystem deterioration, current European agricultural policy and research is highlighting the importance of matrix green infrastructure. Essentially any small patch or linear strip of green habitat, such as Grassland Green Infrastructure (GGI). Though much GGI, such as road verges, has low conservation value, it has potential to restore semi-natural networks (Concepción *et al.* 2020; Jefferson *et al.* 2019; Magaudda *et al.* 2020; Plue and Baeten, 2021). For example, newly created GGI, such as set-aside field edge strips, are seen to increase matrix connectivity by 74 % (using range expansion of flying insects as indicator taxa) (Threadgill *et al.* 2020). Established GGI can harbour species rich assemblages and seedbanks (Aavik *et al*. 2020; Blackstock *et al*. 1999; Hooftman *et al*. 2021; Resch *et al*. 2021; Threadgill *et al*. 2020). Such refugia when located within fields, can have high conservation value where remnant historically species rich communities are partially preserved and buffered from diluting influence of degraded habitat (Cousins, 2006). Adjacent habitat is one of many factors that determines grassland community classification and composition.

1.6 Grassland classification: management and other determinants of community composition

Semi-natural grassland has different species composition from natural systems, though in Britain, no natural grassland remains (Fuller, 1987; Hambler and Canney, 2013). Within the British Isles (excluding Northern Ireland), semi-natural grassland, including habitats prioritised for conservation (such as Sites of Special Scientific Interest (SSSI) (Jefferson *et al.* 2019)), can be broadly classified within 22 plant communities in the British National Vegetation Classification (NVC) (Blackstock *et al.* 1999; Critchley *et al.* 2003; Rodwell *et al.* 1992 and 2000). Community classification is determined by species evolutionary adaptation (or responses) to climate, underlying geology, soil type and hydrology (Rodwell *et al.* 1992). At finer scales, community composition is not fixed. Species migrate as environments change, by a range of dispersal strategies and vectors following suitable conditions (or species niche) (Darwin, 1859).

Cutting sward has significant influence on composition, fewer cuts increasing conservation value as defined by higher species richness and diversity (Darwin, 1859; Jakobsson *et al.* 2016;

Manton and Angelstam, 2018; Sehrt *et al.* 2019) whilst abandonment may have negative impacts (Habel *et al.* 2013). Jakobsson *et al.* (2016) reviewing 48 studies on GGI mowing management along roadsides found cutting once or twice a year, with hay removed increased both species richness and diversity. Topography influences moisture availability (Bartelheimer and Poschlod, 2016; Berg *et al.* 2010; Tamme *et al.* 2014) which in turn determines soil pH and available nutrients (Moeslund *et al.* 2013). Many semi-natural grassland communities requiring low nutrient soils (Bartelheimer and Poschlod, 2016; Grime *et al.* 2007) are adversely affected by eutrophication of water from excess synthetic nitrogen (N) and phosphates, and with airborne pollution (Habel *et al.* 2013; Hooftman *et al.* 2021). It may take decades for habitat to recover from the legacy of past land use, such as intensive agricultural management, and return communities to those more naturally occurring (Cousins, 2006; Horrocks *et al.* 2016; Le Provost *et al*. 2020).

1.7 Suggested research approach within academic literature

More research is required to understand the processes that shape composition (Habel *et al.* 2013) and inform management solutions to address conservation value of GGI and cores (Fleury *et al.* 2015; Hooftman *et al.* 2021; Jakobsson *et al*. 2016: Plue *et al.* 2022; Shukla *et al.* 2019). A cross discipline approach encompassing agriculture, ecology and society is necessary for sustainable management (Manton and Angelstam, 2018). Each local ecological network is unique, requiring individual investigation using appropriate data collection and assessment (Kimberley *et al*. 2021; Plantlife, 2022). Analysis of observational fieldwork, regarding GGI species richness (distribution) and abundance, establishes community structure. Ongoing data collection is important for monitoring impacts of changing management or environment, such as expectations of future local baseline composition with climate forced species range shifts (Pescott *et al.* 2019). Ellenberg Indicator Values allow assessment of underlying environmental variables, such as soil properties, without direct measurements (using estimated species preferences) and provides insight into community function (Bartelheimer and Poschlod, 2016). Such data form the basis of landscape ecology, and is the foundation of understanding conservation aims, priorities, action planning and monitoring, as well as informing evaluation of ecosystem services (Goldstein, 1998; Resch *et al.* 2021; Zirbel *et al*. 2019).

1.8 Vice County Warwickshire

Focus of this research is in the Vice-County of Warwickshire (Vice-County 38). Biological vice-counties are a standard area for biological recording within Great Britain (Biological Records Centre, 2022). Situated in the lowland English Midlands, Warwickshire's (currently) moderate climate and topography provide prime agricultural land (50 % total land area under production), with current land-use patterns established after the Second World War (Falk, 2009). Within this matrix GGI is limited in its conservation potential due to isolation from conservation value core sites, which themselves are rare, fragmented and under threat (Hooftman *et al.* 2021; Threadgill *et al.* 2020). Conservation designation is not full-proof defence from other land use pressures, such as expanding urbanisation and road and rail infrastructure. However, loss of habitat is being addressed through 30 by 30 conservation initiatives (such as Dunsmore Living Landscape (2023)), focusing on reconnecting the landscape for wildlife (Nature Recovery Network, 2022). Included in these plans is GGI in the context of this research, that is, permanent grassland arable field margin habitat defined within the Warwickshire local Biodiversity Action Plan (BAP)). In 2017, 19 km^2 of this habitat existed in the county. With the aid of government financially supported agricultural set-aside, a target of 64 km^2 by 2026 is proposed (Rowe and Moffatt, 2017).

1.9 Research justification and focus

The Sutherland *et al.* (2022) horizon scan of issues for global biodiversity conservation, highlighted the increasing positive role of socially owned and managed natural capitol, with associated significant impacts for conservation predicted in coming decades. Therefore, this research focuses on GGI in two (avoiding pseudo-replication (Belovsky *et al*. 2004; Hooftman *et al*. 2021)), low intensity community supported organic farms (research Replicates). An applied approach to agroecological research is an area under-represented within mainstream academia (Reynolds *et al.* 2014), and the topic is highlighted within Agroecology Research Collaboration 'Research Needs and Priorities' document (CSA, 2022). Horizon scanning of trends in European agriculture stress the necessity of systemic change within the sector towards environmentally low impact production, a trend which England has not yet aligned to (Debonne *et al*. 2022). Low intensity farm-scale management is expected to enhance GGI conservation value (Blackstock *et al.* 1999; Hawkes *et al*. 2021; Hooftman *et al.* 2021; Resch *et al.* 2021; Tscharntke *et al.* 2021). Historic management practices and current crop management may also influence sward composition (Reberg-Horton *et al.* 2010; Tscharntke *et al*. 2021). Oldest swards and GGI managed in a similar way to traditional hay meadow are expected to have highest species richness and diversity, with local core grassland (in designated nature reserves) providing a baseline for what might be achievable with conservation management.

1.10 Research aims and definitions

This research aimed to guide potential management choices regarding identified GGI, providing evidence (quantifiable data) to evaluate the potential for achievable restoration, reestablishment and expansion of conservation value habitat. GGI within this study is grassland in paths, set-asides, orchard and social areas, within arable land. Core communities are habitats with a composition containing high species richness and diversity including grassland species of conservation interest (locally native species, specialists, and rarities). To fulfil aims, research investigated GGI floral community composition (structure: grass and forb species present and abundance, and function: individual species traits which dictate where species will survive and thrive (morphology, physiology and phenology)), and considered GGI connectivity, by addressing the following questions:

i) What NVC class of grassland community exists within Replicate GGI?

ii) Do historical and current farm scale management intensity, or cropland community, influence GGI community?

iii) Do links exist between cutting frequency of GGI, GGI community and species richness and diversity?

iv) Are other environmental factors influencing community composition?

v) What potential exists at Replicates for enhancement of GGI conservation value within the context of the agricultural landscape matrix?

2. Methods

This research was scaled to 'best fit' the limitations and research compromises required for an undergraduate study. The following methodology was proposed, to address the aims (*1.10*).

2.1 Research location: Warwickshire geo-hydrological and botanical natural history

Underlying geology dictates soil profile, which influences plant communities. Warwickshire contains one of the largest geological ranges of any county within Britain. To minimise research bias, research location (area of Vice-County Warwickshire encompassing research sites) was chosen for uniform bedrock, namely Triassic Mercia Mudstone formed 290 – 280 mya (Fig. 2.1). Pleistocene glacial ice covered Warwickshire at least once during the past 500,000 years, overlaying bedrock with glacial till, and major interglacial river systems depositing sand and gravel (Radley, 2009; Shotton, 1953; WGCG, 2021). Palaeo-ice and rivers carved out the current River Avon valley, the catchment draining generally in a south-west direction, forming a major eastern tributary of the River Severn (Radley, 2009; WGCG, 2021) (Fig. 2.1). Pollen records reveal ecological succession after the last glacial maximum, 15000 BP, followed a pattern seen across the majority of Britain of pine to deciduous forest by 5000 BP (Birks *et al.* 1975). It is suggested, with localised variation, that Lowland England was broadly dominated by *Tilia,* hence, The Lime Province. Neolithic forest clearances in Warwickshire began around 4500 BP (Rackham, 2004), with evidence of cultivation from 3000 BP (Falk, 2009). Current Warwickshire climate is humid temperate with a cold season (Met Office, 2022a). Projections for climate warming within this century are predicting increasing temperatures and reduced precipitation (Met Office, 2022b) with expected ecological and agricultural impacts (Berg *et al.* 2010; Debonne *et al.* 2022).

2.2 Research location: sites

Research sites (Replicates and local nature reserves) (Fig. 2.2) were matched for environment (climate, altitude, and soil, as discussed above) and Replicates for cultural variability (land use and size, management practice and business model) (Hooftman *et al*. 2021). Replicates, commercially sustainable Community Supported Agriculture (CSA) enterprises (CSA, 2022), Five Acre Community Farm (Five Acre 'FA'), Ryton, and Canalside Community Food (Canalside 'C'), Leamington Spa, were enthusiastic to host research and participate in sharing and implementing findings. Both farms are organically certified (Soil Association UK) vegetable and fruit producers. Five Acre 28,000 m^2, has GGI permanent pasture established at least 50 years ago. Canalside 57,000 m^2 has GGI re-seeded in 2005 on conversion from conventional arable rotation. Each Replicate was matched (with fine-scale natural soil parameters) with local nature reserves (LNR's), Wolston Fields and Hunningham Meadow respectively, to provide baseline floral comparison (WWT, 2022) (Supplementary Information SI. 1).

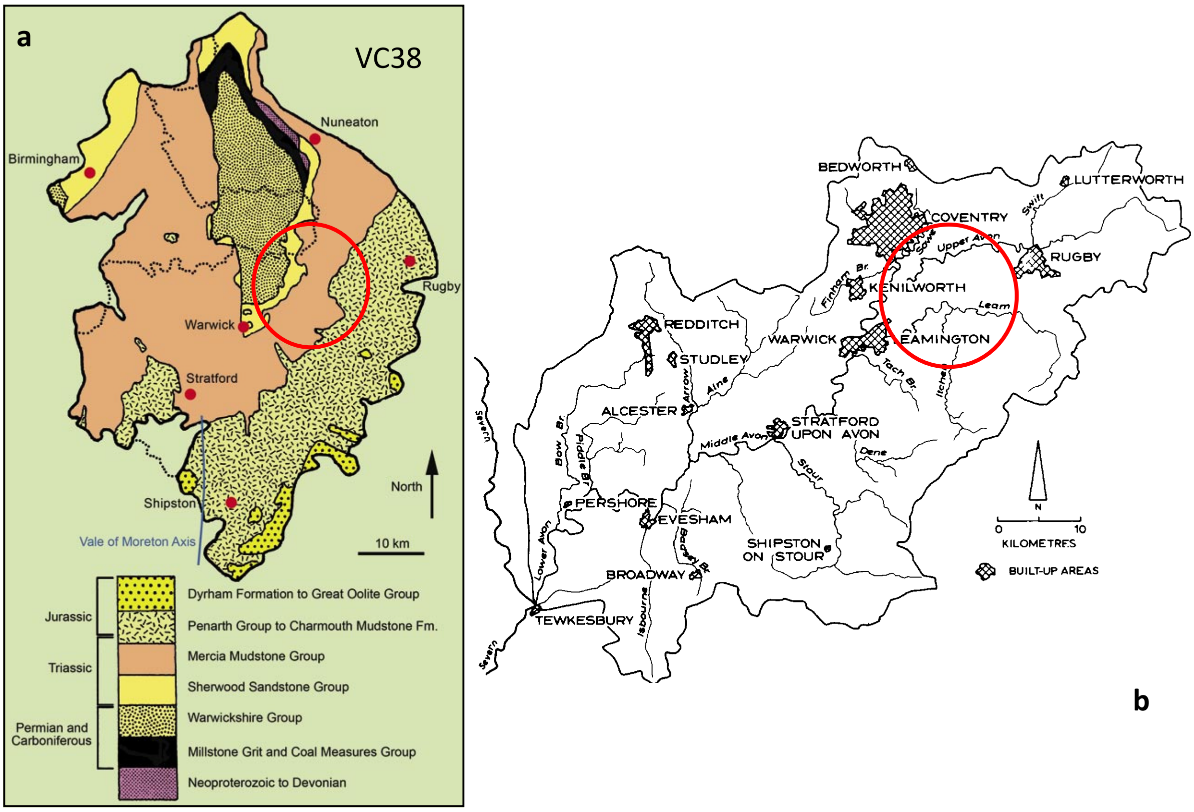

Fig. 2.1 Research location Vice County Warwickshire (VC38) geological context and hydrological catchment. a) Bedrock geology. The research location falls within the Mercia Mudstone group, (orange colouration on the map) in the Triassic lowlands (Radley, 2009; WGCG, 2021). Image adapted from Radley (2009). b) River Avon catchment, the major eastern tributary of the River Severn (conflux at Tewksbury). Pleistocene glaciation and interglacial rivers carved out the current river Avon valley which flows in a general south-west direction through the county (Ledger, 1972; WGCG, 2021). The research area falls between urban centres of Coventry (to the north-west), Rugby (to the east), and Leamington (to the south-west). Image adapted from Ledger (1972). Research area indicated by red ovals.

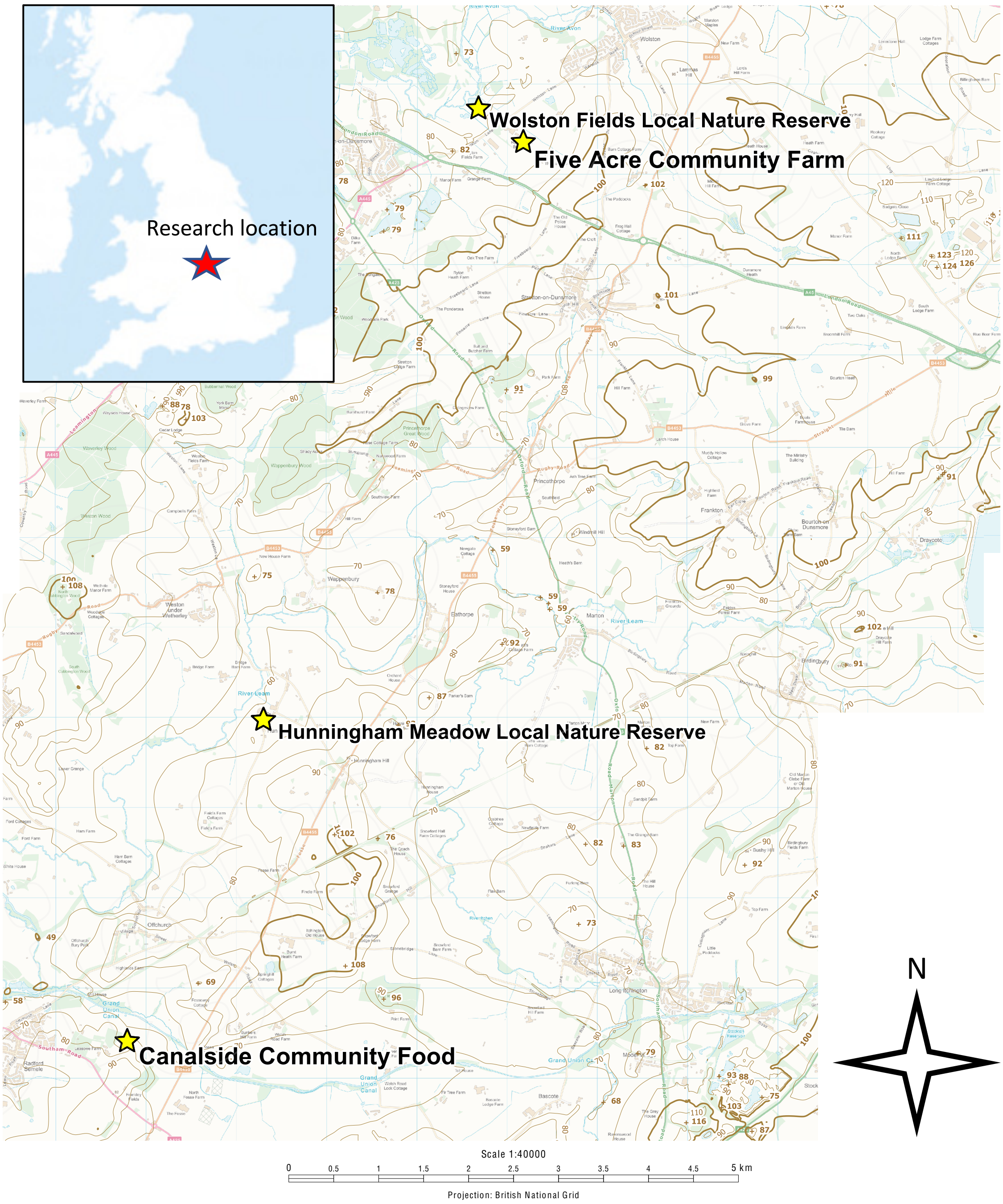

Fig. 2.2 Location of research sites, Warwickshire, UK. Inset, research location within Great Britain and Ireland (red star). Main image, topographic context of research sites (yellow stars). Replicate farm sites Five Acre Community Farm (altitude 74 m) 52°21'59.3"N 1°24'41.7"W lies east of the River Avon. Canalside Community Food (70 m) 52°16'45.4"N 1°29'03.5"W located south of a River Leam tributary, its lower field at a boundary to the Grand Union Canal. Local nature reserves (LNR's) Wolston Fields LNR (71 m) 52°22'10.1"N 1°25'13.4"W situated on the east bank of the River Avon, and Hunningham Meadow LNR (66 m) 52°18'32.0"N 1°27'16.5"W in proximity to the River Leam. (Images generated by Digimap OS Roam with VMD Backdrop. Full map legend given in SI. 2).

2.3 Secondary data collection: landscape ecological context

The following key data sources were identified to establish research landscape scale ecological context. Met Office data provided current climate information and future climate projections (SI. 3) (Met Office, 2022a and b). Landis Soilscapes online soils data (Soilscapes, 2022) and soil site reports (NSRI, 2022a, b and c) requested to establish major environmental parameters of soils and hydrology (Kimberley *et al.* 2021; Manton and Angelstam, 2018). Requested information from Warwickshire Biological Records assisted identification of LNR's (Kimberley *et al.* 2021). Grassland Habitat Biodiversity Audit (HAB) records accessed from Warwickshire County Council (2022) (WWT HBA, 2022) online resources aided identification of habitat adjacent to Replicates for connectivity. Additional historical and contemporary land use information gathered from mapping tools Google Earth Pro (version 7.3.6.9345) and Digimap (Ordnance Survey Roam) (Kimberley *et al.* 2021), the latter used to create site maps, and calculate area (m^2) and distance (m).

2.4 Primary data collection: research sites

At each replicate a consistent methodology using standardized surveying techniques for the chosen ecological parameters was followed to collect primary data. Peak grass and forb flowering season for the local climate, June (2022), chosen to optimise species identification and best capture a representative range of species present (Badenhausser *et al*. 2020; Hooftman *et al*. 2021; Jakobsson *et al*. 2016; Norton *et al*. 2019). A total of five days were allocated to each Replicate for data collection, one day for pre-survey, 3 days GGI treatments (distinct cutting frequencies) and 1 day crop bed habitat treatment, to ensure consistent sampling independent of treatment patch size (Hooftman *et al*. 2021; Kimberley *et al*. 2021). Table 2.1 provides summary of treatments referred to throughout this report (Nichols *et al.* 2022), with representative photographic images of each GGI treatment in Figure 2.3, and sward detail in SI. 4.

Table 2.1 Summary of GGI treatments within research Replicates Five Acre Community Farm (FA1 Paths, FA2 Orchard, FA3 semi-abandoned Set-side) and Canalside Community Food (C1 Social Green, C2 Paths and C3 managed Set-aside) Warwickshire, with description and mowing frequency. Grass cutting usually occurred in growing season between March to October, at relatively regular intervals, with seasonal variation dependant on weather conditions. Cuttings were not removed. (S. Hayward and R. Stevenson, pers. comm., June 2022). Images for GGI treatments given in Fig 2.3 and sward detail SI. 4.

Treatment	**Description/name** Relative sward length	**Location within farm**	**Mowing frequency**	**Area surveyed (m^2)**
FA1	**Paths** intermediate	Surrounding crop beds and polytunnels throughout crop field	Frequent- every 4 weeks (tractor attachment)	1542 m^2
FA2	**Orchard/ community space** long	Adjacent to polytunnels and path at north end of crop field	Intermediate- every 8 weeks (tractor attachment/strimmer)	270 m^2
FA3	**semi-abandoned Set-aside (known as 'Beetle Bank')** longest	Running through length of crop field (north to south) intersected by paths	Partially abandoned- spot mown or disturbed < once per year	997 m^2
C1	**Social Green** shortest	Adjacent to farm buildings and polytunnels	Frequent- every 4 - 6 weeks (ride-on mower)	1546 m^2
C2	**Paths** intermediate	Surrounding crop beds and linking crop fields across farm	Intermediate- every 6 – 8 weeks (tractor attachment)	2076 m^2
C3	**managed Set-aside (known as 'Bermuda Triangle')** longest	At low point of lowest field on farm	Infrequent- 2 - 3 times per year (strimmer)	354 m^2

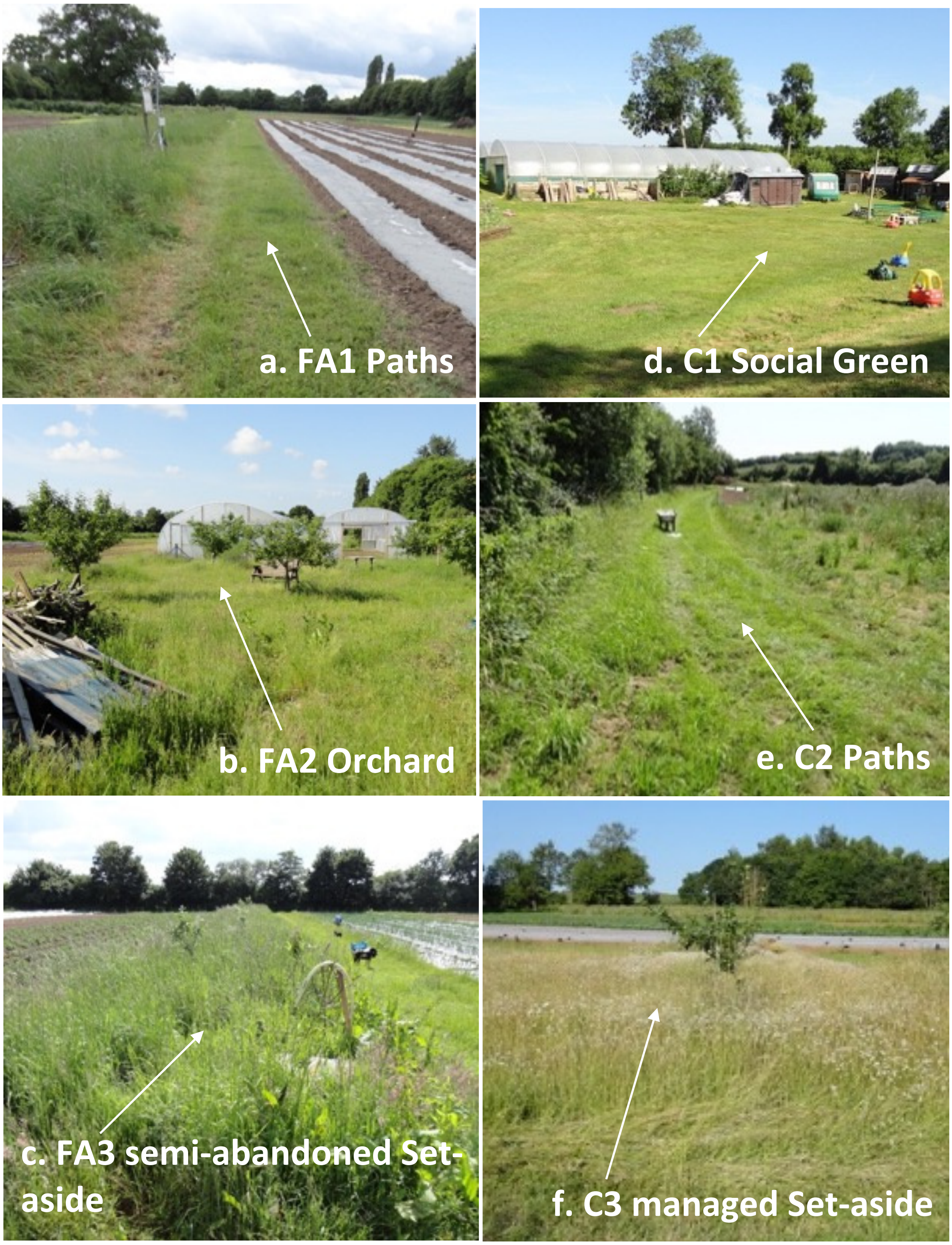

Fig. 2.3 Representative photos (overview) to illustrate each Replicate GGI treatment. Left column, Five Acre Community Farm, a) FA1 Paths, b) FA2 Orchard, c) FA3 semi-abandoned Set-aside (‘Beetle Bank’), and right column, Canalside Community Food, d) C1 Social Green, e) C2 Paths, and f) C3 managed Set-aside (‘Bermuda Triangle’), Warwickshire. Photo credits: report author.

