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E-Planner: A web-based tool for planning environmental enhancement on British agricultural land

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ABSTRACT

E-Planner is a free, web-based, application which provides land managers with fine-scale maps of the suitability of agricultural land in Great Britain for environmental enhancement. E-Planner is designed to streamline decision-making around the choice and spatial targeting of environmental management interventions. Suitability scores are calculated by integrating a range of biophysical data sets and presented as easy-to-interpret maps, at fine resolutions (5 m) equivalent to those used by precision agriculture technology.

The information provided by E-Planner is important for landscape-to field-scale spatial targeting of farm management to maximise the efficiency of both crop production and environmental delivery. Whilst many datasets and tools support the former, equivalents for environmental factors are not widely available. The methods used by E-Planner for collating and presenting data on environmental constraints and drivers are widely applicable, and efficient spatial targeting of agronomic and environmental management forms an essential step towards sustainable agriculture, a global issue.

1. Introduction

1.1. Sustainable agriculture

The challenge of an ever-increasing global demand for sufficient, nutritious food has historically been met by the expansion and intensification of agricultural systems (Foley et al., 2005; Pretty, 2007; Lambin and Meyfroidt, 2011; Stevenson et al., 2013). However, this has come at the cost of widespread declines in environmental quality, including biodiversity (Firbank et al., 2008; Henle et al., 2008; Kleijn et al., 2009), water quality (Moss, 2008; Mateo-Sagasta et al., 2018), air quality (Bauer et al., 2016; Giannadaki et al., 2018) and soil health (Jones et al., 2013; Smith et al., 2016). These declines affect the 'ecosystem services' provided by the environment (Mace et al., 2012) on which agricultural production itself depends (Tscharntke et al., 2005; Emmerson et al., 2016). With global food demand continuing to increase (Godfray et al., 2010), agriculture must remain productive, but must also become more environmentally sustainable.

The goals of keeping agriculture productive whilst reducing its environmental footprint are not mutually exclusive. Actions which deliver environmental benefits can have beneficial effects on agricultural production and *vice versa*. Examples include the spill-over of services delivered by insects (e.g. pollination, natural pest control) from non-crop habitats (Woodcock et al., 2016), the positive effects of increasing soil organic matter on both carbon sequestration and crop yields (Dexter et al., 2008; Johnston et al., 2009; Jensen et al., 2019) or the increased resistance to extreme weather events conferred by biodiverse habitats within agricultural landscapes (Redhead et al., 2020).

These findings have led to such concepts as "ecological intensification" (Bommarco et al., 2013; Kleijn et al., 2019), "sustainable intensification" (Struik and Kuyper, 2017), "agroecology" (Wezel et al., 2020) and "regenerative agriculture" (LaCanne and Lundgren, 2018). These vary in their precise definitions, but all aim to achieve simultaneous increases in the productivity and long-term viability of agriculture, and reductions in its environmental impacts. Achieving this is challenging because the same land must, at some scale, be used to deliver multiple outcomes and because these outcomes are often highly context dependent. Success thus requires a high level of farmer engagement and knowledge – the ability to balance "farming for yield" vs "farming for nature" (de Snoo et al., 2013) – and the capacity to make informed decisions at fine spatial scales. One existing mechanism for the delivery of sustainable agriculture is agri-environment schemes (AES). These

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offer financial incentives (to offset costs or loss of production) to farmers for specific environmentally beneficial management actions (often referred to as AES 'options'). AES have been established in many countries for decades, but their effectiveness in delivering their environmental goals is often inconsistent (Kleijn and Sutherland, 2003; Kleijn et al., 2006, 2011). The chances of an individual AES option delivering the environmental benefits for which it was conceived vary widely with the quality of implementation and management. These in turn depend on the level of experience, knowledge and engagement of the farmer (Lobley et al., 2013; McCracken et al., 2015). There is evidence that providing basic training and easily accessible information significantly increases the success of AES options (Lobley et al., 2013; McCracken et al., 2015).

1.2. Decision support tools for sustainable agriculture

One frequently identified potential solution to the challenges of complex spatial planning required by sustainable agriculture and AES is the use of agricultural decision support systems (ADSS, Doré et al., 2011; Francis et al., 2017; Lindblom et al., 2017; Zhai *et al.*, 2020). The definition of ADSS is usually broad enough to include any computer based system for collating, analysing and displaying data in a way that supports farm decision making (Zhai *et al.*, 2020; Talari et al., 2021). However, advances in remote sensing and information technology mean that effective modern ADSS are expected to support dynamic data (e.g. 'real-time' data on climate or crop condition), the ability to interactively explore alternative management options via "what-if" modelling, and intuitive, multi-scale graphical user interfaces, often supported by open webGIS (Terribile et al., 2015). A key development that has driven the development of many recent ADSS is the uptake of 'precision agriculture'. Precision agriculture implies the use of technology to collect and supply data on spatial and temporal variability in agricultural production, on which to base agricultural management decisions (Bongiovanni and Lowenberg-Deboer, 2004; McBratney et al., 2005). The fine spatial and temporal resolution of precision agriculture data enables targeting and application of management at the sub-field scale. However, this creates very large volumes of data that must be presented in a way that farmers can access and interpret to inform management decisions (Rose et al., 2018b), hence the need for ADSS.

A functional ADSS is likely to be composed of several interlinked tools and services providing specific functionality (e.g. Manna et al., 2020; Bancheri et al., 2022). Very large numbers of ADSS and their component tools are now available (Rose *et al.*, 2016; Zhai *et al.*, 2020), ranging from proprietary software for integrating data from particular precision agricultural sensors (examples in Zhai *et al.*, 2020) to comprehensive, web-based openly accessible ADSS platforms (e.g. Terribile et al., 2015). Many of these tools and systems support sustainable agriculture in the sense that they reduce waste, improve the targeting of actions with negative environmental consequences (Bongiovanni and Lowenberg-Deboer, 2004; Lindblom et al., 2017; Rose et al., 2018a) or explore the consequences of management actions for natural resources such as soils (Terribile et al., 2015) and groundwater (Bancheri et al., 2022). However, few tools within existing ADSS directly address the planning and management of actions intended to promote specific environmental benefits (e.g. AES options). Where tools do address environmental outcomes directly, they tend to operate at the whole farm level (e.g. Hillier et al., 2011; Gooday et al., 2014). Whilst these are helpful in suggesting which environmental management actions a farmer may wish to undertake, they do not operate at the same fine spatial resolution as precision agricultural data, nor help to spatially target actions within the farm or field. So, on the one hand, farmers are increasingly used to having access to agronomic data and tools indicating which areas of land are least agriculturally productive (and may thus be better suited to an alternative, environmentally-focussed management) or most productive (and thus require additional support from environmentally-focussed management that may help to bolster resilience). On the other hand, they do not currently have the equivalent data and tools to support decisions on which management actions might be best suited to such areas, or to identify the most beneficial locations for particular environmental management actions.

