Ready for integrated sustainable agricultural land management?

Are practitioners in archaeology and agriculture **informed, willing, enabled, and motivated** to change how they work with remote and near-surface sensing data to collaboratively address contemporary challenges in sustainable agricultural land management?

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Abstract

Remote and near surface sensing technologies underpin the precision agricultural methods used to manage land productively and sustainably and the archaeological prospection methods used to identify, evaluate, and manage heritage features within that land sustainably and for the public benefit. Users of these technologies and the data they produce are engaged in a shared project, managing agricultural land, but direct collaborations between them remain rare. The disjuncture between individuals and organisations working in these domains has led to **data silos** and collection of incompatible data, **missed opportunities to improve methods** through knowledge exchange and technology transfer, and **gaps in the knowledge** about agricultural soil systems needed for decision making. The ipaast project investigated the extent to which stakeholders in sensing for land management are **informed**, **willing, enabled, and motivated to change their working practices** to facilitate collaborations designed to improve outcomes of using sensing data across precision agriculture, agri-environmental management, archaeology, and heritage management. This report presents an assessment of current stakeholder views and identifies opportunities for collaboration around using sensing data for land management, together with key barriers.

Funding and Ethics

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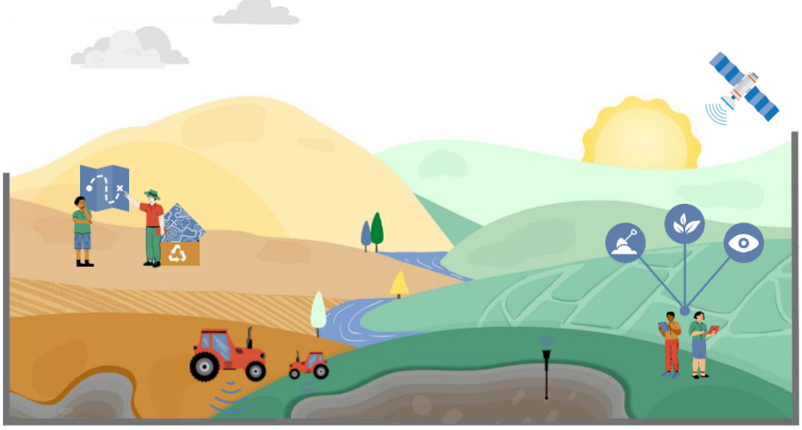


Report

1. Introduction

Advanced sensing technologies and methods have transformed how various components of landscapes, from sub-soil deposits to surface topography to plant biomass, are observed, measured and analysed. These technologies are now widespread, used not just throughout environmental earth sciences but also in the agriculture and heritage sectors, where their adoption by practitioners in agronomy and archaeology are continually impacting on working practices (Weiss, Jacob and Duveiller, 2020; Cowley, Verhoeven and Traviglia, 2021, Wolfert *et al*., 2021; The Royal Society, 2023). Commercial and research-based uptake led to the emergence of specialisms in precision agriculture and archaeological prospection. These specialists measure and analyse related soil and plant properties for domain-specific purposes (Weber *et al*. 2019), respectively emphasising using sensing to understand and inform the management of soil and crop systems and the persistent impacts of past human activity. Key sensing technologies include remote (aerial) sensors such as multi- and hyper-spectral imaging and lidar, as well as near-surface (ground-based) geophysical sensors such as electrical conductivity and magnetometry to investigate the sub-surface. Despite commonalities in practice and the types of data collected, exchange and collaboration between domains- remains limited.

The ipaast project

The *ipaast* project, funded by the British Academy (2021-2023) investigated the potential of the overlapping use of sensing technologies and the data they create to connect (precision) agriculture and (prospection in) archaeology, and explored the potential benefits of sharing data and knowledge to enable integrated sustainable land management (Opitz *et al*., 2023).

In 2021-2022 the project team conducted a literature review to identify specific overlaps in techniques, methods and data type between land management domains. Subsequently, the project team engaged with stakeholders through a series of workshops and interviews to better assess the current state of working practice and their data needs. Preliminary conclusions from the first year of stakeholder engagement are described in Opitz *et al*. (2023, section 3). This report outlines the methods used for data collection and analysis, key themes which emerged from workshops discussions and interviews conducted with stakeholders across the whole project (the 'participatory survey') and presents key opportunities for and barriers to realising these benefits.

Participatory survey – Aims and objective:

The participatory survey aimed to assess needs, current practices, and attitudes of stakeholders across the agriculture, heritage and environment sectors who might be involved in the coordinated collection, use, and exchange of sensing data for land management. To achieve this aim, the project engaged with diverse stakeholders through workshop sessions, semi-structured interviews and written correspondence. Their responses were then transcribed, compiled, and analysed. Based on this assessment, recommendations for actions encouraging data and methodology exchange and data interoperability were formulated.

2. Participatory survey – Methodology

The participatory survey was conducted between May 2021 and October 2022.

Location: The preponderance of stakeholders engaged with are professional practitioners or researchers based in the UK, Belgium, Italy, Cyprus, Spain and France. Sessions occurred remotely (online/phone), as well as on site, during workshops at the University of Glasgow, the Dalswinton Estate, Dumfries, and Manor Farm, Yedingham.

Participants

Selection: A sub-group of 51 high-level participants were selected from a greater network of 86 stakeholders who were engaged with during the *ipaast* project.

Sector: Farmers, researchers, heritage managers, geophysicists, remote sensing specialists, statisticians, soil scientists, service providers, sensor developers, and data archivists, who all deal directly, or indirectly with datasets relating to the measurement of soil and/or plant properties (physical, chemical, microbial) were represented (Table 1)

Expertise: Engagement with mid- to late- career specialists was prioritised, with many participants having over 20 years of experience and most having over 10 years of experience (including time during the PhD).

Professional background – summary			
Sector	*Profession*	*Practice*	*Country*
Agriculture	Agronomist	Data Non-user	BE
Archaeology	Agtech Specialist	Data Provider (Arch)	CY
Environment	Digital Archivist	Data Provider (Envir)	ES
Sensor Development	Ecologist	Data Provider (PA)	FR
Social Science	Environment Manager	Data Provider (Tech)	IT
	Environment Consultant	Data User (Arch)	UK
	Farmer	Data User (Envir)	
	Geophysicist	Data User (PA)	
	Heritage Manager		
	Land Manager		
	Researcher		
	RS Specialist		

Table 1. Professional background of participants – summary.

Interview method

Engagement with stakeholders was primarily through one-to-one interviews and structured workshop discussions, conducted either in person, or remotely over video conference or phone. In some instances, participants provided written input (see Table 2 summary). Follow-up interviews or written exchanges were used to clarify or continue discussions when required. A semi-structured approach to interviews and discussions was preferred, with a mix of general questions (see sample questions), as well as questions specifically tailored to the participants specialist background and experience.

Sample Questions:

- *What types of sensing data do you use/collect?*
- *Where/how do you access/collect these data?*
- *What are your main aims/applications in using or collecting these data?*
- *How often do you access/collect, or anticipate accessing/collecting, these data to be useful to you?*
- *What spatial resolution is necessary for these data to be useful to you?*
- *What, if anything, would encourage/discourage you from sharing your data?*

- *What kinds of additional data types or additional information (metadata) might help you to better understand and use data which you have previously collected or received?*
- *What do you see as the main impacts, if any, of ecosystem service frameworks and/or recent changes to rural/environmental regulations on your work?*
- *What attitudes to sensing data do you see from other stakeholders in rural affairs?*

Documentation: Where viable, interviews and workshop discussions were recorded and transcribed; alternatively, notes were made during engagement by either the interviewer and/or dedicated participant observers (e.g. at workshops). Where notes were used, specific quotes and summary reports were checked with the participants for accuracy.

Method – summary							
Country	*n.*	*Engagement*	*n.*	*Method*	*n.*	*Format*	*n.*
UK	41	Formal	17	Interview	17	Video-conf.	34
BE	4	Informal	34	Workshop	32	Phone	8
ES	3			Correspondence	2	In-person	7
CY	1					Email	2
IT	1						
FR	1						
	51	*Participants*					

Table 2. Participatory survey method summary table.

Analysis Method

Transcriptions and observer notes recorded during the participatory survey were compiled and edited. Participant responses of note were categorised by relevance and referenced with a reference identification number (R-ID).

Codes – summary		
Themes (6)	*Sub-themes (23)*	*Sentiment value*
User requirements	User Req-Resolution, accuracy	Positive (1)
Current practice	User Req-Data formats, exchange, integration	Neutral (0)
Resources	User Req-Data discovery, re-use, re-purpose	Negative (-1)
Tech developments	User Req-Data interaction, interrogation	
Awareness	User Req-Data quality	
Social [value]	User Req-Data types	
	User Req-Outputs	
	Current Practice-Workflow	
	Current Practice-Soil sampling strategy	
	Current Practice-Analytical methods	
	Current Practice-Standards and best practice	
	Current Practice-Changing practice	
	Current Practice-Policy	
	Current Practice-Motivation and drivers	
	Resource-Skills and training	
	Resource-Funding	
	Tech Development-Capabilities	
	Awareness-Cross domain awareness	
	Awareness-Cross domain understanding	
	Awareness-Cross domain collaboration	
	Social-Interoperability and sharing	
	Social-Cost Economics	
	Social-Language communication	

Table 3. Thematic analysis coding – summary of themes, sub-themes and associated sentiment values assigned to participants references.

Coding: All participant references (i.e. comments, quotes) were evaluated according to six main themes of interest. During the process, main themes were expanded and refined at a sub-level to cover a range of 23 sub-theme codes (Table 3).

Every participant reference, either a direct quote or observatory note, was thematically assigned a single code, or multiple codes where appropriate. Each assigned thematic code was further assessed according to a scale of sentiment (positive, negative, neutral), and translated to a corresponding numerical value (1, 0, -1 respectively), which best reflected the attitude of the participant's reference (i.e. response).

