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From relevant to usable: Swedish agricultural extension officers' perspectives on climate change projections

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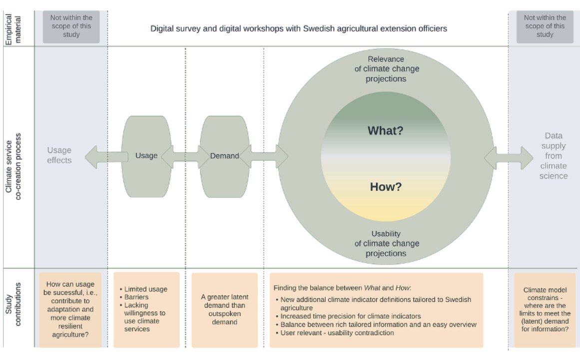
GRAPHICAL ABSTRACT



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ABSTRACT

This study investigates the potential relevance, usefulness, and usability of climate change projections for Swedish agricultural planning and management. Although research indicates the importance of specific users acting as knowledge brokers for climate information, there are knowledge gaps concerning agricultural extension officers' use of climate information. Through a survey and stakeholder workshops, perspectives of Swedish agricultural extension officers on climate change projections were collected. The results provide insights into "what" information in climate change projections that is relevant and "how" climate information may be presented and used. Based on the analysis of the workshop dialogues, four themes outlining the "what" and "how" were identified: (i) a need for additional climate indicators for Swedish agriculture, (ii) the criticalness of temporal precision, (iii) trade-offs between providing precision and an overview, and (iv) a relevance – usability contradiction. These results inform the basis for ongoing research and practical applications focused on agriculturally tailored climate information, as well as the broader development of climate service methodology. The study reveals a latent demand for climate change projections among respondents, indicating a perceived relevance of information on future climates, but limited current use and usability among agricultural extension officers. The requisite for tailored climate indicators is clear – in this case, for Swedish agricultural planning and management – but critical usability challenges need to be addressed to move from providing relevant information to achieving actual usage that can enhance the climate resilience in Swedish agriculture.

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Practical implications

To understand the climate change challenges for society and nature, estimates of future climates are modelled for various emission scenarios and land use practices. Such estimates of possible climate futures are referred to as climate change projections, with time horizons typically ranging from 10 years in the future to the end of the century. National and international climate services provide data and information for different climate variables and indicators based on such projections. A major concern, however, is how to make the data and information from climate change projections relevant and useful to various stakeholders, as well as in decision-maker contexts. Furthermore, it must be considered usable by the practitioners or decision-makers that stand to gain from the information.

This paper contributes with knowledge that supports a continued development and co-creation of climate services based on experiences from the Swedish agricultural sector. Specifically, Swedish agricultural extension officers' perspectives regarding if and how climate information from climate change projections can be relevant, useful, and usable has been studied. Swedish agricultural extension officers responded to a digital survey ($n = 67$) and participated in digital workshops ($n = 12$) on climate information with a focus on climate change projections to support agricultural management and planning in Sweden. Transcripts of the workshop dialogues were qualitatively analysed for key themes and characteristics, and the results were complemented with descriptive statistics of the survey replies.

The survey results demonstrate that climate change projections are not often used among the respondents, but a high future demand for climate change information was reported (regarding both historical observations and projections of future climate scenarios). These survey results along with the results from the stakeholder dialogues indicate that there is a current *latent demand* for climate change projections among Swedish agricultural extension officers – meaning that information is seen as relevant but not used. Furthermore, based on the workshop dialogues, this study presents four themes on how extension officers in Sweden see climate change projections as relevant and useful for agricultural planning and management as well as barriers and challenges for usage:

(i) *Additional climate indicator definitions and scopes.* The workshop dialogues on climate risks in agriculture, as well as discussions supported by the exploration of the national climate change scenario service in Sweden (SMHI, 2021), revealed various climate variables and indicators relevant for agriculture. Out of these, there are several indicators and variables additional to the ones available in the national climate scenario service (SMHI, 2021) and the agroclimatic indicators in Copernicus Climate Change Service (Nobakht et al., 2019). This paper presents definitions of additional meteorological and hydrological indicators that represent those climate characteristics seen as agriculturally relevant by the extension officers, but which are unavailable in any service found in Sweden today.

(ii) *The annual precision of the temporal aggregation of data from climate models is critical.* Seasonal aggregations (as meteorological indicators are presented today by the Swedish climate change scenario service) were generally described by the extension officers as too long for the indicator to be relevant and useful. Even if an indicator was discussed as relevant per se, it was reasoned that its relevance and usefulness is diminished if presented as a seasonal value. Indicators should preferably provide enhanced information about the timing of climate characteristics to assess possible agricultural risks and needs for adaptation actions in management and planning.

(iii) *A need to balance between an easy overview of climate information and detailed contextualised climate information in services.* The extension officers discussed that too many indicators in a climate service would make it difficult to acquire an overview of the climatological characteristics relevant for the user in question as well as interpret the combination of relevant indicators. However, regarding the complex nature of climate change and agricultural interacting aspects, several indicators, both general and agriculturally tailored, were considered necessary to understanding the agricultural climate change risks.

(iv) *A relevance – usability contradiction among Swedish agricultural extension officers.* The results indicate that there are not only gaps between what climate information providers and users understand as useful climate information, there also seem to be contradictory perspectives among agricultural extension officers themselves, which complicates the climate service gaps. The overall results of this study show that agricultural extension officers in Sweden regard climate information, including climate change projections, to be relevant information that needs to be incorporated into agricultural management and planning and hence relevant for them as extension officers. Nevertheless, the results also suggest that several barriers decrease the usability of climate change projections, implying a contradiction where the information is considered relevant but not usable. The key barriers include an inadequate ability to interpret the climate change projections, communication challenges concerning data uncertainty, and an unwillingness and lack of time to use a climate service.

The identified need for additional climate indicators, as well as the usability barriers, need to be dealt with from both scientific and societal perspectives. Based on the conclusions of this paper, expert authorities are encouraged to support capacity building and knowledge-brokering actors in increasing the usability of climate change projections at different levels of society. Specifically, this appear to be a necessity for the Swedish agricultural sector where practitioners currently lack the capacity and time, and to some extent also the willingness, to engage with climate change projections.

Data availability

Data will be made available on request.

Introduction

In light of the necessity to sustainably mitigate and adapt to climate change, there has been a substantial development of climate services and mounting research in the field (Boon et al., 2022). Key features of climate services involve the generation, interpretation, transmission and application of climate information and knowledge that respond to the needs to support planning and decision making in society (Filho, 2020). Although the research community has since the development of the Global Framework for Climate Services (GFCS, 2014) argued for making climate services more relevant and useful to stakeholder needs – namely to provide user-driven and science-informed services with data and information that is 'actionable', 'context specific' and 'tailored' – the 'usability gap' (Lemos et al., 2012) and disconnect between provision and usage still appear to exist (e.g., Findlater et al., 2021; e.g., Larsen et al., 2021). This study analyses this potential disconnect with a focus on Swedish agriculture.