2.4.1 Pre-survey

Pre-survey was undertaken during the first day at each Replicate. This included land manager interviews to collect relevant information with supporting documents (Li *et al.* 2020; Nichols *et al.* 2022) establishing current and historical land use and management (Le Provost *et al.* 2020; Manton and Angelstam, 2018), GGI cutting frequencies, and production inputs (Li *et al.* 2020). Preliminary site inspections (Kimberley *et al.* 2021) were undertaken to collate information for site maps detailing infrastructure, boundaries, broad habitat classification and surrounding land use (Hooftman *et al.* 2021; Li *et al.* 2020), and to include treatment quadrat points (Norton *et al.* 2019) (Fig. 2.4 and 2.5). Confounding environmental factors were identified in considering optimum sampling locations, with potential site GGI cores and network (connectivity potential) considered. Research treatments were identified (Norton *et al.* 2019) using land manager information, visual assessment of habitat, species identification, and measurements of sward height during surveying, as detailed below.

2.4.2 Treatment quadrat surveys

Quadrats were placed to match consistent light availability (identified as the main confounding factor) where sward received full sun for main part of day and year, matching optimal grassland habitat light conditions, reducing experimental bias. Other factors designed out of the experiment, included fragmented sward due to compaction and trampling. Quadrat (1 m^2, n = 10, for each GGI treatment) placement was chosen to attempt best representation of communities observed, from visual assessment, with random placement at micro-scale. Placement was consistently 2 m from habitat ecotones where patch size allowed, minimum of 1 m, distinguishing clearly between treatments (Norton *et al.* 2019).

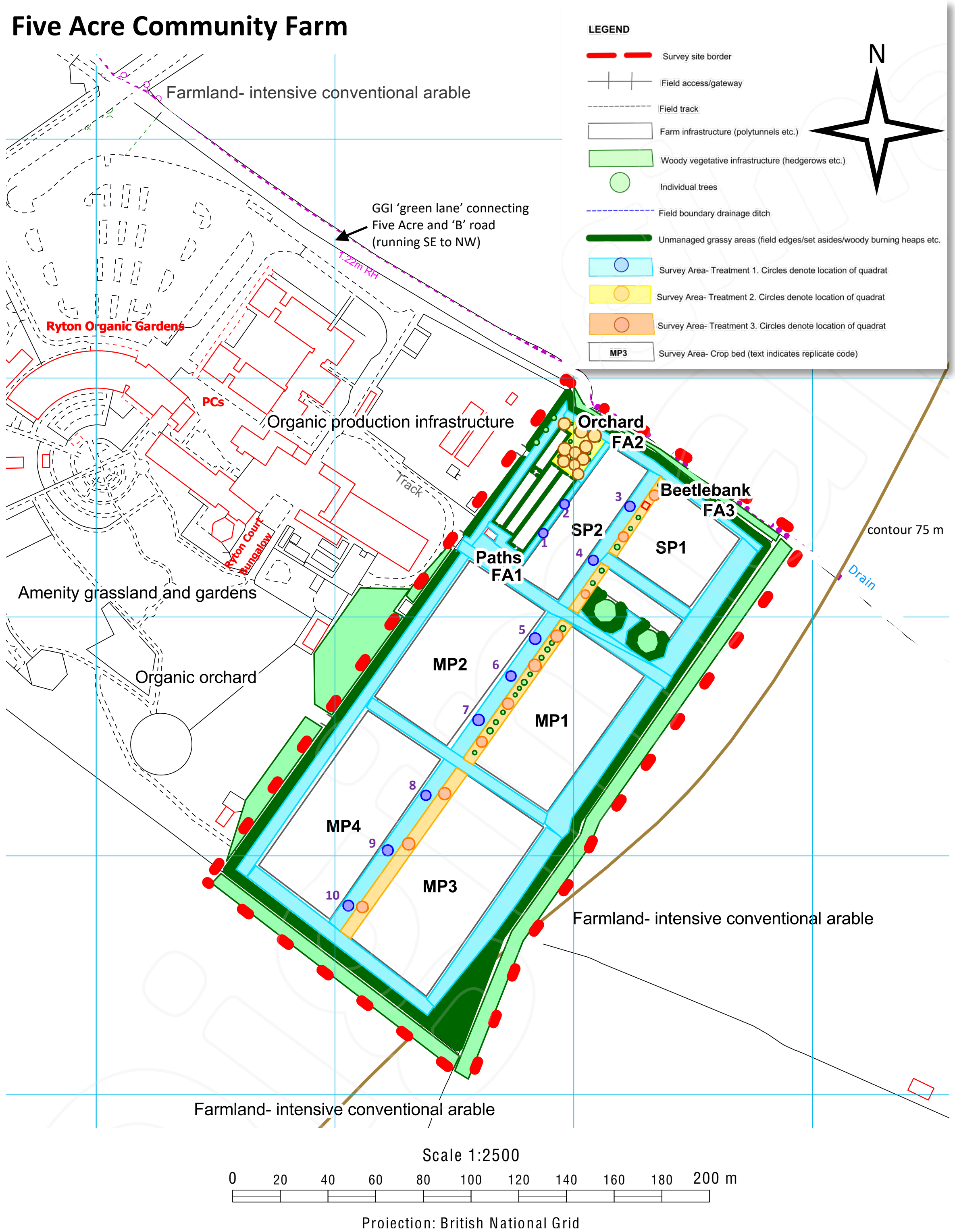

Fig. 2.4 Annotated Digimap (Ordnance Survey VML Plan) representation of Replicate site Five Acre Community Farm, Warwickshire (site boundary red dashed line). Broad habitats within the site are highlighted (pale green woodland/hedgerow; dark green unmanaged grassland) along with each quadrat placement for the three GGI treatments. FA1 Paths, blue shading (frequently mown, shortest sward, with numbered quadrats to track possible connectivity with core GGI), FA2 Orchard, yellow shading (intermediate height sward) (identified as core GGI, potentially of conservation value) and FA3 semi-abandoned Set-aside, orange shading ('Beetle Bank') (tallest sward). Crop bed zones (n = 10) (white rectangles) are labelled SP1, 2 (summer plots) and MP1, 2, 3 and 4 (main plots).

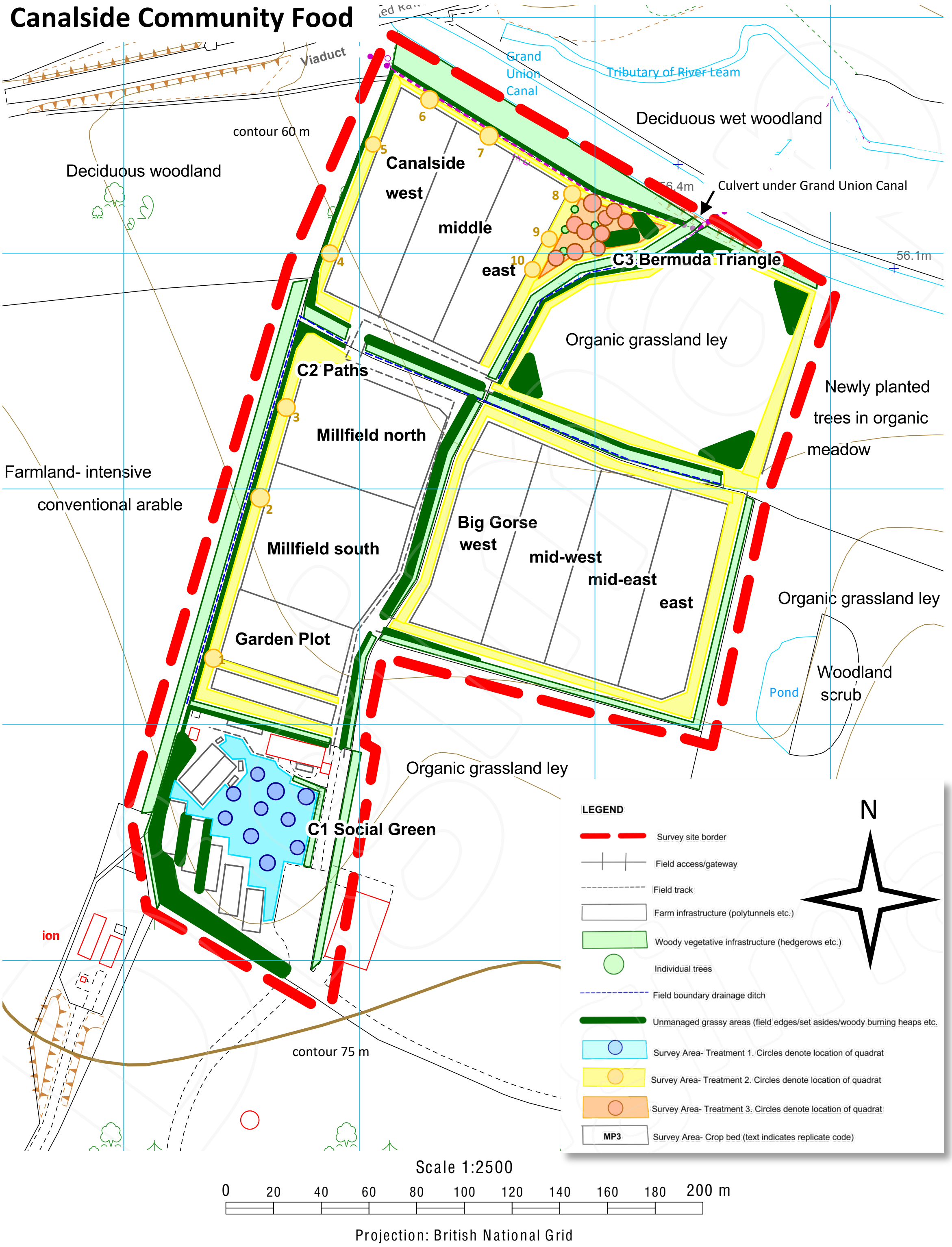

Fig. 2.5 Annotated Digimap (Ordnance Survey VML Plan) representation of Replicate site Canalside Community Food, Warwickshire (site boundary red dashed line). Broad habitats within the site are highlighted (pale green woodland/hedgerow; dark green unmanaged grassland), along with each quadrat placement for the three treatments. C1 Social Green, blue shading (frequently cut, shortest sward), C2 Paths, yellow shading (intermediate height sward) (with numbered quadrats to track possible connectivity with core GGI) and C3 managed set-aside, orange shading ('Bermuda Triangle') (infrequent cutting, tallest sward) (identified as core GGI, potentially of conservation value). Additionally, crop bed zones (n = 10) are labelled, Garden Plot, Millfield, Canalside and Big Gorse.

Records in each quadrat detailed, geographical location using GPS device (Jakobsson *et al.* 2016) (British National Grid 5 figure references for optimum accuracy), soil pH value (field assessed soil solution with hand-held meter), sward height (cm) (mean of 4 random points), and species present (species richness). For each species, a consistent technique (to reduce observational bias) was employed to record estimated abundance using % cover (Kimberley *et al.* 2021; Norton *et al.* 2019), along with % bare ground and % thatch (Rodwell, 1992) (Fig. 2.6).

An alphabetical list of species found and identified to species level (and subspecies or variant where professional assistance was available for confident assessment), with scientific (binomial Linnaean taxonomy) and common names taken from Streeter (2016) was compiled during data entry (Hooftman *et al*. 2021; Jakobsson *et al.* 2016; Kimberley *et al*. 2021). Within time constraints, where grass species were not flowering, a representative sample of species present was estimated using flowering specimens at edges of cut sward and vegetative morphological traits (colour, texture etc.) within quadrats. Where an aggregate of very similar species may exist (agg.) species type was recorded. Additional localised species information was gained using flora by Falk (2009), land manager knowledge, and consultation with Botanical Society of Britain and Ireland (BSBI) County Recorders. In addition to quantifiable data, observations were recorded in field notebook.

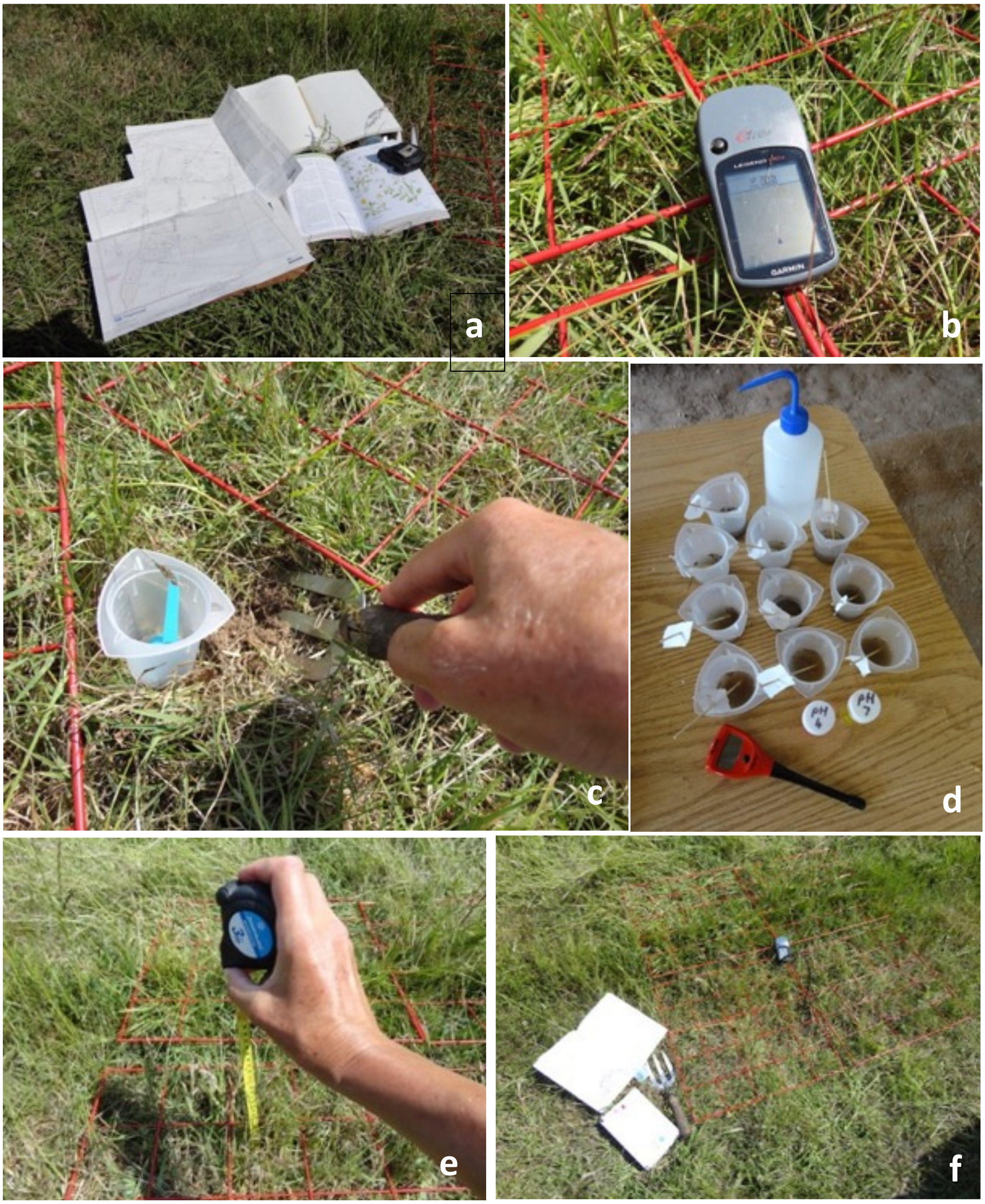

Fig. 2.6 Quadrat (1 m^2 n = 10) fieldwork techniques for each GGI treatment at Replicates Five Acre Community Farm and Canalside Community Food, Warwickshire. a) pre-survey, grass and forb species and treatment identification and annotating site base maps, b) GPS coordinates for each quadrat placement, c) soil sample collection and d) soil pH test, e) measuring sward height (cm), f) recording species present, species % cover, % cover bare ground and thatch. Photo credits: report author.

2.4.3 Treatment crop bed timed walks

Arable 'weed' species richness was recorded to investigate if these communities influenced GGI composition. Crop beds at each replicate were divided into 10 roughly equal portions by area (n = 10). Species present within beds recorded using a walk-through of standardised pace and time covering a representative section of each portion (Hooftman *et al.* 2021). This method rather than plot-based surveying was chosen due to the variability in spatiotemporal occurrence of arable weed species (Munzo *et al.* 2020). Species in sown herbal-ley rotation were omitted.

2.4.4 LNR surveys

Species richness data for LNR's were undertaken using walk-through surveys. Species list for Wolston Fields LNR was compiled by Warwickshire botanical county recorders during a scheduled BSBI field meeting (attended by report author) directly after Replicate survey completion (BSBI, 2022; J. and M. Walton, pers. comm., 25 June 2022). List was subsequently edited to represent grassland species only, for comparison with Replicate GGI data. On the same day Warwickshire botanical county recorders undertook a shorter walk-through survey at Five Acre, enabling cross-referencing and verification of species lists from research field notes. The following weekend, a similar walk-through survey was undertaken by the report author at Hunningham Meadow LNR.

2.5 Analysis

Field work data was initially entered into Microsoft Excel (Version 16.44) to compile species lists, and mean and standard deviation (Jakobsson *et al.* 2016; Norton *et al.* 2019) for soil pH, sward height, species richness (forb and grass species) (for each treatment (alpha diversity) and site (beta diversity) for comparison (Kimberley *et al.* 2021)) % cover bare-ground and thatch, species diversity (calculated using Simpson's Diversity Index) (Badenhausser *et al*. 2020), and Ellenberg Indicator Values (Hooftman *et al.* 2021). Shapiro Test for normal distribution, Kruskal-Wallace Test for significant difference (p = < 0.05) of non-parametric data and pairwise comparisons using Wilcoxon rank sum test (with continuity correction, p value adjustment method BH) for significant relationships between treatments, was undertaken in RStudio (2022.07.2 Build 576). Multivariate analysis, ordination by species and quadrat

(Detrended Correspondence Analysis) in PAST (version 4.04) (Hammer *et al.* 2001) to discern differences in vegetation data apparent from observation in the field, but not obvious within data set.

2.5.1 Identifying GGI community classification

Data required to compile NVC Floristic Table's (used to interpret community classification) is primarily % cover for each species present (2 m^2 surveys used within the NVC). The addition of information regarding soils, % bare ground and % thatch within sward aids classification within class descriptions (Rodwell *et al.* 1992 and 2000; Norton *et al.* 2019). Within this research NVC domin score 3 was assigned to % cover values 1, 2 and 3 across all species, to simplify the process. For example, 1 large species such as *Heracleum sphondylium* (Hogweed) may take up more than 1 %, compared to many *Veronica* spp. (Speedwell) within the same area. Interpretation of community code was attempted, with sub-community where possible. The process of NVC classification contains potential for experimental error and bias, reliant on accurate primary data, with final interpretation a subjective decision, especially for community code and sub-community (Rodwell *et al.* 2000).

2.5.2 Identifying other environmental variables

Cross examination of a range of community traits, to assess influence of environmental variables on composition, was attempted using Ellenberg Indicator Values (Hill *et al.* 2004), which provide broad estimation of species and community function. Values are allotted to species for tolerance to a range of environmental factors. Those appropriate to this research were light (L), moisture (F), soil reaction (R) (reflecting pH) and nitrogen (N). Interpretation of values was undertaken with caution, due to the very broad nature of the tools, and used to enhance fieldwork direct observations and primary analysis (Belovsky *et al*. 2004).

3. Results

Results focus on site and treatment soil variation, Replicate GGI treatment NVC community classification and GGI mean species richness and diversity. An overview of other potential influences on GGI composition (arable weed species richness and Ellenberg Indicator Values) is given, followed by summary potential for GGI conservation value and connectivity within Replicates and surrounding landscape. Data for historical and contemporary land-use and management (land manager interviews) is provided in SI. 5. GGI treatment mean sward height, and additional analysis aiding interpretation of floristic tables (mean % cover bare ground and thatch) are given in SI. 6 and 7.

3.1 Research Replicate soil variability

Naturally occurring soils across research sites are low fertility, neutral to mildly acidic, free draining sandy loam (NSRI, 2022 a, b, and c). A summary of soil secondary data is given in Table 3.1 highlighting variability at fine scale between sites due to differences in sediments overlaying bedrock and hydrology. Soil broad description and soil series maps are provided in SI. 8.

3.1.1 Treatment soil pH

Fieldwork soil pH values reflected naturally occurring slightly acidic soils, with some significant variation between treatments. Values ranged between pH 5.3 (an outlier in FA3 abandoned Set-aside) and pH 7.2 (C3 managed Set-aside). FA crop bed was most consistent, though two outliers in this data set either side of the median may have been due to un-evenly distributed inputs (R. Stevenson pers. comm., 30 May – 3 June 2022) (box plot Fig. SI. 9). Mean and significant difference for all treatments is given in Fig. 3.1 (Kruskal-Wallis chi-squared = 21.415, df = 7, p-value = 0.003). FA2 (Orchard) was significantly more acidic than FA crop beds and C3 (managed Set-aside). C3 had significantly higher pH than FA3 (semi-abandoned Set-aside) and C1 (Social Green) (Wilcoxon p = 0.046). Crop bed mean value of pH 6.5 at Five Acre is lower than previous testing at the site, 6.7 (2001 and 2005) and 6.8 (2006) (Table SI. 1) (R. Stevenson, pers. comm., 30 May – 3 June 2022).

Table 3.1 Summary of research sites National Soil Resources Institute (NSRI) soil site reports, for Five Acre Community Farm, Wolston Fields Local Nature Reserve (LNR) (NSRI 2022a), Canalside Community Food (NSRI 2022b) and Hunningham Meadow LNR (NSRI 2022c), Warwickshire. NB. Additionally, small sections of Wolston Fields LNR are highly influenced by River Avon historical and current channels, being on river alluvium (813b FLADBURY 1), with decreased drainage and increased fertility (SI. 8).

Properties and capacities of soil	Site Five Acre/Wolston	 Canalside/Hunningham
Parent material/	Glaciofluvial drift	Glaciofluvial or river terrace drift
Soil series/description	541r WICK 1 Deep well-drained coarse/sandy/loamy locally over gravel	541r WICK 1
Texture/composition	Loamy	Loamy
Carbon store	Low	Low
Fertility	Low	Low
Typical habitat	Wet acid meadow and woodland	Neutral and acid pasture and deciduous woodland
Hydrogeological rock	Sand	Sand
Hydrology	Free draining. Vulnerable to drought. Permeable. Unconsolidated sand/gravel. Groundwater at < 2 m down Vulnerable to inundation when water table is high.	Free draining. Vulnerable to drought. High permeability. High storage capacity. Unconsolidated sand/gravel.
Groundwater Protection Policy	Deep permeability. High leaching potential. Network of field boundary ditches makes soil water vulnerable to pollution through agricultural waste and run-off.	Deep permeability. High leaching potential. Soils vulnerable to erosion leading to stream siltation and eutrophication and groundwater nitrate pollution.