1.3. Aims

We created the E-Planner tool to address this gap, by providing data on the suitability of land for different environmental management actions, at the fine spatial resolutions typically associated with precision agricultural data whilst covering the full extent of agricultural land in Great Britain (GB). E-Planner is a free, web-based tool that presents complex environmental data as easy-to-interpret webGIS maps. E-Planner presents static information on long-term drivers of environmental potential, and thus does not contain the dynamic elements of a full ADSS. This is partly because even the shortest-term AES options remain in place for at least a year, so compared to agronomic variables there is less requirement for real-time updates on current conditions or the need to quickly explore potential responses. We also avoid duplicating functionality from existing ADSS (e.g. ability to digitize and export management zones), to keep the tool interface simple and avoid apparent competition. Instead, we aimed to produce a free tool that can either be used as a standalone or, by producing mapped outputs accessible via web services, integrated with existing ADSS. Lack of cost, ease of use and presentation of visual outputs have all repeatedly been identified as important drivers of uptake in agricultural decision support tools (see reviews in Rose *et al.*, 2016; Lindblom et al., 2017; Rose and Bruce, 2018). E-Planner is intended to enhance, not replace, local knowledge and field surveys (Fig. 1) and therefore does not attempt to identify an 'optimal' solution but instead focusses on providing easy-to-interpret contextual data to inform the decision making process, a goal for decision support tools that generally receives greater support from farmers (Rose et al., 2018a, 2018b). Although E-Planner has been designed to work in tandem with precision agricultural data or ADSS, by presenting interoperable outputs at similar resolutions and in similar ways, such data are not a prerequisite and E-Planner can be used independently, based on local knowledge.

2. Methods

2.1. Mapping suitability of land for 'environmental opportunities'

The E-Planner tool provides freely accessible and easy-to-interpret maps representing the suitability of land for a range of 'environmental opportunities' (Fig. 1). We define 'environmental opportunities' as suites of potential actions aiming to deliver an environmentally beneficial environmental outcome by changing the management of farmed land or taking it out of production. Each opportunity has a number of ways in which it could be implemented (e.g. AES options), depending on the farming system and local context. For example, the environmental opportunity of 'creation of flower rich pollinator habitat' might be achieved by sowing of annual pollen and nectar mixes in intensive arable systems, the creation of perennial wildflower areas where land can be removed from production longer term, or the restoration of species rich grassland in pasture systems. We did not attempt to model specific outcomes from implementing the environmental opportunity (e.g. ecosystem services), which would be highly dependent on local context, quality of implementation and other factors which are difficult to quantify at fine resolution across national extents and which interact in complex ways. For example, crop pollination service is dependent on complex interactions between landscape and the composition of the local pollinator community (Ricketts et al., 2008; Senapathi et al., 2015), which is itself dependant the quality and extent of pollinator habitats in the landscape (Kennedy et al., 2013; Senapathi et al., 2017). Instead, E-Planner presents maps of relative suitability assessed from combinations of biophysical variables which affect i) the likelihood that

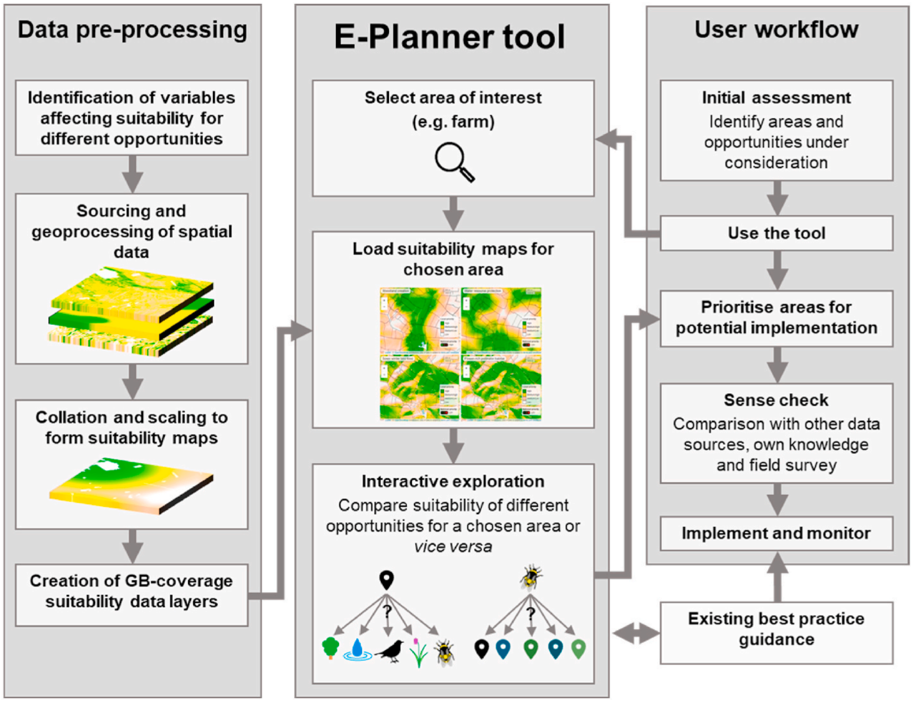

Fig. 1. Schematic illustrating key stages in the creation of the suitability maps underpinning E-Planner, the functionality of the E-Planner tool, and the proposed user workflow. There is a two way interaction between the tool and existing best practice guidance, because the interpretation of the suitability maps should be informed by the latter, and because E-Planner provides links to existing guidance on implementation and monitoring. Precision agricultural data or existing ADSS can be usefully integrated into the user workflow at several points, including the initial assessment and sense check stages.

a given opportunity can be implemented, ii) increase its potential for delivery or iii) decrease the chance for unintended detrimental effects. These variables were identified from academic papers (e.g. Cane, 1991; Maher et al., 2019), published guidance (e.g. Woodland Trust, 2015; Nowakowski and Pywell, 2016; Rothero et al., 2016), AES handbooks (e.g. Natural England, 2018) and consultations with experts in the field of agricultural habitat creation, restoration and management. Once identified and derived from a suitable spatial data source (see section 2.2), each of these variables was then scaled to a range of 0–1 and the relevant scaled variables summed to produce each suitability map, thus giving each variable equal weighting. The final suitability maps are then rescaled by the web application so that the user is presented with simple 'heat maps' ranging from values 0 (least suitable) to 1 (most suitable) for their chosen area of interest. This approach makes it very simple to add or substitute variables when new datasets become available, or new research suggests their importance.