Climate services can include information about the past, present, or future conditions of the climate system and be based on observations and model simulations for various time horizons. Historical observations generally tend to be more frequently used and are regarded as more reliable and interesting by end-users compared to climate change projections (Bruno Soares and Dessai, 2016; Tart et al., 2020). Nevertheless, climate change projections, which "*are estimates of the evolution of possible future climates* [>10 years ahead] *under the assumption of future emission and land use activities (for different policy scenarios)*", are crucial to understanding, identifying and addressing the societal challenges associated with climate change (Hewitt et al., 2021, p.580). Based on previous research, Larsen et al. (2021) summarise that non-expert users of climate change projections typically demand services with data that are reliable, easily understandable and directly applicable. However, the character of projected climates, with its built-in uncertainties, assumptions, and complexities, makes it challenging to meet such needs. Some of the barriers could nevertheless be overcome by knowledge-brokering functions, partnership networks or community platforms, as these are means to bridge gaps between stakeholders of climate science, policy and practice (e.g., Gerger Swartling et al., 2019; Jacobs and Street, 2020).

In addition to the challenges related to the disconnects in the climate service processes, cross-regional and sectoral provision of climate services are uneven (Larsen et al., 2021). Climate services for the agricultural sector, generally object to increase understanding of weather and climate risks and, hence, support planning and decisions that reduce the risks associated with climate impacts in agriculture (Vaughan and Dessai, 2014). The upcoming growing season is often in focus (Born et al., 2021) since short-term information (seasonal, or sub-seasonal forecasts) is regarded as particularly valuable and in demand for agricultural management to inform decision-making (e.g., Mittal et al., 2021; Steynor and Pasquini, 2022). Concerning climate change projections, some barriers for usage have been suggested in previous research (e.g., Nissan et al., 2019; Steynor and Pasquini, 2022), but the potential relevance, usefulness and usability of longer term (>10 year) climate projections in support of agricultural planning and management remain understudied.

In terms of the regional scope, agricultural climate information and services have been extensively studied in relation to developing countries and climate vulnerable regions (Mittal et al., 2021; Steynor and Pasquini, 2022); however, concerning Northern Europe, research on climate services and climate information with respect to agriculture is lacking. Research on climate services for developing countries with critical climate impacts will continue to be crucial, but the limited knowledge for regions that are less vulnerable to climate change, such as Sweden, need to be addressed. Climate change may lead to shifts in the spatial distribution of global agricultural production, necessitating increased and sustainable production in regions less affected by climate change.

The most recent assessment report by the IPCC stresses the need for a better understanding of the value of climate services, particularly indices (in this paper 'indicators') of climate impact drivers (Ranasinghe et al., 2021). It is therefore crucial to comprehend how the specific climate indicators of projected climate change can represent agriculturally relevant characteristics that could support planning and decision making to increase agricultural climate resilience in Sweden.

The specific aim of this study is *to understand if and how information from climate change projections can be relevant, useful, and usable with respect to agricultural planning and management*. The analysis was conducted in the Swedish agricultural context for which the perspectives and experiences of extension officers were collected and analysed to gain insight about their usage of climate information and demand for climate change projections.

The values of co-creation on and for the development of climate services are commonly recognised (e.g., Máñez Costa et al., 2021). IPCC states that the demand for climate information could be met by engaging stakeholders in the identification and prioritisation of climate indicators concerning relevant thresholds for regions and sectors as well as the types of metrics (i.e., magnitude/intensity, frequency, duration, timing, spatial extent) (Ranasinghe et al., 2021). In agriculture, advisors, consultants, and extension officers (henceforth collectively referred to as *extension officers*) are important stakeholders who support farmers in their planning and management (cf., Stuart Carlton et al., 2014) and are therefore potential climate information users in their role as knowledge brokers to facilitate, mediate, and transform information between climate science and agricultural practice. Agricultural extension officers along with their associated climate information demands have previously been studied (e.g., Haigh et al., 2018), but not to the author's knowledge regarding Sweden or Northern Europe. As agricultural experts, the perspectives of extension officers concerning planning, management, and climate-related risks are crucial for the co-creation of knowledge communicated through climate services and for the identification of climate information that aligns with contexts and needs of Swedish agricultural practice. The engagement with extension officers in this study, thus, serves both as a specific user case as well as to represent ranging perspectives in which climate information can support agricultural planning and management.

Materials and methods

Data were collected through a nationwide digital survey and six digital workshops with Swedish agricultural extension officers. Both data collection methods were used to gain insight about Swedish agricultural extension officers' perspectives on their usage and demand for climate information, with particular focus on climate change projections. By employing this mixed method approach, a relatively wide range of experiences and perspectives from the user group could be combined with in-depth workshop dialogues to achieve a deeper understanding of the questions under study.

Survey

The survey was distributed and collected digitally during the summer of 2021 (June-Sep). The survey was intended to target all practitioners working in the extension branch of agriculture in Sweden. E-mail addresses were manually compiled from the websites of agricultural agencies, organisations, and consultant bureaus. An initial e-mail with a link to the survey was sent to agricultural extension officers across Sweden (n = 371) in June 2021, with a follow-up reminder two weeks later. The survey was created and collected using the software Survey&Report (Artologik, n.d.) with anonymous replies publicly accessible to the respondents via a distributed link. The survey is, to the author's knowledge, the first climate service survey targeting the Nordic agricultural sector and extension officers specifically. Nevertheless, similar surveys have been conducted for other regions or user groups, e. g., Bruno Soares et al., (2018). Drawing inspiration from Bruno Soares et al. (2018), the survey included questions concerning respondents' current use of various climate information types (including historical observations and simulations for different time horizons), the importance of these information types in their professional roles, anticipated future demand, and preferences for different formats and time period.

The questions were closed-ended with the option to make comments. The survey was created with built-in rules to skip certain survey items or navigate to a separate question based on previous replies. For example, only respondents who replied that they never use historical climate data or climate change projections in their profession were directed to a question regarding the reasons for not using such climate information. The survey was in Swedish, but an English translation of the questions together with summaries of the replies are available in the *Supplementary Material*. The survey results served as input for designing the workshop meetings and also contributed to the overall findings of the study. The responses were processed and descriptively analysed using IBM® SPSS® Statistics and Microsoft Excel for descriptive statistics and charts. Only the quantitative data from the survey was included in the analysis and results of the present study.

As a final question of the survey, the respondents were to reply if they were interested in participating in digital workshops on climate information for the Swedish agricultural sector. If they responded "yes" to that question, they were directed to a separate 'interest form' (to assure anonymity in the survey replies).

A total of 67 respondents participated in the survey. The characteristics and background of the respondent sample are presented in Table 1 based on their responses. While agricultural 'extension officers' were targeted for the survey, 22.7 % (n = 15) replied that they were also farmers themselves.

Workshop dialogues

In autumn 2021, a total of six digital workshops were conducted via digital video meetings. The set-up of the workshops (Fig. 1) consisted of a sequence of two meetings with three parallel groups, approximately two months apart. In total, 12 extension officers (potential climate information users), two climate scientists (climate information providers) and one moderator (the author of the paper) participated in the workshops.

The agricultural extension officer participants were recruited via email from the list of contacts in the interest form conducted via the digital survey. In total, 35 respondents replied (June-Aug 2021) and confirmed their interest. All of them were contacted with a follow up email at the end of August and 13 of them signed up for suitable times. Finally, 12 participants (six males and six females) were able to join the first workshop meeting. The workshops were conducted digitally (due to the Covid-19 pandemic), and to enable and facilitate good dialogues among the participants in the digital video meeting format, the participants were divided into three separate workshop meeting groups. The grouping was based on participants' availability and with the objective to be gender balanced. The extension officers came from different regions in Sweden; eight from southern parts (Götaland), two from the middle (Svealand) and two the north (Norrland). Five of them were working at different County Administrative Boards in Sweden and the others worked at private consultant agencies or agricultural organisations. The participants' areas of expertise encompassed crop production, plant protection and nutrition, biodiversity, nature conservation, pastures and meadows, animal welfare, organic production, environmental advising, and food quality.