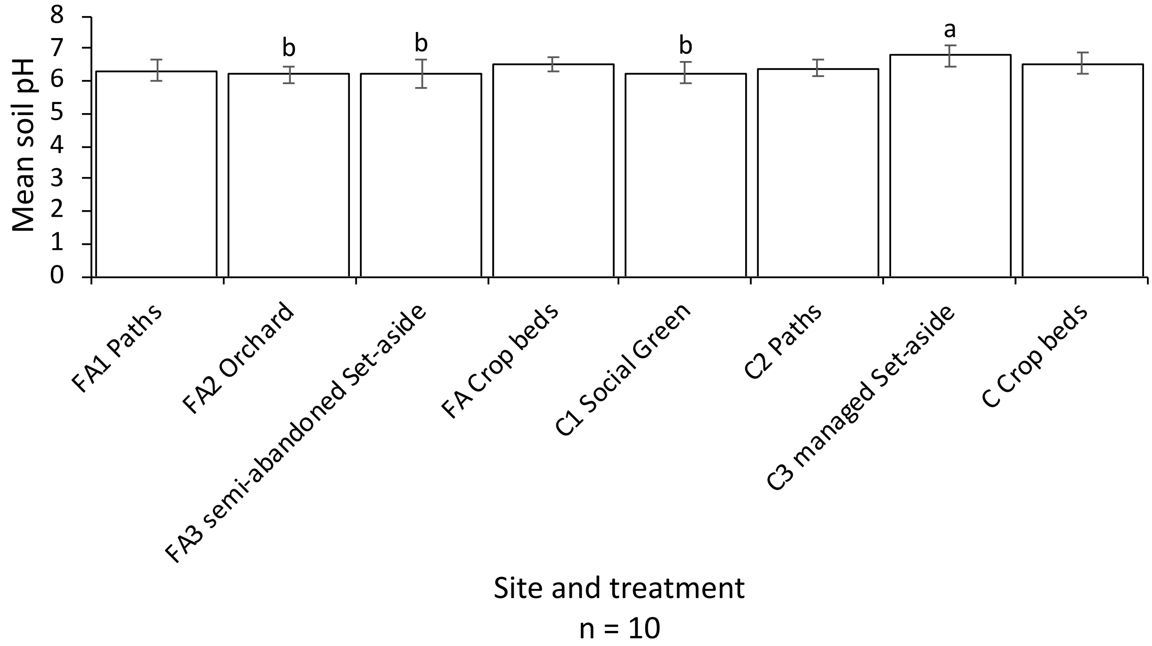

Fig. 3.1 Mean soil pH for research treatments, Warwickshire. Five Area Community Farm (GGI FA1 Paths, FA2 Orchard, FA3 semi-abandoned Set-aside, and crop beds), and Canalside Community Food (GGI C1 Social Green, C2 Paths, C3 managed Set-aside, and crop beds). Subscript above graph bars indicate where main significant difference lies. Additionally, FA2 is significantly less acidic than FA Crop beds. Kruskal-Wallis chi-squared = 21.415, df = 7, p-value = 0.003.

3.2 GGI treatment community classification

Confidence in NVC broad classification is high. All Replicate GGI treatments were interpreted as Mesotrophic Grassland (pH range around neutral) (MG) reflecting soils data and dominated by MG community 5 (Rodwell *et. al.* 1992) (Floristic tables provided in SI. 9). Treatments showed community variation along a gradient of management intensity and could be interpreted within the range of communities found in lowland England proposed by Rodwell *et. al.* (1992) as illustrated in Fig. 3.2. MG5 is clear for FA1 (Paths), FA2 (Orchard), C2 (Paths) and C3 (managed Set-aside). However, composition of the most frequently cut treatment CI (Social Green) showed influence of historical re-seeded community, possibly MG6. The most definitive interpretation, of MG1b (community 1 and sub-community code b), was for FA3 (semi-abandoned Set-aside).

Community	ARRHENATHERION	CYNOSURION		LOLIO-PLANTAGINION
NVC classification	MG1	MG5	MG6	MG7
NVC description	*Arrhenatheretum elatioris* grassland	*Centaureo-Cynosuretum* grassland	*Lolio-Cynosuretum* grassland	*Lolium perenne* leys and related grassland
Corresponding treatment	FA3 (semi-abandoned Set aside)	FA1 (Paths), FA2 (Orchard), C2 (Paths), C3 (managed Set-aside) and historically at Five Acre	C1 (Social Green) and historically at Canalside before 2005 in arable rotation	
Management and inputs	Mown once or twice annually (amenity), un-grazed and unmanured	Mown annually for hay, autumn and winter grazed and manured by livestock	Grazed through the year, chemically fertilised and often resown	Sown swards, chemically fertilized and grazed throughout the year or cut (silage/amenity)

→ Gradient from least to most intensive grassland management →

Fig. 3.2 The range of mesotrophic (neutral), grassland found in lowland England, in relation to management and inputs with corresponding research treatments and historical management at Replicates Five Acre Community Farm (FA) and Canalside Community Food (C), Warwickshire. Within the table from left to right, FA3 (semi-abandoned Set-aside), FA1 (Paths), FA2 (Orchard), Canalside C2 (Paths) and C3 (managed set-aside) and C1 (Social Green). GGI treatments follow a gradient of least often to most frequently cut sward from left to right, with corresponding NVC classification. Adapted from Rodwell *et. al.* (1992).

3.3 GGI treatment species richness and diversity

Full species lists for Replicate treatments (GGI, crop beds) are provided in SI. 10, and research site LNR's in SI. 11. Overall, 124 different species were recorded in treatments, 8 (1 x GGI and 7 x arable weed species) included in the BSBI Great Britain Vascular Plant Red List (Stroh *et al.* 2014) (Fig. 3.3). Species (x 7) categorized as Least Concern are considered important for national biodiversity and may be declining, with action needed to prevent reduction towards threatened status. Inclusion on red list is important for monitoring changes (IUCN, 2022). Arable weed *Spergula arvensis* (Corn Spurrey) found at both Replicates is threatened at nationwide scale, though not regionally within Europe (Bilz *et al.* 2011).

Fig. 3.3 Species found within research treatments at Replicates Five Acre Community Farm (b, d, e, g and h) and Canalside Community Food (a, c, d, e, f, g and h), Warwickshire, listed in Botanical Society of Britain and Ireland (BSBI) Great Britain Vascular Plant Red List. a) GGI species (treatment C2 Paths and C3 managed Set-aside) **Senecio erucifolius* Hoary Ragwort. Arable weed species b) **Anchusa arvensis* Bugloss, c) Warwickshire rarity *Geranium columbinum* Long-stalked Crane's-bill, d) **Lamium amplexicaule* Henbit Dead-nettle, e) *Matricaria chamomilla* Scented Mayweed f) **Sherardia arvensis* Field Madder, g) **Thlaspi arvense* Field Penny-cress and h) nationally vulnerable *Spergula arvensis* Corn Spurrey. Species a) to g) Red Data List, Least Concern (Stroh *et al.* 2014). *Warwickshire notable: scare or indicating especially good quality habitat (Falk, 2009). Photo credits: report author.

3.3.1 GGI treatment mean species richness

FA3 (semi-abandoned Set-aside) recorded significantly least species richness, where as C3 (managed Set-aside) had significantly greatest species richness (Kruskal-Wallis chi-squared = 42.386, df = 5, p-value = 4.92e-08). FA2 (Orchard) showed higher mean values than FA1 (Paths) and C1 (Social Green), however FA1 (Paths) contained higher number of species than FA2 (Orchard) (Wilcoxon range p = < 0.001 to 0.006) (Fig. 3.4). Box plot (SI. 11) highlights FA1 and C2 (Paths) showing highest variability, with several outliers spread across other treatments. Variability within paths was observed as due to influence of adjacent habitat (SI. 12). For example, *Calystegia sepium* (Hedge Bindweed) recorded in FA2 Paths Quadrat (Q)8 adjacent to the species recorded in FA3 (semi-abandoned Set-aside) Q8, 9 and 10. Additionally, successional woody species were found in FA1 (Paths), FA2 (Orchard), C2 (Paths) and C3 (managed Set-aside) (*Crataegus* sp. (Hawthorn), *Prunus spinosa* (Blackthorn), *Rubus 'fruticosus'* (Blackberry), *Salix* sp. (Willow) and *Quercus robur* (Pedunculate Oak)), reflecting seeds dispersed from native species hedgerow boundaries.

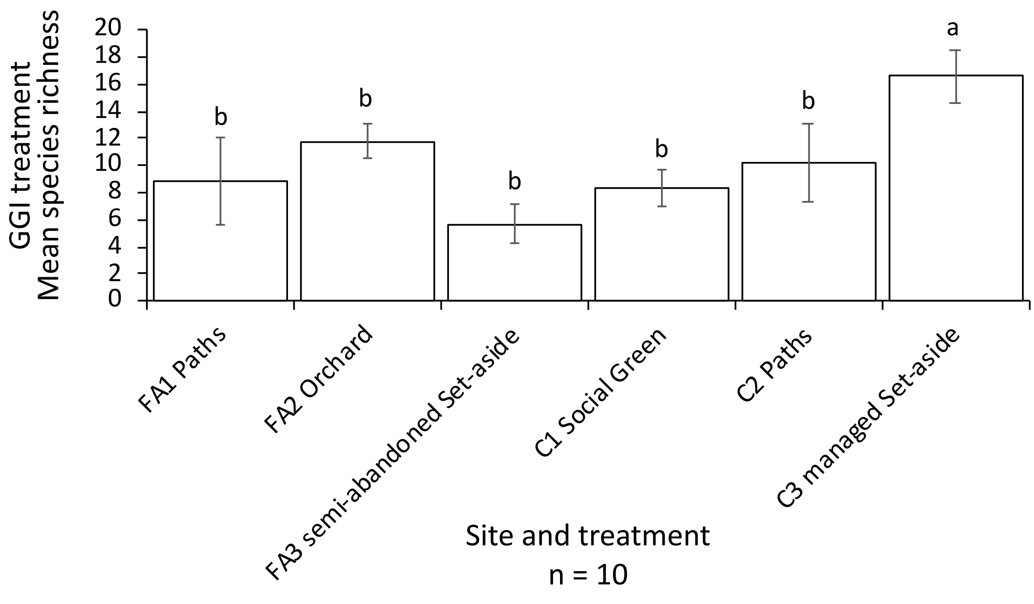

Fig. 3.4 Mean species richness for GGI treatments at Five Area Community Farm (FA1 Paths, FA2 Orchard FA3 semi-abandoned Set-aside), and Canalside Community Food (C1 Social Green, C2 Paths, C3 managed Set-aside), Warwickshire. Superscript above graph bars indicates where significant difference for greatest species richness lies. Additionally, FA3 returned significant difference between all other treatments for least species richness, and FA2 was significantly different from FA1 and C1. Kruskal-Wallis chi-squared = 42.386, df = 5, p-value = 4.92e-08.

3.3.2 GGI treatment mean species diversity

For diversity (Fig. 3.5) C3 (managed Set-aside) had significantly higher values to all other treatments (Kruskal-Wallis chi-squared = 31.878, df = 5, p-value = 6.281e-06). FA2 (Orchard) had significantly higher diversity compared with FA1 (Paths), C2 (Paths) and C1 (Social Green) (Wilcoxon range p = < 0.001 and 0.005). FA3 (semi-abandoned Set-aside) had lowest diversity and greatest variability between quadrats, with least variability in FA2 (Orchard). C2 (Paths) contained the biggest range, returning lowest diversity (0.293 in Q4) where grasses dominated, *H. sphondylium* (Hogweed) was the only forb present, and highest value (0.917 in Q8) situated directly adjacent C3 (managed Set-aside) (box plot SI. 11).

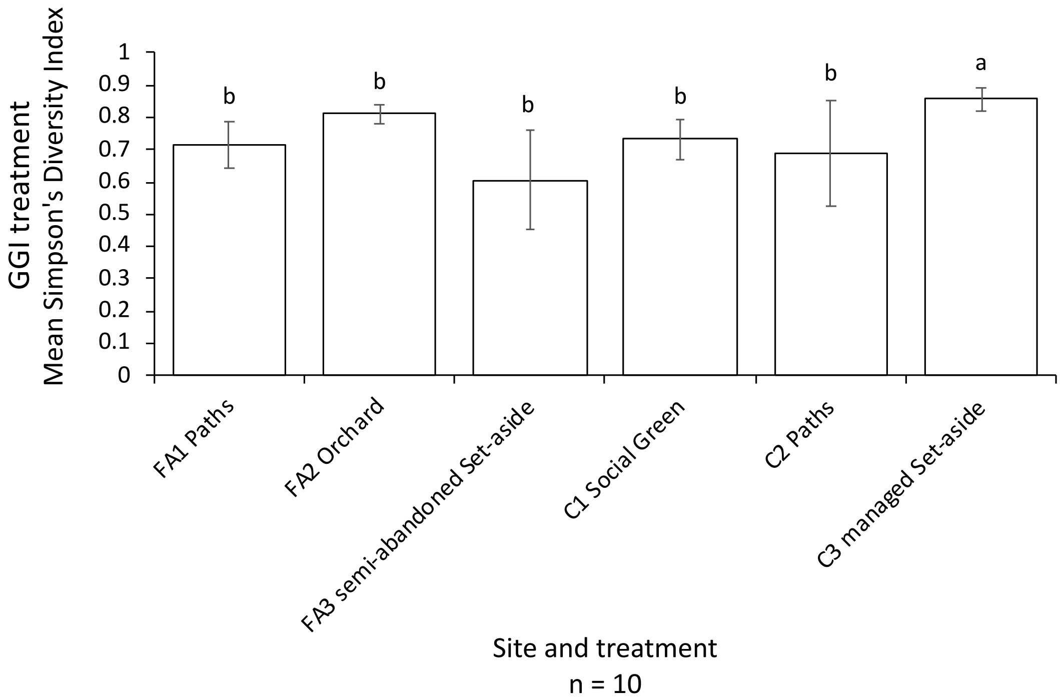

Fig. 3.5 Mean Simpson's Diversity Index values for GGI treatments at Five Area Community Farm (FA1 Paths, FA2 Orchard, FA3 semi-abandoned Set-aside), and Canalside Community Food (C1 Social Green, C2 Paths, C3 managed Set-aside), Warwickshire. Superscript above graph bars indicates where main significant difference lies. Additionally, FA2 is significantly different with higher diversity values than all other treatments except C3. Kruskal-Wallis chi-squared = 31.878, df = 5, p-value = 6.281e-06.

3.4 GGI treatment ordination (DCA)

By grouping data points, species and quadrat ordinations highlighted where a range of possible environmental gradients influenced the communities. A two-dimensional DCA was employed as Axes 1 (73 %) and 2 (54 %) returned markedly highest eigenvalues, Axes 3 and 4 having weaker signals (29 % and 21 % respectively). The strongest gradient (Axis 1) is interpreted as the cutting frequency (Kent, 2012; Palmer, 2022), which influenced community classification.

3.4.1 GGI treatment species DCA

Species ordination (Fig. 3.6) shows relative distribution of the 67 different GGI treatment species. A gradient is seen from NVC MG6 influence (C1 Social Green, with grass seed-mix species *Agrostis stolonifera* (Creeping Bent), *Festuca rubra* (Red Fescue) and *Schedonorus arundinaceus* (Tall Fescue) (Rodwell *et al.* 1992)), through MG5 (FA1 Paths, FA2 Orchard, C2 Paths, C3 managed Set-aside), to MG1b (FA3 semi-abandoned Set-aside) driven by decreasing cutting frequency. Some species are also grouped by other underlying environmental spatial variables such as soil moisture, with species wetter soil preferences (*Angelica sylvestris* Wild Angelica and *Prunella vulgaris* Selfheal found in C3 managed Set-aside) and drier soils (*Achillea millefolium* Yarrow and *Origanum vulgare* Marjoram in FA2 Orchard) highlighted.

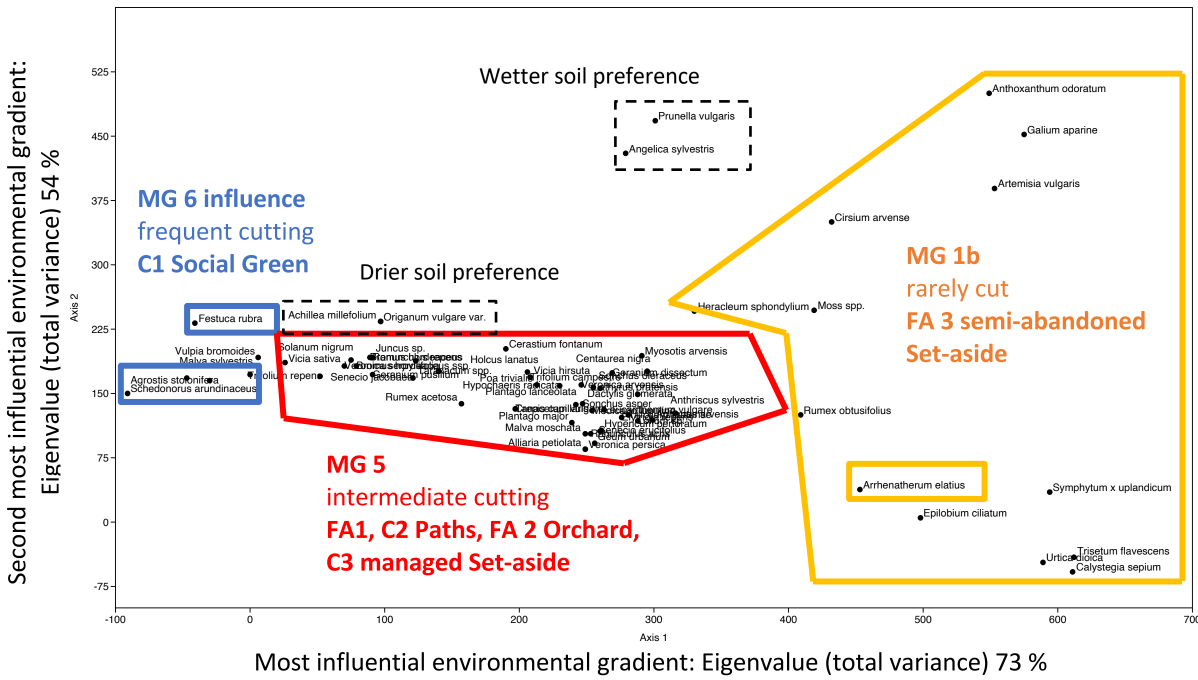

Fig. 3.6 Two dimensional DCA ordination showing relative distribution of 67 GGI treatment species for Replicates Five Acre Community Farm and Canalside Community Food, Warwickshire. It broadly shows a trend of decreasing cutting frequency from left to right, reflecting the spectrum of NVC communities present. C1 Social green (MG6 influenced) (blue boxes) through to FA3 abandoned set-aside (MG1b) (gold polygon) (dominant grass species *Arrhenatherum elatius* False Oat-grass, gold box). Most species are grouped centrally (red polygon), suggesting dominant MG5 community (FA1 Paths, FA2 Orchard, C2 Paths and C3 managed Set-aside). Species adapted to specific soil moisture levels are also highlighted (black dashed boxes) (Kent, 2012; Palmer, 2022).

3.4.2 GGI treatment quadrat DCA

Quadrat ordination (Fig. 3.7) shows each of 60 GGI quadrats in relation to one another, highlighting similarities and differences in composition (Kent, 2012; Palmer, 2022). As for species DCA, a broad gradient can be discerned from C1 (Social Green) most frequently cut, through to FA3 (semi-abandoned Set-aside) rarely cut sward, the latter showing most variability within a treatment. However, the GGI path quadrats (FA1 and C2) are mixed in with the most species rich and diverse treatments (FA2 Orchard and C3 managed Set-aside) highlighting a strong connection between them. For example, FA2 (Orchard, species rich) adjacent to C1 (Social Green, species depauperate) indicates the possibility of a stronger underlying influence on composition than cutting frequency.

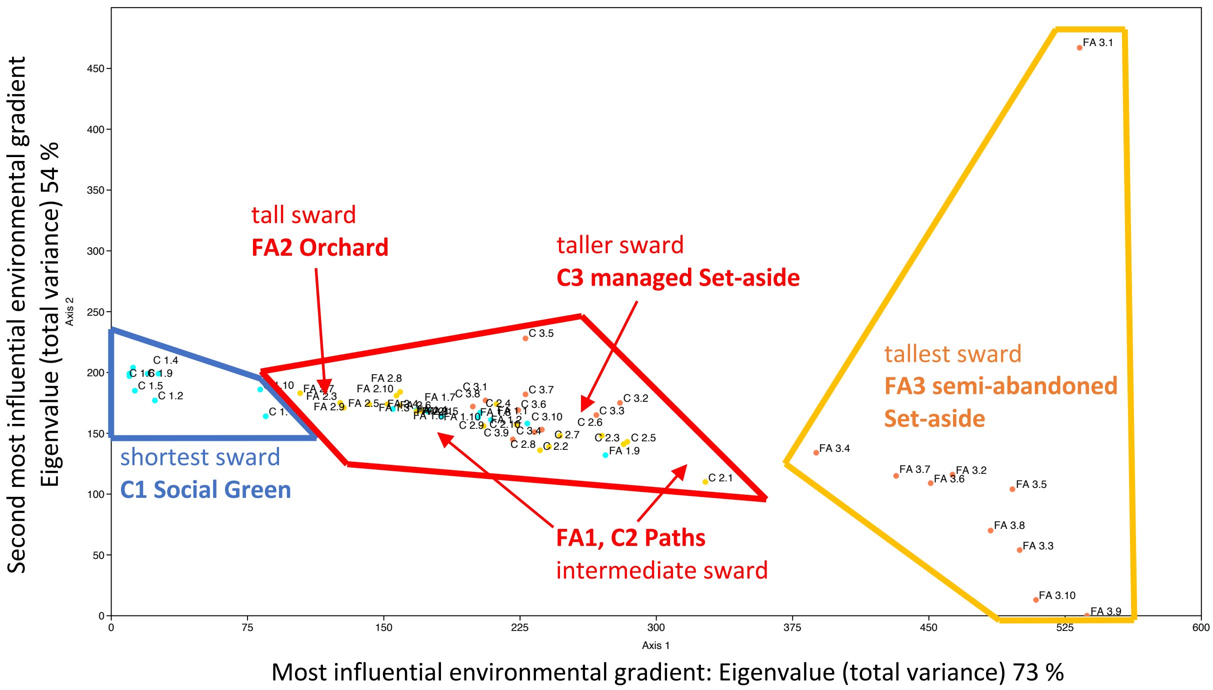

Fig. 3.7 Two dimensional DCA Ordination comparison of GGI treatment composition by quadrat (n = 10 for each treatment) for Replicates Five Acre Community Farm (FA) and Canalside Community Food (C), Warwickshire. Quadrats with more similar composition (species richness and abundance) are placed closer on the graph. The two extremes of most (shortest) to least (tallest) frequently cut sward, C1 (Social Green) (blue polygon), on the left, and far right FA3 (semi-abandoned Set-aside) (gold polygon) are clear. However, another underlying environmental gradient appears to be influencing treatments FA1 and C2 (Paths), FA2 (Orchard) and C3 (managed Set-aside) (red polygon) as expected trend of decreasing cutting frequency from left to right is not followed within this data (Kent, 2012; Palmer, 2022).

3.5 GGI treatment community composition: other environmental influences

As hinted by ordination interpretations other underlying environmental variables, beyond cutting frequency, appear to be influencing GGI composition.

3.5.1 GGI treatment community composition: influence of crop bed arable weeds

Floristic tables are not possible to produce without species % cover data, however for Replicate arable weed community in crop beds, an estimated classification of NVC OV3, Vegetation of open habitats, *Papaver rhoeas- Viola arvensis* community is proposed (Rodwell *et al.* 2000). Both Replicates contained variable crop bed habitat ranging from newly cultivated to overwintered plots containing previous seasons spring planted crop residue. Representative habitat images are given in Fig. SI. 14 (SI. 13). The greater range of habitat due to larger area and longer rotation at Canalside (significantly highest species richness (Kruskal-Wallis chi-squared = 8.0721, df = 1, p-value = 0.001)), is evidenced in greater data variability (Fig. SI. 15). Comparison of GGI forb species and arable weeds were very similar at both sites, with just under one third of species shared between the habitats (Fig. SI. 16), which may infer influence beyond arable weed specialists colonising path/crop bed boundaries. However, grass species other than *Elytrigia repens* (Common Couch) and *Poa annua* (Annual Meadow Grass) were not recorded due to time constraints, therefore grasses were omitted from analysis. Quantitative evidence for influence is therefore minimal, and not sufficient to draw conclusions from.

3.5.2 GGI treatment community composition: Ellenberg indicator values light, moisture, acidity, nitrogen

Mean Ellenberg indicator values (Hill *et al.* 2004) for GGI treatment species highlighting significant differences are given in Fig. 3.8 (box plots SI. 14). Values for light (L) confirmed success of experimental design to reduce bias regarding light levels between quadrats, being most consistent across treatments. For L, significant difference (Kruskal-Wallis chi-squared = 20.766, df = 5, p-value = 0.001) was seen where longest sward FA3 (semi-abandoned Set-aside) species had more tolerance of lower light levels than FA2 (Orchard), C1 (Social Green), C2 (Paths) and C3 (managed Set-aside) (Wilcoxon p = 0.044). Long sward C3 treatment had biggest data range. Mean values close to 7 (plants adapted to well-lit situations, though tolerant of partial shade) were returned for FA1 (Paths), and all Canalside treatments.

Soil moisture (F) values were more variable. FA3 (semi-abandoned Set-aside) had significantly more moisture tolerant species (Kruskal-Wallis chi-squared = 17.394, df = 5, p-value = 0.001) than FA2 (Orchard), C2 (Paths) and C3 (managed Set-aside) (Wilcoxon p = 0.005). Values highlighted moisture adapted species at C3 (managed Set-aside).

Soil reaction (R) broadly followed previous pH soil analysis, values across treatments falling between 5 and 7, corresponding to mildly acidic to weakly base conditions. Value variability within treatments highlighted compositions of more generalist species, C1 (Social Green) containing the widest range of values, and those more aligned to locally acidic conditions in FA2 (Orchard). FA2 contained species significantly more tolerant to more acidic conditions than those in FA3 (semi-abandoned Set-aside) (Kruskal-Wallis chi-squared = 12.956, df = 5, p-value = 0.024) (Wilcoxon p = 0.16).