All suitability maps presented by E-Planner are 5 m resolution rasters, which is sufficiently fine scale to target habitat management actions at the sub-field scale (e.g. many AES arable field margins in GB are 6–12 m in width) and similar to the resolutions commonly produced by precision agricultural data and tools. As discussed above, it is important that E-Planner uses a similar resolution and presentation of the data to existing precision ADSS, because E-Planner is intended to work in tandem with such software where available. This integration will help identify the areas where changing management to deliver environmental benefits would have minimal, neutral or even beneficial impacts on productivity. The visualisation of the suitability maps and user interface were designed using an iterative co-design approach, with repeated consultations with focus groups of farmers, agronomists and farm advisers, since the incorporation of user feedback is critical to delivering a successful agricultural decision support tool (Rose *et al.*, 2016; Lindblom et al., 2017; Rose and Bruce, 2018; Rose et al., 2018a, 2018b). The E-Planner user guidance places a strong emphasis on the importance of practitioners 'sense checking' or 'ground truthing' the results by local site inspection (Fig. 1), as local factors (e.g. disturbance, site access, pest pressure, visual impact) are likely to affect suitability in ways that cannot be readily predicted by E-Planner. This is also important in selecting exactly which management method is best suited to implementing an environmental opportunity in a given area – for

Table 1
Summary of the environmental opportunities for which suitability is mapped in the E-Planner tool, along with the biophysical variables contributing to each opportunity and the values of each variable contributing the highest suitability for each opportunity. Also given are examples of possible implementation actions for each opportunity, although these are not exhaustive lists and not all will be relevant to all agricultural contexts.

Environmental opportunity	Variables used in calculation of suitability	Suitability highest when …	Possible implementation actions
Flower-rich pollinator habitat	Aspect Soil texture Shading Topographic wetness Existing flower rich habitat	South-facing Light (sandy or silty) Out of shade Low wetness Increases habitat connectivity	Sown pollen and nectar mixes Perennial wildflower areas Restoration of species rich grassland
Winter bird food	Aspect Shading Topographic wetness Watercourses Woodland	South-facing Out of shade Low wetness Far from watercourses Close to woodland	Sown wild bird seed mixes Supplementary feeding
Water resource protection	Watercourses Slope Soil erodibility	Close to watercourses Steeper slopes Highly erodible	Grass buffer strips Cover crops Water storage features Reduce agrochemical use
Wet grassland restoration	River flood risk Topographic wetness Existing wet grassland habitat Soil hydrology	High risk of flooding High wetness Increases habitat connectivity Suitable for floodplain meadows	Reseeding Drainage management Mowing/grazing management
Woodland creation	Existing woodland Slopes Soil erodibility	Increases habitat connectivity Moderate slopes Highly erodible	Planting of trees Protection of existing trees Agroforestry

example the 'wet grassland' for which E-Planner maps suitability for restoration (see Table 1) covers both floodplain floristically-diverse meadows and grazed wet grassland suitable for waders and wildfowl. The former are much more restricted in the range of environmental conditions under which they can be successfully established, so only field data and local knowledge can distinguish exactly which management to implement within an area estimated as highly suitable for an overarching environmental opportunity.

2.2. Sourcing and processing input spatial data

Suitability maps were created for five environmental opportunities. The variables used in the calculations of suitability, and the potential different management actions for implementing each opportunity are listed in Table 1.

Existing, high quality wildlife habitats were also deliberately excluded from the E-Planner maps as they are not appropriate for some management activities and these practices may cause unintended damage. For each biophysical variable identified as being indicative of suitability (as listed in Table 1), we identified a source spatial dataset. Spatial datasets had to have GB-wide extent (or equivalent national-extent datasets for England, Scotland and Wales) and sufficiently fine resolution to indicate relative differences in suitability at the within-field scale (i.e. raster resolutions of 50 m × 50 m or finer, or vector data mapped at 1:50000 scale or finer). Source datasets are listed in Table 2. In the majority of cases spatial datasets required further processing to derive the variables required for the suitability maps.

Regardless of the format (vector or raster) and resolution of the data sources used to create the spatial datasets listed in Table 2, they were all generated as collections of 10 km × 10 km raster tiles at 5 m resolution. Splitting these large, high-resolution datasets into 10 km tiles made them easier to handle and amenable to parallel processing techniques. For many variables, the value at any given 5 m pixel depended on the values of pixels elsewhere in the landscape (e.g. assessments of proximity and connectivity), so to avoid edge effects tiles were buffered.

E-Planner also incorporates information on national-level priority of the different environmental opportunities, to help place the user-defined area in its wider context, inform decisions about which opportunities to prioritise, and to 'break ties' if areas are equally well-suited to different opportunities. These data are derived from a centile-based classification (Low <50th centile, Medium = 50th – 75th centile, High = > 75 centile) of a single data layer for each opportunity, summarised in Table 3. These are then used to present a 'traffic light' indicator of national priority for each map in the tool interface.