The workshop meetings were 2 h each. The setups for the first and second meeting were the same for all three groups. The first workshop meeting started with an introduction of the research project, background on climate change projections by the climate scientists, and a presentation of the preliminary results of the survey. Thereafter, the participants were asked to reflect upon, note down (using the tool Menti.com) and discuss climate risks that they regard as requiring agricultural adaptation, thus affecting their planning and management.

Approximately two months later, the second round of workshop meetings (also 2 h) were held in the same groups as meeting one (with two participants unable to participate in the second meeting). While the first meeting was open in its character within the scope of climate risks and adaptation in agriculture, the second workshop was designed to focus specifically on information from climate change projections.

The Swedish national climate service provider, The Swedish Meteorological and Hydrological Institute (SMHI), had at the time of the workshop launched a new climate change scenario service (SMHI, 2021). SMHI has long experience in climate modelling and communication with a range of different user groups to meet their needs (Kjellström et al., 2016). Their service includes climate change scenarios for RCP2.6, 4.5 and 8.5 until year 2100, presented for various climate indicators at county scale as maps, diagrams and downloadable data (SMHI, 2021).This newest version of the climate service builds upon the foundation laid in Kjellström et al. (2016), where the precursor to the current version is presented.

The SMHI climate change scenario service was used as a basis for the second workshop discussions on relevant and useful information in climate change projections for agricultural management and planning. The participants received a short introduction to the service followed by some time to test the functionality and ask questions to the two climate scientists (information providers). Subsequently, the focus was on discussing the climate information included (and not included) in the service and their relevance in relation to agricultural risks and adaptation needs and usability for them as extension officers.

The dialogues were audio-recorded, and the recordings transcribed verbatim. Transcripts were treated as one joint material with no intention to make, for example, demographic comparisons. Due to the workshop meeting design, the material includes user perspectives from both pre- and post-experiences of exploring and being introduced to the SMHI climate scenario service.

Thematic analysis was conducted for this qualitative data (e.g., Braun and Clarke, 2006; Kvale and Brinkmann, 2014). After familiarising with the material, the transcripts were inductively coded based on the study objectives (using the software NVivo 12). The codes were sorted into potential themes which were subsequently revisited in relation to the coded material. The analysis resulted in a set of themes that were defined and named (Braun and Clarke, 2006).

Since much of the workshop dialogues centred around climate risks and climate aspects covered in climate change information, all climate aspects, variables, indicators, and indices mentioned by the extension officers from all meetings were coded and analysed. While the participants discussed potentially relevant climate change projection information, they rarely spelled out specific definitions of indicators including, for example, defined thresholds. However, climate variables and indicators[1] could be identified (with varied levels of details) from their raised perspectives. The synthesis of the defined climate indicators from the dialogues was analysed in relation to the available climate indicators in the SMHI climate change scenario service (SMHI, 2021) and the agroclimatic indicators in Copernicus Climate Change Service (C3S) (Nobakht et al., 2019). These two lists of indicators are relevant for comparison since SMHI is the Swedish national climate service provider and the authority that Swedish stakeholders probably turn to first, and their climate change scenario service is openly accessible to anyone. Similarly, at the European Union level, C3S has the central role of climate information provision and includes an official list of climate indicators for agriculture on that regional scale.

Limitations

While the SMHI climate change scenario service served as a foundation in the second workshop meetings and was used for comparison in the analysis, it is not specifically customized for agriculture due to its nature as a national climate service. Nevertheless, using it as a base enabled discussions on how information from climate projections could be transformed to become relevant and usable for agricultural management and planning. A discussion in such close association to climate projections would be difficult to achieve with non-climate-experts without support from existing information. The fact that two climate modelling scientists participated in the workshop, providing background information on climate modelling and scenarios and being available in the discussion on relevance and demands, enabled valuable co-learning among the climate scientists and extension officers and probably increased the legitimacy of the workshops. It is, however, not within the analytical scope of the present study to analyse the co-learning process as such. No transcripts from the climate scientists' inputs were included in the analysis or results presented in the paper.

[1] The term climate 'indicators' is in this study used synonymously with climate 'indices' (Wiréhn, 2021), which can be described to characterise and quantify one or several aspects of climate phenomena, including climate impact drivers and extremes (IPCC, 2021). The term 'indicator' is used in both the SMHI climate change scenario service (SMHI, 2021) and the Copernicus Climate Change Service (C3S) (Nobakht et al., 2019).

Table 1
Characteristics and background about the 67 (n) respondents that participated in the survey.

Inquired information	Statistics to background questions (multiple choice options)					
Gender *n = 67*	**Female** 58.2 % (n = 39)	**Male** 40.3 % (n = 27)	**Other** 1.5 % (n = 1)			
Age *n = 65*	**22–32 years** 18.5 % (n = 12)	**33–43 years** 20.0 % (n = 13)	**44–54 years** 27.7 % (n = 18)	**55–65 years** 32.3 % (n = 21)	**66–76 years** 1.5 % (n = 1)	
Where in Sweden are you active? *(Multi select)*	**South (Götaland)** 76.1 % (n = 51)	**Middle (Svealand)** 25.4 % (n = 17)	**North (Norrland)** 7.5 % (n = 5)			
Among which category of agriculture are you active? *(Multi select)*	**Crop production** 61.5 % (n = 40)	**Animal husbandry** 41.5 % (n = 40)	**Horticulture** 20.0 % (n = 13)	**Economy** 20.0 % (n = 13)	**Construction** 7,7 % (n = 5)	**Other** 13.8 % (n = 9)

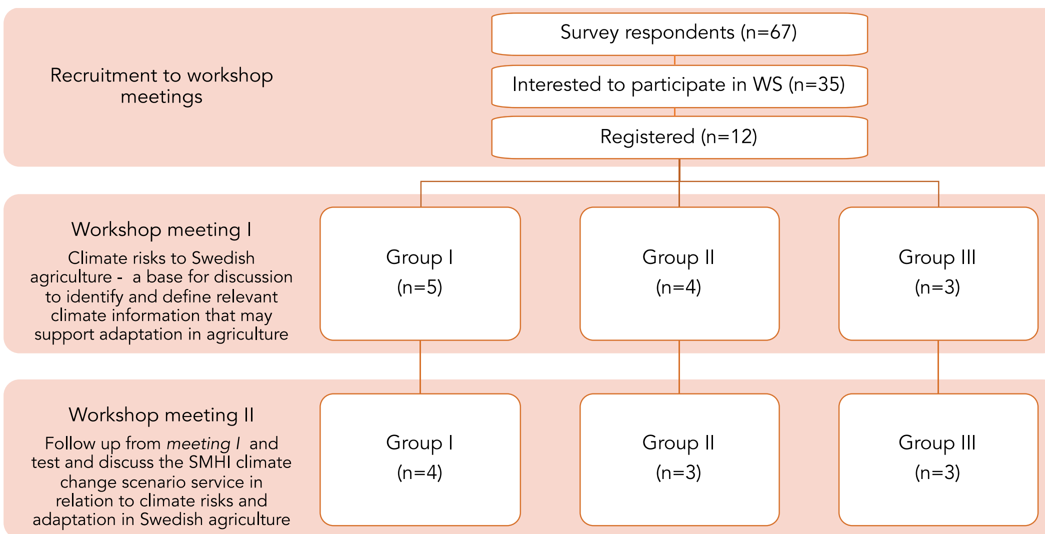

Fig. 1. Recruitment and set-up for digital workshop meetings on climate information for Swedish agriculture with agricultural extension officers in Sweden, held in September (meeting I) and November/December (meeting II) 2021. In both meetings and all groups, two climate model experts and one moderator (the author of this study) participated (not included in the number of participants in the figure).