Soil nitrogen (N) indicates where species with low values are tolerant of nutrient deficiency. This factor was the most variable across both Replicates with significant differences found in all 6 treatments (Kruskal-Wallis chi-squared = 35.864, df = 5, p-value = 1.011e-06) (Wilcoxon range p = above 0, to 0.043). FA3 (semi-abandoned Set-aside) had significantly more species tolerant of higher nutrient levels than all other treatments (Wilcoxon p = 0.003). Though not significant, most species rich and diverse treatments (FA2 Orchard and C3 managed Set-aside) recorded lowest nutrient values. C1 (Social Green) and C2 (Paths) had most consistent values, close to Ellenberg Value 6 (intermediate between sites of medium fertility and rich fertility).

a – d mean allotted values for GGI treatment species

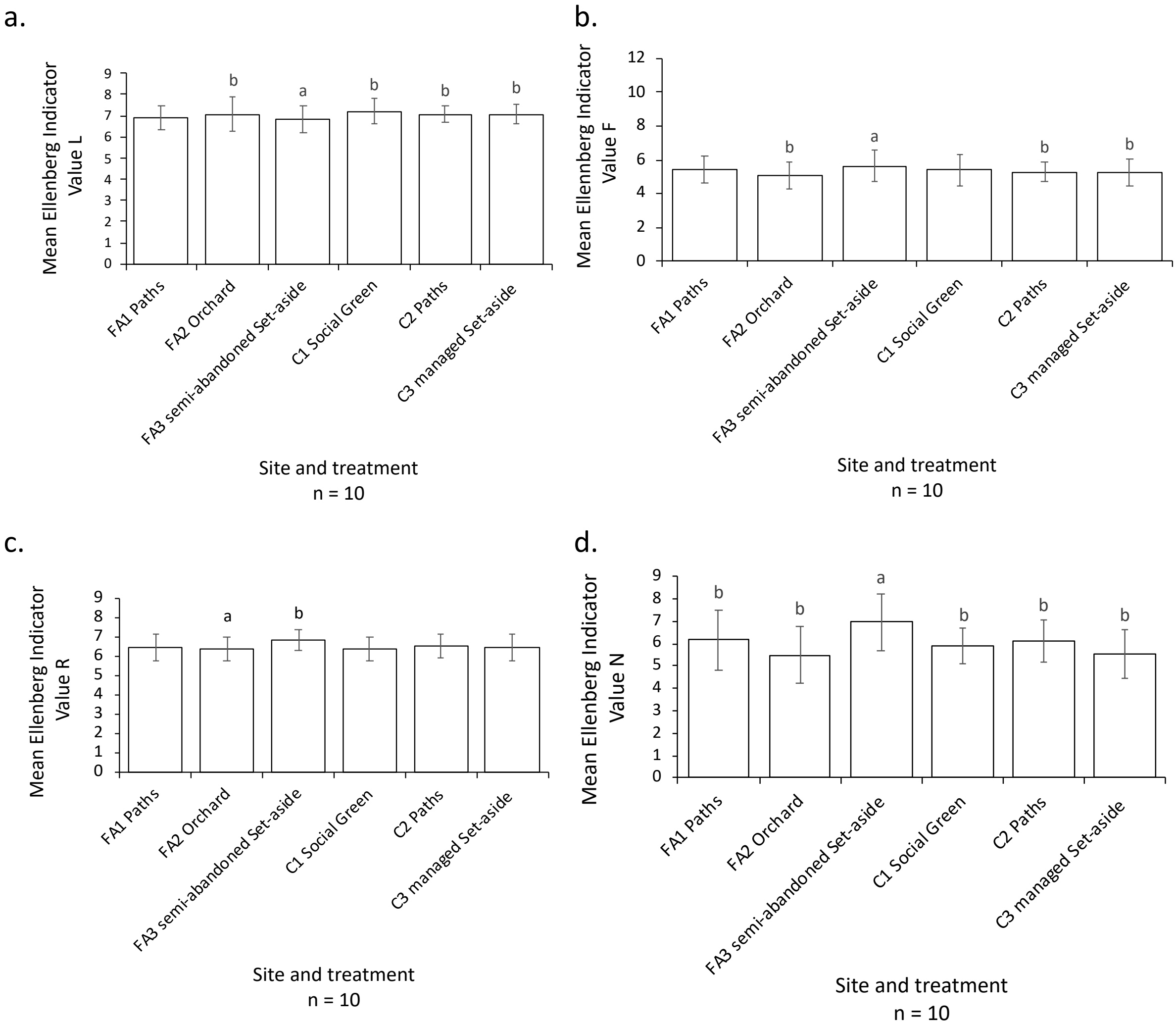

Fig. 3.8 Mean species Ellenberg indicator values for GGI research treatments at Five Area Community Farm (FA1 Paths, FA2 Orchard, FA3 semi-abandoned Set-aside), and Canalside Community Food (C1 Social Green, C2 Paths, C3 managed Set-aside), Warwickshire. Main significant difference between treatments is indicated with superscript. Y-axis values follow scale for each factor within Hill *et al.* (2004). a) L- light (Kruskal-Wallis chi-squared = 20.766, df = 5, p-value = 0.001), b) F- moisture (Kruskal-Wallis chi-squared = 17.394, df = 5, p-value = 0.001), c) R- soil reaction (Kruskal-Wallis chi-squared = 12.956, df = 5, p-value = 0.024), and d) N- nitrogen where difference is not seen between FA2 (Orchard) and C3 (managed Set-aside), and FA1 (Paths), C1 (Social Green) and C2 (Paths), with a range of minor significant higher and lower values found elsewhere (Kruskal-Wallis chi-squared = 35.864, df = 5, p-value = 1.011e-06).

3.6 Identifying GGI treatment core conservation value communities and potential for enhancement

Replicate GGI core communities (of highest conservation value) were identified as those having highest species diversity at FA2 (Orchard) and C3 (managed Set-aside). Cores appeared to influence Path (FA1 and C2) composition with shared species as discussed above, suggesting network connectivity within Replicate boundaries. Species distribution extended approximately 93 m from the core at Five Acre (FA2 Orchard) with grass *Bromus* spp. Soft-brome spp., and 77 m at Canalside (C3 managed Set-aside) with forb *Senecio erucifolius* Hoary Ragwort. GGI treatment composition compared favourably with LNR's with mean 32 % of total species shared. Canalside had greater species richness (46 spp.) than Hunningham LNR (38 spp.). Wolston Fields recorded highest research site species richness (84 spp.) (SI. 15). Replicate GGI connectivity between the surrounding landscape is potentially more limited at Five Acre (potential to the north-west only) than at Canalside (potential at all farm boundaries except to the west) (SI. 16).

4. Discussion

4.1 Synthesis of results

With reference to research questions (*1.10*) Replicate GGI soils supported a range of naturally occurring mesotrophic grassland, dominated by NVC MG5 (including 1 nationally red listed species in C3 managed Set-aside). Influence on GGI community composition of distinct Replicate management histories, current farm scale management intensity and arable community OV3 (containing 7 nationally red listed species) was inconclusive due to limitations of methodology. However, GGI community classification and composition correlated with cutting frequency, returning highly significant differences for species richness and diversity. Identified Replicate GGI core treatments (most species diverse) (FA2 Orchard, C3 managed Set-aside) and Paths (FA1, C2) are seen to correlate, suggesting environmental influence beyond cutting frequency. New hypotheses drawn from ordinations, using evidence from Ellenberg Indicator Values, propose additional influence of soil properties in turn partially influenced by management practice. Replicate Cores (FA2 Orchard, C3 managed Set-aside) compared favourably in species richness to local nature reserves. Potential exists for, GGI network connectivity within and beyond Replicate boundaries and enhancement of swards through management sensitive to conservation aims.

4.2 GGI community classification

Replicate communities are classified at the acidic end of the MG5 spectrum, consistent with soil pH values. Published NVC descriptions of MG5 do not cover the diverse floral variability found with ground truthing (Jefferson *et al.* 2019; Rodwell *et al.* 1992), therefore sub community classification is not attempted in this instance. Additionally, experimental error, though consistent across treatments providing relative confidence in broad trends, indicates fine-scale data is deficient. Surveying limitations including surveyor inexperience and cut sward prior to fieldwork, resulted in unreliable grass species identification and % cover values, with less abundant species overlooked. For example, *Elytrigia repens* (Common Couch), was not recorded in Five Acre Paths (FA1), though unlikely to be absent as ubiquitous in crop beds. Distinguishing between superficially similar species was problematic, for example flowers in grasses *E. repens* and *Lolium* spp. (Rye Grass spp.). Assessment undertaken within time constraints confounded these issues.

4.3 GGI community classification: historic and current farm scale management intensity

Replicate historical sward management was distinct. Five Acre known history (since 1970s) with no synthetic inputs or sward 'improvements', suggests MG5 community was longstanding, the associated seedbank and gene-pool supporting current composition. Conversely, Canalside soils underwent decades of conventional arable rotation with synthetic inputs, ploughing and re-seeding. All C treatments will be transitioning from herbal leys (research data suggesting MG6) sown 17 years ago. MG6 can be species rich at the extreme spectrum bordering MG5 (Jefferson *et al.* 2019), and suggested as best candidate for MG5 restoration, where seed-mix appropriate to soil type and suitable soil properties prevail (Critchley *et al.* 2002; Horrocks *et al*. 2016). Subsequent management at Canalside (conversion to organic production in 2005) appears to have facilitated relatively rapid restoration considering recovery of specialist communities may take decades (Kimberley *et al.* 2021). Mitigating conventional inputs is problematic where farms rely on short term (less than 5 years) financially supported government agri-environment schemes to undertake restoration (Horrocks *et al*. 2016; Nichols *et al.* 2022; Rowe and Moffatt, 2017). Replicate farms do not currently qualify for such payments, yet Canalside swards now support more natural composition, native forb and grass species re-colonising through natural dispersal and from the seedbank (Kimberley *et al.* 2021). For example, native *Lathyrus pratensis* (Meadow Vetchling), recorded by Bagnell and Grove (1891) in the Leam River basin, has reestablished at C2 (Paths) and C3 (managed Set-aside) given appropriate conditions.

4.4 GGI community classification: influence of arable habitat

Further evidence of natural regeneration at Canalside was seen in the species rich arable weed community OV3, also recorded at Five Acre. Canalside's significantly higher arable weed species richness (compared to Five Acre) may be due to larger cultivated land area and extended length of time between disturbance (ploughing in longer rotation). A range of soil disturbance allows establishment of a greater range of species adapted to different successional stages (annual ruderals and establishing perennials). Dutoit *et al.* (1999) found 76 arable species in adjacent low intensity grassland, compared with mean 24 species at Replicates. Just under one-third of species were shared between GGI and arable treatments, which aligns with Munzo *et al.* (2020), finding one-third of total French flora as arable weeds. Correlation between replicate ephemeral crop bed species and perennial grass swards is not possible to define within this research. However, Paths may influence arable species and vice versa, where species are adapted to establishing in variable levels of soil disturbance, with migration between habitats by natural or human mediated seed distribution (Reberg-Horton *et al.* 2010). Additionally, with over 60 crop varieties grown on both Replicates each season (R. Stevenson and G. Davies, pers. comm. June 2022), it is possible crop diversity positively influences swards. Tscharntke *et al.* (2021) found crop diversity benefited calcareous grassland diversity. An increase from 10 – 80 % in adjacent arable monoculture correlated with a 29 % loss of grassland species.

4.5 GGI community composition: cutting frequency

A balance of sward cutting frequency is required to enhance conservation value. It is proposed that high cutting frequency at Canalside C1 (Social Green) compared to C2 (Paths) and C3 (managed Set-aside) is hindering regeneration of natural composition (Rodwell *et al.* 1992). At the other extreme abandoning habitat degrades floral structure, even in long established grassland as at Five Acre. MG1 communities, such as MG1b (FA3 semi-abandoned Set-aside), occur primarily through lack of grazing or cutting rather than soil properties (Critchley *et al.* 2002; Rodwell *et. al.* 1992) and are common across Europe within a range of agricultural grassland (Ridding *et al.* 2020; Rodwell *et al.* 1992). Ordination data reflects this wide distribution, suggesting weak links between data points (Kent, 2012). In MG1 previous species richness is depressed through litter accumulation (Rodwell *et al*. 1992) and phytotoxins released with decomposition inhibit seedling establishment (Bonanomi *et al.* 2013). Taller vegetation shades out seedlings and grassland specialists (Hooftman *et al.* 2021), for example, native *Bromus hordeaceus* spp., (Soft-brome grass spp.) present in FA1 (Paths), FA2 (Orchard) and regenerating C3 (managed Set-aside) (Grime *et al.* 2007). Low light tolerant species in MG1b FA3 are evidenced by low Ellenberg light (L) values (Hill *et al.* 2004).

Other studies show that resuming cutting reverses degradation. Proposed historical MG5 community at FA3 (semi-abandoned Set-aside) is observed in small sections (with similar composition to FA1 Paths and FA2 Orchard) regularly cut for access or recovering from recent disturbance. Removal of dominant perennial grass species, in this instance *Arrhenatherum elatius* (False Oat-grass) (Rodwell *et al*. 1992), allows space for less competitive, shorter sward and short-lived species to establish (Bonanomi *et al.* 2013). For example, annual grass *Bromus commutatus* (Meadow Brome) found at Wolston Fields LNR (J. and M. Walton, pers. comm. June 2022). Rodwell *et. al.* (1992) suggests that MG1 communities readily succeed to woody vegetation without regular intervention. The absence of woody species within MG1b FA3 (semi-abandoned Set-aside) is therefore surprising as plagio-climax habitat (where natural ecological succession is curtailed) was evidenced from successional woody species in all other GGI and arable bed treatments (except most frequently cut C1 Social Green). Paradoxically, FA3 (significantly lowest species rich and diverse habitat) was the only treatment managed purposefully as wildlife refuge. This reinforces Plantlife, (2022) claims that through lack of guidance, well-meaning conservation initiatives often unwittingly degrade habitat.

However, conservation strategy is dependent on aims (Blake and Karr, 1984; Diamond, 1976). Whilst MG1 is classified as having low botanical conservation value (Jefferson *et al.* 2019) other ecosystem services (or ecological functions) may be a conservation priority (Critchley *et al.* 2002). For example, MG1 habitat may support complete life-cycle stages of beneficial invertebrate pollinators (Nichols *et al.* 2022) and crop pest predators (Feng *et al.* 2021). Creating a mosaic of complex and diverse habitats, such as maximising site grassland successional stages (Alison *et al.* 2021; Díaz and Cabido, 2001; Feng *et al.* 2021; Hawkes *et al.* 2021; Nichols *et al.* 2022; Noreika *et al.* 2019) is valuable within homogenised matrices. Conservation of function is considered a viable alternative where restoration of more naturally occurring communities is no longer possible (Hambler and Canney, 2013) such as at Replicates, where available land and land use restrictions determine priorities.

Species diversity is argued as the highest criteria for conservation priority (Jefferson *et al.* 2019). Cutting frequency like that of a traditional hay meadow created the most species diverse treatments at FA2 (Orchard) and C3 (managed Set-aside) (Replicate core GGI). Within this research these treatments represent intermediate cutting frequency, correlating with

Connell (1978) whose hypothesis proposes intermediate disturbance generates highest biodiversity. Timing of cutting is also critical (Critchley *et al.* 2002), for example, after seed set has occurred, as is removal of cuttings (Jakobsson *et al.* 2016) as discussed above. The MG5 community class of 'Old Meadow' suggested in Rodwell *et al.* (1992) and possibly appropriate at Five Acre, is not necessarily one that contains rarities. It is often comprised of diverse common species, with careful consideration of those indicative of adverse conditions or non-natives (Jefferson *et al.* 2019). Quality of community is suggested as key to conservation potential, with more grassland specialist species seen in established GGI (ecological sources), than in restored GGI (ecological sinks) (Hooftman *et al.* 2021; Kimberley *et al.* 2021; Vanneste *et al.* 2020). That C3 (managed Set-aside) restored GGI recorded highest species richness and diversity is therefore unexpected, though several factors may be reducing quality at Five Acre and enhancing conditions at Canalside.

4.6 GGI community composition: other influential environmental variables

DCA analysis found strong correlation between Core and Path treatment composition. Confounding experimental factors may partially explain this. Lack of distinction between cutting frequencies at FA1 (Paths) and FA2 (Orchard) (the latter left to grow longer than Paths for only two seasons) highlights long temporal scales required for recovery of species richness, discussed previously. Methodological imprecision extended to quadrat placement in Path (FA1, C2) treatments, where 2 m within habitat boundary was not possible within 3 – 4 m path width. Replicate paths represented ecological ecotones, where composition of adjacent habitat blends. Therefore resulting edge-effect (changes in composition due to multiple habitat influence) is expected to be highly influential for this treatment (Hambler and Canney, 2013).

Additionally, local fluctuating environmental conditions and species responses may over-ride influence of cutting frequency (Belovsky *et al.* 2004). For example, soil properties (such as soil moisture, pH, and nutrient availability) (Hill *et al.* 2004; Moeslund *et al.* 2013) suggested as a major influence (Vanneste *et al.* 2020), create heterogeneity and strong gradients of species richness and composition at very small scales (m) (Cousins, 2006; Moeslund *et al.* 2013). Highest value communities are most sensitive to changes due to specialist species adaptations to their niche (Critchley *et al.* 2002). Within this research such change in properties can be linked to topography and management inputs and waste disposal.

4.6.1 Soil moisture: Ellenberg Indicator Value F

Replicates share freely draining soils that control soil moisture at macro and micro-scale, including amplifying drought stress (Moeslund *et al.* 2013). However, soil moisture is also determined by topography, distinctive between Replicates. Bennie *et al.* (2008) advises caution when directly comparing composition between sites as the effect of slope and aspect on composition can be large. For example, Canalside north facing slope buffers against extremes of moisture loss by insolation and drying winds (Flanagan and Johnson, 2005). Five Acre flat site with underground field drainage (installed in 1986 for research purposes) provides uniform conditions. This is evidenced by lower mean species precipitation tolerance compared to Canalside (following Hill *et al.* 2004) (SI. 2.3), and drought tolerant species such as *Achillea millefolium* (Yarrow) and *Origanum vulgare* (Marjoram) in FA2 (Orchard). However, these artificial conditions may be a barrier to re-establishment of local native species (Critchley *et al.* 2002; Moeslund *et al.* 2013), such as old wet meadow habitat specialist *B. commutatus* (Falk, 2009). Conversely, Canalside has natural field drainage to boundary ditches on a slope with around 15 m difference between C1 (Social Green) and C3 (managed Set-aside). However, soils at C3 are influenced by the canal boundary where drainage is curtailed, slowed and diverted into a sub-canal culvert (Fig. 2.5) (Canal and River Trust, 2022). Either side of the culvert ditch, seasonally wet soils are evidenced by *Angelica sylvestris* (Wild Angelica) distinctive in C3, and similarly moisture adapted species *Filipendula ulmaria* (Meadowsweet) observed as abundant in set-aside to the east. Micro-topography diversity at Canalside is seen as important for increasing species richness and diversity (Hooftman *et al.* 2021), a factor reflected in variable micro-habitats and high species richness at Wolston Fields LNR. Soil moisture also affects transport and uptake of nutrients, and pH (Moeslund *et al.* 2013).

4.6.2 Soil reaction: Ellenberg Indicator Value R

Mesotrophic grassland usually occurs within soil pH range 5.0 – 6.5 (Jefferson *et al.* 2019), pH influencing sub-community classification (Critchley *et al.* 2002). Critchley *et al.* (2002) states that inputs, such as liming, most adversely affect composition of communities on acidic soils (as at Replicates). The presence of calcicole *Gnaphalium uliginosum* (Marsh Cudweed) (Five Acre crop beds and Wolston Fields LNR) may be a result of high leaching potential from adjacent intensive agricultural inputs and Replicate liming, where water table is within 2 m of surface (NSRI, 2022a). At Canalside, leaching and draining from crop bed liming may explain significantly highest pH at C3 (managed Set-aside) (lowest point within the Replicate). Calcicolous species can be present within pH range of 6.5 – 8.5 (Jefferson *et al.* 2019). This correlates with Red listed calcicole *Senecio erucifolius* (Hoary Ragwort) (Falk, 2009) present in pH 6.9 (C2 Paths Q8), 6.8 (C3 managed Set-aside Q4) and 6.5 (C3 Q8). Significantly lowest pH values may explain more specialist species at FA2 (Orchard), though it is surprising that *Rumex acetosa* (Common Sorrel) a species largely restricted to acidic soils (Grime *et al.* 2007), was not recorded at Five Acre, but ubiquitous in Canalside treatments.

4.6.3 Soil nitrogen and species preference for soil fertility: Ellenberg Indicator Value N

Communities of high conservation value were found by Critchley *et al.* (2002) across soils with a range of nitrogen values, however Mesotrophic grassland community identity is nitrogen sensitive. The most species rich swards are associated with low nutrient conditions, that repress the dominance of a few competitive low conservation value grass species. Historical synthetic fertilizer residue is known to suppress conservation value communities and may be apparent with a lag in more natural nutrient cycling and uptake by re-establishing plants (Horrocks *et al.* 2016). Lowest research Ellenberg nitrogen (N) value at C3 (managed Set-aside) is possibly due to Canalside sloping topography aiding necessary ‘flushing’ of historical nutrient input, supporting natural re-establishment of highest GGI treatment species richness and diversity (Critchley *et al.* 2002). Lowest Five Acre N value at FA2 (Orchard) also supported highest species diversity at this Replicate. The addition of nutrients to FA3 (semi-abandoned Set-aside) from waste disposal may have contributed to community change to MG1b (Jefferson *et al.* 2019). This is evidenced by highest species N values (plants that thrive in higher nitrogen levels) *Galium aparine* (Cleavers) and *Urtica dioica* (Common Nettle) found at this treatment. Kleijn *et al*. (2008) established that synthetic nitrogen application rates reduce field margin and arable species richness. Therefore, influence of surrounding intensive production with eutrophication by synthetic fertilizer drift (Bonanomi *et al.* 2013) and run-off (Scotton and Rossetti, 2021) may be a factor at Replicates, especially Five Acre.

4.7 Potential for GGI restoration and conservation value

MG5 communities, increasingly rare due to agricultural 'improvements' (Rodwell *et al.* 1992), are classified as having high conservation potential (Jefferson *et al.* 2019). Surrounding agricultural landscape plays an important role (Hooftman *et al.* 2021; Zirbel *et al.* 2019). Critchley *et al.* (2002) advises that, at the time of surveying, researched swards may be enhancing in quality or degrading, due to the dynamic nature of plant communities. Is it possible, therefore, that Canalside is regenerating and benefitting from surrounding connectivity (with recent change towards less intensive surrounding land-use) and a slow decline through extinction debt occurring at Five Acre? Conversely, the isolation of Five Acre GGI may be beneficial. Cousins (2006) found that small arable midfield 'islets' of species rich semi-natural grassland were refugia, harbouring species pools from historical landscape prior to fragmentation for 50 years or more. With appropriate local and national conservation planning, such as reducing matrix eutrophication (Hooftman *et al.* 2021), Replicate cores (FA2 Orchard and C3 managed set-aside) have potential as ecological sources and dispersal stepping-stones. They may contribute to maintaining natural processes that restore matrix species richness beyond their boundaries, with minimum conservation effort in landscapes where priorities compete (Hobbs, 2007). Additionally, small patches (such as the Replicate cores) are suggested as a more effective conservation strategy than corridors (Baum *et al.* 2004) due to edge-effects (Chase *et al.* 2020; Vanneste *et al.* 2020).

4.7.1 Existing conservation importance of Replicate habitat

Widely, conservation value of vegetation communities is based on the presence of specialist species, often threatened due to diminishing suitable habitat (Jefferson *et al.* 2019; Plantlife, 2022). Applying this, core conservation value GGI is present at Replicates. Additionally, crop bed arable weed species richness is important at national level and is evidence of viable species rich seedbanks. The habitat and specialist species it supports (including nationally vulnerable *Spergula arvensis* and 6 other red listed species (Stroh *et al.* 2014) reliant on regular cultivation to persist) are rare and in decline (Munzo *et al.* 2020). Widespread industrialised agriculture discourages arable weeds with intensive mechanical and chemical controls. Byfield and Wilson (2005) reported 7 extinctions, and 54 species listed as threatened, within the 150 British species sharing the same ecological niche as crop plants.

4.8 Replicate management recommendations

Individual site assessment is crucial to restoring and extending conservation value GGI (Jiang *et al.* 2013). Resch *et al.* (2021), comparing semi-natural grassland (such as MG5) and 'improved' grassland (MG6 and MG7), reinforced long standing evidence that agricultural intensification is an unsustainable management option, reducing ecosystem function, climate resilience and conservation value. It is acknowledged that management within any land-based setting is restricted by resources. Despite this, many recommendations for sustainable agricultural habitat management are currently practiced at the Replicates in alignment with low intensity production (Hawkes *et al*. 2021; Hooftman *et al*. 2021; Resch *et al*. 2021; Tscharntke *et al*. 2021) and local BAP advice (Rowe and Moffatt, 2017). The ecological response is reflected in the high arable weed species richness. To augment this state, recommendations summarized in SI. 17, aim to increase Replicate GGI plant species richness, diversity and conservation value. With due consultation amongst stakeholders, habitat conservation goals are required to be realistic within resource limitations, logistical constraints, aspirations and levels of expectation, aiming to drive action plans and ongoing monitoring (Ehrenfeld, 2000).

5. Further research

5.1 The role of professional botanical expertise

Further research is required to enhance confidence in results and expand data sets, to increase the validity of the study. To test if results are influenced by surveyor inexperience, a repeat survey is advised undertaken by personnel with professional botanical expertise. This might allow more detailed examination of NVC composition, possibly revealing sub-community classification for all treatments. Professional assessment provides confidence in proposing Replicate sites for botanical conservation prioritization (Jefferson *et al.* 2019), with especial consideration of arable field communities found in this research.