2.3. E-Planner construction and technical infrastructure

All handling and pre-processing of spatial datasets was performed in R (R Core Team, 2019), making use of the *raster* (Hijmans, 2020), *sp* (Pebesma, 2018), *insol* (Corripio, 2021), *fasterize* (Ross, 2020), *nabor* (Elseberg et al., 2012) and *whitebox* (Wu, 2020) packages. For a full description of how variables were derived from source data, including relevant formulae, R functions and packages, see Supplementary Material, Appendix A. The JASMIN LOTUS batch and parallel processing cluster was used to carry out the processing with each job working on a single 10 km tile. JASMIN is a national data computing facility for the environmental sciences community, operated by the Science & Technology Facilities Council (STFC) on behalf of the Natural Environment Research Council (NERC). It provides large-scale storage (45 PB) and processing (12,000 cores) to enable data-intensive environmental science. Running an operation on one of the datasets typically involved running a batch of approximately 2,800 jobs (one per 10 km tile), all of which could potentially be run in parallel. The tiled opportunity map data then reside on the UK Centre of Ecology and Hydrology (UKCEH) storage area network (SAN). This file system sits behind UKCEH's firewall but is accessible to a Kubernetes cluster hosted by UKCEH. The

Table 2
Source spatial datasets from which variables used in calculation of suitability were derived. Some variables were calculated by combining multiple data sources, others required multiple data sources to achieve GB coverage.

Variable	Description	Source dataset
Slope	Gradient of slope in degrees	NEXTMap Britain Digital Terrain Model (DTM) © 2009 Intermap Technologies Inc
Aspect as Southness	Closeness to due south of the direction that downhill slope faces	As above
Topographic wetness	Index of propensity for a site to hold water	As above
Shading	Index of exposure to direct sunlight	NEXTMap Britain Digital Surface Model (DSM) © 2009 Intermap Technologies Inc
Soil erodibility	Index of propensity to soil particle detachment and transport by rainfall	National Soil Map of England and Wales (NATMAP Vector) National Soil Map of Scotland (Soil Survey of Scotland Staff, 1981)
Soil texture	Index of soil 'lightness' calculated from clay, sand and silt content	As above
River flood risk	Inundation in floods of 100-year return period level from non-tidal rivers	IH130 Digital Flood Risk Maps resolution (Morris and Flavin, 1996)
Proximity to watercourses	Straight line distance to nearest watercourse/waterbody	Digital watercourse network (Moore et al., 1994) Watercourse and waterbody data from Ordnance Survey OpenData
Soil hydrology	Assessment of soil hydrology class as suitable or unsuitable for floodplain meadow communities	Hydrology of Soil Types (HOST, Boorman et al., 1995) Rothero et al. (2018)
Connectivity (flower rich habitat)	Index of connectivity to existing flower rich habitat	UKCEH Land Cover Map 2015 (Rowland et al., 2017) Natural England Priority Habitats Inventory
Connectivity (wet grassland)	Index of connectivity to existing wet grassland habitat	As above
Connectivity (woodland)	Index of connectivity to existing woodland habitat	As above, plus Ordnance Survey OpenData woodland data
Existing high quality wildlife habitat	Areas of existing biodiverse habitat vulnerable to damage by inappropriate management, and thus masked out	UKCEH Land Cover Map 2015 (Rowland et al., 2017) Natural England Priority Habitats Inventory

E-Planner tool is then comprised of three services deployed in Docker containers running on the Kubernetes cluster. These are: 1) the web application and associated interface; 2) the service providing the opportunity maps to the web application; 3) a web mapping service (WMS) serving OS MasterMap field boundary data to the web application. Each of these is described below, and illustrated in Fig. 2.

Firstly, the E-Planner web application was written in Javascript, with the main architecture provided by the React framework and the mobile-first graphical user interface (GUI) components provided by the Ionic framework. The Ionic GUI components provide a responsive interface that works well on both large computer screens and small mobile devices. The mapping functionality is implemented using the Leaflet framework, with basemaps provided by OpenStreetMap. E-Planner is best thought of as a 'web app' but the frameworks employed give the mobile user an experience close to that of a 'native app'. As a web app built with Javascript the majority of the code runs in the user's browser. However the web app does not itself host any of the data presented to the user, e.g. the opportunity maps. These are provided to the app via the second, backend service with which the web app communicates over

Table 3
Variables and datasets used to assess national priority for each environmental opportunity.

Environmental opportunity	National level priority variable	Source dataset
Flower-rich pollinator habitat	Species richness of pollinating insects (hoverflies, bees and butterflies), 10 km resolution	Species richness modelled from occurrence data (Redhead et al., 2018)
Winter bird food	Farmland bird indicator species richness, 10 km resolution	Species richness modelled from occurrence data from NBN gateway
Water resource protection	Area of catchment covered by Nitrate vulnerable zones	Nitrate vulnerable zones for England, Scotland and Wales Catchments from Water Framework Directive River Waterbody Cycle 2 catchments
Wet grassland restoration	Area of catchment covered by existing wet grassland priority habitats	Existing wet grassland priority habitats from Priority Habitats Inventory and data from Floodplain Meadows Partnership Catchments from Water Framework Directive Cycle 2 catchments
Woodland creation	Presence of woodland priority AES criteria	Woodland Priority Habitat Network (England) Glastir Woodland Creation Opportunities (Wales) Forestry Grant Scheme target areas (Scotland)

standard HTTP protocols. To view an opportunity map layer, a user must first specify an area of interest which can be done in one of three ways: dragging a box over the basemap, uploading a shapefile or by entering a Single Business Identifier (SBI). An SBI is a code that uniquely identifies a farm to the English Rural Payments Agency (RPA). If a user enters an SBI, the web app contacts an external application programming interface (API) provided by the RPA and retrieves the boundary for the farm. Once an area of interest has been identified, the user can request one or more opportunity maps for that area and the web app sends a series of HTTP requests to the opportunity map service. This second service runs R code behind a REST API (implemented in Plumber). The service connects to the file system hosting the 10 km tiles and retrieves any required to cover the area specified in the REST request from the web app. The tiles are then mosaicked and clipped to the area of interest specified in the REST call. At this point the service is holding in memory a single-band raster for the specified opportunity layers covering the area of interest specified by the user. This raster is then re-scaled over the area of interest before being converted to a colour image (using a palette specified in the REST call) and streamed back to the web app which displays it over the Leaflet OSM basemap. The local scaling of the opportunity maps carried out by the opportunity map service is important to highlight the *relative* importance of different areas within a single farm in terms of their opportunity for the different biodiversity interventions. So a farm with very little land that is suitable for a given opportunity will still show the areas that are relatively best suited to it, and a farm where all the land is well suited to a given opportunity will still highlight the least well suited areas. This avoids situations where the entirety of a selected area might be assigned uniformly intermediate suitability, but does mean that the maps should be always be interpreted as comparing relative suitability *for the chosen user defined area.* The relative suitability of the farm to its surroundings can be assessed by the user selecting a wider area for comparison and using the national-scale priority indicators. This need for local scaling requires processing by the R code in the service. Because this service is relatively slow, there is a danger that calls to the service could back up and impact performance. The Kubernetes platform used to host this service is important in mitigating this risk. Kubernetes enables replicas of Docker containers to be run concurrently and routes calls to the service to any of the replicas that are available.