Since the study endeavored to reach out to *all* available Swedish extension officers in Sweden for their input through the survey and subsequently invited the survey respondents to voluntary participate in workshops, it is important to acknowledge the possibility of a certain bias in the sample composition due to the self-selection process inherent in voluntary participation. Extension officers who have a specialized concern or expertise in the climate change – agriculture interface may be more motivated to engage in both the survey and workshop, which could lead to a final sample composition skewed toward individuals with this interest. While this limitation is acknowledged, the survey respondents and workshop participants include a broad and consistent representation of gender, regions, and agricultural branches for Swedish

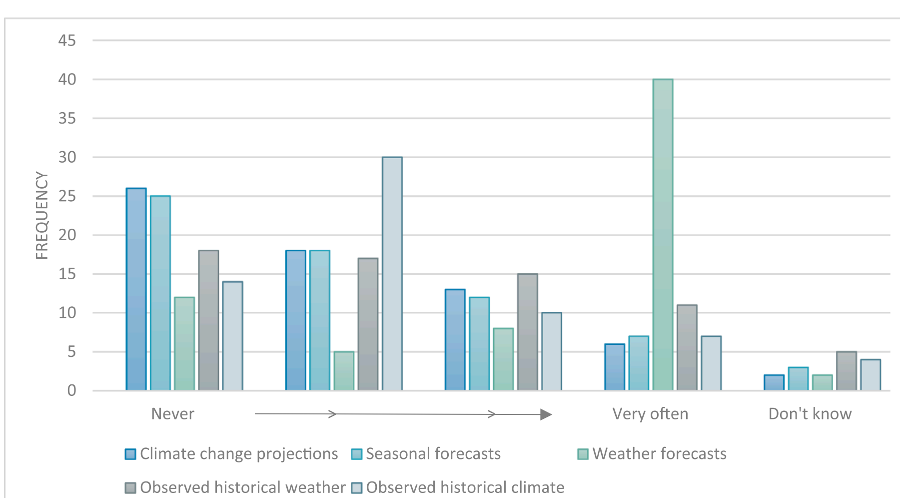

Fig. 2. Frequency of responses to the question on what type of weather or climate information respondents currently use in their profession.

agricultural extension officers, and thus still offers valuable insights into the perspectives of the participating extension officers regarding climate change projection demand and usage.

Results

Survey results - usage and demand among Swedish extension offices

The respondents were asked what type of weather or climate information they *currently* use in their profession, and the results show that weather forecasts are the most common type of information used among the respondents (Fig. 2), whereas climate change projections are the least used. On the four-point Likert scale ranging from 'Never' to 'Very often' using the information, 26 (40.0 % of the respondents to that question) replied that they never use climate change projections. While only six respondents use climate change projections 'very often', 52.5 % (n = 21) of the respondents that replied that they have used projections at some point (n = 40,) regarded the information as very important to their profession (see, Supplementary Material). Conversely, two respondents that use climate projections responded that they do not regard the information as important in their profession.

The respondents who answered that they do not use climate change information at all in their profession were asked to motivate their reason. Very few responded to this, and interpretations on trends and patterns cannot be drawn based on the small sample size. Nevertheless, the results do indicate a diverse set of views among the respondents regarding the reasons for not using the information (Fig. 3).

All respondents were asked if they see a future demand in their profession for information specifically regarding climate change, regardless of whether they use such information today. The answers present a tendency where respondents see a demand or even a great demand for climate change information in their profession, which contrasts with current usage that has the opposite tendency. Fig. 4 illustrates this disconnect between the current usage and the foreseen demand among extension officers.

Climate change projections – Relevant and usable?

The workshop dialogues revealed insights into the extension officers' perspectives on whether and how climate change projections are perceived as relevant and usable for supporting agricultural planning and management. The thematic analysis revealed four key themes outlining "what" information in climate change projections that is relevant for agricultural extension in Sweden and "how" climate information may be presented and used. The themes include (i) a demand for *additional climate indicators* relevant for Swedish agricultural management and planning; (ii) a criticalness of high *temporal precision* for indicators of climate projections to be relevant; (iii) contradictions and trade-offs concerning the possibilities and limitations in order to provide both an *overview and precision* in the information provided by the many indicators included in the climate service; and (iv) a *relevance-usability contradiction* suggesting that extension officers find the information relevant but not usable. The first two themes center on the question of identifying relevant data and information in climate change projections for agricultural extension, while the latter two themes address the presentation and usage barriers of this information. Each of these four themes are described in detail in the subsequent sections.

Additional climate indicators

Many possible risks, challenges, and possibilities were discussed in relation Swedish agriculture under climate change, both concerning specific as well as interconnected aspects of climate and weather events. Climate indicators were identified based on extension officers' input to the workshop dialogues. Several of the identified indicators were shown to be 'additional' relative to those included in the advanced climate change scenario service by SMHI (2021) and the agroclimatic indicators in Copernicus Climate Change Service (Nobakht et al., 2019), see Table 2. Overall, the climate variables discussed included temperature, precipitation (rain, snow, hail), wind, humidity, water runoff and ground water. While several indicators for temperature, precipitation and runoff exist in the two compared climate services, the identified additional climate indicators represent complementary aspects. Humidity was mentioned as a relevant variable that influences crop productivity and different associated risks such as drought and fungal diseases, but it was limitedly discussed and no specific indicator for humidity was specified.

Additional indicators for temperature concerned the demand to understand the risk of frost damage, wintering problems, heat stress, as well as general crop growth potentials. Regarding the latter, participants called for an indicator with degree days for the growth period. Moreover, high temperatures, and especially the *duration* of high temperatures, were discussed as creating challenges with heat stressed plants. In contrast to heat stress, frost damage was also discussed as a risk where an indicator could be the number of frost days or zero crossings specifically for the period after the onset of the growing season. 'Zero crossings' for different winter periods were of interest rather than the provision of an aggregated annual value for the indicator. Generally, fluctuations in temperature for the winter and early growing season were raised as a risk for crop production in terms of wintering crops and frost damage. Accordingly, participants addressed the relevance of an indicator including the number of events with a period of consecutive days with a minimum temperature significantly above zero followed by

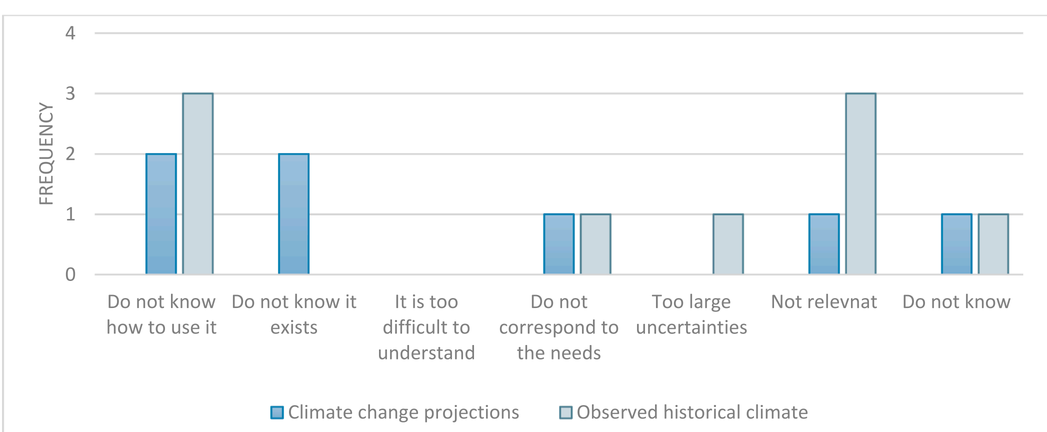

Fig. 3. Frequency of responses (n = 9) to the single-select, multiple-choice question regarding the reason why respondents do not use climate change information. This question was exclusively presented to respondents who indicated that they never use climate change projections or observed historical climate data.