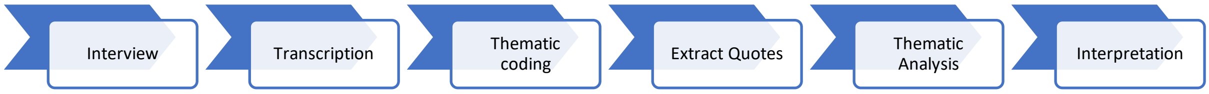


Fig 1. Overview of the process of information gathering, from interview to interpretation, to gain insights into community views and attitudes toward use of sensing data across archaeological prospection and precision agriculture.

All recorded references and associated thematic codes were tabulated for quantification and statistical analysis to help identify patterns and key insights into themes, while gauging the attitudes and needs of stakeholders across domains.

Participants were assigned a unique identifier prior to analysis and their names removed from the analysis to anonymise the survey results, except where participants agreed to partake on a named basis – these have been referenced accordingly.

3. Participatory survey – Results

Preliminary analysis of the participatory survey resulted in the identification of 256 direct quotes and 284 comments which were relevant for analysis. Each reference was assigned a single or multiple thematic codes which were translated into a corresponding sentiment value (positive (1), neutral (0), negative (-1) as described above. This process generated 1057 thematic codes with associated sentiment values. All participant references were compiled with associated codes and values in a summary dataset (see Supplementary data).

Thematic Analysis

These data were summarised and visualised to provide an overview of participant sentiments across a range of relevant themes and, where possible, identify general trends in attitudes. Summary statistics of overall codes assigned (codes counted by theme, participant, total, etc.) and overall sentiment score (sum of sentiment values by theme, participant, total, etc.) are presented in Appendix 1, Table A1 and form the basis of following overview at main theme level.

Results overview – main themes

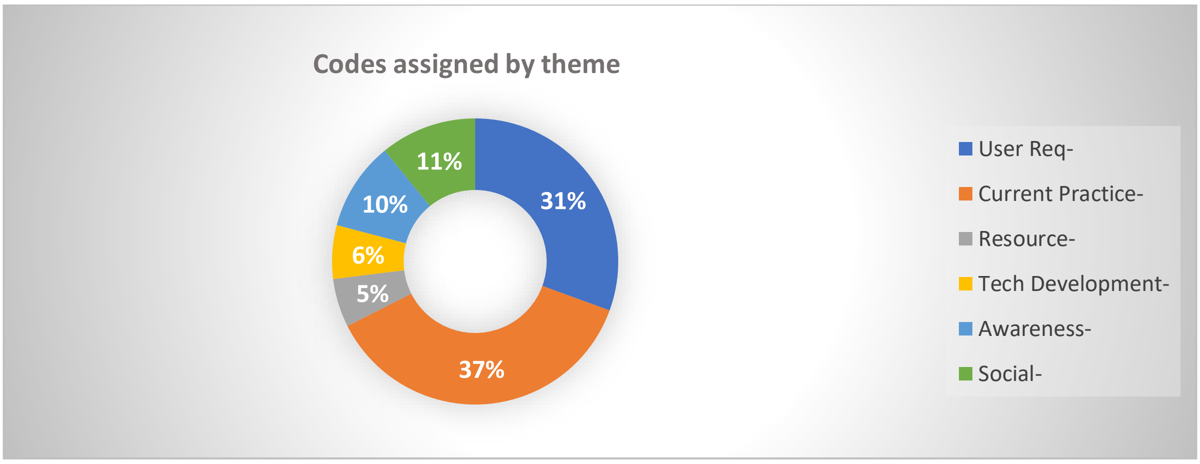


Fig.2 What participants talked about – a clear focus on current practices and user requirements surrounding the use of sensing data in their respective disciplines.

Main themes – general observations

What are participants discussing?

Quantification of codes: The distribution of total codes assigned by main theme (Fig. 2) reveals that participants focused on topics related to the main themes of current practice (37%) and user requirements (31%) when discussing the use of sensing data in land management and related disciplines.

Observation: Participants are most comfortable speaking about topics where they have direct practical experience (i.e. what they do and need in their practice), and hesitated to speculate on developments outside their experience (e.g. future technological developments) or to comment on wider trends in their sector.

"The combine yield data we use more frequently – for variable seed plans, cost of production analysis and now looking at which land we take out of production in line with the new environmental schemes which we are being encouraged to join."

R046 Quote PID534 Nick Wilson

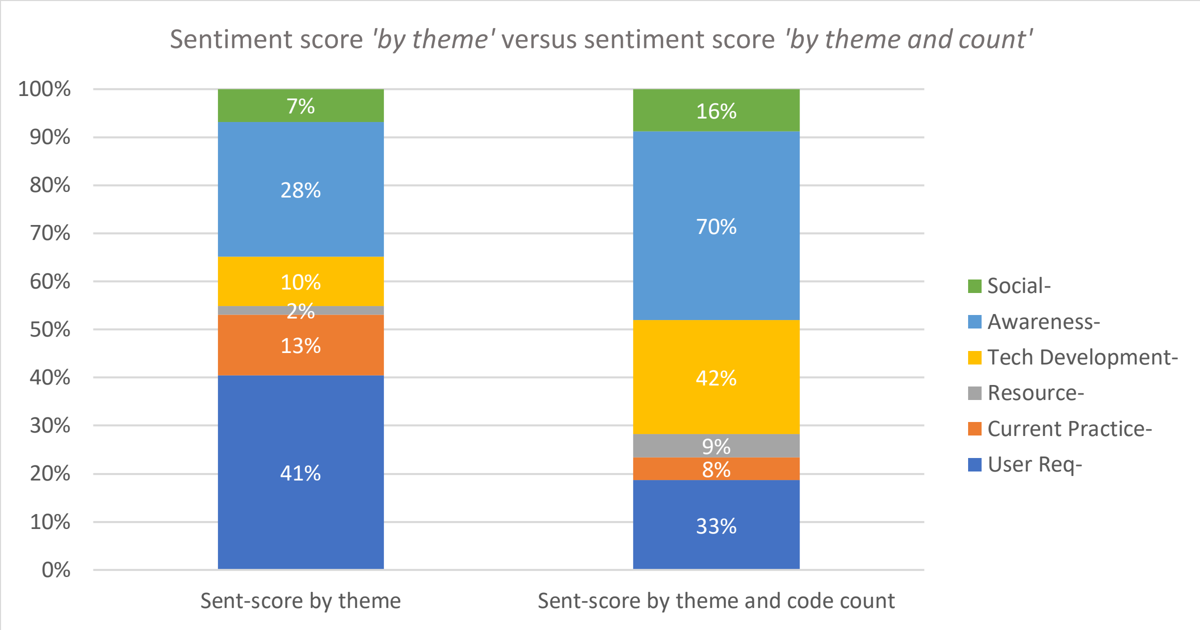


Fig. 3. What participants felt positive about – proportionally, most participant positivity was directed towards topics related to cross-domain awareness, suggesting general approval for collaborative exchange between domains.

What do participants feel?

Quantification by sentiment: Sentiment values of assigned codes were summed by theme (sentiment score) to help visualise the general sentiment expressed by participants across all themes (see Fig. 3). Initial sentiment scores (series 1) were adjusted (normalized) proportionally against the total count of codes assigned by theme (series 2) to show most positivity was related to the main theme of awareness, i.e. in the sense of cross-domain understanding.

"Those precision agriculture datasets could be relevant here – 'Guideline 12' has only been used in 5 instances out of the 330 plus cases I've been involved in – I think we'd use it more often if we had precision agriculture data."

R442 Quote PID530 David Robertson

Observation: In general, participants were willing to engage in cross-domain exchange and collaboration and approved of these activities in principle, as noted previously in Opitz *et al*. (2023). However, comments on the two themes most talked about, user requirements and current practice, had lower scores (33% and 8%), indicating a greater range or mix of feelings revealed during discussions.

Despite the great potential of hyperspectral data, challenges remain. Even extracting information is difficult because of time and training constraints due to file size and technical requirements of datasets, especially in comparison to traditional soil sampling – it's simply quicker physically to visit site, core and analyse.

R145, R146: PID 555 Matt Aitkenhead

Which participants felt strongly?

To understand better which groups amongst participants expressed the strongest or most '*emphatic*' sentiment, statistical analysis was undertaken to examine sentiment score according to participant's background attributes: sector, profession and practice (as listed in Table 1 above).

Statistical analysis: Scatter plots were created for each of the six main themes to investigate the relationship between sentiment score and total codes assigned for each individual participant. This isolated participant outliers (i.e. high code count and high (positive or negative) sentiment score) and helped choose two threshold sentiment-score values (positive and negative) per theme, with which to separate series-outliers from the main series-grouping (i.e. participants with the most emphatic responses).

The threshold values formed the basis of a new count by sector, profession and practice: sentiment score equal to, or greater/lesser than, the threshold value according to theme. The results identify the most emphatic responses of participants and are documented in Appendix 2; a results summary is presented here in Table 4. It forms the basis for Fig. 4a–c (below) and following observations.

		p-count	sum-pos	sum-neg	sum-combi	% p-count
Sector	Agriculture	17	3	6	9	33%
	Archaeology	16	8	12	**20**	31%
	Environment	14	0	5	5	27%
	Sensor Development	2	2	1	3	4%
	Social Science	2	0	0	0	4%
Profession	Agronomist	2	1	0	1	4%
	Agtech Specialist	3	1	0	1	6%
	Ecologist	1	0	0	0	2%
	Environment Manager	2	0	1	1	4%
	Farmer	8	1	4	5	16%
	Geophysicist	4	0	1	1	8%
	Heritage Manager	10	6	12	**18**	20%
	Land Manager	1	0	2	2	2%
	Researcher	15	3	4	7	29%
	RS Specialist	5	1	0	1	10%
Practice	Data Non-user	3	0	0	0	6%
	Data Provider (Arch)	1	0	1	1	2%
	Data Provider (PA)	4	2	0	2	8%
	Data User (Arch)	16	8	12	**20**	31%
	Data User (Envir)	14	2	4	6	27%
	Data User (PA)	12	1	7	8	24%
	Platform Provider	1	0	0	0	2%

Table 4. Who feels strongly? – breakdown of 'emphatic' sentiment expressed by participants according to sector, profession and practice: positive, negative and combined sentiment scored in relation to the participant count and percentage. Combined sentiment score reflects by strength of response: in this case, high values are interpreted as 'emphatic'.