The third service is required because the basemap (OSM) does not include field boundaries, which are important for interpretation of maps in agricultural contexts. These are provided via a WMS created from field boundaries derived (under license) from Ordnance Survey MasterMap and displayed over the opportunity map layer.

A glossary of software and hardware terminology and brief description of key functions is provided in Appendix B.

2.4. Validation on study farms

In addition to iterative feedback from potential users throughout E-

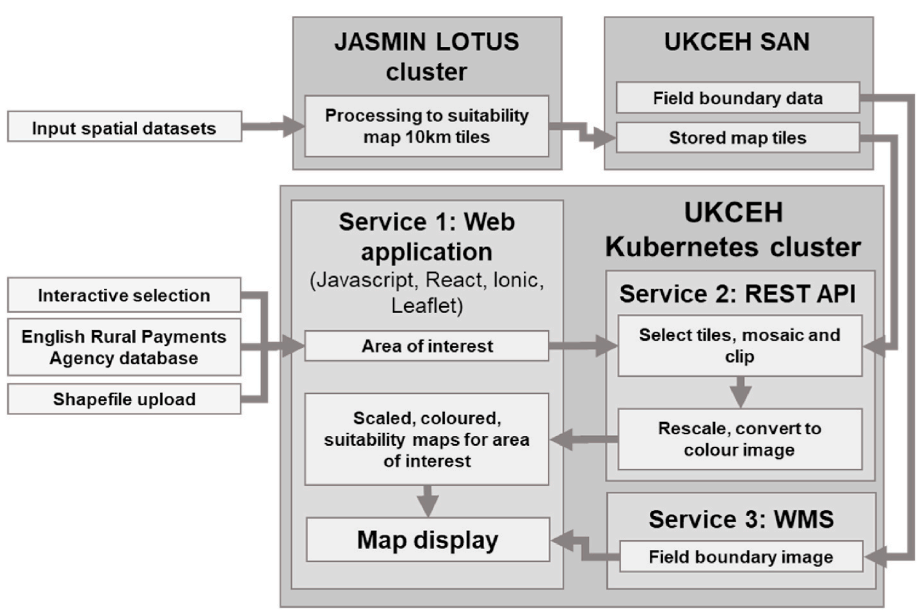

Fig. 2. Schematic illustrating the technical infrastructure of the E-Planner tool. Light grey, internal boxes indicate data, darker grey boxes indicate services or infrastructure, arrows indicate data transfer via web services e.g. APIs.

Planner's development, we also undertook a formal validation exercise. For this, two large farms (222 and 276 Ha, mixed dairy and arable enterprises) in the south of England were used. These farms were not used for the initial development and testing of E-Planner. For each farm, we split each suitability map into five zones using suitability score intervals of 0.2, 0.4, 0.6 and 0.8, with zone 1 being least suitable (i.e. a score of 0–0.2) and zone 5 being most suitable (i.e. a score of 0.8–1.0). An independent surveyor with expertise in farm environmental land management planning then visited at least one site within each zone for each opportunity (five zones x five environmental opportunities = 25 sites per farm). The surveyor assigned and recorded a suitability score to each location based on their own experience and expertise (1 = least suitable, 5 = most suitable). The surveyor was instructed to base their scoring on the potential of the location to deliver the relevant environmental opportunity, regardless of current management. The surveyor also recorded the reason for their score, including local factors that modified the basic suitability of a site (e.g. disturbance, pest pressure, farm access, visual impact) but for which we did not have national-extent data and which do not thus contribute to the suitability scores produced by E-Planner. The surveyor could also record scores for additional sites (e.g. those they saw as being particularly highly suitable or unsuitable for a particular opportunity).

3. Results

3.1. The E-Planner tool and interface

The E-Planner tool can be accessed via a web browser on a desktop or mobile device at https://assist-e-planner.ceh.ac.uk. Although the exact appearance of E-Planner varies depending on the device and browser used for access, functionality remains virtually unchanged. The E-Planner site consists of four main pages ('About E-Planner', 'User Guide', 'E-Planner Tool' and 'Next Steps'). The first of these gives the background to E-Planner and a brief summary of how the tool works and the suggested user workflow (see Fig. 1). The second outlines the functions of the various controls in the tool and how to interpret the output maps. The Next Steps page provides links to existing best practice guidance on how to implement and manage the different opportunities, and to some sources of potential agricultural subsidies for doing so (i.e. AES). The tool is split over two tabs. The first of these, the Select tab (Fig. 3) controls user-defined selection of an area of interest for which to show the suitability maps (referred to as 'opportunity maps' in the E-Planner interface), with the options to draw an area of interest, upload one in shapefile format or use the Rural Payments Agency Land Data API to access the field boundaries of a single farm based on the user inputting a unique farm identifier (SBI). The user can zoom or pan around the map to make their selection, and can remove an area of interest. The opportunity maps to be displayed (up to four at once) and transparency and colour palette for visualisation of the maps can also be chosen on this page before viewing the maps. Once the desired area is chosen, the user selects that they wish to load the opportunity maps. Attempting to retrieve the maps for a selected area over 25 km^2 in area will display a message requesting that a smaller area is chosen, to prevent very high volumes of data being retrieved and ensuring rapid and reliable running of the tool for multiple users.

Loading the maps will automatically switch to the second tab, the Opportunities tab (Fig. 4). This presents the opportunity maps and allows the user to explore them.

By comparing suitability within and between maps, the user can make decisions about which areas to prioritise for further investigation in the field, narrow down the list of opportunities to consider for a given location or identify the most suitable uses for areas already under consideration. Fig. 5 illustrates the interpretation of the maps for some of these potential uses.