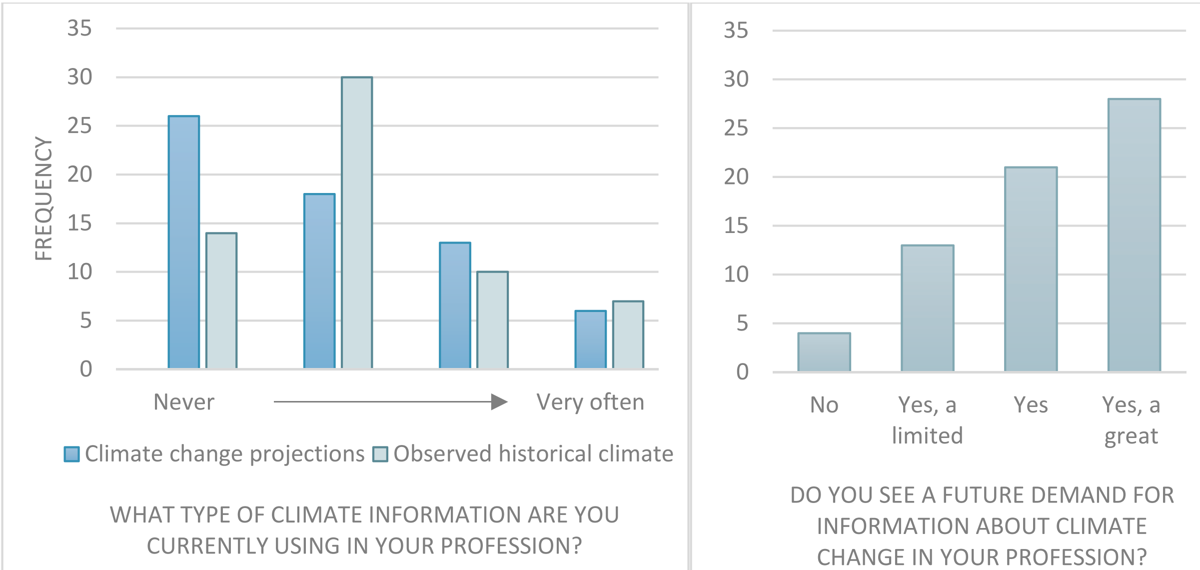

Fig. 4. Current usage (left) and foreseen demand (right) for climate change information by Swedish agricultural extension officers who responded to the survey.

a period of consecutive days with temperatures below zero (or vice versa in autumn).

In relation to precipitation, snow cover and the relevance of information concerning decreased prevalence and periods with snow cover were raised. It was suggested that an indicator with such information should include a snow depth threshold to represent the snow cover limit that is sufficient to protect the crops from frost damage and wintering problems. The indicator would also advantageously be combined with temperature to represent periods that lack snow cover in combination with cold spells. The participants did not mention any specific thresholds for the snow cover indicator, but the late winter period was argued to be especially relevant in relation to frost damage risks since crop sensitivity is the highest during that time.

Information demands concerning precipitation were commonly mentioned in relation to drainage management and specifically the planning of drainage dimensioning. Intensive rain during a period of consecutive days was raised as an indicator in relation to drainage dimensioning. Such intensive rain would not necessarily have to be "extreme" but only intense enough to cause problems to transport water away from fields and hence cause a risk of yield loss. It was emphasised that the feature of *consecutive days of raining* would be central to such an indicator. In relation to the need to adapt drainage dimensioning, an indicator with surface runoff of water was also emphasised. Surface runoff was mentioned as an important variable in understanding the risk of not being able to drive on the fields due to buoyancy problems and soil packing during the most important cultivation periods of the year – spring and autumn.

Another type of precipitation, hail, especially in combination with wind, was presented as an aspect that influences the risk of crop lodging in fields. The combination of heavy rain and wind were also mentioned as posing lodging risks; however, wind speed levels, rain loads or the combinations of these that cause lodging were unknown. Moreover, wind was discussed as a climate factor that influences the agricultural conditions and practices in different ways. For example, wind was discussed in relation to spray management, in terms of, e.g., safety distances, techniques, or the possibility to spray. While the information demand in terms of spray challenges were described as more concerned with weather information than climate projections, significant changes in wind conditions would be important to understand and plan for. The wind speed limits from the spray guidelines and regulations were suggested to be used as thresholds for such indicators. Other discussed wind-related challenges concerned damages to, for example, grazelands as well as the risk of wind erosion (especially if wind events occur when soils are bare). Furthermore, an indicator combining temperature and wind was desired to assess risks related to plant evaporation or drought. For drought risk assessments, the relevance of humidity and ground water levels were also stressed.

Much of the discussion on relevant climate information concerned the frequency and intensity of extreme weather events. The combination of different types of extremes were emphasised as particularly challenging for agricultural production both in terms of direct agricultural losses and effects on already implemented adaptation measures, such as the planting of trees on grazeland. Indicators that cover the frequency of different combinations of extremes, e.g., wind, water runoff, temperature, and precipitation during a defined period of time were suggested as useful and relevant to increasing the knowledge of these risks and understanding the need for preparedness.

Temporal precision

The precision of time for climatic aspects, hence the time-period characterised by the indicators, was a central issue in the workshop discussions. Specifically, it was discussed in relation to the usefulness and relevance of different indicators (as meteorological indicators in the SMHI service are aggregated per season or year). Although the participants regarded indicators as relevant in terms of the climatic aspects covered, the discussions implied that the temporal aggregation per season or year diminishes the usefulness of the information since the annual timing of the climatic aspect is hidden. The discussions suggested that the level of temporal data aggregations is critical to ensuring that the indicators of climate change projections are relevant and useful. Too long a period of data aggregation was described as problematic; for example, if a precipitation indicator demonstrates an increase during the spring season (MAM), it is still not possible to reveal "when" during the spring period the increase is projected. While indicators with seasonal aggregation were generally regarded as too long, one participant mentioned that even monthly periods would be too long, for example, to be able to explore projected precipitation changes throughout the vegetation period [WS2G3]. The same issue was asserted by another participant, saying that the precision in time, specifically in relation to precipitation indicators, should ideally correspond to periods of spring farming operations and harvesting – "[…] *the period of spring farming operations is quite…, at least here* [Northern Sweden]*, a fairly short period. It's the end of May, the beginning of June, then it's over. So that… that's the precision I'm looking for.*" [WS2G2].