Outcome: As seen in Figure 4a (top), archaeology emerges as the sector whose members expressed the most emphatic responses overall (20). Despite similarly proportioned representation between main sectors (agriculture 33%, archaeology 31% and environment 27%), it scored over double its closest neighbour (9) in combined sentiment score.

"Normally we ask for [raw data] to be handed over, but we don't really work with it because I'm not a specialist. I'm not a technician at all, so I cannot work with it, but we want to preserve it so that it's available in the future – to enable people who can work with it or want to look at it again."

R195 Quote PID522 David Depraetere

Figure 4b (centre) reveals that heritage managers are the source of these strongly held views, with an emphatic sentiment score of 18 relative to being the second most represented profession (20%) in this part of the analysis. In this respect, researchers (29%) are interestingly, significantly underrepresented with a score of 9.

Similarly, in terms of practice, Figure 4c (bottom) confirms the 20 most emphatic responses were made by archaeological data users (31%), proportionally more than expected.

Observation: Archaeology's prominence in this analysis seems to be driven by the emphatic responses of heritage managers, who generally work at regional and national level with county councils, or national landowning agencies. In the UK they are mainly data consumers, whose work is closely linked to the commercial sector. Working in an advisory capacity, they are reliant on receiving and collating relevant and diverse datasets from external sources. Their prominence in the ranking of emphatic responses, especially in comparison to researchers from all sectors, may indicate concerns around not having well integrated data or access to the information they need on a more regular basis.

"Much of it is already there, all you have to do is harvest existing datasets – we've already done some – but formats can be problematic, often no [attribute] fields are in common, there's no way of verifying data, and locational data is missing."

R122 Quote PID575 Joseph Elders

"There are shared interests and goals that we find a lot [...] but we're still finding a lot of conflicts in many things, including this concept that natural and historic environment are separate."

R216 Quote PID523 Ruth Beckley

To nuance the conclusions drawn from the main thematic overview, sub-themes were explored to identify the topics within themes which prompted strongly expressed views in discussion with participants.

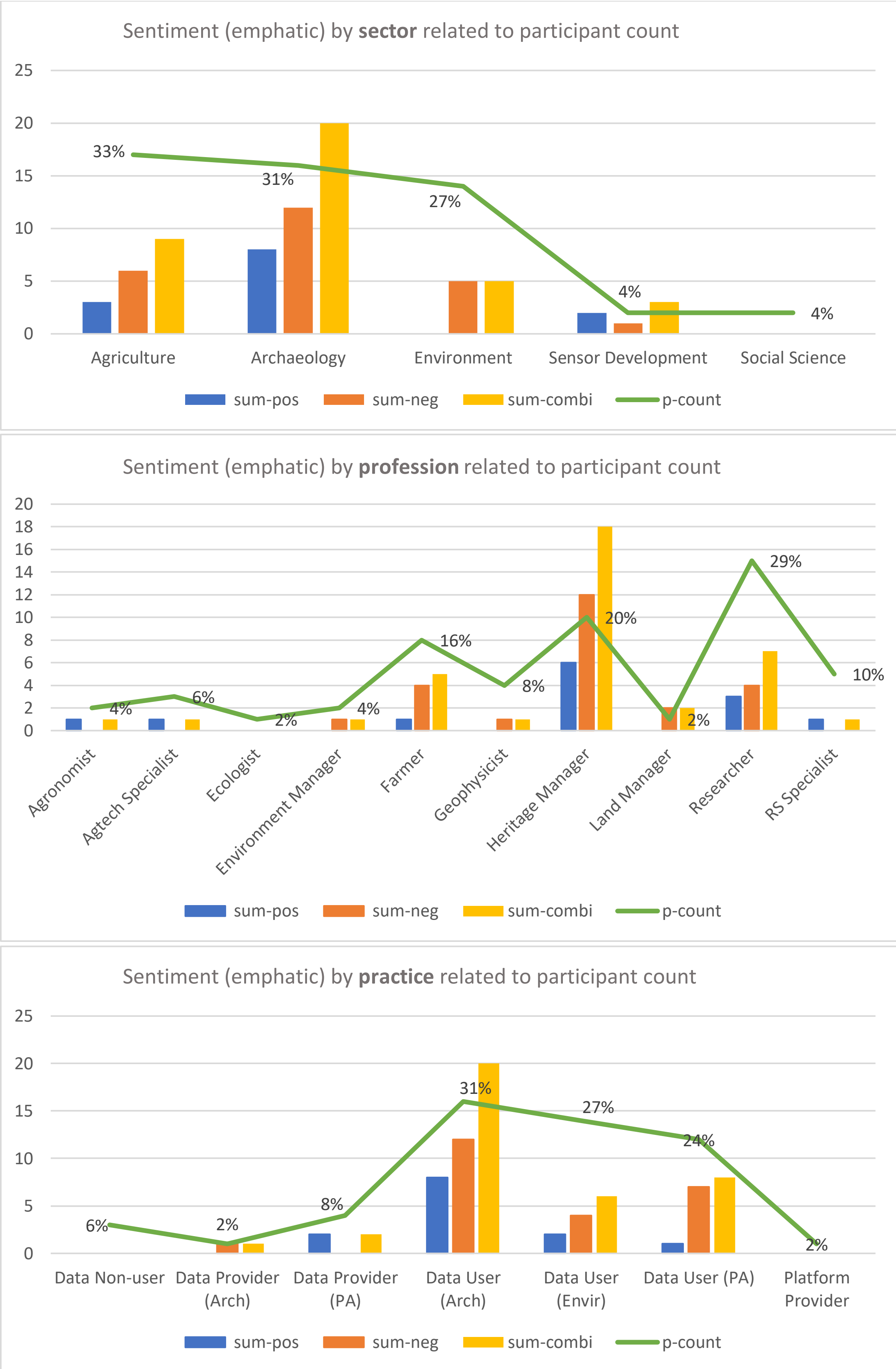


Fig 4a–c. Emphatic sentiment score by sector (top), profession (centre) and practice (bottom) in relation to their respective percentage of participants (line).

Results overview – sub-themes

In total, 1057 thematic codes were assigned to 541 references (quotes and notes). Codes related to 23 sub-themes with associated scale-of-sentiment values, which were quantified; the results are presented in Table 5 (below) and form the basis of the following charts (Figs 5 and 6) and observations at the sub-theme level.

Sub-theme	Pos-Sent	Neut-Sent	Neg-Sent	Total-Sent	Sum-Sent
User Req-Resolution accuracy	29	23	13	65	16
User Req-Data formats exchange integration	3	9	21	33	-18
User Req-Data discovery re-use re-purpose	20	0	4	24	16
User Req-Data interaction interrogation	1	1	3	**5**	-2
User Req-Data quality	18	14	27	59	-9
User Req-Data types	**109**	17	6	**132**	**103**
User Req-Outputs	2	2	1	**5**	1
Current Practice-Workflow	10	22	33	65	**-23**
Current Practice-Soil sampling strategy	5	4	2	11	3
Current Practice-Analytical methods	3	2	6	11	-3
Current Practice-Standards and best practice	15	13	6	34	9
Current Practice-Changing practice	97	13	14	**124**	**83**
Current Practice-Policy	8	17	**36**	61	**-28**
Current Practice-Motivation and Drivers	25	**27**	33	85	-8
Resource-Skills and training	14	8	14	36	0
Resource-Funding	13	1	8	22	5
Tech Development-Capabilities	42	7	15	64	27
Awareness-Cross-domain awareness	8	0	1	9	7
Awareness-Cross-domain understanding	33	4	6	43	27
Awareness-Cross-domain collaboration	45	4	5	54	40
Social-Interoperability and Sharing	25	8	11	44	14
Social-Cost Economics	22	14	22	58	0
Social-Language communication	7	3	3	13	4
Totals	*554*	*213*	*290*	*1057*	*264*

Table 5. Sub-themes – quantification of assigned codes by scale-of-sentiment value: summary count of sentiment (positive, negative, neutral) with total sentiment count and sentiment score (sum-sent).

Count

Most talked about sub-themes: Figure 5 ranks by percentage the sub-themes which registered the most positive sentiment count. '*Cross-domain awareness*', '*data discovery re-use re-purpose*', and '*cross-domain collaboration*' top the chart, reflecting the goodwill noted earlier (above) towards collaboration, openness and sharing. Conversely, '*data formats, exchange, integration*', and '*data interaction and interrogation*' registered the highest negative sentiment count, perhaps reflecting that practitioners' frustrations lie in this area.

Sentiment

Scoring sentiment values by sub-theme helps give further insight into participant perceptions of what they feel enables or hinders them to work better, i.e. where the opportunities for or barriers to change lie.

Strongly positive sub-themes – top three: In Figure 6, two areas with particularly strong positive attitudes stand out: '*user req-data types*' and '*current-practice-changing practice*'. This could indicate a general openness or growing necessity to use of different data types and explore new data types, including those from other disciplines and domains, for use in everyday practice.