3.2. Validation on study farms

Agreement between the scores derived from E-Planner scores and field-based scores assigned by the expert surveyor was generally high (Spearman's correlation coefficient = 0.80, $p < 0.01$, for both farms combined). This was especially so for the most and least suitable areas, with more variation around intermediate scores (Fig. 6A). Agreement between the scores did not appear to differ greatly between the two farms (Fig. 6B and C, Spearman's correlation coefficients = 0.78 and 0.82, respectively, $p < 0.01$ for both).

The different environmental opportunities showed some variation in agreement between scores (Fig. 7). Agreement was generally high for all, but it was notably stronger for wet grassland creation and weaker for winter bird food (Spearman's correlation coefficients: Flower-rich pollinator habitat = 0.77, Water resource protection = 0.80, Wet grassland restoration = 0.97, Winter bird food = 0.54, Woodland creation = 0.83). However, it is important to note that where there were discrepancies between scores, E-Planner generally tended to underestimate suitability for all opportunities (i.e. most points are on or above the

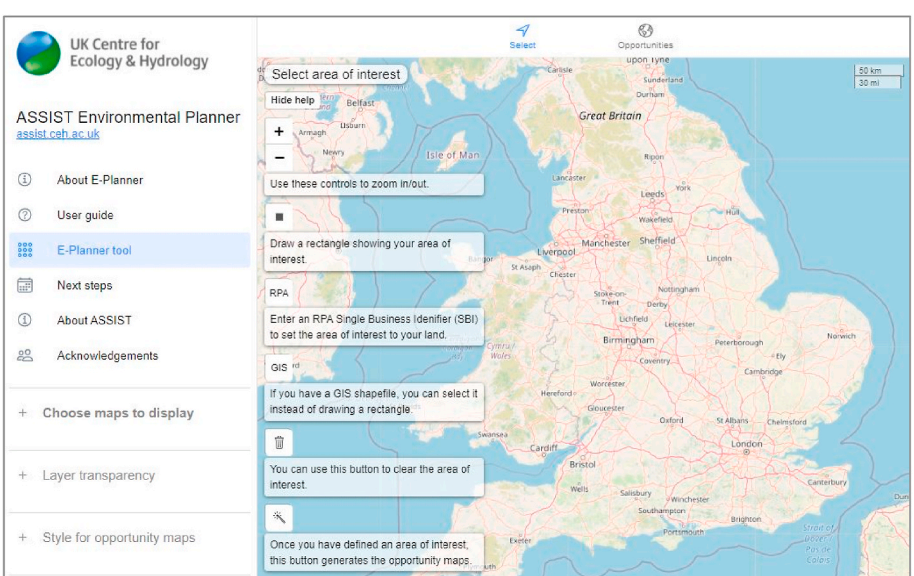

Fig. 3. Screen capture of the E-Planner Select tab. User controls are labelled with their functions. The left hand menu allows navigation to the other E-Planner pages. Menu items can be expanded to allow selection of the opportunity maps to view ("Choose maps to display"), alteration of the relative transparency of the maps compared to the background OpenStreetMap data ("Layer transparency") and the colour palette for suitability map visualisation ("Style for opportunity maps"). As viewed in Microsoft Edge Version 90.0.818.51, May 2021.

Fig. 4. Screen capture of the E-Planner Opportunities tab for an example farm, as visualised using the red-blue colour palette. E-Planner provides a legend for ease of interpretation, and allows panning and zooming of any map, with all other maps tracking the same extent. The "Choose maps to display" menu can be expanded to switch maps on and off, with a minimum or one and a maximum of four being displayed simultaneously. As viewed in Microsoft Edge Version 90.0.818.51, May 2021.