5.2 Addressing research data deficiency

Research data is deficient, providing only a single snapshot of floral composition in one growing season. Extending surveying to encompass the whole main growing season, for example three surveys undertaken early (May), mid (June/July) and late (July/August) season, would better capture full range of flora present (Nichols *et al.* 2022). Additionally, high variability within and between seasons depending on weather conditions can result in different species being observed and widely fluctuating abundance data (Flanagan and Johnson, 2005). Therefore, a longer-term study encompassing whole seasons and several consecutive years provides clearer indication of communities. Long-term repeated surveying allows monitoring of environmental changes and is vital for assessment and adjustment of conservation management outcomes (Pescott *et al.* 2019). Increasing the number of replicates tests if effects seen are due to localised factors or represent wider trends. Extending the research into the national network of agroecological production units, for example, is important to assess the wider ecological value of these enterprises (CSA, 2022).

5.3 Investigating other factors influencing community composition

Comparison studies between low intensity and conventional production systems would also be valuable, as would further analysis of historical site production intensity (Jiang *et al.* 2013).

Further hypotheses from ordination analysis regarding influence on composition beyond cutting frequency might be tested. Existing research data for soil pH overlayed onto species and quadrat ordinations may identify possible links (Kent, 2012). Other detailed measurements of soil properties, such as water capacity, organic matter, nitrogen, potassium, magnesium, and phosphorus (Critchley *et al.* 2002), would enhance Ellenberg Indicator Value data. For example, high plant available phosphorus levels can limit grassland species richness, especially impacting specialist species (Gilbert *et al.* 2009; Plue and Baeten, 2021). Such investigation may illuminate possible eutrophication from surrounding landscape at Five Acre, and its role in species dispersal limitation (Hooftman *et al.* 2021).

5.4 Testing hypotheses regarding matrix connectivity

Future studies might include testing hypotheses regarding the role of treatment habitat as connecting network within the matrix. Factors to consider include species biological dispersal strategy including human dispersal mechanisms (farm machinery or footfall) (Bullock *et al.* 2003; Bullock and Pufal, 2020) and proximity (m) of environmentally compatible habitat (Fagan *et al.* 2008; Hooftman *et al.* 2021). The latter is suggested in *4.6.2* regarding *S. erucifolius.* Extending surveying through potential connecting corridors to matrix core patches, such as between Five Acre and Wolston Fields LNR, might test if replicate core sites are functioning as ecological sources or sinks (Threadgill *et al.* 2020). Methodology to achieve this may include genetic analysis with population comparison in and outside of site boundaries, of seedbanks and historical herbarium records. Evidence of genetic distinctiveness adds weight to an argument for conservation priority and reflects patterns for dispersal highlighting network connections within the landscape which guides conservation planning (Beatty *et al.* 2014; Hambler and Canney, 2013).

6. Conclusion

Grassland Green Infrastructure, GGI, is an important component of agricultural landscapes. Within this research evidence suggests variability in Replicate GGI NVC (classification) and species richness and diversity, are significantly influenced by current sward cutting frequency. Historical farm scale management intensity (though not quantified) also appears to influence classification and composition. At finer scale soil properties are evidenced as influential, highlighting the fluidity of sward composition at variable spatial and temporal scales. This state of flux provides reason to be positive that small changes in management might improve the status of Replicate swards going forward. This conclusion is reinforced by relatively rapid recovery from conventional sown sward to more natural composition containing red listed species at Canalside. The species rich diverse habitat mosaics found within this research are important contributions to overall agri-environment heterogeneity required for sustainable ecology within production settings. Though Individual treatment habitats are of small area, they have potential as valuable dispersal stepping-stones within the homogenous and specialist depauperate matrix. It is proposed that the high quality of Replicate habitats will also contribute to landscape ecosystem services such as water and soil protection (Munzo *et al.* 2020). Utility value, highly threatened habitat containing diverse composition, specialist local natives and red listed species, provides a basis for further investigation towards conservation priority (Hambler and Canney, 2013).

This research highlights knowledge gaps in existing agricultural GGI survey targets for local Biodiversity Action Plans (Rowe and Moffatt, 2017) and a need for increased surveying resources (Hooftman *et al.* 2021). Strengthening the national and global status of semi-natural grassland sites, such as those found within agroecological settings, requires acknowledgement in agricultural policy and legislation, with supporting financial incentives for their conservation and expansion (CSA, 2022). Agriculture based finance for GGI would allow scarce conservation focused resources to continue supporting larger more natural core reserves and source populations (Hambler and Canney, 2013). It is recommended that such support become available within current reforms of UK agricultural policy (GOV.UK, 2022). Funding issues highlight the current inadequacies within a global food system that separates maximised production and environmental outcomes, and that requires cross-discipline (ecology, agriculture and societal) approaches to resolve. The full complexity of ecosystems is mostly unknown. This research highlights the importance of continual investigation and refinement of established (subjectively labelled) sustainable production systems, to address current challenges of climate change and lessen human impacts on the environment (Hambler and Canney, 2013).

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Supplementary Information (SI)

SI. Methodology

SI. 1 Summary description of research local nature reserve (LNR) sites.

Grassland at Wolston Fields has naturally regenerated since 2018 from previous land use as a sand and gravel extraction site (Wolston Fields BAP, 2018). It has since been designated as an LNR. Hunningham Meadow semi-improved pasture was previously grazed year-round by horses, though at some point after 2015 was converted to Hay Meadow management with its LNR status (Warwickshire CC, 2022). Currently it is harvested for hay once a year in summer, with sheep and cattle grazing in autumn and winter, and grazing from a resident rabbit population (WWT Hunningham Meadow, 2022) (Fig. SI. 1).

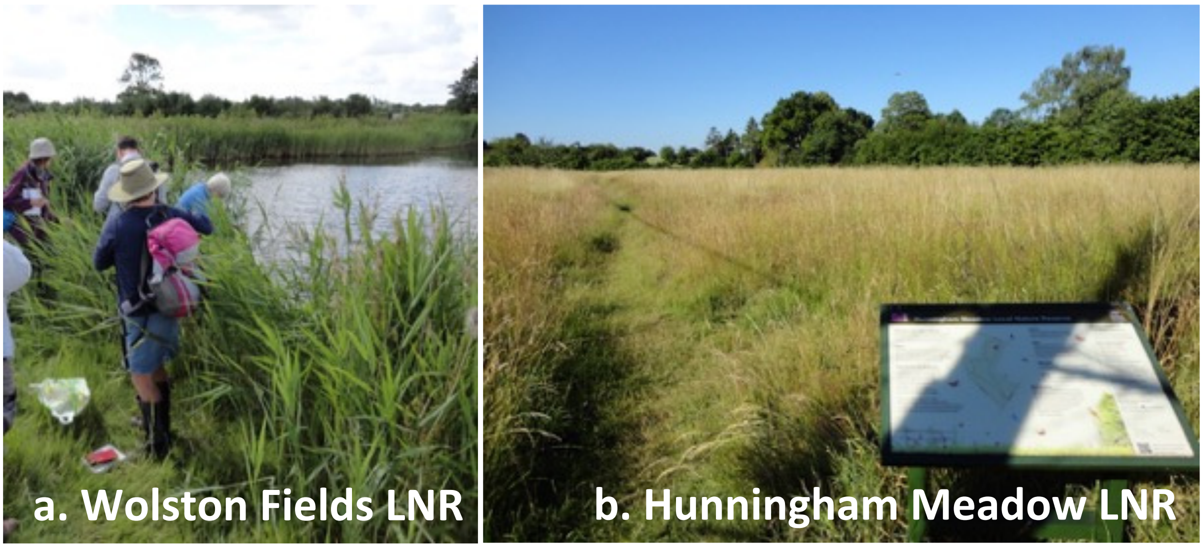


Fig. SI. 1 Research local nature reserve sites, Warwickshire. Images taken on day surveyed for floral species richness, as comparable (by soil type) baselines for research Replicate sites. a) BSBI Warwickshire Floral Group field meeting at Wolston Fields LNR (matched with Five Ace Community Farm) highlighting diverse range of habitat within the site as floodplain meadow including permanent and temporary pools (25 June 2022), and b) Hunningham Meadow LNR (matched with Canalside Community Food) relatively uniform habitat (7 July 2022). Photo credits: report author.

SI. 2 Legend for research site location map.

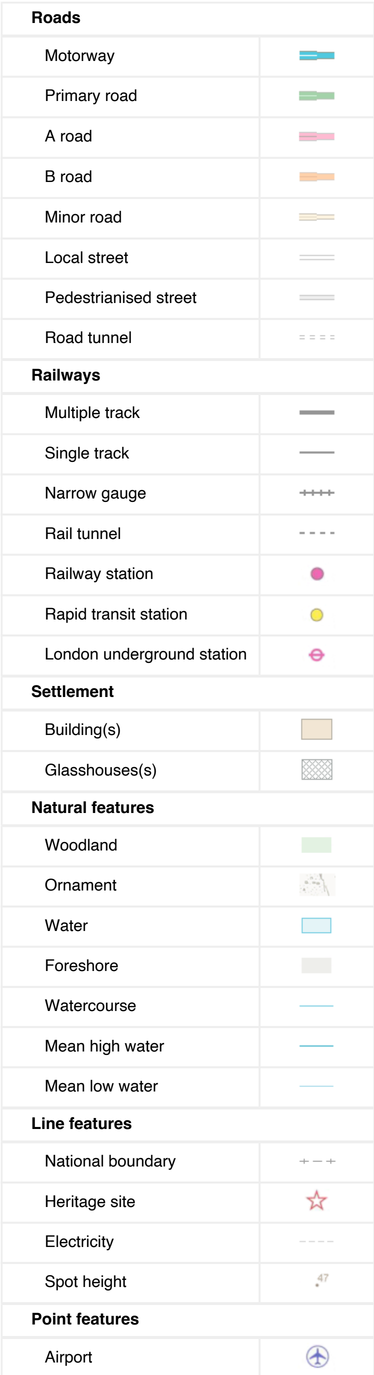


Fig. SI. 2 Legend for research site location map (Ref: Chapter 2. Methodology Fig. 2.2). Digimap OS Roam: VectorMap District Raster: VMD Backdrop (Digimap, 2022).

SI. 3 Climate data for Warwickshire and Replicate treatment species

Replicate treatment species climate tolerance ranged between January mean temperature of 3.6^{oC} and July 14.7^{oC}, for both replicates, with mean precipitation tolerance slightly lower at Five Acre (1034.1 mm y) than at Canalside (1046.9 mm y) (Hill *et al.* 2004), correlating with Met Office climate data (Met Office, 2022a) (Fig. SI. 3). Current climate predicted changes show continuing trends towards warming temperatures and reduced precipitation drifting north-east across lowland England from the south-east during this century (Met Office, 2022b). Increasing reliance for irrigating crops earlier in the season and for a greater part of the growing season are being seen, trends that will impact GGI community and composition (Berg *et al.* 2010; Debonne *et al.* 2022; R. Stevenson and G. Davies, pers. comm. June 2022).

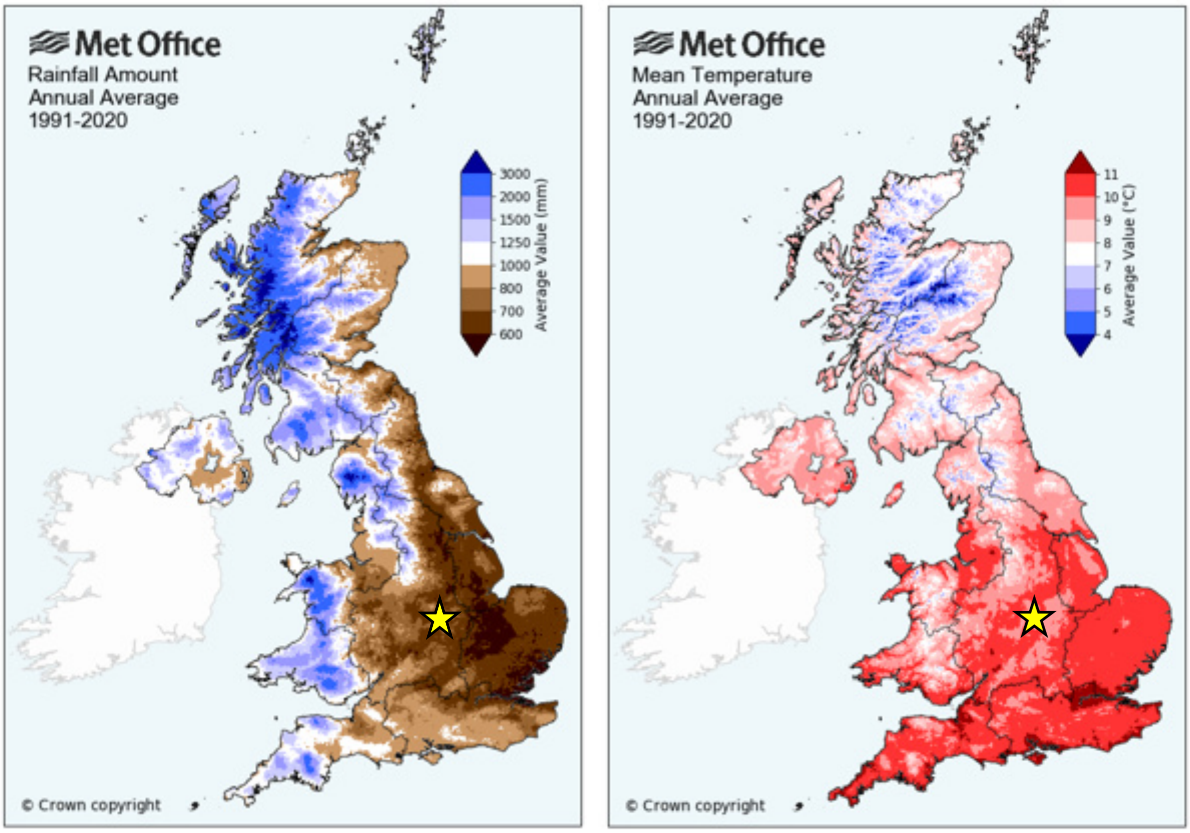


Fig. SI. 3 UK Met Office mean annual rainfall and temperature, highlighting Warwickshire (yellow star) (approximately rainfall 800 mm and temperature 11^{oC}. Annual Average 1991-2020) (Met Office, 2022a).

SI. 4 Sward detail of GGI treatments at research Replicates Five Acre Community Farm and Canalside Community Food, Warwickshire.

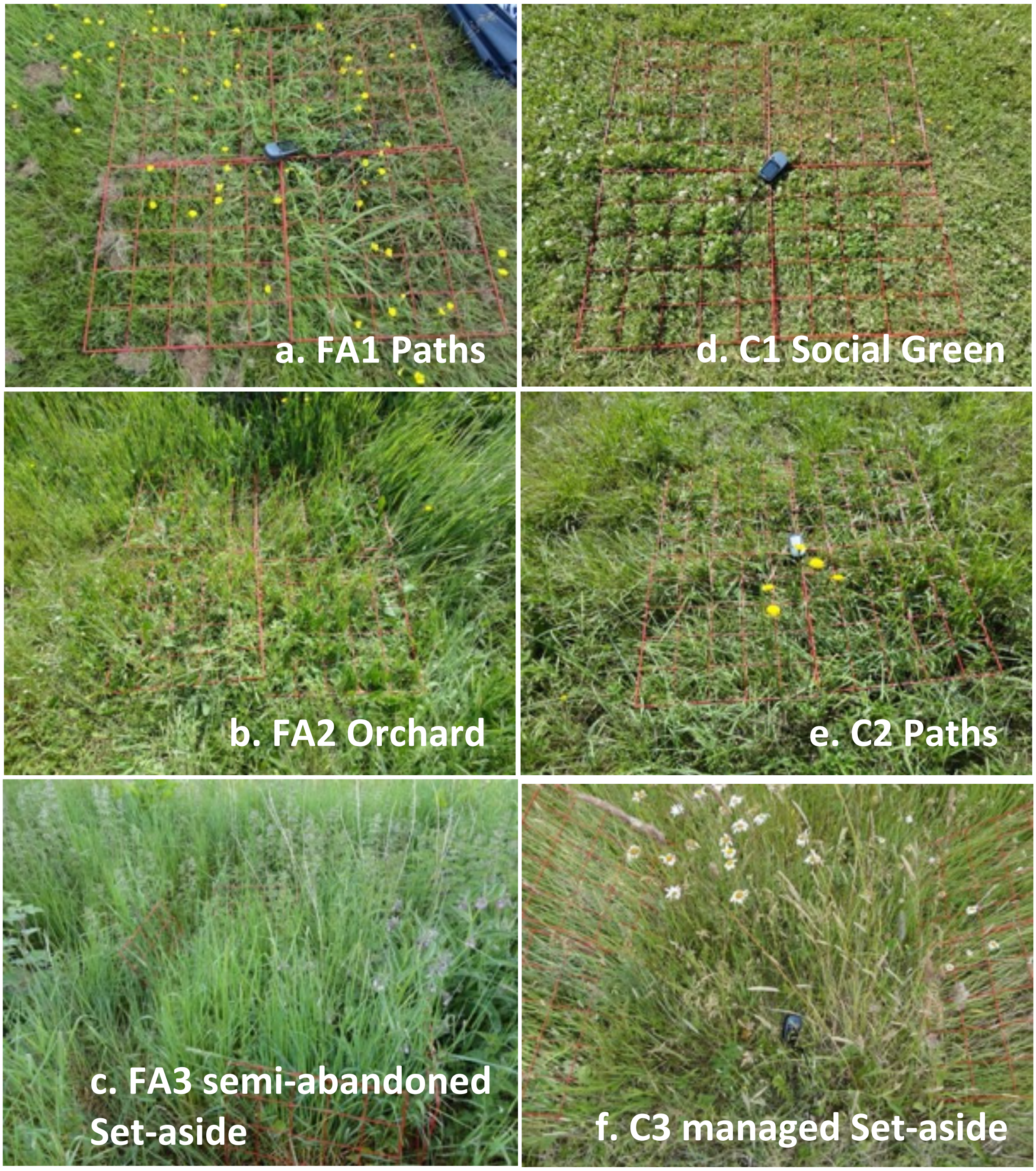


Fig. SI. 4 Representative images of sward detail for each GGI treatment at research Replicates, Warwickshire. Left column Five Acre Community Farm, quadrat in a) FA1 Paths, b) FA2 Orchard, c) FA3 semi-abandoned Set-aside, and right column Canalside Community Food, quadrat in d) C1 Social Green, e) C2 Paths, f) C3 managed Set-aside. Photo credits: report author.

SI. Results

SI. 5 Land manager interviews at research Replicates.

Five Acre Community Farm

SI. 5.1 Five Acre Community Farm: historical management

It is possible, the site (current Five Acre Community Farm crop field) has been cultivated since the medieval era. The Cottage on the adjacent Ryton Gardens site exists on oldest known maps. It is not known if the crop field had been ploughed prior to current land use since WWII, therefore it potentially has had no major inputs of synthetic fertilizers or pesticides. In the 1970's the site hosted a riding school, the current farm field used as horse grazing.

In 1985 the site became the research field for the Henry Doubleday Research Association (HDRA). Certified organic, it is certain that no synthetic inputs have been applied since this date. Crop beds were defined at this time by ploughing. Undisturbed sward from the original field provided the current grassland infrastructure (paths etc.). The only exceptions to this are, narrow linear strips excavated to lay underground drainage system (to create uniform hydrology for experimental control) during conversion in 1985; and a 4 m wide strip north of two Oak trees within the field, now allocated to soft fruit production with grass path access re-seeded around 8 years ago. In 1989 an irrigation line was laid which defines the Beetle Bank (FA3 semi-abandoned Set-aside) habitat. Originally it was short mown for access to water points, but for the last 20 years it has been mown occasionally with a strimmer to halt succession to woody vegetation, the area allowed to serve as midfield wildlife habitat.

In 2012 the site transferred to commercial fruit and vegetable production as the current community enterprise, where over 60 different crops are produced in any given season. Additionally, fruit from orchards adjacent to the site, previously managed by Garden Organic (previously HDRA), is now included in the 'share'. The land (which is rented) changed hands in 2019 and is now owned by Coventry University, with previous display gardens of HDRA/Garden Organic remaining and maintained.

SI. 5.2 Five Acre Community Farm: current management

Grassland mowing regime follows a predictable pattern across years. Mowing only occurs between March and October, and follows the following schedule, dependent on weather patterns during the season. Drier weather means less growth and maintenance, though wetter weather encourages sward growth but can hinder attempts to keep the swards maintained. Managers aim to mow Paths (FA1) once every 4 weeks using a tractor attachment. The Orchard (FA2) is mown once every 8 weeks with a tractor attachment and a strimmer to clear around orchard trees.

Regarding the Beetle Bank (FA3 semi-abandoned Set-aside), current managers have not cut the area (since 2012), though vegetation has been disturbed by storage of crop nets etc., and the habitat used to dispose of crop residues. Additionally, 2 years ago, spot disturbance occurred during planting of fruit trees at intervals along the length of the strip, and recovery of all irrigation points. The area immediately around the weather station (in situ since 1985) has continued to be mown frequently for ease of access and maintenance of equipment.

SI. 5.3 Five Acre Community Farm: current inputs

Green manures are sown in a 5-year rotation in crop beds (location of arable weed survey), mainly rye grass, vetch, clover and phacelia. These swards are only left for the current growing season or overwintered (maximum of 1-year lays) due to pressure of land required to fulfil commercial requirements for crop production. However, a 2-year herbal lay with chicory has been recently achieved. These species mixes and previous crops (such as *Symphytum x uplandicum* Russian Comfrey and *Medicago sativa sativa* Lucerne, Alfalfa) influence the grassland swards. In the past 3 years clover paths have been sown in between crop rows to aid weed suppression that provide additional soil nutrient.

Graded council produced green waste compost “Greengrow” (Worcestershire County Council, 2022) is used sparingly on the beds, with each bed not under green manure receiving an inch or two at surface before crops are planted at the beginning of growing season. Lime is occasionally applied as and when crops display symptoms of deficiency. Previous additional soil pH for crop beds is summarized in Table SI. 1.

Table SI. 1 Summary of historical soil pH for Five Acre Community Farm, Warwickshire. Data collected for regular monitoring of soil properties during period when Five Acre cropping field was the research field for Henry Doubleday Research Association (S. Stevenson, pers. comm., June 2022).

Date	Soil pH range	mean
2001	6.4 – 7.0	6.7
2005	6.4 – 7.3	6.7
2006	6.5 – 7.2	6.8

Canalside Community Food

SI. 5.4 Canalside Community Food: historical management

The land has been run as a family farm going back at least to the beginning of the last century (Leasowes Farm identified on OS map, covering over 58 hectares). Previous to 2005, the majority of land was under conventional production as an arable rotation, though an ancient meadow (never ploughed or improved in living memory) exists (north side of the canal) that was last grazed by cattle 2 years ago.

In 2005 the landowners converted their land to certified Organic production. Cereals continue to be grown on the bulk of the land in a rotation of ploughing for wheat and barley, and grass leys for livestock grazing. Additionally, the owners have converted large portions to woodland, and more recently, pastoral permanent meadow. At the time of organic conversion around 4 hectares of land (the survey site) was transferred to commercial vegetable production as the existing community farm. The grassland infrastructure was established at this time using grass and clover ley mixes, the whole site sown, and the crop beds subsequently ploughed and maintained. This land was purchased from the family in 2018. The farm produces around 60 varieties of vegetable each season, with additional fruit from an orchard, and eggs and honey produced on the Leasowe land.

SI. 5.5 Canalside Community Food: current management

As with Five Acre, mowing of the GGI occurs between March and October. The Social Green (C1) is mown every 4-6 weeks (and more frequently if required for a 'social') using a ride-on mower, undertaken by contractors (the Leasowe family). All other management is done by farm managers. Paths (C2) are mown with tractor and attachment every 6-8 weeks. The set aside known as Bermuda Triangle (C3) is cut with a strimmer 1-2 times a year. Here, communities are influenced by damp ground, being at the bottom of the site with proximity to the canal and natural water course.

SI. 5.6 Canalside Community Food: current inputs

The additional hectarage (compared with Five Acre) allows for 2-year herbal leys (ryegrass, clover and chicory), a 1-year (ryegrass and clover) mix, and temporary (September to April) ley (ryegrass) also employed. The drainage ditches across the site are cleared periodically and spoil from these operations have been put on the Bermuda Triangle (C3 managed Set-aside), with additional woody inputs from hedgerow maintenance etc. stored here. No other inputs are used due to effectiveness of the longer-term leys.

Table SI. 2 Summary timeline of land management information provided by land managers at Five Acre Community Farm and Canalside Community Food, Warwickshire, regarding historical and contemporary land-use and management. Interviews took the form of informal conversations as and when personnel were available during the surveying week at each Replicate (G. Davies; S. Hayward; F. Rayns; R. Stevenson; pers.comm. June 2022).