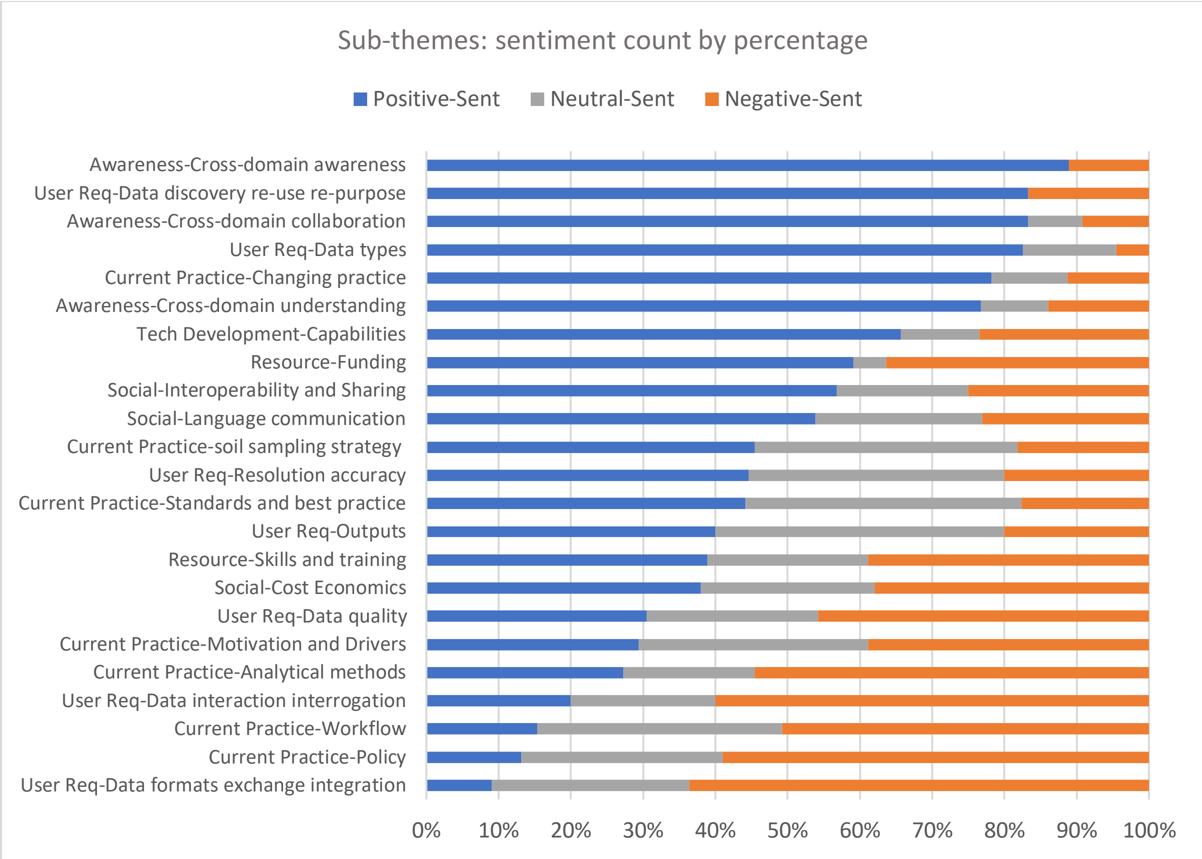


Figure 5. Sub-theme – quantification of positive, negative and neutral sentiment values from Table 5 (above) visualised by percentage.

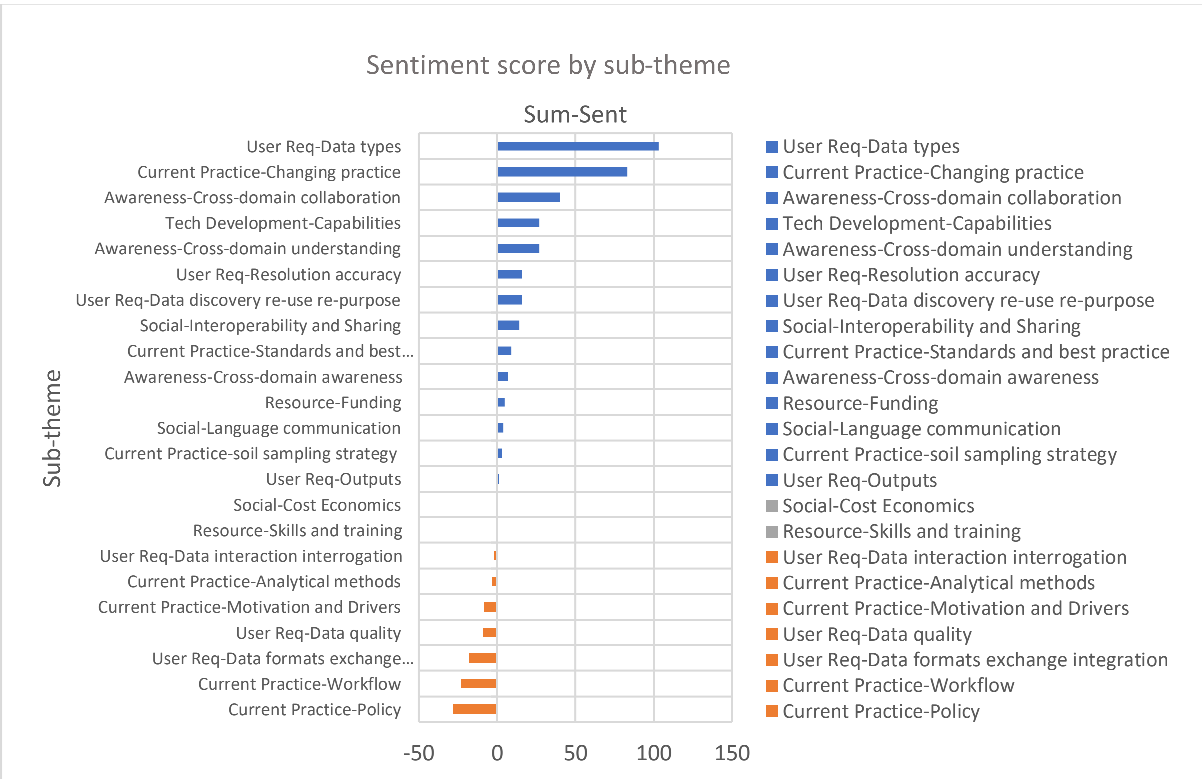
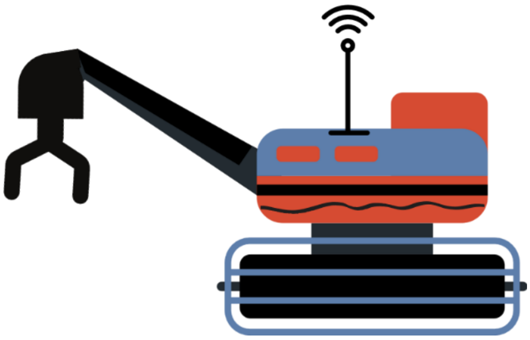


Figure 6. Quantification of sentiment score from Table 5 (above) visualised by sub-theme.

"I totally agree, you can't have just geophysical alone to do the work. You need to have some samples to calibrate your geophysics. But once you have good calibration – geophysics basically enables you to expand the measurements quite far and at a very high resolution."
R176 PID519 Guillaume Blanchy

Similarly, participants are also acknowledging a need to change current practice due to a variety of considerations, such as environmental or economic conditions, technological developments and/or changes to land management policy and regulations.



Strongly negative sub-themes – bottom three: As previously noted, participants were most comfortable discussing '*User req.*' and '*current practice*' (Fig. 2). At a sub-theme level, Figure 6 suggests that participants felt most strongly negative about topics relating to '*data formats exchange integration'* and '*data interaction interrogation*', as well as topics concerning current '*workflow*' and '*policy*'. Again, this indicates a level of frustration with these issues, highlighting the areas where participants feel change is most needed and perhaps most attainable. While policy is mostly dictated at a higher level and therefore outside of their control, the positive attitude of participants towards collaboration, openness and sharing regarding sensing data (see Figs 5 and 6), suggests strongly that participants feel solutions to their current frustrations might be found here (i.e. better co-ordination of working practices across domains).

"It's not only about the datasets – we use a lot of common datasets – it's also about the processing chain of how to process your data; I think we have a lot to learn from precision agriculture and also about the theoretical models that have not been yet developed."
R245 Quote PID511 Athos Agapiou

Key sub-themes were selected for further analysis based on the initial overview analysis. Further detailed analysis focussed on contexts where participants displayed mixed sentiment or notably negative sentiments in order to identify issues on which opinions are actively shifting and consequently might be more readily influenced by recommendations or where strong dissatisfaction could motivate change.

Thematic scatterplot distributions generated through the earlier statistical analysis were used to identify participants displaying a greater range of feeling in their comments (i.e. references with sentiment scores clustering around '0'). References of interest were used to gauge stakeholder attitudes and identify patterns and key insights into themes, which are and described in the next section and summarised in Table 6.

Themes:	Key insight	Topic
User Requirements	1	Data Resolution
	2	Legacy data – data repositories
	3	Data Compatibility
Current Practice	4	Changing practice – exchange
	5	Comfort in current practice
Resource	6	Education and funding
Tech-development	7	Proof of value – or overload?
Awareness	8	Perception, education and co-ordination
Social (value)	9	Economics
	10	Communication

Table 6. Summary of key insights by theme with related topic.

Key observations – What many participants are saying: (benefits and barriers)

"I firmly believe in data only being created once – captured at source, then shared many times – and not having to go back and ask for extra."

R093 Quote PID576 Guy Salkeld

Themes: User Requirements

Key insight 1 Data Resolution

Participants clearly expressed interest in exploring additional data streams from outside their domains, recognising opportunities to supplement research, management actions, incomes, and/or comply with land management regulations. However, data resolution was seen as a major stumbling block to implementing exchange between domains.

Archaeologists expressed the need for high resolution data characterising soils and crops. In some cases, particularly among heritage managers, the need to evaluate heritage (archaeological) significance, which relies on a detailed assessment of the likely type and period of archaeological remains present, made high spatial resolution data a hard requirement linked to achieving a specific project outcome. For other users, the understanding that using high resolution data reflects 'good practice' and the practitioner community's emphasis on the ability to characterise features in detail were key factors in a perception that high resolution data are necessary. In the latter case, the 'need' for high resolution data is tied to professional standards and community norms of good practice, rather than to what is required to achieve the objectives of a specific project.

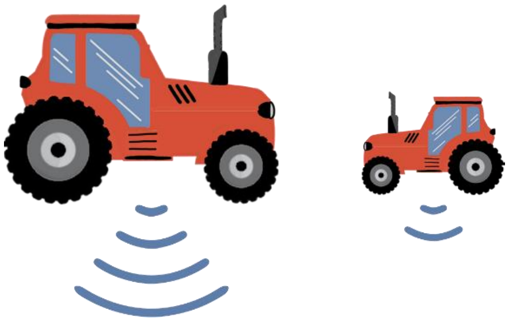
In contrast to this, agriculturalists expressed a need for significantly lower (typically ten times) resolution data to perform standard tasks. Some agricultural users translate the need for the lowest cost data which can be used to achieve minimal management requirements into a 'need' for low resolution data. In this context, data requirements are tied directly to economic efficiency, rather than to optimal outcomes in any other sense. Higher resolution data might improve management, but without economic gains flowing from these improvements, its acquisition is perceived as difficult to justify. An exception to this were farmers with high-value crops such as vines, which could justify the extra investment [R255].