Table 2
Agriculturally relevant climate variables and indicators, additional to those available in the Swedish advanced climate change scenario service (SMHI, 2021) and the agroclimatic indicators in Copernicus Climate Change Service (Nobakht et al., 2019).

Climate variable/s	Climate indicator (climate aspect represented)	Relevant in relation to:	In WS meeting
Precipitation (rain)	Consecutive days (>2 was suggested) with intensive rain (magnitude not defined)	Intensive raining (not only extreme) affects the required drainage dimensioning, to avoid yield loss.	I
Precipitation (hail)	Occurrence of hail	Risk of lodging on fields	II
Snow	Snow coverage, or lack of snow coverage in combination with temperature < 0 °C	Lack of snow cover in combination with cold periods → wintering problems in crop production (winter crops). Highest crop sensitivity during late winter. Decreased snow coverage → risk of frost damage	I and II
Humidity	–	Fungal disease risk	II
Humidity	–	Drought risk	II
Temperature	Temperature < 0 °C after start of the growing season (for example degree-days > 400 with a 3–4 °C threshold)	Frost damage on crops; Wintering problems	II
Temperature	Degree days; temperature sum for daily mean temperature > 5 °C	Crop growth potential, crop types and species potential	II
Temperature	Zero crossings during one or several defined winter and spring periods	Winter temperature variation → wintering problems in crop production (winter crops). Highest crop sensitivity during late winter	I
Temperature	Consecutive days (7 days was suggested) with temperature ≫ 0 °C followed days with temp < 0 °C	Significant temperature fluctuations in spring and autumn → crop damage. Earlier start of vegetation period plus frost in May → negative effects on crops.	I
Temperature	Consecutive days (number not defined) with daily mean temp > 20 °C	High temperatures (especially in combination with wind and drought) → risk of heat stressed plants.	I
Runoff	Surface runoff - excess of infiltrated water to the soil	Drainage capacity requirements	II
Ground water levels	—	In relation to drought events, access to ground water becomes important	II
Wind	Intensity and frequency of extremes	Storm damage on grazeland (e.g., diminishes the effects of planting trees as adaptation to heat); wind erosion (when soils are bare).	I and II
Wind	Days with daily wind average > x m/s, where x are thresholds for which large safety distances or wind reducing techniques are required	Agricultural sprayers for pesticides cannot be used without certain additional technical material/shields above certain thresholds.	I
Wind	General tendencies	–	II
Wind, soil moisture	Mean wind intensity for periods with bare soils, before the root formation, and in combination with drought (low soil moisture)	Wind erosion	I
Wind, precipitation	The occurrence of wind and precipitation (with defined thresholds) simultaneously	Risk of lodging on fields	II
Wind, temperature	Evaporation index that includes wind	Increase in plant evaporation can become a problem	I
Wind, temperature	The occurrence of the two (with defined thresholds) simultaneously	An indication of drought risk	II
A combination of different variables	The frequency of extremes (including different types such as storm, flooding, drought, heavy precipitation)	Direct agricultural losses as well as effects on implemented adaptation measures. Crucial for crop production.	I and II

The same discussion emerged in relation the existing indicators ‘longest dry period’, ‘longest heat wave’ and ‘number of frost days’ – namely that it is essential to understand when, for example, during the vegetation period, that heat waves or dry periods will generally occur. Heat and drought stressed plants were considered important aspects, but specifically, the *timing* of high temperatures and/or drought was emphasised as the critical aspect concerning the risk of plants being stressed, resulting in negative effects on production. This overall demand for data aggregations on shorter temporal periods can be exemplified with one of the comments on the ‘number of frost days’ indicator (with an annual aggregation in the SMHI climate service): *“[…] once again, when is it happening? That’s what’s critical.”* [WS2G3].

In relation to the discussion on indicators’ temporal precision in time, all workshop groups, independently of each other, asked for graphs with the annual cycles of the climate indicators, when feasible. It was discussed that such an aggregation and presentation of the data would ease possible comparisons and interpretations of the climate change projections.

Overview and precision

As agricultural experts, the participants stressed the significance of interlinked and combined effects of climate aspects (and other aspects) relative to various management questions. The discussions repeatedly came back to the effort to grasp information from a combination of different agricultural aspects of climate change, i.e., concerning several climate indicators. In the discussions on indicators, the relevance of the individual indicators was acknowledged but much focus was placed on the complexity of interacting climate aspects affecting agriculture in numerous ways depending on the combined conditions. A lack of ability to acquire an overview of the climate information considered relevant to agricultural-related risks and adaptation decision support within the service was stressed. Comments like, “*this becomes very complex*” [WS2G1] “*everything is connected*” [WSG2], and “*there is a lot of good information, but it is difficult to get the whole picture*” [WSG3] were common when discussing the potential usefulness and usability of climate change indicators.

The participants discussed *the number* of different indicators regarding agricultural and climate complexity on the one hand and data overview on the other. The following two perspectives were offered:

(too) many indicators in the climate service make it difficult to acquire an overview of the information provided to interpret the indicators in combination; and many indicators are required to understand climate risks in agriculture and plan for adaptation. Statements from two participants exemplify these trade-offs – "*there are quite a few indicators so it's not that easy to just… it sort of requires that you must become… if you want to be able to use this in a good way, you have to get acquainted with it, and know where to find things*" [WS2G3]. Another participant described what affects the dimensioning and management strategies for drainage systems and said *"So, there will be quite a few layers for a really good overview, […] would you really take the time…and also understand what you're doing…?*" [WS2G3].

Thus, while the participants were "*seeking for that easy overview*" [WS2G3] of agriculturally relevant climate aspects and periods, as well as more tailored indicators, the participants recognised trade-offs between the details, complexity, contextualisation, and generalisability of a climate service – acknowledging that some of the discussed indicators might be too detailed in a national climate service.

Relevance - usability contradiction

Perspectives on the usefulness and usability of climate change projections came across as a theme in the discussions, or rather the limitations and barriers for useful and usable climate information in terms of extension officers' use of climate projections, or their willingness to do so.

Generally, almost all participants in the workshops discussed the climate projections as relevant for them as agricultural extension officers. It was particularly discussed as relevant in relation to decision support for investments that will last for 20–30 years, like new barns, drainage systems or irrigation dams – as one of the participants exemplified: "*if you make an investment that will last for 30 years, then you want to make it the right way*" [WS2G3]. Nevertheless, in respect of planning and management on shorter time horizons, e.g., year-to-year changes in crop types, climate projections were not considered very useful. Moreover, not all participants agreed about the relevance or usefulness of climate projections in agricultural extension. One participant argued that the climate change projections can contribute to the very generic picture about the changing climate but not something that is useful in extension. The same participant emphasised that advice to farmers depends on so many other factors that affect, e.g., the soil and, in turn, drought risk more, which makes other information more important to account for than climate change projections.