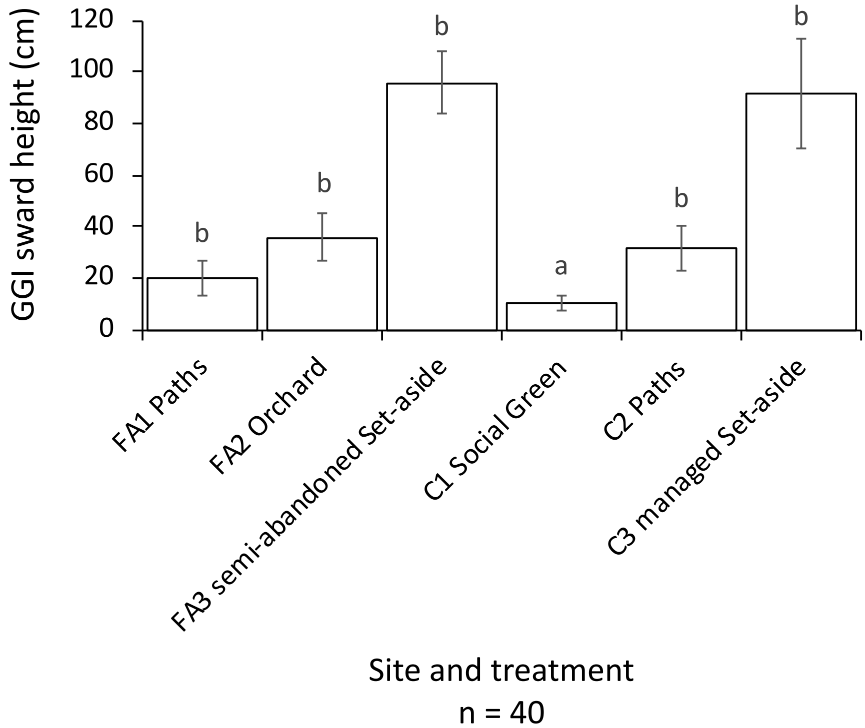
Interview topic timeline	Five Acre Community Farm	Canalside Community Food
History- pre-1850	Possibly cultivated since Medieval period	
Early 1900's		Land owned by Leasowe family (58 ha)
Post WWII	Potentially not ploughed or applied with synthetic inputs	Conventional cereal (wheat. barley) rotation (ploughed). One small field known to be 'ancient' meadow is grazed.
1970's	Horse grazing (Riding School)	
1985	Ownership to Henry Doubleday Research Association (HDRA). 'Site' became research field. Organic certification- no synthetic inputs from this time. Current crop beds ploughed, and drainage installed to create uniform hydrology. Original grassland sward remains intact.	
1989	Irrigation line installed down length of field (area of current Beetle Bank). Regularly mown for access to water points.	

(cont.) Interview topic timeline	Five Acre Community Farm	Canalside Community Food
2002	Beetle Bank land strimmed intermittently to halt succession to woody species. Area around weather station regularly mown for access.	
2005		Leasowe farm converted to Organic production. Rotation of wheat, barley, and grass leys for livestock grazing, and with recently planted woodland and pastoral meadow. Commercial vegetable production at 'Site' (4 ha) begins- re-seeded grass/clover herbal leys established (current grassland), and crop beds defined by ploughing.
2012	Commercial vegetable production begins.	
2018		Site purchased by Community
2019	Land ownership transferred from Garden Organic (previously HDRA) to Coventry University.	
2020	Beetle Bank spot disturbance with fruit trees planted and water points recovered.	
Inputs- historic	Green manures (herbal leys) and research crops including Russian comfrey, lucerne and alfalfa.	
Inputs-current	Herbal leys in 5-yr rotation (mainly rye grass, vetch, phacelia, also chicory) ploughed in after overwintered or 1-yr (2-yr max.). Some clover leys between crop rows. Crop beds (not under herbal leys) pre-season application < 5 cm green waste compost. Lime application occasional. Waste management and equipment stored in GGI.	Summer season, 1-yr and 2-yr rotational herbal leys on crop beds (including red clover, Westerwold ryegrass and chicory). Spoil from drainage ditches and woody hedgerow clippings put on Bermuda Triangle

SI. 6 Mean and significant difference for GGI treatment sward height (cm) at research Replicates.

Mean and significant difference for GGI treatment sward height at both Replicates are given in Fig. SI. 5. The expected differences were significant (Kruskal-Wallis chi-squared = 209.44, df = 5, p-value < 2.2e-16). FA1 (paths) and C1 (social green) were each shorter than all other treatments. The longest swards at each site (FA3 semi-abandoned Set-aside and C3 managed Set-aside) were not different from each other, as were FA2 (Orchard) and C2 (Paths) (Wilcoxon p = between 0 and > 0.000). Values for C1 (Social Green) were most consistent, with C3 (managed Set-aside) containing greatest variability.

a.



b.

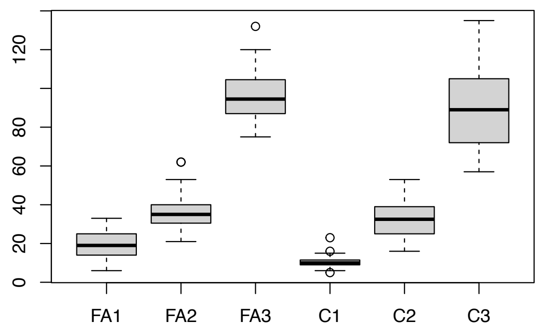
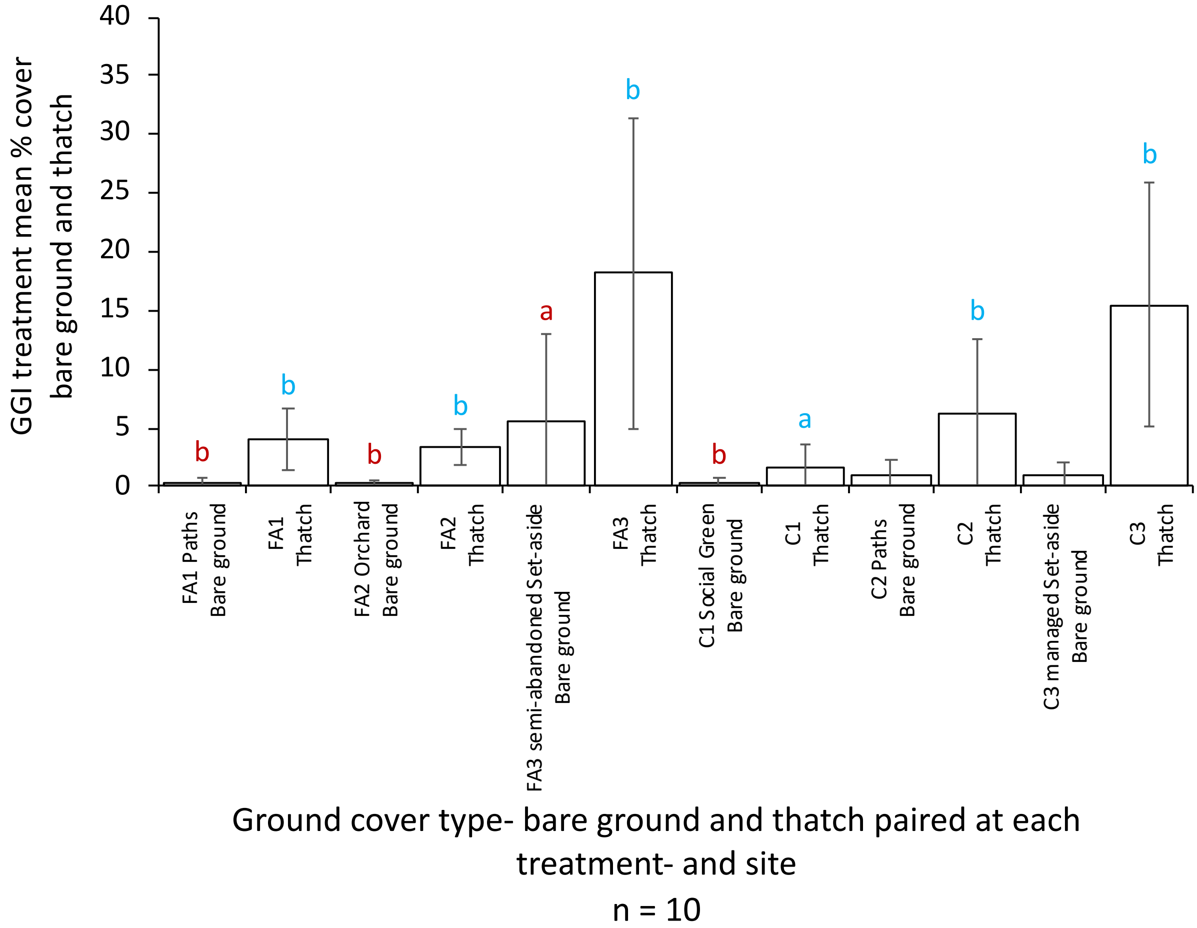


Fig. SI. 5 a) Mean sward height (cm) for all GGI treatments at research Replicates Five Area Community Farm (FA1 Paths, FA2 Orchard, FA3 semi-abandoned Set-aside) and Canalside Community Food (C1 Social Green, C2 Paths, C3 managed Set-aside), Warwickshire. Superscript above graph bars indicates where main significant difference is seen. Several other significant differences occurred across treatments most notably between FA3 and all other treatments. Kruskal-Wallis chi-squared = 209.44, df = 5, p-value < 2.2e-16). b) Box plot for mean sward height (y-axis sward height (cm) and x axis treatment codes).

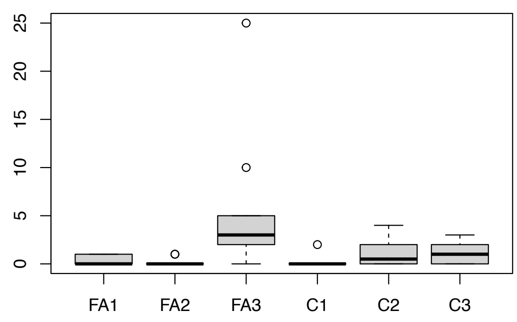
SI. 7 Mean and significant difference for % cover bare ground and thatch in GGI treatments at research Replicates.

For % cover bare ground and thatch in GGI treatments at Five Acre Community Farm and Canalside Community Food, Warwickshire, half of all samples contained outliers. Data for bare ground was more consistent than thatch, the latter showing greatest variation within the tall swards of FA3 (semi-abandoned Set-aside) and C3 (managed Set-aside). Significant differences for bare ground (Kruskal-Wallis chi-squared = 20.28, df = 5, p-value = < 0.001) are seen with more in FA3 (semi-abandoned Set-aside) than FA1 (Paths), FA2 (Orchard) and C1 (Social Green) (p = 0.018), and in thatch (Kruskal-Wallis chi-squared = 30.821, df = 5, p-value = 1.016e-05) where less was found in C1 (Social Green) than all other treatments, and more in FA3 (semi-abandoned Set-aside) and C3 (managed Set-aside) than all treatments (Wilcoxon range p = 0.049 to 0.003) (Fig. SI. 6).

a.



b. mean % cover bare ground



c. mean % cover thatch

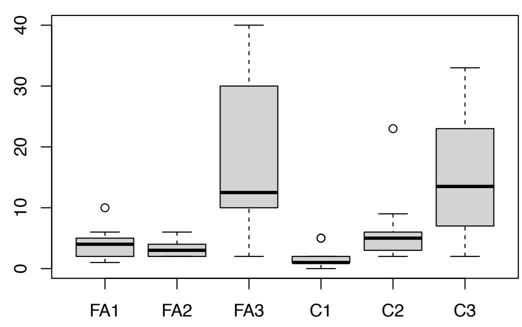


Fig. SI. 6 a) Mean % cover bare ground (Kruskal-Wallis chi-squared = 20.28, df = 5, p-value = < 0.001) and % cover thatch (Kruskal-Wallis chi-squared = 30.821, df = 5, p-value = 1.016e-05) for all GGI treatments at Replicates Five Area Community Farm (FA1 Paths, FA2 Orchard, FA3 semi-abandoned Set-aside) and Canalside Community Food (C1 Social Green, C2 Paths, C3 managed Set-aside), Warwickshire. Superscript, brown (bare ground) and blue (thatch), above graph bars indicate where main significant differences lie. Box plots for data (y-axes % cover and x axes treatment codes) b) mean % cover bare ground, and c) mean % cover thatch.

SI. 8 Soil series and soil broad description maps for research sites (Replicates and local nature reserves) in Warwickshire, and box plot for treatment mean soil pH.

Base map legend

- Freely draining slightly acid loamy soils
- Lime-rich loamy and clayey soils with impeded drainage
- Loamy and clayey floodplain soils with naturally high groundwater
- Loamy soils with naturally high groundwater
- Slightly acid loamy and clayey soils with impeded drainage
- Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils
- water

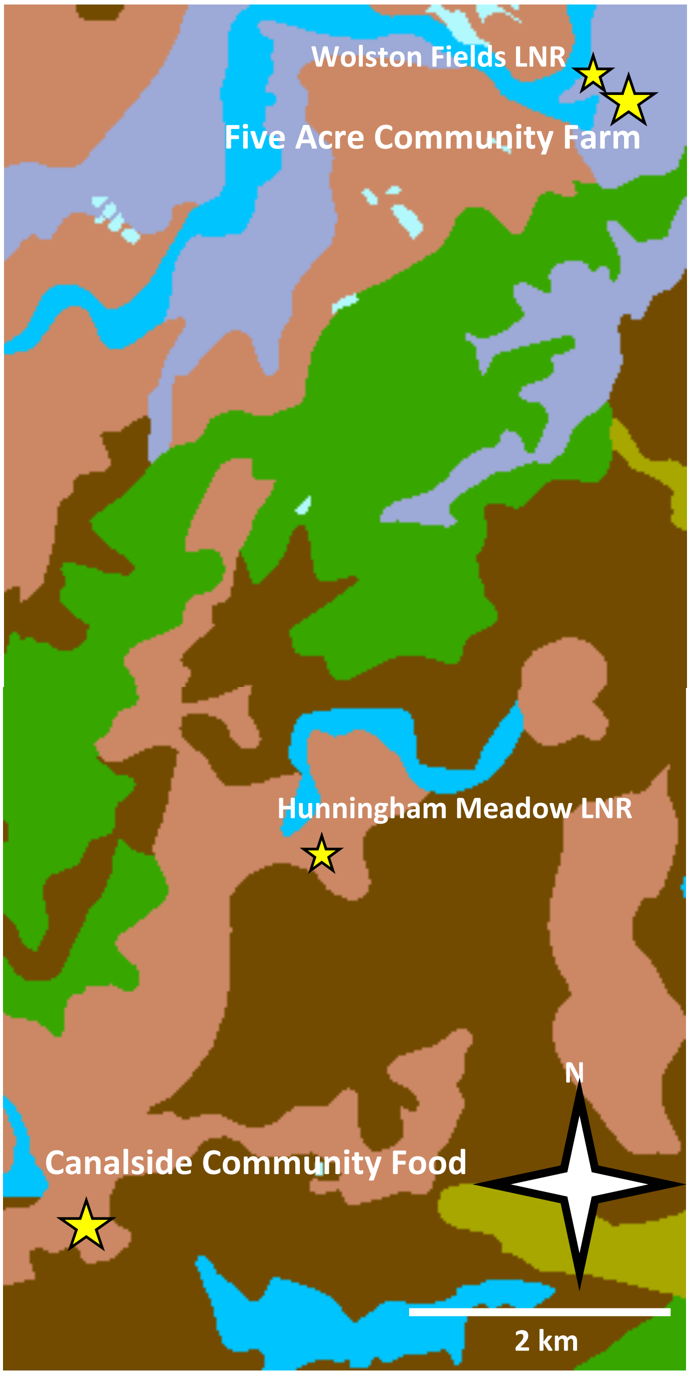


Fig. SI. 7 Soilscapes (2022) map of research area in Warwickshire, UK, showing broad soils descriptions for Replicate sites. Paired local nature reserves (LNR's) (yellow stars) match Replicate soil type and indicate baseline for floral composition for research GGI treatments. Five Acre Community Farm and Wolston LNR are on loamy soils with naturally high groundwater. Canalside Community Food and Hunningham Meadow LNR are on freely draining slightly acid loam.

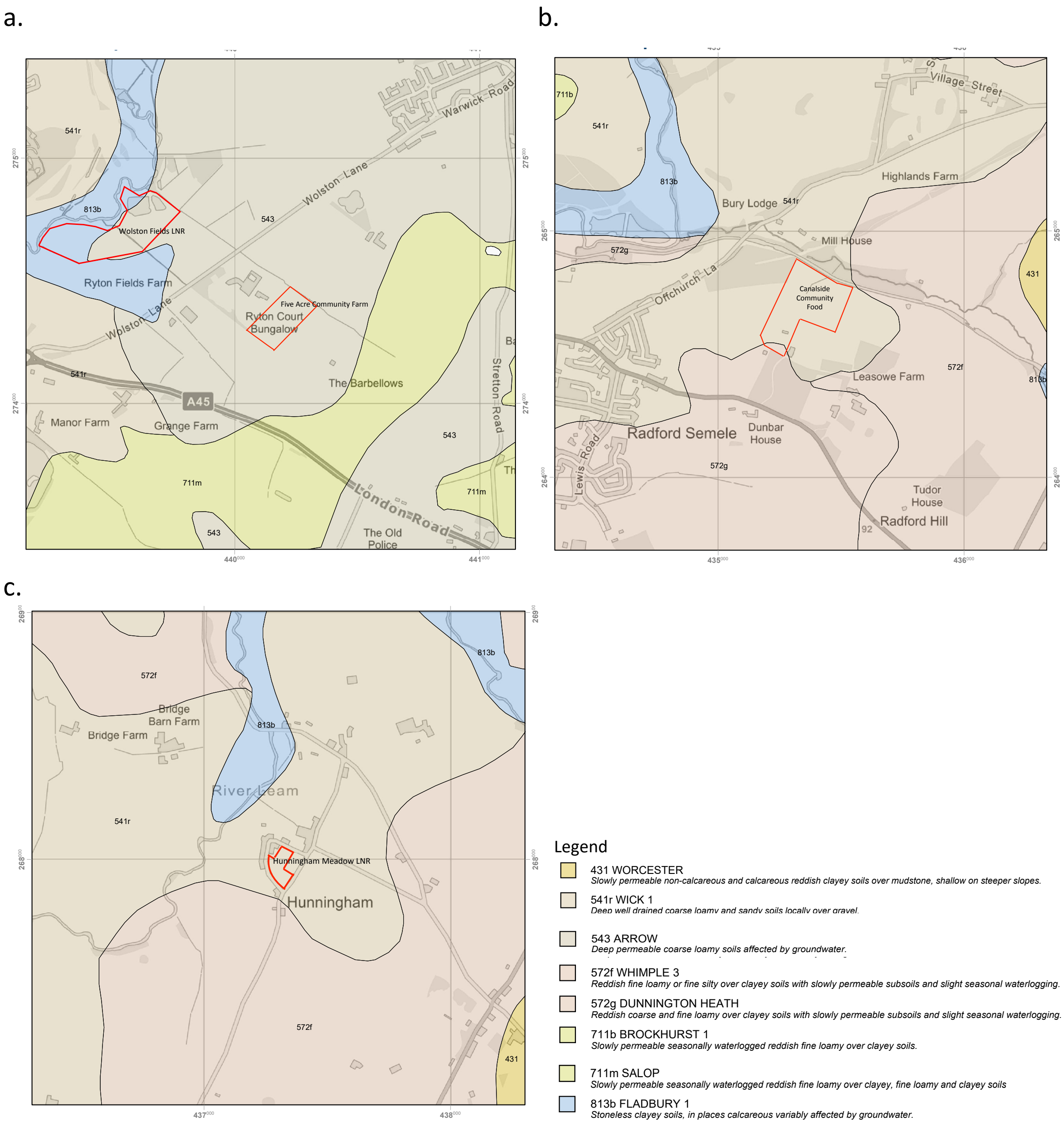


Fig. SI. 8 Soil series for research sites 541r Wick 1. a) Five Acre Community Farm and Wolston Fields Local Nature Reserve, b) Canalside Community Food and c) Hunningham Meadow LNR. The Fladbury soil series (blue shading) indicates the course of the River Leam in b and c, and the River Avon in a. Research sites are highlighted by red polygons. (North to top of map; gridlines denote 1 km [2]). (National Soil Resources Institute, 2022a, b and c).

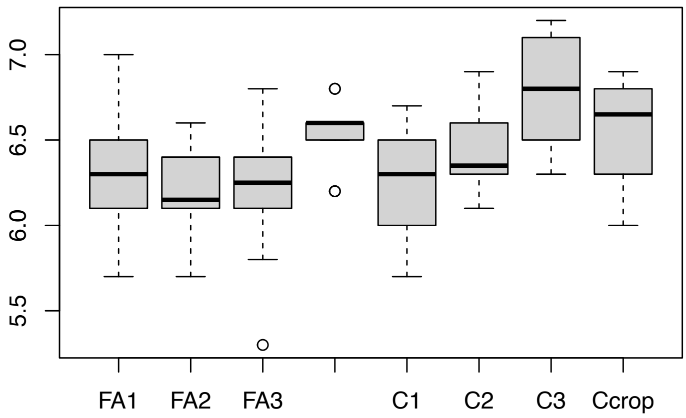


Fig. SI. 9 Box plot for mean soil pH (y-axis labels) (including crop beds) at research Replicates, Warwickshire. x-axis labels treatments at Five Acre Community Farm (FA1 Paths, FA2 Orchard, FA3 semi-abandoned Set-aside and crop beds-missing label) and Canalside Community Food (C1 Social Green, C2 Paths, C3 managed Set-aside and Ccrop crop beds). Kruskal-Wallis chi-squared = 21.415, df = 7, p-value = 0.003.

SI. 9 Research Replicate GGI treatment National Vegetation Classification (NVC) floristic tables.

Table SI. 3 NVC floristic tables constructed (using species richness and species % cover data) to interpret GGI treatment sward classification at Replicates Five Acre Community Farm (FA1 Paths, FA2 Orchard, FA3 semi-abandoned Set-aside) and Canalside Community Food (C1 Social Green, C2 Paths and C3 managed Set-aside), Warwickshire (Rodwell *et al.* 1992).