The value of higher-resolution data is recognised by all participants but a change to higher density sampling, particularly in agriculture, will not occur without clear financial gains or incentives.

"Justifying that business case to a farmer – at this moment – is impossible."

R340 Quote PID509 Clive Blacker

Nonetheless, many participants expressed optimism that data of varying resolution could be applied between domains and cited examples of potential use. For example, archaeologists and heritage managers could benefit from a wider range of (low-res) data at a landscape scale, providing contextual information (e.g. geomorphology, soil pH levels) as well as indicating broadly areas of archaeological potential [R263, R266, R181, R182, R457]. Notably, participants repeatedly emphasised the need for case studies demonstrating the potential benefit of exchange (e.g. the value of higher resolution data in agriculture, and lower resolution data in archaeology and heritage) in order to successfully create a business case for the additional costs and time involved in producing data in this way. This demonstrates an obvious opportunity for continued research [R299] to support the required case studies. It also suggests that the main barriers are economic and social (perceived community norms) rather than differences in the processes and characteristics of agricultural land systems to be analysed.



Key insight 2   Legacy data – data repositories

Many participants, particularly from the environment sector, saw clear benefit of pooling not just current data (on soils for example) across domains but emphasised a need for legacy data to monitor and understand processes (agricultural or other) effecting various soil and plant properties over longer timespans; these data could encompass specific measurements of soils or plant properties, or relate to 'historical' land use (i.e. from the last 20-25 years) [R144, R151].

"Research into the impacts of farm management practices on soil microbial communities relies on data from Initiatives holding long-term [soil] samples and"

R523 Note PID558 Ciara Keating states.

Documenting and sharing these data is viewed as an asset for current research on, and management of the environment, particularly regarding the influences of anthropogenic processes, such as the application of fertiliser, on soil properties. Participants suggested that these data could also assist in the interpretation of geophysical soil measurements across all domains. Similarly, research into the impacts of farm management practices on natural, environmental processes (e.g. soil microbial communities) relies heavily on accurate high-quality data from initiatives holding long-term soil samples and soil data [R523]. Information on soil depths was also seen as environmentally valuable [R143, R141, R178, R401, R474]. Many participants felt that both archaeology and agriculture could contribute relevant information on these topics, especially as agricultural processes are now being documented in real time in some cases [R392].

Whilst all participants agreed on the importance of high-quality data and metadata (e.g. cross-sector consistency in collection or terminology), it remained unclear exactly who participants thought would take charge (pay for and regulate) of coordination at this level.

Participants also noted that the drive to collate soils and other environmental information is already underway, with many agencies, institutions and initiatives providing mapping and other data at national or even international scale through online databases and platforms [R192, R456].

Chief concerns voiced by participants pertaining to currently archived data, related to data consistency and quality, data coverage (gaps or missing data), as well as data access (open versus closed behind paywalls). Despite these potential barriers, the fact that so much relevant data – soil, environmental, archaeological, other – is already available, was equally perceived as an opportunity on which to build. In this regard, it was agreed by participants that better coordination of metadata guidance and standards could address the previously mentioned fears surrounding data quality by encouraging better metadata practice in the archiving and/or collating of shared data. Participants were very supportive of the reuse or repurposing of existing data – especially when accompanied by metadata and guidance on data-use – viewing it as a 'quick win' [R191, R469].

Key insight 3 Data Compatibility

"It's a crowded marketplace with many data formats – often with more data than farmers want to deal with."

R410 Quote PID584 Jeff Richings

Data format incompatibility was repeatedly highlighted as an obstacle in discussions about the potential of sharing data. Most participants already experience compatibility-related hindrances in their current work routines [R091]. Agriculturists are confronted with a bewildering array of proprietary data, poorly documented, in formats from a range of incompatible machines, sensors and platforms [R410]. This makes collating data within a single agricultural operation or coordination within an agricultural consortium difficult.

Creating compatible data for exchange with users in other domains seems too much to ask to many agricultural users, given their mixed experiences to date using platforms attempting to create compatibility within precision agricultural and other agricultural data sources, e.g. DEMETER, Agrimetrics. On top of this, a further frustration for agriculturalists is the frequent inability to access data without paying for it. While data collected for research purposes or by governments is regularly licensed for non-commercial reuse, the potential for commercial value of precision agricultural data is seen as a major challenge to widespread, open sharing of agricultural data [R354].

In parallel, heritage managers frequently have access only to PDF copies of sensing data, rather than raw data which might be reprocessed by users in other domains. Further, PDF reports on data cannot be integrated (easily) into heritage management systems or GIS. This is expressed as being particularly frustrating for practitioners in the heritage sector, who increasingly perceive a need for data in GIS-compatible formats, or even raw data files, to be usefully integrated into their work(flow).

"Sadly, we don't get geophysical shape files of the interpretation – I would love that! It would make my life a lot easier."

R203 Quote PID523 Ruth Beckley

Many end users have little time, capacity or training to engage with data-providers on simplifying data-sharing formats/workflows, and feel frustrated by the inclination around sensing data to protect its commercial or research value – raising questions about data ownership (i.e. who is in charge of data?).

Despite their experiences, participants from all sectors remained very positive about benefiting from the integration of new data streams and workflows into their practice [R025]. Many were also, acutely aware of the limitations of their own technical skills – and those of colleagues, [R026] when dealing with unfamiliar data types, as well as of the technical limitations of respective organisations in storing and/or supporting new and potentially larger data files [R030, R201]. This frustration extended to the design of data management systems and the inability to query or interrogate data already stored within organisations or archives [R092, R099] – whilst some participants felt databases/management systems were only usable if designed to answer questions, and were usable as more than a simple storage system.

Participants agreed that technical notes and guidance documents could complement the sharing of datasets and alleviate some of barriers around data compatibility. These documents could include use or scope notes detailing typical practice and applications as well as describing relevant data-format types and requirements underpinning the collection, processing and archiving of specific datasets. Technical documents could form part of wider best practice guidance, a subject returned to in Key insight 4 (below).

Themes: Current Practice

Key insight 4 Changing practice – exchange

*"The question is not so much **what** data types are shared – but rather **how** data are shared?" Are they known and available to all? Have they been contextualized within the limitations of the techniques and methods for non-specialist users?"*

R037 Quote PID573 Nick Snashall

Participants were strongly positive about potential benefits, including access to more contextual information, better informed decision-making, and demonstrating alignment with environmental policies, of changing work practices to facilitate more data exchange between domains. However, they were equally emphatic that change was dependant on overcoming certain barriers, most importantly unfavourable economic conditions [R132, R324, R339], a lack of technical skills, and insufficient knowledge of data types [R132, R166, R206, R358, R020, R477, R364]. The need for investment by their own organisations in digital infrastructure and relevant staff to support change was also made clear [R132, R020], including the need to provide access to staff with expertise from related disciples or domains [R265]. Participants emphasised the importance of not just finding and accessing data, but also being able to understand, interpret and use data correctly, with several participants pointing out that a lack of data-education can often unintentionally lead to misreading or misrepresentation of data, and their use for unintended purposes [R022, R037, R477]. Access to support to ensure sound interpretation of data was needed to address questions such as how an agriculturalist would benefit from magnetic data collected by archaeologists, or alternatively, how a heritage manager would use yield data to inform a management plan.

"Standards are important, as they make data useful to all…,
and there is a real need to translate data into something usable."

R095 & R097 Quote PID576 Guy Salkeld

Participants overwhelmingly agreed that the availability of good practice guidance and standards would be a significant first step in overcoming their reservations around digital competence and the quality of data use and would be pivotal in making shared data more useable between domains [R095, R097, 499]. Common data guidance and good practice was seen by participants as going hand-in-hand with case studies proving the value of gathering and sharing data; especially with reference to specific data types and applications [R357]. Case studies detailing workflows and analyses were further viewed by participants as opportunities to learn new or alternative methods and workflows concerning both the collection and processing of data form other domains [R176, R245], and coupled with good practice guidance, they are seen important mechanisms to enable changes in practice.

There is a definite desire from data end-users for education on sensing data (types, formats, understanding, use and application), including the provision of sector-specific guidance and use-notes which could empower them to participate more actively in shaping data collection and sharing workflows, encouraging a mind-shift from data-consumption to more active data-production amongst end-users.

Key insight 5: Comfort in current practice

A mix of early-adopters and individuals who prefer to wait for a method or technology to become more mature is expected in any area undergoing significant change. In discussions with this land management community, reasons for hesitation to change current practice included comfort derived from the use of familiar methods, perceived economic risks of trialling new methods, and regulatory requirements linked to data produced through current methods.

At the very least, data collected from the precision agriculture side could help tailor archaeological prospection – ideally, it might guide the choice of techniques for developers, as opposed to just carrying out routine magnetometer surveys of up to 1000ha.

R130 Note PID 535 Paul Baggaley states.

One commercial archaeological-prospection participant explained the impact of comfort with current practices explicitly, noting that developer's reliance on certain established data types and sometimes dated guidance documents contributed to the perpetuation of the *status quo* in prospection methods. They further suggested that in certain situations this hindered the use of improved workflows and results. For example, in archaeological prospection, an insistence on the use of large-scale magnetometer survey in situations where an alternative targeted technique may yield more appropriate results [R134, R136] was linked to comfort with following community norms around 'good practice'. The same individual however, noted that recent national large-scale infrastructure projects have demonstrated an emerging willingness to explore alternative methods and workflows [R137] and that research revaluating archaeological methods is ongoing [R138]. Bringing this together with earlier discussion on the benefits of good practice, we emphasise that to be effective, guidance on good practice needs to be regularly updated, and these updates must be disseminated to data producers and consumers.