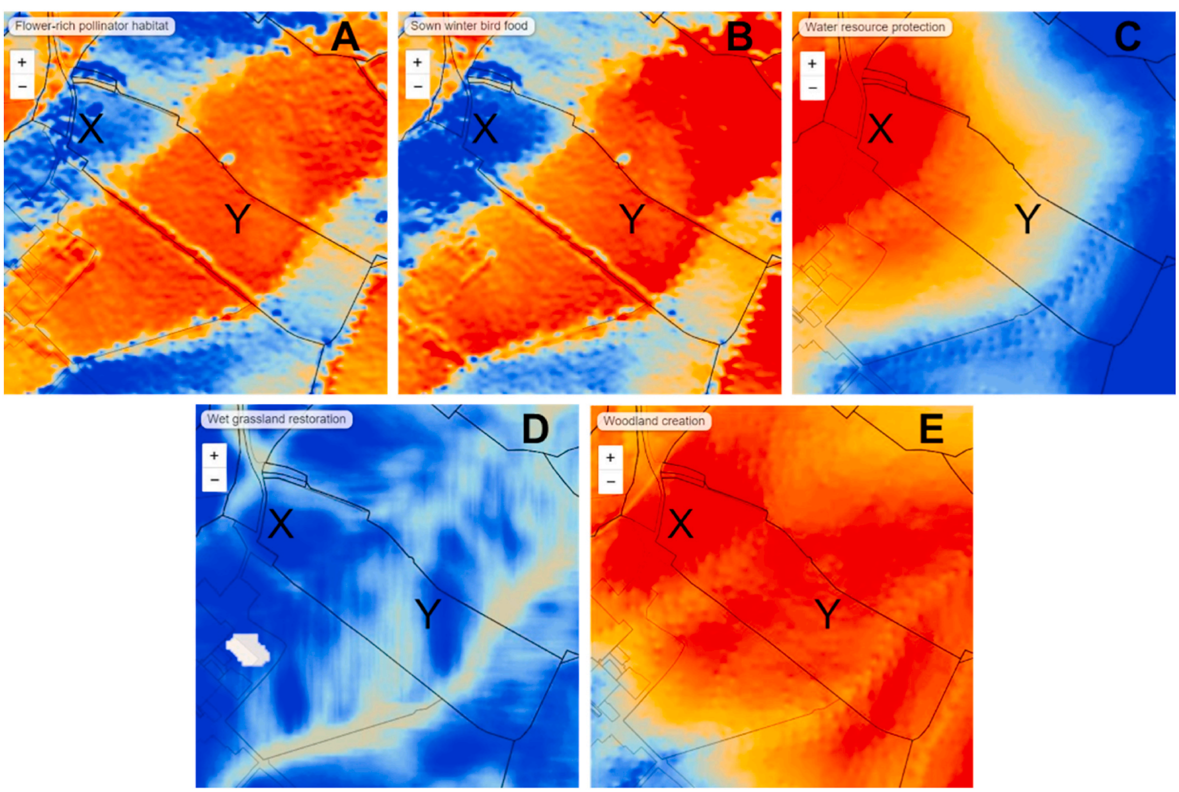

Fig. 5. Screen captures from the E-Planner tool showing opportunity maps for a single field, part of a larger farm selected for visualisation. This demonstrates the interpretation of the E-Planner maps for two uses. Firstly, selection of the most suitable environmental opportunity for a given area: if, for example, area X was under consideration for taking out of agricultural production, comparison across the five maps shows it to be most suited to management actions focussed on the opportunities of water resource protection (C) or woodland creation (E). If instead, field boundary Y was under consideration, suitability appears highest for pollinator habitat (A) or winter bird food (B). Secondly, selection of the most suitable area for a given opportunity: if a user was only interest in identifying the best areas for woodland creation, the map (E) suggests that all areas of this field would be potentially suitable, whereas if wet grassland restoration was the opportunity under consideration, the map (D) strongly suggests that the user look elsewhere on the farm for more suitable sites. Legends removed from each panel for clarity, colours indicate suitably as in Fig. 4 (blue = least suitable, orange = intermediate suitability, red = most suitable).

1:1 line on Fig. 7), including for winter bird food, rather than assigning misleadingly high suitability scores to unsuitable areas.

The most common factors recorded by the surveyor as reducing the field-assigned score of otherwise suitable areas were the possible effects of wildlife disturbance from roads and footpaths. The E-Planner suitability scores also did not always reflect the presence of wet ditches which would make good potential candidates for water resource protection, because these are not consistently mapped in the national

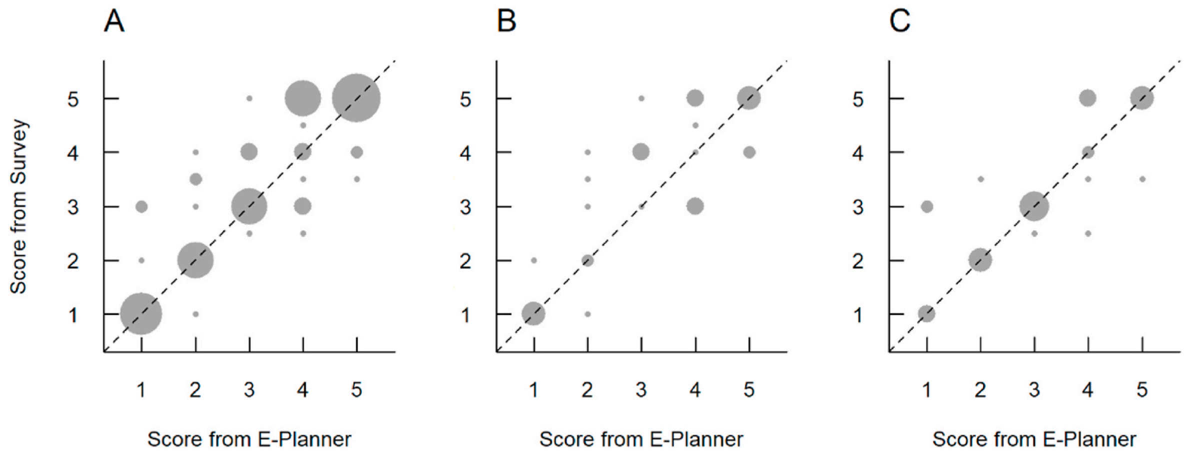

Fig. 6. Plots comparing suitability scores derived from E-Planner to those assigned from field survey, for both farms combined (A) and for each farm separately (B, C). Symbols are sized by the number of overlapping points (smallest circles indicate one point, the largest indicates 8 points). The dashed line indicates a hypothetical 1:1 relationship.

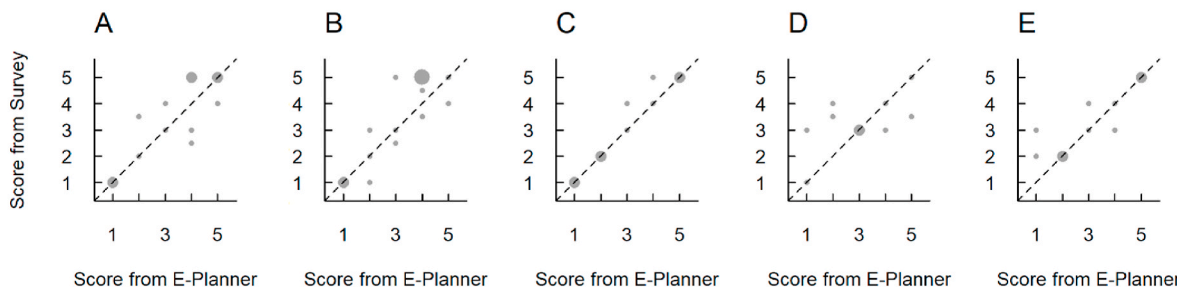

Fig. 7. Plots comparing suitability scores derived from E-Planner to those assigned from field survey, for each environmental opportunity across both farms: A) Flower-rich pollinator habitat, B) Water resource protection, C) Wet grassland restoration, D) Winter bird food, E) Woodland creation. Symbols are sized by the number of overlapping points (smallest circles indicate one point, the largest indicates 3 points). The dashed line indicates a hypothetical 1:1 relationship.

watercourse data that E-Planner uses.