FA1
Floristic table MG5
Paths

Holcus lanatus	V	(5-9)
Poa trivialis	V	(7-9)
Taraxacum spp.	V	(2-8)
Trifolium repens	IV	(4-7)
Ranunculus repens	III	(3-8)
Geranium dissectum	III	(1-5)
Rumex obtusifolius	III	(1-4)
Trifolium pratense	II	(4-7)
Dactylis glomerata	II	(4-4)
Geranium pusillum	II	(1-1)
Arrhenatherum elatius	I	(5-7)
Lolium sp.	I	(3-5)
Geum urbanum	I	(4)
Plantago lanceolata	I	(4)
Urtica dioica	I	(4)
Tanacetum vulgare	I	(3)
Anthoxanthum odoratum	I	(1-2)
Bromus hordeaceus	I	(1-2)
Bromus hordeaceus ssp.	I	(1-2)
Malva sylvestris	I	(1)
Veronica persica	I	(1)
Alliaria petiolata	I	(1)
Aphanes arvensis	I	(1)
Calystegia sepium	I	(1)
Cerastium fontanum	I	(1)
Cirsium arvense	I	(1)
Crepis capillaris	I	(1)
Heracleum sphondylium	I	(1)
Hypochaeris radicata	I	(1)
Solanum nigrum	I	(1)

Number of samples	10
Mean number of species/sample	8.8
Mean vegetation height (cm)	20 cm
Mean total cover (%)	181%

FA2
Floristic table MG5
Orchard

Taraxacum spp.	V	(6-9)
Holcus lanatus	V	(5-9)
Poa trivialis	V	(4-9)
Trifolium repens	V	(4-8)
Bromus hordeaceus	V	(1-6)
Geranium dissectum	V	(1-5)
Bromus hordeaceus ssp.	IV	(1-7)
Cerastium fontanum	IV	(1-5)
Solanum nigrum	IV	(1-4)
Ranunculus repens	III	(1-4)
Senecio jacobaea	III	(1-3)
Lolium sp.	II	(4)
Veronica serpyllifolia	II	(1-4)
Arrhenatherum elatius	II	(1-3)
Vulpia bromoides	I	(9)
Vicia sativa	I	(4-5)
Origanum vulgare var.	I	(5)
Moss spp.	I	(4)
Dactylis glomerata	I	(4)
Juncus sp.	I	(4)
Leucanthemum vulgare	I	(4)
Trifolium pratense	I	(4)
Plantago lanceolata	I	(1-2)
Agrostis stolonifera	I	(2)
Achillea millefolium	I	(1)
Aphanes arvensis	I	(1)
Hypochaeris radicata	I	(1)

Number of samples	10
Mean number of species/sample	11.8
Mean vegetation height (cm)	36 cm
Mean total cover (%)	243%

FA3

Floristic table MG1b
semi-abandoned Set-aside

Arrhenatherum elatius	V	(5-9)
Galium aparine	IV	(2-4)
Moss spp.	III	(4-8)
Urtica dioica	III	(4-8)
Cirsium arvense	III	(3-5)
Rumex obtusifolius	II	(2-5)
Lolium spp.	II	(2-4)
Calystegia sepium	II	(3)
Epilobium ciliatum	II	(1-2)
Heracleum sphondylium	I	(6)
Symphytum x uplandicum	I	(5)
Geranium dissectum	I	(4)
Dactylis glomerata	I	(4)
Holcus lanatus	I	(4)
Artemisia vulgaris	I	(4)
Ranunculus repens	I	(1-2)
Anthoxanthum odoratum	I	(2)
Trisetum flavescens	I	(2)
Aphanes arvensis	I	(1)

Number of samples	10
Mean number of species/sample	5.7
Mean vegetation height (cm)	96 cm
Mean total cover (%)	126%

C1

Floristic table MG5 (5-6)
Social Green

Festuca rubra	V	(6-10)
Trifolium repens	V	(4-9)
Phleum pratense	V	(4-8)
Ranunculus repens	IV	(4-8)
Taraxacum spp.	IV	(1-7)
Lolium sp.	IV	(2-5)
Agrostis stolonifera	III	(2-6)
Poa trivialis	III	(4-5)
Holcus lanatus	II	(4-8)
Dactylis glomerata	II	(3-4)
Plantago major	II	(1-4)
Rumex acetosa	I	(3-4)
Arrhenatherum elatius	I	(4)
Schedonorus arundinaceus	I	(4)
Cerastium fontanum	I	(2-3)
Malva sylvestris	I	(1-2)
Heracleum sphondylium	I	(1)
Plantago lanceolata	I	(1)

Number of samples	10
Mean number of species/sample	8.2
Mean vegetation height (cm)	11 cm
Mean total cover (%)	207%

C2

Floristic table MG5
Paths

Elytrigia repens	V	(3-5)
Poa trivialis	IV	(4-10)
Lolium sp.	IV	(3-8)
Dactylis glomerata	IV	(2-8)
Holcus lanatus	IV	(2-8)
Heracleum sphondylium	IV	(1-5)
Taraxacum spp.	IV	(1-5)
Arrhenatherum elatius	III	(3-7)
Trifolium repens	III	(1-6)
Plantago major	III	(1-5)
Phleum pratense	III	(1-4)
Lathyrus pratensis	II	(2-6)
Ranunculus repens	II	(1-4)
Cerastium fontanum	II	(1)
Cirsium arvense	II	(1)
Festuca rubra	I	(3-4)
Geranium dissectum	I	(2)
Medicago lupulina	I	(5)
Centaurea nigra	I	(4)
Senecio erucifolius	I	(4)
Moss spp.	I	(3)
Rumex acetosa	I	(2)
Anthriscus sylvestris	I	(1)
Hypochaeris radicata	I	(1)
Trifolium pratense	I	(1)

Number of samples	10
Mean number of species/sample	10.2
Mean vegetation height (cm)	32 cm
Mean total cover (%)	128%

C3

Floristic table MG5
managed Set-

Holcus lanatus	V	(5-8)
Poa trivialis	V	(4-8)
Taraxacum spp.	V	(1-8)
Dactylis glomerata	V	(3-7)
Geranium dissectum	V	(2-4)
Arrhenatherum elatius	IV	(4-6)
Moss spp.	IV	(2-6)
Trifolium repens	IV	(1-6)
Cerastium fontanum	IV	(1-5)
Lathyrus pratensis	IV	(1-5)
Leucanthemum vulgare	III	(3-8)
Centaurea nigra	III	(1-8)
Ranunculus repens	III	(2-7)
Heracleum sphondylium	III	(1-5)
Elytrigia repens	III	(2-4)
Medicago lupulina	II	(4-7)
Festuca rubra	II	(4-7)
Ranunculus acris	II	(2-6)
Sonchus oleraceus	II	(1-4)
Angelica sylvestris	II	(1-4)
Cirsium arvense	II	(1-4)
Prunella vulgaris	II	(1-4)
Plantago lanceolata	I	(4-5)
Senecio erucifolius	I	(4)
Hypericum perforatum	I	(1-4)
Rumex acetosa	I	(1-4)
Myosotis arvensis	I	(1-3)
Lolium sp.	I	(2)
Hypochaeris radicata	I	(1-2)
Senecio jacobaea	I	(1-2)
Sonchus asper	I	(1-2)
Anthoxanthum odoratum	I	(5)
Phleum pratense	I	(5)
Trifolium pratense	I	(5)
Trifolium campestre	I	(4)
Bromus hordeaceus	I	(2)
Vicia hirsuta	I	(2)
Epilobium ciliatum	I	(1)
Geum urbanum	I	(1)
Malva moschata	I	(1)
Veronica arvensis	I	(1)

Number of samples	10
Mean number of species/sample	16.6
Mean vegetation height (cm)	91 cm
Mean total cover (%)	218%

SI. 10 Research sites species lists (Replicate treatments and local nature reserve (LNR's)).

Table SI. 4 Species list for each research treatment (GGI x 3 and crop bed arable weeds) at Replicates Five Acre Community Farm (FA), Canalside Community Food (C), Warwickshire. 'p' denotes species present within treatment. (Not including woody species seedlings). FA1 Paths, FA2 Orchard, FA3 semi-abandoned Set-aside (grass *Elytrigia repens* omitted from GGI survey at Five Acre), FA c (crop bed), C1 Social Green, C2 Paths, C3 managed Set-aside, C c (crop bed). Due to time constraints Crop bed grasses were not recorded apart from *E. repens, Poa annua, Secale cereale, Triticum aestivum* at Five Acre, and *E. repens, P. annua and S. cereale* at Canalside. (sp.: species; spp.: species plural; ssp.: subspecies; agg.: aggregate of very similar species).

Species	**Common name**	**Recorded in:**							
		FA1	**FA2**	**FA3**	**FA c**	**C1**	**C2**	**C3**	**C c**
Achillea millefolium	Yarrow		p		p				p
Agrostis stolonifera	Creeping Bent		p			p			
Alliaria petiolata	Garlic Mustard	p							
Amaranthus retroflexus	Common Amaranth								p
Anagallis arvensis	Scarlet Pimpernel				p				p
Anchusa arvensis	Bugloss				p				
Angelica sylvestris	Wild Angelica							p	
Anthoxanthum odoratum	Sweet Vernal-grass	p		p				p	
Anthriscus sylvestris	Cow Parsley						p		
Aphanes arvensis	Parsley-piert	p	p	p					
Arrhenatherum elatius	False Oat-grass	p	p	p		p	p	p	
Artemisia vulgaris	Mugwort			p	p				p
Atriplex prostrata	Spear-leaved Orache								p
Brassica napus	Rape								p
Bromus hordeaceus	Soft-brome	p	p					p	
Bromus hordeaceus ssp.	Soft-brome ssp.	p	p						
Calystegia sepium	Hedge Bindweed	p		p					
Capsella bursa-pastoris	Shepherd's-purse				p				p
Cardamine hirsuta	Hairy Bitter-cress				p				
Centaurea nigra	Common Knapweed						p	p	
Cerastium fontanum	Common Mouse-ear	p	p		p	p	p	p	p
Chenopodium album	Fat-hen				p				p
Chenopodium polyspermum	Many-seeded Goosefoot				p				p
Cichorium intybus	Chicory				p				p
Circaea lutetiana	Enchanter's-nightshade				p				
Cirsium arvense	Creeping Thistle	p		p	p		p	p	p
Cirsium vulgare	Spear Thistle								p
Convolvulus arvensis	Field Bindweed								p
Conyza canadensis	Canadian Fleabane								p
Crepis capillaris	Smooth Hawk's-beard	p							
Crepis vesicaria	Beaked Hawk's-beard				p				
Dactylis glomerata	Cock's-foot	p	p	p		p	p	p	
Elytrigia repens	Common Couch				p		p	p	p
Epilobium ciliatum	American Willowherb			p				p	p
Epilobium hirsutum	Great Willowherb								p
Epilobium tetragonum	Square-stalked W.herb								p
Euphorbia helioscopia	Sun Spurge								p
Euphorbia peplus	Petty Spurge				p				p
Fallopia convolvulous	Black-bindweed				p				p
Festuca rubra	Red Fescue					p	p	p	
Fumaria sp.	Fumitory				p				p
Galinsoga parviflora	Gallant-soldier				p				
Galinsoga quadriradiata	Shaggy-soldier				p				
Galium aparine	Cleavers			p	p				p
Geranium columbinum	Long-stalked Crane's-bill								p

(cont.) Species	Common name	FA1	FA2	FA3	FA c	C1	C2	C3	C c
Geranium dissectum	Cut-leaved Crane's-bill	p	p	p	p		p	p	p
Geranium molle	Dove's-foot Crane's-bill								p
Geranium pusillum	Small-flowered Crane'sbill	p			p				p
Geum urbanum	Wood Avens	p						p	p
Gnaphalium uliginosum	Marsh Cudweed				p				p
Helminthotheca echioides	Bristly Oxtongue								
Heracleum sphondylium	Hogweed	p		p		p	p	p	p
Holcus lanatus	Yorkshire-fog	p	p	p		p	p	p	
Hypericum perforatum	Perforate St John's-wort							p	
Hypochaeris radicata	Cat's-ear	p	p				p	p	p
Juncus sp.	Rush sp.		p						
Lamium album	White Dead-nettle								p
Lamium amplexicaule	Henbit Dead-nettle				p				p
Lamium purpureum	Red Dead-nettle				p				p
Lathyrus pratensis	Meadow Vetchling						p	p	
Lepidium didymum	Lesser Swine-cress				p				p
Leucanthemum vulgare	Oxeye Daisy		p					p	p
Lolium sp.	Rye Grass sp.	p	p	p		p	p	p	
Malva moschata	Musk-mallow							p	p
Malva sylvestris	Common Mallow	p			p	p			p
Matricaria chamomilla	Scented Mayweed				p				p
Matricaria discoidea	Pineapple-weed				p				p
Medicago lupulina	Black Medick						p	p	p
Medicago sativa sativa	Lucerne, Alfalfa				p				
Moss spp.	Moss spp.		p	p			p	p	
Myosotis arvensis	Field Forget-me-not							p	p
Origanum vulgare var.	Marjoram		p						
Papaver rhoeas	Common Poppy				p				p
Persicaria lapathifolia	Pale Persicaria								p
Persicaria maculosa	Redshank				p				p
Phacelia tanacetifolia	Phacelia				p				
Phleum pratense	Timothy					p	p	p	
Plantago lanceolata	Ribwort plantain	p	p		p	p		p	p
Plantago major	Greater Plantain				p	p	p		p
Poa annua	Annual Meadow Grass			p	p				p
Poa trivialis	Rough Meadow Grass	p	p			p	p	p	
Polygonum aviculare	Knotgrass				p				p
Prunella vulgaris	Selfheal							p	p
Ranunculus acris	Meadow Buttercup							p	p
Ranunculus repens	Creeping Buttercup	p	p	p	p	p	p	p	p
Rumex acetosa	Common Sorrel					p	p	p	p
Rumex crispus	Curled Dock				p				p
Rumex obtusifolius	Broad-leaved Dock	p		p	p				p
Schedonorus arundinaceus	Tall Fescue					p			
Scorzoneroides autumnalis	Autumn Hawkbit								p
Secale cereale	Rye				p				p
Senecio erucifolius	Hoary Ragwort						p	p	
Senecio jacobaea	Common Ragwort		p					p	p
Senecio vulgaris	Groundsel				p				p
Sherardia arvensis	Field Madder								p
Sinapis arvensis	Charlock								p
Solanum nigrum	Black Nightshade	p	p		p				p
Solanum tuberosum	Potato				p				
Sonchus arvensis	Perennial Sow-thistle								p
Sonchus asper	Prickly Sow-thistle				p			p	p
Sonchus oleraceus	Smooth Sow-thistle				p			p	p
Spergula arvensis	Corn Spurrey				p				p
Stachys sylvatica	Hedge Woundwort								p

(cont.) Species	Common name	FA1	FA2	FA3	FA c	C1	C2	C3	C c
Stellaria media	Common Chickweed				p				p
Symphytum x uplandicum	Russian Comfrey			p	p				
Tanacetum vulgare	Tansy	p							
Taraxacum agg.	Dandelion	p	p		p	p	p	p	p
Thlaspi arvense	Field Penny-cress				p				p
Trifolium campestre	Hop Trefoil							p	
Trifolium pratense	Red Clover	p	p				p	p	p
Trifolium repens	White Clover	p	p		p	p	p	p	p
Tripleurospermum inoderum	Scentless Mayweed				p				
Trisetum flavescens	Yellow Oat-grass			p					
Triticum aestivum	Bread Wheat				p				
Urtica dioica	Common Nettle	p		p					p
Urtica urens	Small Nettle								p
Veronica arvensis	Wall Speedwell							p	
Veronica chamaedrys	Germander Speedwell				p				
Veronica persica	Common Field-speedwell	p			p				p
Veronica serpyllifolia	Thyme-leaved Speedwell		p		p				p
Vicia hirsuta	Hairy Tare							p	
Vicia sativa agg.	Common Vetch agg.		p		p				
Viola arvensis	Field Pansy				p				p
Vulpia bromoides	Squirrel-tail Fescue		p						

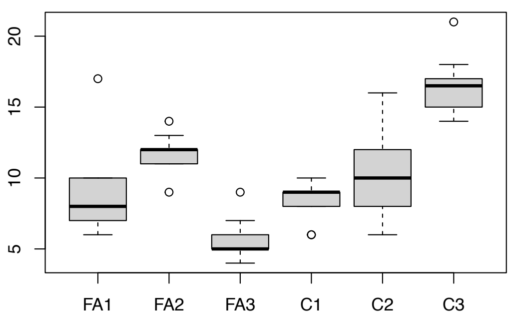
Table SI. 5 Grassland species Lists for research site local nature reserves (LNR's), Warwickshire. Primary data Hunningham (H LNR) and selected secondary data from Wolston Fields (W LNR) (J. and M. Walton, pers. comm. June 2022). 'p' denotes species present within treatment. (sp.: species; spp.: species plural; ssp.: subspecies; agg.: aggregate of very similar species).

Species	**Common name**	**Recoded at-** W LNR	H LNR
Achillea millefolium	Yarrow		p
Agrostis stolonifera	Creeping Bent	p	p
Alopecurus pratensis	Meadow Foxtail	p	p
Anthoxanthum odoratum	Sweet Vernal-grass	p	p
Anthriscus sylvestris	Cow Parsley	p	p
Arctium minus	Lesser Burdock	p	
Arrhenatherum elatius	False Oat-grass	p	p
Atriplex prostrata	Spear-leaved Orache	p	
Bromus commutatus	Meadow Brome	p	
Calystegia sepium	Hedge Bindweed	p	
Carduus crispus	Welted Thistle	p	
Carex hirta	Hairy Sedge	p	
Centaurea nigra	Common Knapweed	p	p
Cerastium fontanum	Common Mouse-ear	p	
Chamerion angustifolium	Rosebay Willowherb	p	
Chenopodium album	Fat-hen		p
Cirsium arvense	Creeping Thistle	p	p
Cirsium vulgare	Spear Thistle	p	
Crepis capillaris	Smooth Hawk's-beard	p	p
Dactylis glomerata	Cocksfoot	p	p
Dactylorhiza fuchsii	Common Spotted-orchid	p	p
Daucus carota carota	Wild Carrot		p
Deschampsia cespitosa	Tufted Hair-grass	p	
Dipsacus fullonum	Wild Teasel	p	
Elytrigia repens	Common Couch	p	p
Epilobium ciliatum	American Willowherb	p	
Epilobium hirsutum	Great Willowherb	p	
Equisetum arvense	Field Horsetail	p	
Festuca rubra	Red Fescue	p	
Galium album	Hedge Bedstraw	p	
Galium aparine	Cleavers	p	
Galium verum	Lady's Bedstraw	p	
Geranium dissectum	Cut-leaved Crane's-bill	p	
Geranium molle	Dove's-foot Crane's-bill	p	
Geranium pratense	Meadow Crane's-bill	p	
Glechoma hederacea	Ground Ivy	p	
Gnaphalium uliginosum	Marsh Cudweed	p	
Helminthotheca echioides	Bristly Oxtongue	p	
Heracleum sphondylium	Hogweed	p	p
Holcus lanatus	Common Couch	p	p
Hordeum secalinum	Meadow Barley	p	
Hypericum perforatum	Perforate St John's-wort	p	
Hypericum x desetangsii	Hybrid H. perforatum x H. maculatum	p	
Hypochaeris radicata	Cat's-ear	p	p
Lamium album	White Dead-nettle	p	
Lapsana communis	Nipplewort	p	
Lathyrus pratensis	Meadow Vetchling	p	
Leontodon hispidus	Rough Hawkbit	p	
Leucanthemum vulgare	Oxeye Daisy	p	p
Lolium perenne	Perennial Rye Grass	p	
Lollium sp.	Rye Grass sp.		p
Malva moschata	Musk-mallow		p
Matricaria chamomilla	Scented Mayweed	p	

(cont.) Species	Common name	W LNR	H LNR
Medicago lupulina	Black Medick	p	
Myosotis arvensis	Field Forget-me-not	p	
Papaver rhoeas	Common Poppy	p	
Phleum pratense	Timothy		p
Plantago lanceolata	Ribwort Plantain	p	p
Poa trivialis	Rough Meadow Grass	p	p
Polygonum aviculare agg.	Knotgrass	p	
Potentilla reptans	Creeping Cinquefoil	p	
Primula veris	Cowslip	p	
Prunella vulgaris	Selfheal	p	
Ranunculus acris	Meadow Buttercup	p	p
Ranunculus repens	Creeping Buttercup	p	
Raphanus raphanistrum	Wild Radish	p	
Rhinanthus minor	Yellow-rattle		p
Rhinanthus minor subsp. Minor	Yellow-rattle ssp.	p	
Rumex acetosa	Common Sorrel	p	p
Rumex crispus	Curled Dock	p	p
Rumex obtusifolius	Broad-leaved Dock	p	p
Rumex x pratensis	Hybrid R. crispus x R. obtusifolius	p	
Schedonorus arundinaceus	Tall Fescue	p	
Scorzoneroides autumnalis	Autumn Hawkbit	p	
Scrophularia nodosa	Common Figwort	p	
Senecio jacobaea	Common Ragwort	p	p
Silene dioica	Red Campion	p	
Sinapis arvensis	Charlock	p	
Sonchus asper	Prickly Sow-thistle	p	
Stachys sylvatica	Hedge Woundwort	p	
Stellaria graminea	Lesser Stitchwort		p
Taraxacum agg.	Dandelion		p
Torilis japonica	Upright Hedge-parsley	p	
Tragopogon pratensis	Goat's-beard	p	p
Trifolium dubium	Lesser Trefoil	p	
Trifolium pratense	Red Clover	p	p
Trifolium repens	White Clover	p	p
Tripleurospermum inodorum	Scentless Mayweed	p	p
Trisetum flavescens	Yellow Oat-grass	p	
Tussilago farfara	Colt's-foot	p	
Urtica dioica	Common Nettle	p	p
Veronica chamaedrys	Germander Speedwell		p
Veronica persica	Common Field-speedwell	p	
Vicia cracca	Tufted Vetch		p
Vicia sativa	Common Vetch	p	

SI. 11 Box plots for mean Simpson's Diversity Index and species richness for GGI treatments at research Replicates.

a. mean species richness



b. mean Simpson's Diversity Index

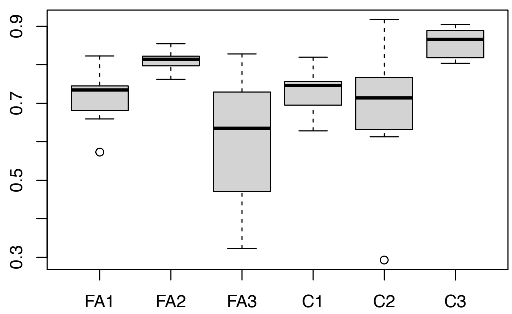


Fig. SI. 10 Box plots for a) mean species richness (Kruskal-Wallis chi-squared = 42.386, df = 5, p-value = 4.92e-08), and b) Simpson's Diversity Index (Kruskal-Wallis chi-squared = 31.878, df = 5, p-value = 6.281e-06) for GGI treatments at Five Acre Community Farm (FA1 Paths, FA2 Orchard, FA3 semi-abandoned Set-aside) and Canalside Community Food (C1 Social Green, C2 Paths, C3 managed Set-aside) Warwickshire. y-axis species and diversity values, x-axis treatment codes.

SI. 12 Range of GGI habitat (other than treatments) at research Replicate Five Acre Community Farm.

Fig. SI. 11 Examples of the range of GGI habitat (other than treatments) at Replicate Five Acre Community Farm, Warwickshire. a) Possibly influencing Path (FA1) communities, detail of herb rich assemblage in between polytunnels and treatment FA1. *Tanacetum vulgare* (Tansy) was observed here adjacent to FA1 Q1 and Q2, b) scrub field boundary at north-west end with woody species, compost bins and perennial weed waste; c) Unmown long sward due to machinery attachment and green waste compost storage; d) tall herb assemblage at unmown polytunnel sides. Photo credits: report author.

SI. 13 Crop bed treatment (arable weed species richness) at research Replicates.

A representative range of crop cultivation stages seen at research Replicates is given in Fig. SI. 12, with species richness box plots in Fig. SI. 13. Total crop bed area at Five Acre was approximately 0.014 km^2 and 0.024 km^2 at Canalside. A comparison of composition between GGI and crop bed species is given in Fig. SI. 14.

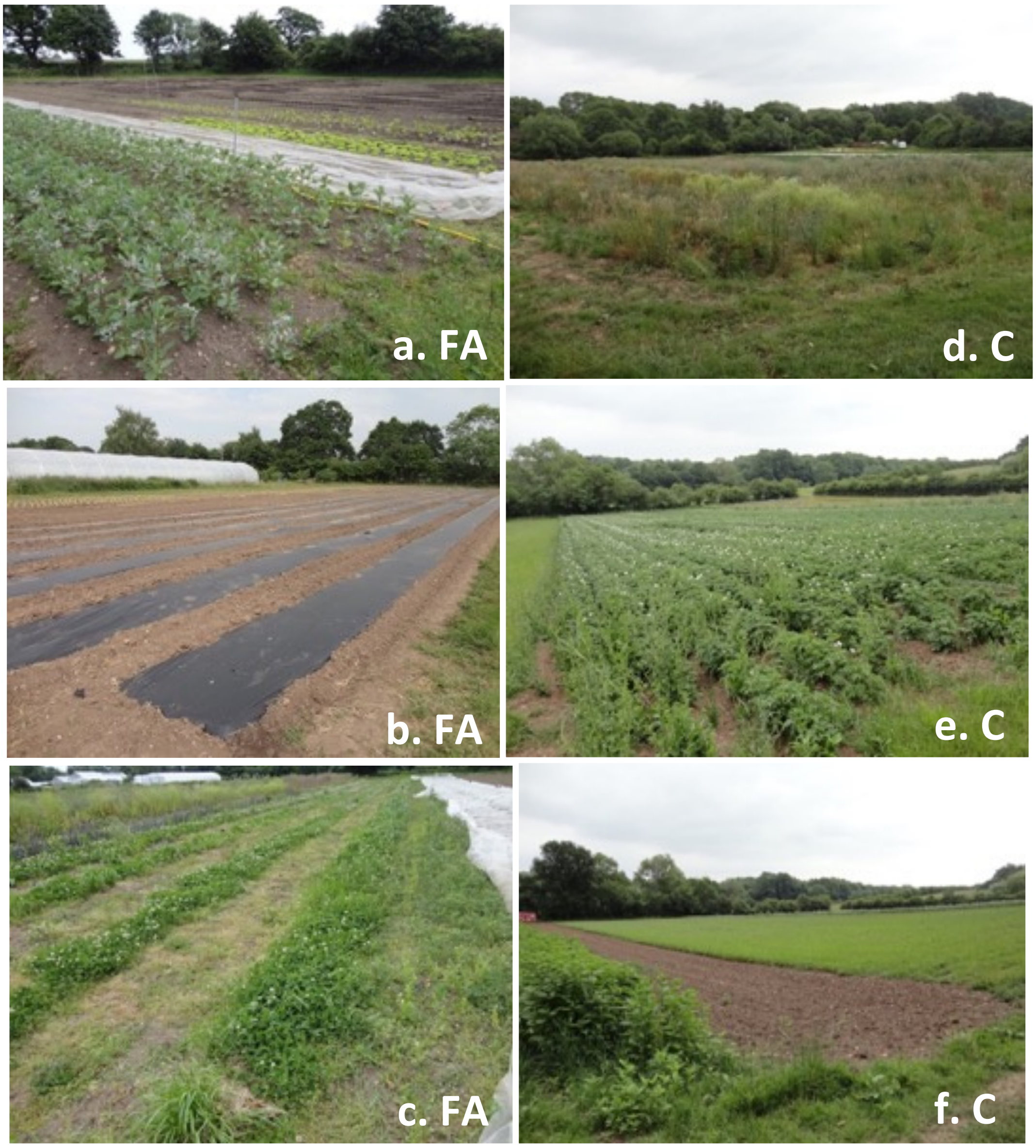
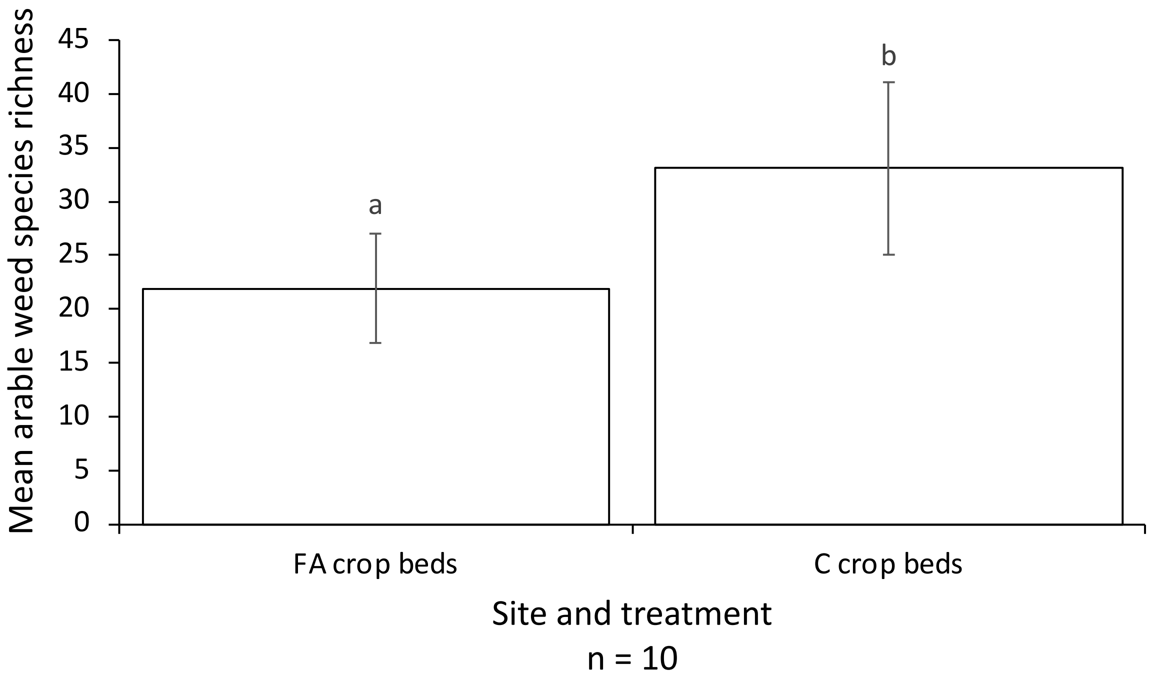


Fig. SI. 12 Range of cultivation within treatment crop beds at Five Acre Community Farm (FA) and Canalside Community Food (C), Warwickshire. At Five Acre (left column) a) Summer Plot 1 (SP1), autumn sown overwintered crop, spring planted current season crop, enviro-mesh crop protection, and freshly cultivated beds with compost applied; b) Summer Plot 2 (SP2), freshly cultivated with corn starch weed suppressant ground cover; c) Main Plot 1 (MP1)- sown clover paths between previous season squash beds; at Canalside (right column) d) Canalside West previous spring sown overwintered crop residue, e) Big Gorse Mid-west spring planted potato crop; and f) Big Gorse West perennial artichoke bed, freshly cultivated bed and green manure ley. Photo credits: report author.

a.



b.