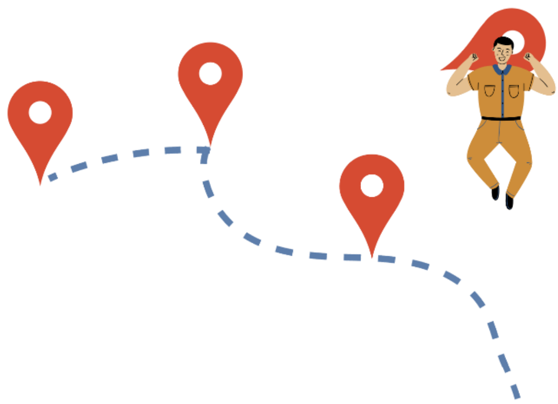
The importance of updated education should be emphasised: disseminating guidance, training, awareness – otherwise it's possible that practice will be fossilized – for example with local government archaeologists through the planning process.

R157 Note PID554 Lisa Brown states.

Agricultural technology trials were also highlighted by participants, and in another parallel, these were seen as predominantly carried out by large-scale farms and estates [R039, R225], as well as through research initiatives to evaluate methods [R161, R175, R299, R231, R270, R504]. The ability to take financial risks was perceived as key to the capacity of larger organisations to trial new methods. Changing regulation was seen by some as a mechanism for broadening shifts in practice [R504]. Many researchers stressed that recent changes in environmental regulation, which encourage the drive to net-zero (carbon) infrastructure, are economically incentivising alternative methods of monitoring and mapping land use and currently presenting more favourable conditions (opportunities) for changing practices across domains [R108, R046]. Recent changes introduced with agri-environment schemes were viewed as presenting improved opportunities for the inclusion of all land management stakeholders in the decision-making process [R021].

However, several participants from agriculture and heritage management noted challenges to changing practice stemming from regulatory policies and bodies and their capacity to support open dialogue and flexibility in implementing practice [R307, R036, R019, R016, R136]. This was exemplified by discussions, with two separate farmers from different regions, relating to restrictions on permitted management techniques in heritage areas which make it difficult to trial alternative practices such as planting different grass species mixtures in pastures, or change/realign farming practice in line with evolving environmental schemes promising financial incentives [R309, R379, R069].

While all participants agreed that community-wide adherence to 'good practice' is necessary to set and enforce working standards, several participants felt a more flexible attitude to their implementation could allow the community to benefit from emerging technological developments and/or evolving environmental regulations through methodological experiments, especially where financial support is available to do so.



Themes: Resource

Key insight 6 Education and funding

When discussing data exchange, participants unanimously agreed that as more data streams become available, more pressure is placed on practitioners to educate themselves and acquire knowledge and digital skills. Training and skills 'needs' expressed included practical training in how to use and extract information from diverse datasets, ongoing learning to keep up-to-speed on what data were available, who held them, and how to access them, and ongoing support to better understand how to interpret different types of data and use them in practice [R476, R454, R478, R440, R391, R154].

"Digital skills are absolutely essential now for helping new young farmers learn to manage their land."

R358 Note PID578 David Lumley

Many participants felt this pressure is compounded at an organisational/institutional level by low staffing levels, increased workloads and little or no access to additional funding, leading many organisations increasingly to seek external partners (commercial or educational for training and/or work collaborations [R226, R448]. Participants agreed that education around data understanding and digital skills would be best assisted by coordinating the embedding of good metadata practices across disciplines through updated best practice guidance and case studies [R157, R484, R486, R495].

Furthermore, it was felt that this could lead to funding opportunities especially if the research potential and/or environmental compliance and economic value of data-exchange could be thereby highlighted [R120, R272, R105]. For example, at least one large national landowner has invested heavily in digital infrastructure with a view to achieving net-zero targets by 2030 [R106].

Many participants were agreed that better access to data-education and funding, coupled with a current trend amongst their respective organisations to collaborate with external partners, research-based or commercial, could led to a wider understanding and use of diverse datasets within or between organisations, essentially stated that fewer data silos would lead to fewer barriers.

Themes: Tech-development

Key insight 7 Proof of value – or overload?

Keen interest in ongoing development of sensors for mapping and monitoring of soil and plant properties was displayed by participants across all sectors. Enthusiasm was tempered equally with major concerns about the reliability of emerging technologies and associated data (often thought that more development is needed), compatibility issues (as already experienced on agricultural side), lack of training, understanding and motivations surrounding the adoption of any new technology and data, as well as associated costs in relation to any potential wins – benefits and/or profit [R514], R345, R204, R508, R338, R356, R183, R409, R357, R512, R228]. In essence, participants felt its worth still needed to be proved.

There is a need to see published case studies of shared data gathering, and proof that techniques from precision agriculture can be useful for heritage management and that these data can be used in a worthwhile way – it's about these case studies that can build confidence.

R357 & R323 Notes PID553 Sarah Poppy states.

In this respect, many participants were also optimistic feeling that, given time and its fast rate of development, technology will provide its own solutions and prove its own worth [R360, R365, R339], for example through robotics, machine learning and artificial intelligence (AI). It was noted how some national agencies have already instigated collaborations on automation tasks within the commercial sector [R448]. Similarly, it was noted that financially attractive 'low cost – low output' systems (e.g. remote monitoring sensors) are becoming increasingly mainstream (especially with the global adoption of IoT solutions), and will appeal to the farming and environmental sectors [R404, R497, R502].

"With long term monitoring, we can move towards prediction and modelling with confidence – increasingly these technologies are going from development to consumer-available, particularly in the last 2 years."

R365 Note PID547 Rachael Wakefield

On the computational side, some participants felt that better statistical and computer modelling techniques could improve the future reliability and quality of associated datasets, for example filling in data gaps in areas of poor coverage or reducing statistical uncertainty [R511, R519, R365]. This chimed with a concern frequently expressed by participants regarding the lack of consistent, high-quality data shared between all sectors, and demonstrates a need for continued and more coordinated research to be undertaken.

The move to web-based services, particularly in agricultural sector, was also seen in positive light, with recent examples being given of large-scale investment by large private landowners moving in a similar direction [R114]. Once again, participants agreed that demonstrating value, through case studies aligned with current shifts in environment polices provide the impetus for funding awards or financial investment – many making the case for joined-up thinking across sectors [R355, R534].

"We also have been trying to work in partnership with other groups and institutions, largely universities – primarily, the way that we've been trying to push things forward is to work in partnership with others who have the expertise that we don't have, so that we can learn from them".

R226 Quote PID513 Kirsty Millican

In summary, participants displayed an optimistic but cautious attitude to technological development, many preferring to wait for convincing demonstration of their value in terms of time and cost savings.

A preference was noted, particularly in agriculture, for 'user friendly' outputs and tools. This preference, coupled with a market which values 'unique' solutions, has resulted the development of 'closed' sensor systems and the dissemination of highly modified data outputs derived from original measurements, which effectively hide sensor specifications and original field measurements from the consumer. This situation restricts the consumer's ability to evaluate data quality, for example by checking consistency or modelling uncertainty, as well as limiting the data's compatibility and re-use value.

Themes: Awareness

Key insight 8 Perception, education and co-ordination

Despite a general level of awareness and understanding across domains of how farmers and archaeologists undertake their work, many participants felt the more could be done to educate practitioners on both sides about broader commonalities between domains. While the group gathered in this project found obvious points of connection through overlaps in technology and data-use, some participants felt more needed to be done to address perceptions of the motivations and objectives that drive each community. For example, some farmers were surprised that the primary objective of archaeological prospection wasn't always excavation but rather an interest in identifying regional patterns of settlement and activity [R394]. Conversely, in was noted that many farmers felt their roles as custodians of the land (heritage and environment) was under-appreciated, and that beliefs that they valued the economic benefits of being 'good farmers' over social and cultural ones [R408, R403] remain widely held. Professional misperceptions such as these were interpreted by participants as a potential barrier to successful collaboration across domains [R216, R493].

"More generally though, I have usually found farmers to value their role in cultural heritage very highly. What farmers mean by the "preservation of cultural heritage" is, from my experience, a broader understanding rather than synonymous with buried archaeology"
R407 Quote PID526 Jennifer Dodsworth

Participants agreed that increased education through co-ordinated dialogue between communities would help ease potential conflicts in understanding and perception, much like the successful discourses between farming and heritage communities of the 1960/70s, which resolved tensions prompted by the introduction of deep-ploughing techniques [R172]. Discourse could be built up around the proposed co-ordination (best practice guidance and case studies) centred on sensing data practices of both domains; again, a 'joined-up' approach seen as necessary to avoid a, perhaps inevitable, duplication of effort [R355]. Interaction with, and input from practitioners and experts from across the board (environment, agriculture, heritage) was stressed by some participants as essential to aligning the aims of respective sectors in a more holistic manner with a view to influencing policy makers at a nation, or even global scale [R534, R539].

Participants displayed varied degrees of awareness of the similarities in sensing methods and workflows between domains (agriculture, heritage, environment). In many cases, the potential of these overlaps hadn't been given extensive thought or hadn't been considered previously. Assumptions regarding the aims of different domains, for example the idea that archaeology is primarily about excavation, may also feed into low levels of awareness of shared practices. Once however, the possibilities of these links were pointed out and mutual benefits established, participants immediately understood the potential value (easy-win) of cross-domain collaboration.

Themes: Social

"The main issue is the lack of profitability of this exercise – no economic purposes from farmers to carry out these data collection activities in the absence of financial incentives, or making collecting this data easier and more affordable by standardising the data collection processes. Financial effect is the key point in all of this."
R324 & R361 Note PID504 James Willoughby

Key insights 9 Economics and Regulations

Participants from the agricultural sector unanimously agreed that economics was the most fundamental barrier to changing practice [R340]. However, most participants from the same sector emphasised that they would be more receptive to change if circumstances shifted and/or economic or other value could be demonstrated. One participant practitioner who was reluctant to use precision farming methods to date stated that if they bought new, unfamiliar farmland then a change in practice may prove worthwhile [R059]. Similarly, another hesitant practitioner stated if equipment costs came down and fuel and fertilisers continued to increase, there would be more economic incentive. A third practitioner stated that they could be persuaded by a farming neighbour's adoption of new methods, again if the benefits could be demonstrated [R049]. This suggests many practitioners are not against change in principle but want a clear demonstration of the benefit – economic or other. Similar sentiments were echoed by commercial archaeological and heritage practitioners [R126], where a downturn in availability of archaeological work (e.g. on large infrastructure projects) would incentivise exploring alternative income opportunities [R127].