4. Discussion

4.1. Use and limitations of E-Planner

E-Planner was launched in June 2020. Feedback from users has been generally positive, although we have also used feedback to make improvements to the user interface and will continue to do so over the lifetime of E-Planner. The need for users to quickly understand the purpose of E-Planner and what it does and does not consider led to the creation of the user guide and suggested user workflow (Fig. 1). The workflow places E-Planner within the wider context of farmer-led decision making and ADSS. This includes the importance of making an initial assessment of land that might be available for environmentally-focussed uses, and of the context of sustainable agriculture and its goals of enhancing both environmental delivery and crop production. In some systems neutral or beneficial impacts on crop production can be achieved by removing areas from production. This can occur where yields do not outweigh the input costs, where potential recompense from AES outweighs the income from crop production, or where increased ecosystem services from the environmental opportunity increase productivity in the remaining cropped land (Pywell et al., 2015; Woodcock et al., 2016). In other situations, land is not taken out of agricultural production to implement an environmental opportunity (e.g. restoration of species rich grassland or floodplain meadow on improved pasture), so users may wish to target already productive areas to increase ecosystem service delivery (Lawson et al., 2018) or deliver additional benefits such as increased climate change resilience of more biodiverse swards (Isbell et al., 2015).

E-Planner scales the maps to highlight the most and least suitable areas from each opportunity within the selected area. This was chosen as being most intuitive to farmers and because existing research suggests that farmers prefer decision support outputs which are made relevant to their particular farm rather than applying rulesets based on national or regional averages (Rose *et al.*, 2016). That said, it should be borne in mind that this scaling means that E-Planner will still identify the 'best' areas in an area of interest that is uniformly poorly suited or the 'worst' areas in an area that is uniformly well-suited. We found in preliminary analyses that the difference between maps which were scaled to a user defined area of interest and those which were not scaled but retained national scale suitability were not as extreme as might be imagined, unless the user selects an area of interest which is very small (i.e. a single field). This is because of the multiple variables making up each index of suitability, the scaling of each variable to a 0–1 scale and the high resolution of the input data. This issue therefore unlikely to lead to misleading interpretations of the maps unless a user selects only a very small area and neglects to check the recommendations of E-Planner on the ground. We consider the latter unlikely given our strong emphasis on site inspection to validate selection in the suggested user workflow and the general disinclination of farmers to act on the recommendation of decision support tools without first checking that these match with their own experience (Rose et al., 2018a). However, the issue of scaling may have driven the reduced correlation between the E-Planner scores and expert scores for bird food in the validation exercise, as the surveyor reported that much of the surveyed farms was potentially well-suited to this opportunity, and thus scaling resulted in low suitability scores for areas which were in fact moderately suitable. It should be borne in mind that our validation of E-Planner is based on only two farm estates, and a single expert. Ideally, we would complete a large scale validation exercise with multiple experts over multiple sites, so that potential biases from site or expert are averaged out and it becomes possible to explore the relative performance of E-Planner under different situations (e.g. farming systems). However, such an exercise is currently prohibitively time consuming and costly, so we are continuing to validate the tool based on user feedback and comparison with other, local data sources where available.

Ultimately, even if E-Planner is widely used and accurate, the successful implementation of environmentally-focused management actions requires more than just an understanding of where best to put them, and farmers must learn new skills and knowledge to implement, maintain and monitor such environmental management (de Snoo et al., 2013; Lobley et al., 2013; McCracken et al., 2015; Francis et al., 2017). However, there is a wealth of information available on these skills, as well as separate decision support tools, and E-Planner provides links to these in its Next Steps page.

4.2. Integration with agricultural decision support systems

E-Planner is not in itself a full ADSS and is focused on delivering intuitive display of a specific set of mapped outputs. However, the map-based webGIS framework and underlying web services of E-Planner make it easy to incorporate the suitability maps into existing ADSS that are already widely used by farmers. For example, the E-Planner maps are now available via the xarvio® field manager platform. This allows the direct overlay or comparison of the E-Planner maps with agronomic data from precision agriculture systems (e.g. real time crop condition, soil conditions, yield, historic average productivity) to identify areas that satisfy both agronomic and environmental criteria. Users can then digitize environmental management zones and set them as automated exemptions from farm machinery operations, bringing several aspects of the workflow required to balance "farming for yield" vs "farming for nature" into the same integrated ADSS. Such integration could potentially also be used to bringing more dynamic elements to E-Planner itself, under the current framework, for example by dynamically updating the suitability models based on hypothetical new habitat patches digitised by the user. Links to other ADSS would also bring the possibility of directly simulating the impact of potential changes to environmental management on key environmental indicators or ecosystem service using predictive models already implemented in ADSS with the functionality to collate data from other systems and tool on the complex local factors required to make accurate estimates.

5. Conclusions

The ultimate criterion for success of any decision support tool is for its recommendations to be translated into successful action. There are already a vast number of agricultural decision support tools potentially available to farmers (Rose *et al.*, 2016) and the uptake of any given tool is often poor (Terribile et al., 2015; Rose *et al.*, 2016; Lindblom et al., 2017; Rose and Bruce, 2018). Tools can be too expensive or time consuming, overly simple or overly complex or, critically, fail to meet the needs of their intended users. We have attempted to design E-Planner is such a way as to maximise its chances of uptake - it is freely accessible, easy to use, visually oriented, co-designed and supports integration with existing ADSS.

Although currently operational only for Great Britain, the methods used by E-Planner for collating and presenting data on environmental constraints and drivers are widely applicable, limited only by the availability and resolution of environmental datasets. The efficient spatial targeting of agronomic and environmental management aided by E-Planner, in combination with other ADSS, forms an essential step towards the globally relevant goal of sustainable agriculture.

Finally, E-Planner is likely to have wider relevance to habitat restoration beyond farmland. For example, the UK government's draft Environment Bill states that after 2023 new developments will be legally required to achieve 'Biodiversity Net Gain'. Developers will be required to increase the area or quality of appropriate habitats over and above that affected by the development. Spatial planning tools, such as E-Planner, could have a key role in supporting improved outcomes of this policy through provision of guidance on where best to target on- or off-site habitat restoration.

Software availability

Name of software: E-Planner.
Developer: Richard Burkmar, UK Centre for Ecology & Hydrology, Lancaster Environment Centre, Library Avenue, Bailrigg Lancaster, LA1 4AP, UK.
Year first available: 2020.
Hardware required: Web-enabled desktop or mobile device.
Software required: Web browser.
Availability: Openly accessible web-based application.
Cost: Free.

Author contributions

J.W.R and R.F.P conceived the tool. J.W.R collated and analysed data and coordinated validation. R.B analysed data and led construction of the tool and its interface, with support from M.B. All authors contributed to the design of the tool and the writing of the paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envsoft.2022.105437.

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