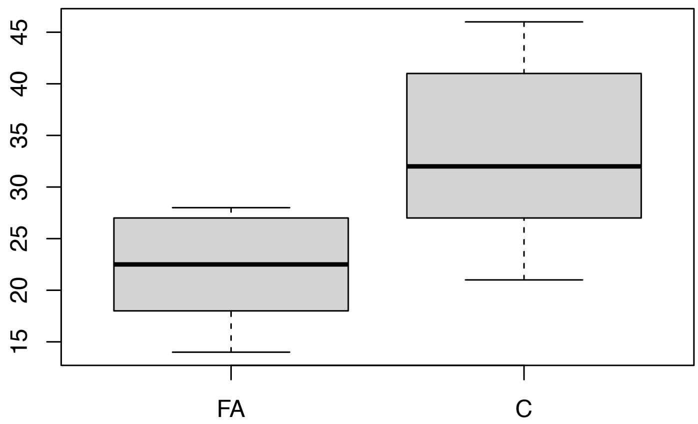


Fig. SI. 13 a) Mean species richness for treatment crop bed arable weed species at Five Area Community Farm (FA / FA crop beds) and Canalside Community Food (C / C crop beds), Warwickshire. Superscript above graph bars indicate significant difference. b) box plot for data (y-axis mean species richness, x-axis Replicate codes) (Kruskal-Wallis chi-squared = 8.0721, df = 1, p-value = 0.005).

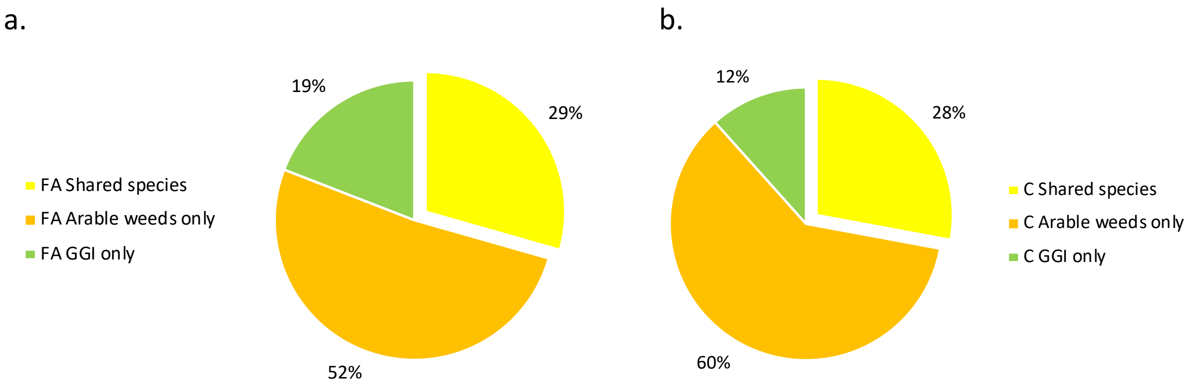


Fig. SI. 14 Comparison of composition (% species), between forb species in GGI treatment and as arable weeds in crop bed treatment at a) Replicate Five Acre Community Farm (FA) and b) Canalside Community Food (C). Yellow exploded pie slices highlight shared species.

SI. 14 Box plots for mean Ellenberg Indicator Values for GGI treatment species at research Replicates.

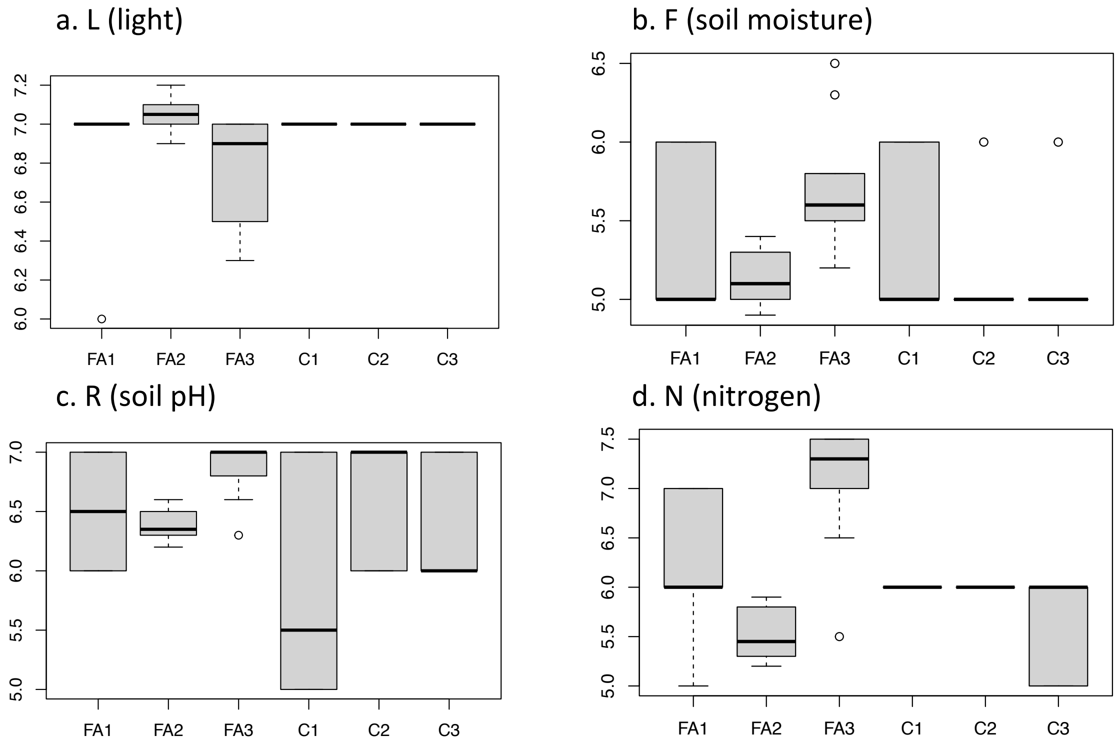


Fig. SI. 15 Box plots for mean Ellenberg Indicator Values for GGI treatment species at Five Acre Community Farm (FA1 Paths, FA2 Orchard, FA3 semi-abandoned Set-aside) and Canalside Community Food (C1 Social Green, C2 Paths, C3 managed Set-aside), Warwickshire. a) mean Ellenberg Indicator Values for L (light) (Kruskal-Wallis chi-squared = 20.766, df = 5, p-value = 0.001), b) F (soil moisture) (Kruskal-Wallis chi-squared = 17.394, df = 5, p-value = 0.001), c) R (soil pH) Kruskal-Wallis chi-squared = 12.956, df = 5, p-value = 0.024) and d) N (nitrogen) (Kruskal-Wallis chi-squared = 35.864, df = 5, p-value = 1.011e-06). Y-axis values follow scale for each factor within Hill *et al.* (2004), x-axis treatment codes.

SI. 15 Comparison of research sites (Replicate treatments and local nature reserves) beta species richness

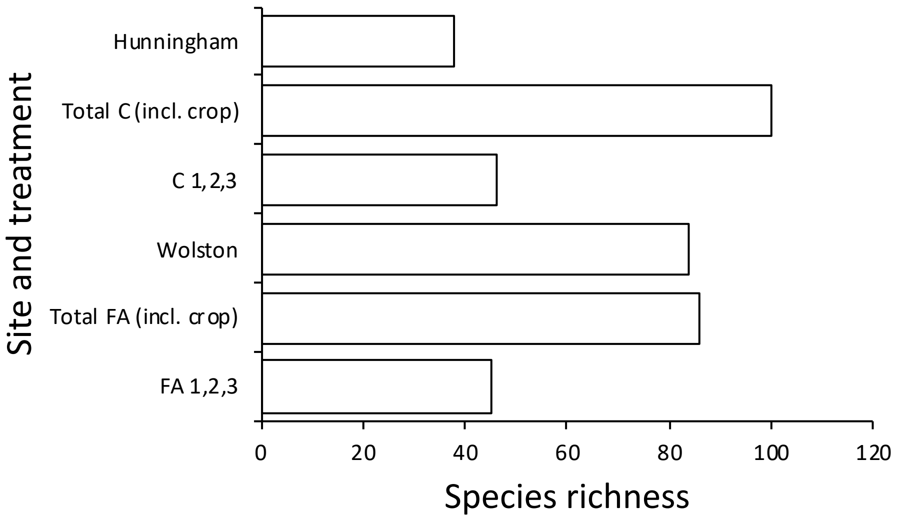


Fig. SI. 16 Comparison of research sites beta species richness (raw data, numbers of different species recorded), Warwickshire. Five Acre Farm GGI treatments (FA 1, 2, 3), total Five Acre species (GGI and crop bed arable weeds), Wolston Fields local nature reserve matched for soil type to Five Acre, Canalside Community Food GGI treatments (C 1, 2, 3), total Canalside species (GGI and crop) and Hunningham local nature reserve matched for soil type with Canalside.

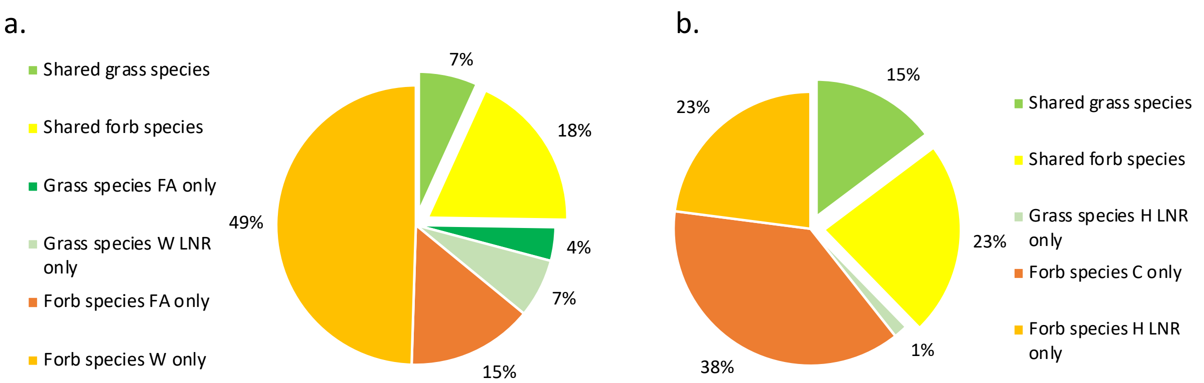


Fig. SI. 17 Comparison of composition (% species) grass and forb species at paired Replicate GGI treatments and research site local nature reserve's (LNR's). a) Replicate Five Acre Community Farm (FA) and Wolston Fields (W) (LNR) and b) Canalside Community Food (C) and Hunningham Meadow LNR (no grass species were found exclusively at Canalside). Green exploded pie slices highlight shared grass species, yellow slices forb species. A mean 32 % of total species were shared between Replicates and LNR's.

SI. 16 Potential for landscape connectivity beyond research Replicate boundaries.

Though beyond the scope of this research to quantify, it is proposed that ecological connectivity beyond research Replicate boundaries has less potential at Five Acre Community farm than at Canalside Community Food due to adjacent land use and land ownership.

SI. 16.1 Five Acre Community Farm

At Five Acre land to the north, east and south was dominated by intensive arable monoculture, though a grassland green corridor (green lane) was in evidence at the north boundary. Additionally, at the western boundary, production units, demonstration production gardens and lawns under the same land ownership as Five Acre (Coventry University) may provide network up to the 'B' road. To the north-west of the 'B' road lie green corridors to the recently established Wolston Fields local nature reserve and, and on the opposite bank of the River Avon, Brandon Marsh Nature Reserve SSSI (Site of Species Scientific Interest) (Fig. SI. 18).

SI. 16.2 Canalside Community Food

At Canalside, land use to the west is arable monoculture, with the Grand Union Canal forming the northern border. On the opposite bank of the canal, where land has been identified as having conservation value by the Wildlife Trust, and at all other farm boundaries, potential for direct connectivity exists with sympathetic and pro-active conservation ongoing on the Leasowe Farm boundaries to the south and east (Fig. SI. 19).

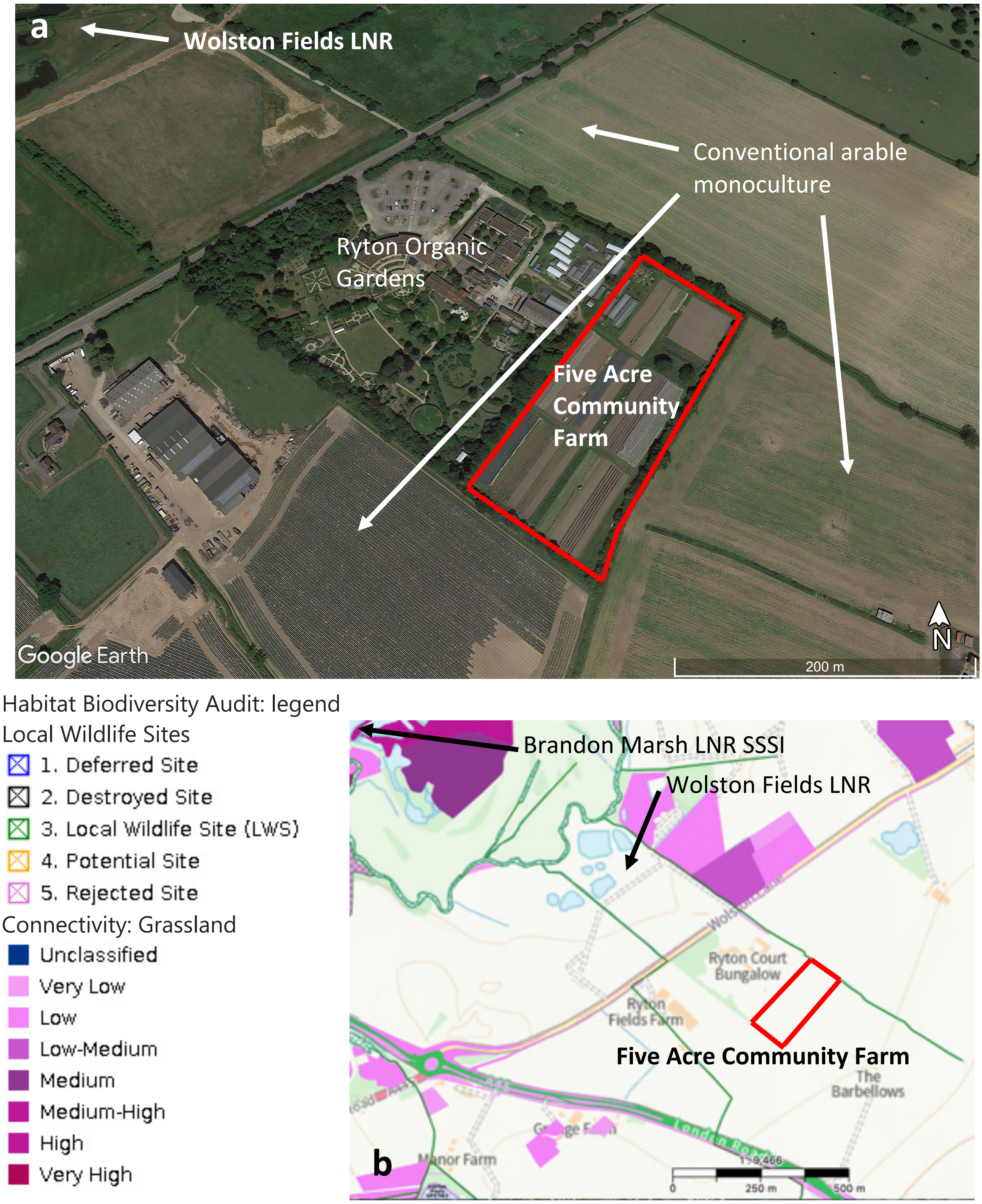


Fig. SI. 18 Surrounding land use and potential for GGI connectivity at research Replicate Five Acre Community Farm, Warwickshire. a) Google Earth Pro arial satellite photography (scale bar 200 m) (image dated April 2021). b) OS Road Map showing detail of GIS layers for Habitat Biodiversity Audit (HBA) Green Infrastructure information for Grassland connectivity and Local Wildlife Sites (dated 2015) highlighting the potential for connectivity at Five Acre to the north-west of the site. HBA base map does not show more recent LNR designation for Wolston Fields (scale bar 500 m) (Warwickshire CC, 2022). Red polygon indicates Five Acre Farm boundary.

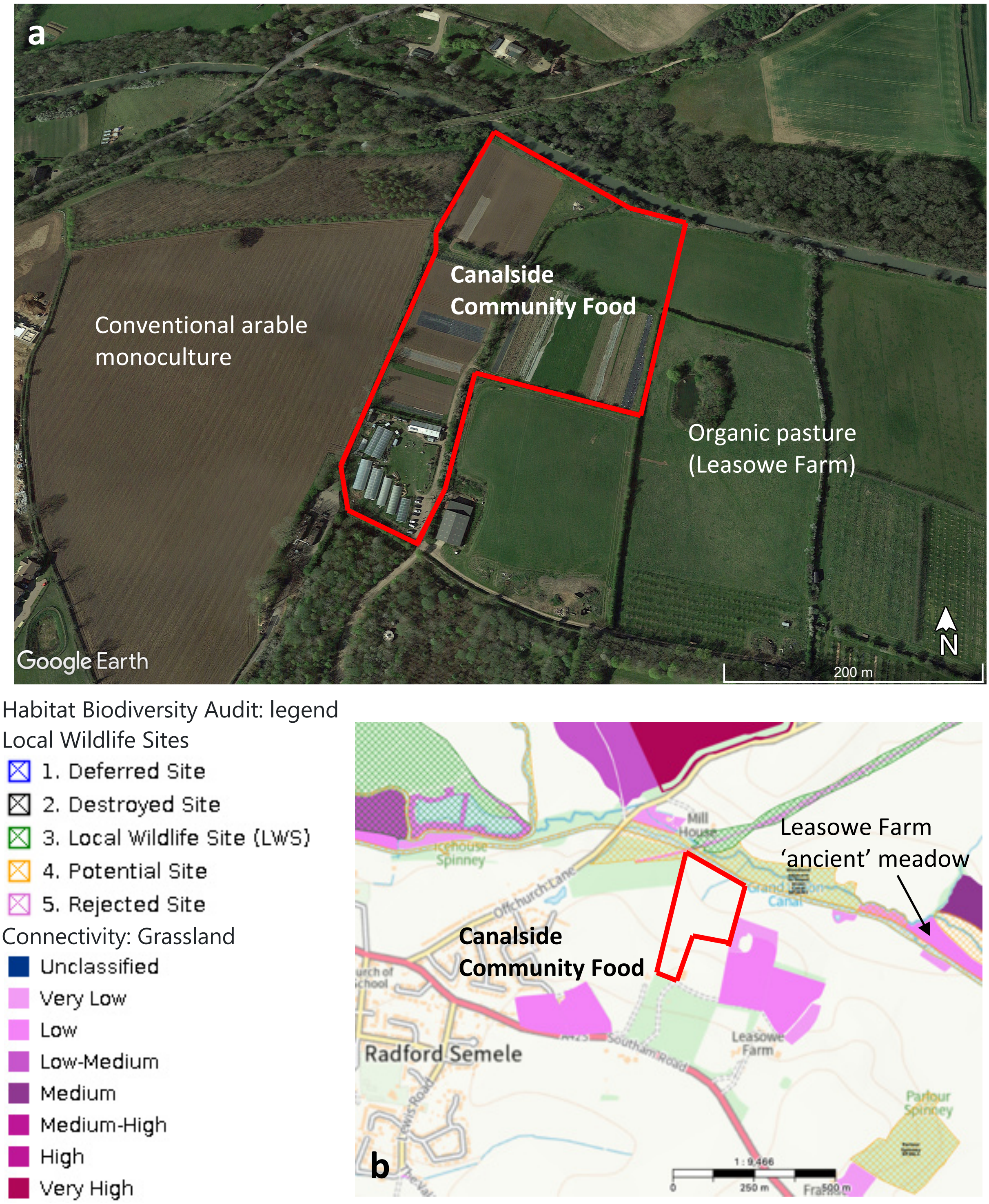


Fig. SI. 19 Surrounding land use and potential for GGI connectivity of research Replicate Canalside Community Food, Warwickshire. a) Google Earth Pro arial satellite photography (scale bar 200 m) (image dated April 2021). b) OS Road Map showing detail of GIS layers for Habitat Biodiversity Audit (HBA) Green Infrastructure information for Grassland connectivity and Local Wildlife Sites (2015) (Warwickshire CC, 2022) highlighting location of 'ancient meadow' on Leasowe Farm (black arrow) (scale bar 500 m) (Mr. Leasowe, pers.comm. June 2022) (red polygon indicates Replicate site boundary).

SI. Discussion

SI. 17 Replicate management recommendations table

Table SI. 6 Management recommendations for enhancing conservation value of GGI at research Replicate Five Acre Community Farm and Canalside Community Food, Warwickshire.

Aim	Location within Replicates	Management recommendation	Outcome
Maintain current levels of plant successional biodiversity	Canalside and Five Acre	Maintain current management strategy	Prevent deterioration of current value
Increase current levels of successional plant biodiversity		Cutting and/or grazing regime to create mosaic of regularly mown to abandoned sward	Maintain a succession of grassland habitat for maximum site diversity to include long and short sward species; year-round support for beneficial invertebrates and taxa of higher trophic levels
	Paths (FA1, C2)	Identify path boundary habitat to be managed as for 'hay-meadow'*	
	Canalside Paths (C2)	Identify plan to restore compaction and bare ground	
	Five Acre Orchard (FA2)	Where land-use allows implement management as for 'hay-meadow'	
	Five Acre Set-aside (FA3)	Identify plan for staggered (over consecutive growing seasons) restoration of 'Beetle-bank' to MG5 community	
	Canalside Set-aside (C3)	Reconsider land-use at 'Bermuda Triangle' to extend and refine current cutting regime	

(cont.) **Aim**	**Location within Replicates**	**Management recommendation**	**Outcome**
(as above)	Polytunnel-edges and other potential habitat (Five Acre and Calalside)	Identify plan for creating mosaic of communities and composition	(as above)
Restore natural soil properties to increase successional biodiversity	Canalside and Five Acre	Create site waste disposal plan sensitive to natural soil pH and nutrient levels	Enhance potential of locally native species establishment and dispersal
Creation of connecting habitat	Canalside and Five Acre	Create site plan for potential on site and landscape connectivity	Enhance potential for conservation value, eco-system services and climate change resilience
Assess effectiveness of conservation measures	Canalside and Five Acre	Establish formal contact with Warwickshire Biological Records office (Rowe and Moffatt, 2017)	Raise awareness of conservation value of site; evidence to support continuing land-use
		Arrange regular monitoring	Establish long-term records

* Management 'as for hay-meadow' may comprise twice yearly cut (July after seed-set and October) with removal of cuttings (Bonanomi *et al.* 2013; Jakobsson *et al.* 2018).