Many participants felt there are potential opportunities to demonstrate benefits to changing practice, these centre on identifying commercial opportunities around unmet needs, (e.g. low cost sensors to provide reliable soil (or other) monitoring data to the agriculture and environment sectors) [R497]. One research initiative in Belgium recently demonstrated to land remediation agencies the pragmatic benefits of using calibration data from targeted soil samples with geophysical investigations in devising a 'smart' sampling scheme and reduce costs [R175].

Others felt that the environment is currently the biggest driver of what current data requirements are [R116, R384]; for example, increasing pressures on landowners and farmers to demonstrate compliance with carbon capture and storge regulation is offering alternative incentive to change working practice [R349, R346, R326, R325, R304]. It is agreed amongst many participants that these environmental compliance requirements offer promising avenues towards a more co-ordinated approach from private industry, academia and public sector organisations – but more research is needed [R284].

"There's money for it – if value can be demonstrated."
R120 Quote PID575 Joseph Elders

"There is still a need for a suitable regulatory and policy environment to support these practices [...] within this there is a need for a regulatory framework encouraging best practice in data collection."
R364 Quote PID538 Keith Challis

Economic incentives remain the top priority for almost all stakeholders, regardless of their professional domain, during discussions on the adoption of new sensing data practices. Other important challenges are regarded by participants as more surmountable.

Key insight 10 Communication

"The other thing is to have that common language, or at least to have that common translation between ourselves and the farming side of things as well – [otherwise] why make it harder for ourselves?"
R480 & R481 Quote PID524 Bruce Mann

A recurring theme in discussions with participants was the use of language, in its broadest sense, in communicating the benefits of potential change between domains; for example, the need to use clear, concise, consistent and non-specialistic language in best practice guidance and use-note documents [R480, R481, R528, R524], with applications and benefits (value added, boxes ticked) clearly highlighted and given positive spin [R478]. This encompassed the use of consistent definitions across agencies and domains, especially when dealing with metadata [R422, R035], as well as specifically using the most relevant/recommended ontologies [R418].

Several participants also made the point that not every interaction between domains is digital, and that alternative outputs and language are sometimes necessary to connect to a wider range of audiences linked to land management [R098, R353].

To facilitate open data-sharing between domains, it is necessary to move away from 'gatekeeping' through specialist terminology towards more inclusive language, across general and technical documents as well as in metadata. This includes a real need to describe what practitioners actually do, as well as describing the manner in which these things are communicated, and to align and link glossaries, thesauri, etc..

“We should focus on delivering insight versus delivering data – taking data and turning this into actionable insight. A lot of the time, the issue is around the meaning that is being created based on the data, and the implications this has for [land] management.”

R002 Quote PID538 Keith Challis

4. Conclusions

Are stakeholders informed about the use of remote and near-surface sensing in a broad range of land management applications?

To some extent. Readiness level 3/5. Some stakeholders, particularly specialist technical service providers, are already aware of the applications of the sensing methods they use in both archaeological and agricultural domains, though they often perceived these application domains to be widely separated, rather than closely linked. Almost all stakeholders presented with new information about further applications of sensing for land management quickly grasped the connections between their specific applications and other applications in land management. Few stakeholders expressed strong confidence in their understanding of both the specific requirements of applications across different domains and the range of sensing technologies with potential to meet these.

Barriers

- Training - Insufficient opportunities for education in the technical requirements of different land management domains are available for specialist technical service providers.
- Training – Insufficient opportunities for education about the applications of remote sensing across land management are available within organisations with specific remits, e.g. for environment, heritage, agriculture, or rural economy.
- Language – the need for clear understandable language and common terminology across domains, both general and technical; adopting common standards and technical guidance between domains and translating them into lay-person terms for wider, general audiences will make common data and methods more accessible.
- Technology – It is challenging for stakeholders to keep up to date with new sensing technologies and their applications. Distinguishing between technology hype, unproven applications of sensing technologies and established uses of sensing technologies is particularly challenging as the range of available technology products and services expands.

Opportunities and Actions

- Develop accredited short courses which provide BASIS points for both specialist technical service providers and land management agency staff. Deliver these courses online, at conferences or through established training providers with continuing education programmes e.g. agricultural universities.
- Embed the use of plain language wherever possible in training course materials and advocate for the use of plain language in key data infrastructures, such as the Defra Data Platform, in development or refresh stages.
- Aggregate case studies from sensing technology trials on active community platforms such as FarmPEP or GEO.

Are stakeholders willing to change their practices?

Yes. Readiness level 5/5. Discussions and interviews with stakeholders reveal a high level of interest, positivity and willingness to support, in principle, a more coordinated approach to cross-domain data and workflow interoperability within the land management community. Participants recognised an opportunity and, in some cases, a growing necessity to explore new and diverse data streams and to make changes to their own current practices and workflows which could facilitate data exchange and support diverse applications for mutual benefit across all representative domains (agriculture, archaeology and heritage, environment).

Barriers

- Advocacy - Lack of awareness about the potential benefits of sharing sensing data or the uses of sensing technologies in other domains prevent stakeholders from developing an open mindset about changing how they work with sensing data.

Opportunities and Actions

- Collaborate with working groups within influential organisations such as the Open Geospatial Consortium and the EU Soil Observatory to raise awareness of the benefits of interoperable sensing data.
- Document and disseminate robust information on stakeholder views to build the strategic and business case for providing interoperable sensing data.

Are stakeholders enabled to change their practices?

To a limited extent. Readiness level 2.5/5. Almost all stakeholders were willing to change how they use sensing data and were aware of potential benefits. While this is encouraging, they universally identified multiple barriers to taking action now to begin to produce, exchange and use sensing data differently. Barriers ranged from lack of training to complications imposed by regulation, to financial and licensing constraints. All stakeholders were conscious that they faced multiple barriers at the outset of the project and engagement with others in the ipaast project community typically resulted in the identification of further barriers, as they considered in detail what would be necessary to implement changes in their work with sensing data. As more barriers which constrained stakeholder's ability to make changes were raised, motivation to attempt to make changes decreased.

Barriers

- Training - Many stakeholders stated that, as data users, they would need more training and support to understand how to find and make effective reuse of data produced for a different application.
- Digital Infrastructure - Some stakeholders expressed concerns that they or their organisations did not have access to the necessary technical infrastructure to flexibly acquire and reanalyse sensing data from other domains.
- Data accessibility and control –Discussions with stakeholders in the agricultural sector revealed that the trend toward user-friendly data products and software tools designed to support farm management decision-making based on sensing data is resulting in the original data measurements (raw data) being less accessible. Many agricultural practitioners acknowledged the inability to access these data, which curtails their re-use or re-purposing for other applications, including for environmental and heritage management.
- Data accessibility and control - Agricultural sector stakeholders highlighted data license constraints or lack of clarity around data licensing as a further constraint on their ability to change how they work with sensing data.

- Finance - Some stakeholders stated that when acting as commissioners of data collection projects, financial support would be required to enable them to trial new methods or to cover the costs of collecting higher quality data with greater reuse potential or public benefits, but without added benefits for their immediate application.
- Finance - Some stakeholders felt the size of current agricultural machinery was a significant barrier to flexibility around the spatial resolution of datasets collected, as many farmers feel 'locked in' to their current equipment, which is purchased as a medium-term investment and only enables coarse-scale management interventions.
- Regulation - Many institutionally linked stakeholders stated that regulatory changes or reporting requirements would be needed to be altered to allow them the flexibility necessary to undertake a collaborative cross-domain approach.

Opportunities and Actions

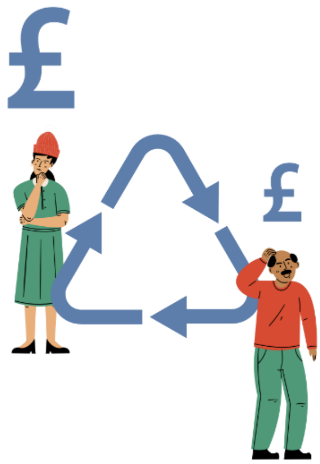
- Develop accredited short courses which provide BASIS or parallel CPD scheme points for all potential data user groups. Deliver these courses online, at conferences or through established training providers with continuing education programmes e.g. agricultural universities and CiFA.
- Work through existing open spatial data initiatives, e.g. those led by the OGC (https://www.ogc.org/innovation/active/), to engage with stakeholders from across land management domains, e.g. sensor manufacturers, data services suppliers, and data consumers and end-users, to promote a culture of expectation that 'raw' data measurements (essential to enabling ownership, quality-control, re-use) are available to end users.
- Collaborate with Demonstrator and Lighthouse farms to trial new sensing methods in a wider range of contexts to build confidence that investment in high quality interoperable sensing data will be good value.
- Collaborate with research engineering groups and equipment manufacturers to pilot retrofitting of agricultural equipment to enable data collection and management interventions at a finer spatial scale.
- Collaborate with research engineering groups and equipment manufacturers developing smaller, lighter agricultural equipment and sensors to build data interoperability into their design at an early stage.
- Provide information briefs on the value of interoperable sensing data and methods and key regulatory barriers to organisations with a track record of effective advocacy related to sustainable land management.
- Raise awareness of cloud platforms and data exchanges which may be suitable for institutional users with limited in-house technical capacity

Are stakeholders motivated to change their practices?

To a very limited extent. Readiness level 2/5. Participants were motivated to attempt change their practice, even in the face of barriers, when they felt empowered to take action as individuals and believed their actions might succeed. However, barriers to changing practices where participants did not feel they could take useful action, for example constraints on practice embedded in requirements set by regulators, were regularly identified. On balance, the obstacles to deriving benefits from changing practice posed by technological, regulatory, and financial factors which participants viewed as beyond their control were perceived to be so significant that they would negate the benefits of any individual action participants could take. Consequently, motivation to take any action is very limited. These extrinsic barriers must be addressed to leverage the willingness of farmers and others involved in land management to explore and coordinate new working practices through their individual actions. In particular, financial support is needed to incentivise and reward changes in how sensing data is used within farming, environmental and heritage management practice.