One important feature in the discussions concerned actual usage. Although participants generally discussed that much of the information included in the service is relevant for them, they argued that it is not likely that they, as individual extension officers, will or can use it. In this context, participants mentioned several barriers for usage, one being the lack of ability to interpret and draw conclusions from the climate data. As one participant phrased it, *"I immediately thought that I want to try to apply this to an active advice situation […] I feel I can get a lot of information here* [in the climate scenario service]. *It is a super good service, but then, if I have to make … dare to draw conclusions…,* […] *I would like to discuss it with, for example, someone at SMHI or someone who knows this better than I do."* [WS2G2]. Another related barrier to using climate projections in extension discussed by some of the participants concerned how to relate to the uncertainty in projections, e.g., in communication with the farmers, or how to interpret the uncertainty and robustness for a further understanding of the risks. The uncertainty with climate change projections, including different emission scenarios, makes it problematic to use the information, one participant argued. Furthermore, the same participant asserted that increased precision could lead to a misinterpretation of the data – "*if we will get forecasts* [referring to climate change projection indicators] *with shorter, or more precise in time like that…, well, in May it will look like this, in June like this, …then I really think that could tend to be understood as the truth, how it WILL turn out, and we don't know that…, and then I rather see the risks* [with that type of information]" [WS2G]. Other perspectives raised in relation to the challenges with communication were rather linked to their capacity to interpret the uncertainty and model robustness and how to ensure that what they as extension officers communicate is scientifically correct.

A third type of barrier for usage revealed by the discussions concerned the extensions officers' time and commitments. The possibility to interact with the climate data in web applications, download statistics and shapefiles for one's own analytical purpose was generally seen as positive. It was said to create a possibility to deeply explore climate data for a region and make comparisons (nevertheless, with the limitations presented in previously). However, on the contrary, several participants mentioned their limited amount of time or even willingness to do such analytical work. One participant that was generally enthusiastic about the climate service and further development of the climate information to suit the extension work to farmers in terms of their long-term planning and investments, said "*although it's possible, it is not certain that we extension officers will take over that* [the role of being climate analysts] *and somehow immerse ourselves in hydrology and meteorology."* [WS2G3]. The dual perspectives on the relevance of climate change information for extension officers and the (un)probable usage of information by extension officers were evident from the discussions – they think it is relevant, but they will probably not use it. Some of the participants recognised this issue themselves and suggested that a national expert authority should have the responsibility for the task of interpreting climate change projections for agricultural extension in a way similar to Sweden's plant protection centrals, which is part of the Swedish board of agriculture.

Discussion and conclusion

This study contributes to an understanding of how potential climate information users, here Swedish agricultural extension officers, may (or may not) regard climate change projections as relevant, useful, and usable. Insights are obtained into the overall usage and perspectives regarding climate information among Swedish agricultural extension officers. Agriculturally relevant information in climate change projections is presented and the study highlights aspects within the overarching climate service methodology that warrant attention.

While there is a common emphasis on the need for user-driven and science-informed climate services, there are nuances in what 'user-driven' could mean (Findlater et al., 2021). A completely user-driven process would require a climate information demand among stakeholders who are, or will become, users of the information. This study presents results that suggest that the question on demand for climate information among agricultural extension officers is not clear and pronounced. Both the digital survey and the workshop dialogues indicate that there is *latent demand* for climate change information among agricultural extension officers in Sweden. This means that while the information is generally seen as relevant and interesting, its current use is limited for various reasons (cf. Tart et al., 2020). The survey shows that extension officers foresee a future demand for climate change information, but the currently available data (historical observations and climate change projections) is in limited use (Fig. 4). Similarly, the workshop discussions highlight a pronounced contradiction between relevance and usability, with associated barriers for usage.

The four identified themes in this study present different features that, if addressed, could contribute to a progression from a latent demand to actual demand and usage. The insights into *what* content and *how* climate change projections can be relevant and usable need to be considered and balanced in-between the demand and supply sides of an iterative co-creation processes of climate service development and use. Fig. 5 presents a flow diagram of the iterative climate service process of development and use, and places the results of this study within that process.

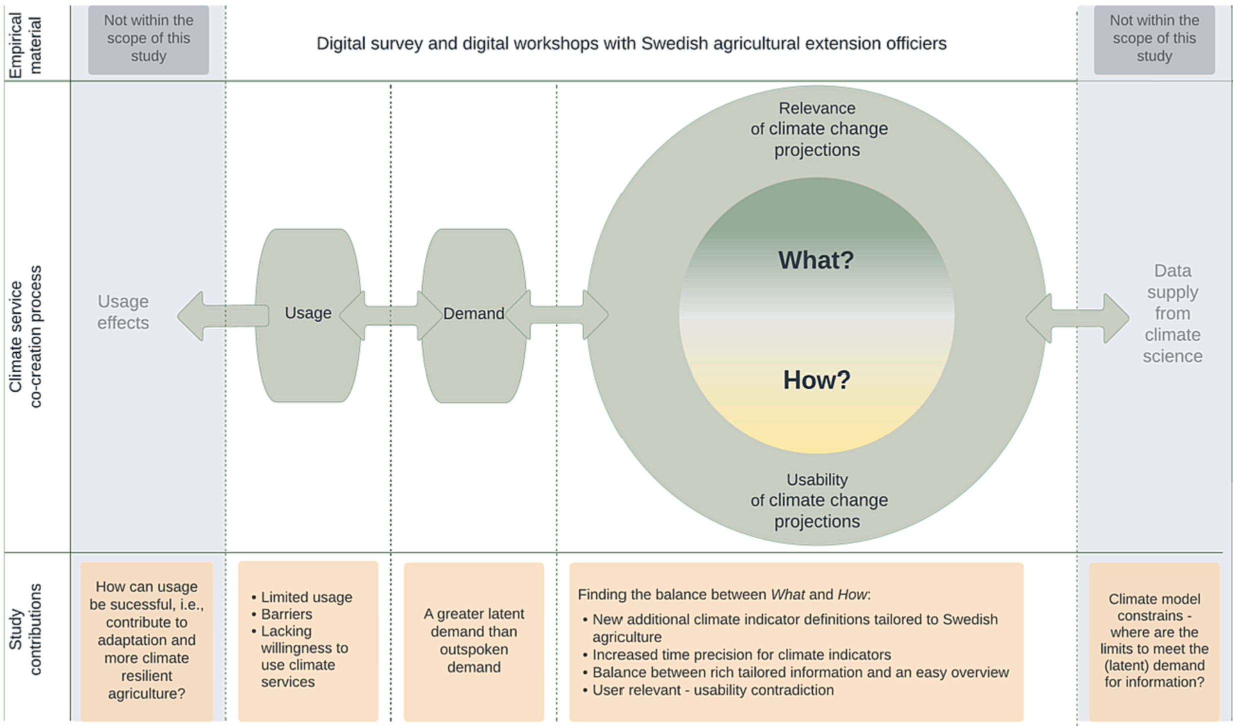

Fig. 5. Flow diagram with the localities of this study's contribution in an iterative climate service process.

What - Information content from climate change projections

The analysis of the indicators identified in the workshop discussions revealed indicator definitions or variable scopes that are additional compared to the freely accessible indicators in two climate services at national and regional level (the SMHI advanced climate change scenario service (2021) and Copernicus Climate Change Service (C3S) (Nobakht et al., 2019)). These findings will contribute the continued research and applied work on developing climate indicators for Swedish agriculture. The results, indicate a need to customize the climate projections into data that represent relevant physical climate conditions that affect the Swedish agricultural system, i.e., *indices of climate impact-drivers* according to the IPCC AR6 WGI terminology (WGI; Ch1; AR6). This importance of 'tailoring' (e.g., Wilby and Lu, 2022) climate indicators have been emphasised in research previously, for example demonstrated in studies that focus on local climate adaptation in German municipalities (Hackenbruch et al., 2017), the forestry sector in Sweden and Finland (Bärring et al., 2017), and the European energy sector (Bartók et al., 2019).