Barriers

- Finance – Participants regularly cited unfavourable economics, ranging from sunk costs in current equipment, to insufficient payments for implementing sensitive management schemes on high-value land, to the financial risks involved in collecting data which might not lead to improved yields or cost savings through another mechanism, as the greatest barrier to changing practice. Economic viability was the most cited non-negotiable requirement any discussions about changes in practice, most strongly expressed by practitioners in the agricultural sector.
- Proof of concept – To move from being willing to being motivated to take action and change practices, most stakeholders want to see concrete demonstrations of the benefits of cross-domain data and workflow exchange, set in a context similar to their own. The limited number and lack of diversity in demonstrator projects and case studies is a frequently cited reason for not acting to make changes now.
- Regulations - Many landowner and farmer stakeholders were disincentivised from making changes in their sensing data use by the uncertainty and lack of clarity around current and forthcoming regulation, notably the ELMs schemes for UK participants, because it was not clear what data would be required under them.
- Finance – Some stakeholders, particularly farmers and landowners, expressed the view that sensing data have commercial value which should be exploited privately, and that sharing sensing data might competitively disadvantage them in other ways, both of which disincentivise them from taking up open data or data sharing practices.



Opportunities and Actions

- Collaborate with economists to undertake research to assess the full economic costs of the changes in the collection, analysis and use of sensing data needed to support cross-domain interoperability.
- Collaborate with economists to undertake research to assess the full economic value of open archiving of data deemed to have significant potential public benefit on accessible online repositories.

- Ongoing research and industry initiatives create opportunities to produce, publish and disseminate case studies which raise awareness of and provide evidence for the value of FAIR sensing data or community sensing data hubs for land management.
- Collaborate with organisations with a track record for effective advocacy to promote interoperable sensing data as a mechanism to reinforce the recognition of the historic environment, especially archaeological soils, as essential to understanding the contemporary environment. This might include engagement with programme's such as the National Land Data Programme in the UK (https://www.landusedialogues.gov.uk/about-the-national-land-data-programme/).

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Appendix 1 – Summary table: thematic analysis by participant (overall sentiment score, code count)

	Summary - overall 'sentiment score' by theme						*Summary – 'number of codes' by theme*						
P-ID	*User Req-*	*Current Practice-*	*Resource-*	*Tech Devel-*	*Awareness-*	*Social-*	*User Req-*	*Current Practice-*	*Resource-*	*Tech Devel-*	*Awareness-*	*Social-*	*Total*
504	-2	-7	0	0	0	-5	2	9	0	0	0	5	*16*
505	1	2	0	1	0	1	1	2	0	1	0	1	*5*
509	10	7	-1	4	0	-2	21	24	3	12	0	5	*65*
510	5	13	1	2	5	2	19	24	1	4	5	2	*55*
511	0	-1	0	0	4	0	14	10	0	0	4	0	*28*
512	-2	0	0	0	-1	1	8	4	0	0	1	1	*14*
513	0	0	1	1	1	0	2	0	1	1	1	0	*5*
515	5	2	0	0	1	-1	5	5	1	0	1	1	*13*
517	3	4	0	3	2	-1	11	6	0	3	2	1	*23*
518	-1	0	0	0	2	-3	12	7	0	1	2	3	*25*
519	2	3	0	0	0	1	11	3	0	0	1	1	*16*
521	2	1	1	2	0	1	11	7	1	2	3	3	*27*
522	3	-6	-2	0	2	-2	4	10	2	0	2	4	*22*
523	-2	-7	0	-1	-1	0	2	13	1	1	3	0	*20*
524	29	4	1	1	7	11	31	24	8	1	9	12	*85*
525	4	4	0	0	4	7	4	6	0	0	4	7	*21*
526	0	0	0	0	1	1	0	2	0	0	2	2	*6*
527	0	-1	0	0	0	1	0	4	0	0	1	2	*7*
528	0	0	0	0	2	-1	0	5	1	0	2	4	*12*
529	0	-6	0	1	0	-4	1	17	1	1	0	6	*26*
530	18	-4	1	2	4	3	19	26	1	2	4	3	*55*
531	-1	3	0	0	0	-2	2	12	0	0	0	3	*17*
532	0	2	0	0	2	1	0	2	0	0	2	1	*5*
534	5	9	0	2	3	0	16	12	0	4	3	2	*37*
535	0	-1	1	-1	5	0	2	14	1	1	5	3	*26*
538	6	5	0	0	6	3	8	12	2	0	6	4	*32*
542	3	0	1	1	1	1	10	3	1	1	1	3	*19*
544	4	0	0	2	1	0	4	0	0	4	1	0	*9*
545	1	0	0	1	2	4	1	0	0	1	4	4	*10*
547	-3	3	-1	5	3	1	3	6	1	7	3	1	*21*
553	4	0	1	-1	1	0	6	14	3	1	1	0	*25*
554	2	1	1	0	0	0	3	3	2	0	1	0	*9*
555	0	-1	-1	0	0	0	9	6	1	0	0	1	*17*
556	0	0	0	-1	0	0	0	0	0	1	0	0	*1*
557	0	0	0	1	1	0	0	0	0	1	1	0	*2*
558	2	0	0	0	1	0	5	2	0	0	3	0	*10*
560	0	-1	0	1	0	0	2	1	0	1	0	0	*4*
571	-5	-1	0	-1	0	0	6	5	0	2	2	0	*15*
573	-1	-6	-4	0	-2	-7	6	15	6	0	2	13	*42*
574	0	2	-1	0	2	0	5	15	2	0	5	3	*30*
575	6	5	9	1	5	1	18	17	9	1	7	3	*55*
576	-8	-5	0	0	1	3	11	12	0	0	1	3	*27*
577	3	-1	-3	0	2	0	5	4	5	0	2	0	*16*
578	4	2	1	0	1	2	6	8	1	0	1	2	*18*
579	2	1	1	1	0	0	2	1	1	1	0	0	*5*
580	1	2	0	1	2	1	6	3	0	3	2	2	*16*
581	1	1	0	1	1	0	1	1	0	2	1	0	*5*
582	2	-1	-2	-1	-1	1	2	4	2	1	1	1	*11*
583	4	4	0	0	3	1	4	4	0	0	3	1	*12*
584	0	2	0	1	0	-1	0	5	0	1	0	1	*7*
585	0	0	0	-2	1	-1	2	2	0	2	1	1	*8*
Sum	*107*	*33*	*5*	*27*	*74*	*18*	*323*	*391*	*58*	*64*	*106*	*115*	***1057***

Table A1 Left: summary statistics of overall sentiment score (sum of sentiment values) by participant (p-id) and by theme. Right: total number of comments (codes counted) by participant (p-id) and by main theme (user requirements, current practice, resources, technological development, awareness, social).

Appendix 2 – Summary table: thematic analysis by sector, profession and practice (emphatic sentiment score, code count)

Emphatic responses – count of sentiment score greater or equal to '**positive**' threshold value* by theme								
	Themes:	User Req	Current Practice	Resource	Tech Development	Awareness	Social	
	*Threshold values**	*15*	*5*	*8*	*5*	*8*	*6*	*Sum*
Sector	Agriculture	0	3	0	0	0	0	3
	Archaeology	2	2	1	0	1	2	**8**
	Environment	0	0	0	0	0	0	0
	Sensor Development	0	0	0	1	1	0	2
	Social Science	0	0	0	0	0	0	0
Profession	Agronomist	0	1	0	0	0	0	1
	Agtech Specialist	0	1	0	0	0	0	1
	Ecologist	0	0	0	0	0	0	0
	Environment Manager	0	0	0	0	0	0	0
	Farmer	0	1	0	0	0	0	1
	Geophysicist	0	0	0	0	0	0	0
	Heritage Manager	2	1	1	0	1	1	**6**
	Land Manager	0	0	0	0	0	0	0
	Researcher	0	0	0	1	1	1	3
	RS Specialist	0	1	0	0	0	0	1
Practice	Data Non-user	0	0	0	0	0	0	0
	Data Provider (Arch)	0	0	0	0	0	0	0
	Data Provider (PA)	0	2	0	0	0	0	2
	Data User (Arch)	2	2	1	0	1	2	**8**
	Data User (Envir)	0	0	0	1	1	0	2
	Data User (PA)	0	1	0	0	0	0	1
	Platform Provider	0	0	0	0	0	0	0

Emphatic responses – count of sentiment score greater or equal to **negative** threshold value* by theme								
	*Threshold values**	*-5*	*-4*	*-3*	*-1*	*-2*	*-4*	*Sum*
Sector	Agriculture	0	2	0	1	1	2	6
	Archaeology	1	4	1	3	2	1	**12**
	Environment	1	1	1	2	0	0	5
	Sensor Development	0	0	0	1	0	0	1
	Social Science	0	0	0	0	0	0	0
Profession	Agronomist	0	0	0	0	0	0	0
	Agtech Specialist	0	0	0	0	0	0	0
	Digital Archivist	0	0	0	0	0	0	0
	Environment Manager	0	0	1	0	0	0	1
	Farmer	0	1	0	1	1	1	4
	Geophysicist	0	0	0	1	0	0	1
	Heritage Manager	1	5	1	2	2	1	**12**
	Land Manager	0	1	0	0	0	1	2
	Researcher	1	0	0	3	0	0	4
	RS Specialist	0	0	0	0	0	0	0
Practice	Data Non-user	0	0	0	0	0	0	0
	Data Provider (Arch)	0	0	0	1	0	0	1
	Data Provider (PA)	0	0	0	0	0	0	0
	Data User (Arch)	1	5	1	2	2	1	**12**
	Data User (Envir)	1	0	1	2	0	0	4
	Data User (PA)	0	2	0	2	1	2	7
	Platform Provider	0	0	0	0	0	0	0

** Informed by scatter plot analysis*

Table A2 Count of most emphatic participant responses relating to professional background where the sentiment score threshold was informed through statistical analysis (scatter plot) by main theme.