Some of the additional climate indicators are available in the scientific literature, at least with similar definitions (cf. Wiréhn, 2021), such as, for example, degree-days above certain thresholds (e.g., Eckersten et al., 2012) or frost damage conditions (not frost occurrence) (e.g., Lalic et al., 2013). On the Swedish regional level, there is, however, no freely available climate service, generic or agriculturally tailored, that includes climate change projections for any of the additional indicators presented in this study. The participants emphasised the need for indicators that could represent heat stress conditions for crop production or animal husbandry as well as indicators for precipitation and hydrological conditions that cause direct losses in the production and indirect negative effects from management problems.

The identified climate information needs should preferably be developed in coproduction between climate scientists and stakeholders to find indicators and temporal precisions that balance these needs with model capabilities. The participant discussions on relevant indicators were often related to their call for more precise information on the temporal timing of different climate change characteristics. From this perspective, generic climate indicators, such as precipitation sum, were discussed as relevant but not for temporal aggregations longer than a month, and preferably for shorter periods than that. This study does not assess the theoretical or technical capabilities to develop any of the identified additional indicators or aggregations for the temporal periods asked for in a reliable and valid way. Nevertheless, the state-of the art climate datasets (CORDEX-CORE and CMIP6 data) have been argued to be a "formidable resource" to be provided in climate services for impact assessment purposes, or similar, but they require observations of high quality and an adequate number of simulations to explain the uncertainty (Coppola et al., 2021, p. 1381). However, criticism towards using climate change projections for climate adaptation decision making purposes exists due to model uncertainties and an illusion of precision in the representations of climate projections (Nissan et al., 2019). It may, for example, be technically feasible to select and aggregate data for shorter temporal periods, but the annual and interannual variations in the model are not in sync with the real variability. Overconfident representations of climate projections causes an illusion of precision in the climate information that is not feasible or even ethical to provide to users (Nissan et al., 2019). Similarly, biases in models affect the representation of the intensity and frequency of extreme weather and climate events (e.g., Hewitt et al., 2021), which causes complications with indicator definitions that include thresholds, if these are not captured in the models (Nissan et al., 2019). The capability and feasibility to develop tailored indicators and aggregate data for the requested temporal precisions should thus be assessed in each specific climate data case.

How – Co-creation and capacity building

The results of the workshop discussions indicate four types of challenges and barriers related the provision and use of climate change projections: (I) finding the balance between rich tailored information and an easy overview; (II) user capacity to interpret the climate projections; (III) communication challenges associated to the uncertainties in climate information; and (IV) a lack of willingness or time to use a service and become a knowledge broker. These results extend beyond the mere provision and use within the Swedish agricultural community. Instead, understanding and addressing these factors are essential for contributing to the overarching challenge of climate service methodology, aiming to narrow the usability gap (cf. Lemos et al., 2012), regardless of the targeted sector or region.

While tailored climate indicators and appropriate temporal aggregations are essential for climate information to be relevant and useful (the *what*-part in Fig. 5), a provision of such information would not resolve these barriers that are related to *how* to provide and present climate change projections. Similarly as with climate service research for other regions or sectors, this study found that the use of climate change projections is limited compared to other types of climate information (cf. Bruno Soares et al., 2018; Singh et al., 2018), and it is considered to be more useful to a different role within the sector than to the role of the person being surveyed (cf. Tart et al., 2020).

In delving into the matters of *what* and *how* information is provided, presented, and used one comes back to the question of *who* – the user. Similar to the results of the present study, Tart et al. (2020) found that users in the food and drink sector envision the value that climate services could bring, but the individual user generally considers it irrelevant for their own usage. Instead, the interviewees in Tart et al. (2020) placed their trust in other actors upstream or downstream in the sector to use the climate service. Similarly, the participants in this study advocated for designated users, potentially as part of an expert authority, to have the responsibility to convey climate change projection information for the sector.

In a potential development from a latent demand to actual demand and usage by a sector or region, it is important to understand *how* information can be usable. Nevertheless, in future research and development, it is crucial not only to understand the barriers but also to address them. Co-creation or co-production is a commonly emphasised methodology and approach for climate service development and maintenance (e.g., Hewitt et al., 2017; Suhari et al., 2022; Vedeld et al., 2019), but it might be challenging if there is no user demand. Previous research although suggests that the development of relevant and useful climate information should adopt co-creation methodology in alignment with 'undemanded' capacity-building (cf. Tart et al., 2020). While *undemanded* capacity-building and co-creation may not be contradictory, alignment would probably involve challenges to initially engaging stakeholders. Nevertheless, if overcome, undemanded capacity-building through co-creation could possibly address the barrier concerning the lack of capacity to interpret climate projections and might to some extent also address the second barrier regarding uncertainty and communication challenges. It has been shown that engagement and capacity building among stakeholders can even generate a demand among the involved stakeholders, a demand that they themselves did not know they had (McNie, 2013), and similarly, a willingness to use information that is more reliable and more readily available than what they previously called for (Findlater et al., 2021). However, as indicated by the results of this study, the gaps between providing relevant climate change projections and achieving effective usage still require a deeper understanding, as well as addressing the associated challenges and barriers.

Conclusions and recommendations for future research

The results of this study are contributing to a foundation for continued research and applied work on agriculturally tailored climate information as well as to climate service theory and methods generally. As climate change is gradual and long-term, the limited usage implied by the results could probably partly be due to a shorter term (<10 years) focus on agricultural plans and management. However, waiting to act on climate change adaptation will likely make the situation more complex and costly for businesses in avoiding major consequences (Groth and Seipold, 2020). Even if a latent demand for climate change projections may involve challenges for user-driven approaches, a latent demand is not to be regarded as an absolute barrier for co-creation of such climate services.

The identified additional indicators and the call for increased temporal annual precision must be further studied in terms of specific definitions and thresholds, balanced with model data adequacies and feasibilities, to provide information that inform sound adaptation decisions. Although climate service research suggests that demand should drive or inform the climate service process (e.g., Findlater et al., 2021), it needs to be balanced with the data supply from climate science. It may be theoretically or technically feasible to provide the information on climate projections that is requested by potential users, but it is of fundamental importance and an ethical responsibility for climate scientists to consider and communicate the limitations of climate data in the translation from model outputs to the provided information. Along with the work on new additional climate indicators and increased temporal precision in the aggregation of data, there is a need for a deeper understanding of how to address the trade-offs in presenting climate information and overcoming the user barriers among agricultural stakeholders. To advance climate services and the support of climate change projections for adaptation decisions as well as to bridge the gaps between the provider and user "sides" of climate service processes, the present study provides important contributions in understanding that the current demands may be limited, but information from climate projections can still be relevant if packaged into existing and new indicators that reflect important climate risks and agricultural time periods throughout the annual cycle. However, for the Swedish agricultural sector, key issues remain concerning who the specific user of such agriculturally relevant information can be, as agricultural extension officers do not typically view themselves as primary users. Consequently, the study's conclusions raise questions on how to move from providing relevant and useful information to achieving actual usage, and finally, successful usage that leads to increased climate resilience in a system.

CRediT authorship contribution statement

Lotten Wiréhn: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Lotten Wirehn reports a relationship with Swedish Meteorological and Hydrological Institute that includes: funding grants. Guest researcher at the Swedish meteorological and hydrological institute.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cliser.2023.100441.

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