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Moving beyond organic – A food system approach to assessing sustainable and resilient farming

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ABSTRACT

Organic farming aims to minimize negative impacts on the local environment, but its contributions to global food sustainability also depend on a resilient food supply. We studied a farm aiming to move beyond organic and become "a sustainable farm of the future", in the farmer's own words. This meant going beyond local impacts to consider how the farm could contribute to global food security by transitioning to production of more crops for direct human consumption. Over a five-year period (2015–2019), the farm improved on the food security and resilience indicators included in the assessment (e.g., number of persons fed per hectare, diversity of products, and connections), while producing food at greenhouse gas intensity similar to regional averages. This approach of including global food security aspects along with environmental efficiency and resilience in farm-level sustainability assessments provides a way for farmers to engage as globally responsible biosphere stewards.

1. Introduction

Today's food systems impose enormous pressures on ecosystems (Gordon et al., 2017; Willett et al., 2019). The complex challenge of protecting ecosystems while sustainably feeding the global population has attracted increasing attention in recent years. The discourse has moved from 'environmentally friendly production' towards 'food system sustainability', which includes both production and consumption side improvements, as research has shown that reducing the pressures from production alone will not be enough to reach environmental targets. Substantial consumption changes, especially fewer animal products, and reductions in waste are needed (Bajzelj et al., 2014; Röös et al., 2017; Springmann et al., 2018).

Life-cycle assessment (LCA) studies that compared organic and conventional farming methods showed mixed results, depending on impact category (climate change, eco-toxicity) and crop studied (Bacenetti et al., 2016; de Backer et al., 2009; Tricase et al., 2018). LCA studies do not yet cover all impact categories relevant for comparing organic and conventional farming, for example plant and faunal diversity, soil fertility and animal welfare. It has been shown that organic farming often outperforms conventional farming in those more local environmental impacts and also tends to be more profitable (Reganold et al., 2016; Venkat, 2012). However, studies have shown that conversion to organic farming under the assumption of sustained food demand would considerably increase agricultural land expansion (Muller et al., 2017; Smith et al., 2019), leading to detrimental effects from deforestation (IPBES, 2019). If organic farming with current crops and yields were introduced on all agricultural land globally, it would only produce enough food for 6 billion people (Barbieri et al., 2017). To be globally 'responsible', organic farms thus have to achieve higher yields and/or alter the ratio of feed and food crops grown (more food, less feed), without jeopardizing local environmental gains.

At farm level, this can be measured as the farm's contribution to global food supply. However, it is challenging to assess how an individual farm that produces only one or a few commodities contributes to global food security. The assessment depends greatly on how the food system is organized (e.g., mainly local supply or relying heavily on global trade). However, one simple indicator to capture this aspect is

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'*number of people* actually *actually fed per hectare of cropland*' (Cassidy et al., 2013), expressed as edible energy (kcal) and protein (kg) produced per hectare (ha), which accounts for the use of crops as either food, feed or fuel. More sophisticated measures could take into account a whole range of different nutrients (DeFries et al., 2015). However, measuring energy or protein per hectare can provide interesting and easy-to-understand information about how much food a farm produces. It is also a way to aggregate estimates across several different products, which can be useful when comparing different farms or assessing impacts of a change in the products grown on a particular farm. Farm-level sustainability assessment tools have been developed to capture the broad concept of farm-level food system sustainability (Marchand et al., 2014; Schader et al., 2014). These include many sustainability indicators and capture local farm-level sustainability outcomes, but seldom consider crucial food security issues, including what and how much food is produced on the farm and how that fits into wider food system sustainability.

In addition, food has to be produced in a resource-efficient way, minimizing the negative impacts per unit product. LCA measures the environmental impact per kg product, e.g., per kg wheat or beef, and shows the 'environmental efficiency' of a production system (ISO, 2006a; 2006b). In LCA, emissions and resource consumption at all stages of production, use, and disposal of a product are aggregated, including emissions from land use, animals and manure, and production and transport of input materials, e.g., fertilizer and energy. However, efficiency measurements, especially using LCA, have difficulty including diverse outcomes generated by multiple products or services from one system, such as a farm in a landscape, and cannot capture landscape-level effects on biodiversity (van der Werf et al., 2020). Therefore, LCA cannot be used as the sole determinant of sustainable agriculture, but must be combined with other area-based assessments, e.g., farm-based biodiversity assessments. However, LCA is still useful as a tool for measuring environmental *efficiency* on product level. If food production on a farm is found to be very inefficient, re-wilding or more extensive use of land (for greater biodiversity outcomes) could be a better option.

In addition to delivering on global food security goals and resource efficiency, resilience is an indispensable feature of future sustainable farming, especially in a context of increased uncertainties from climate change and variability exceeding 'expected' conditions. Resilience concerns the capacity to cope with, and adapt to, changes and disturbances. It also refers to the capacity for transformation when the current system is untenable (Folke, 2006). The concept of food system resilience (Tendall et al., 2015; Seekell et al., 2017; Jacobi et al., 2018) is less well-studied than food systems sustainability. Some frameworks for farm-level resilience have been developed, but these have not been fully tested on real farms (Darnhofer et al., 2010a; Meuwissen et al., 2019).

The aim of this study was to explore the broad concepts of sustainable and resilient farming from *a food systems perspective, applied at farm level.* In particular, we considered: what the need to move towards food systems sustainability at global scale means for individual farmers, who want to run their farm in the most sustainable and resilient way possible; how individual farmers can navigate this complexity and strategies they can use to improve sustainability and farm-level resilience; and how to measure the sustainability and resilience outcomes of such strategies. Thus, the study sought to move beyond (but not downplay) the role of the farm in its local context and describe how an individual farm can meet the greater challenge of sustainably feeding a growing world population, and how to measure the outcomes.

We used the real case of a Swedish organic farm that has embarked on a very deliberate transition with the aspiration to become a "sustainable farm of the future", in the farmer's own words. This farm has gone beyond current farm-centered approaches such as organic to take responsibility for the type of food produced on-farm and development of a culture of biosphere stewardship (Folke et al., 2016) that also accounts for non-food related contributions to sustainability and resilience.

2. Methods

2.1. Case study description

The farm is located in the forest district of central Sweden, which has relatively low productivity compared with the adjacent plains district. It is run as a family farm, under organic production since 1995. In 2016 the family, led by the son, made a conscious choice to change from organic certified lamb production to becoming a 'fully sustainable farm', i.e., from reducing local impacts of production to contributing to a sustainable and resilient future food system. Since then, the farm has diversified production to include more crops for direct human consumption (to feed more people per hectare). It has also started to engage in different collaborations on sustainable development, framed around an identity as biosphere stewards: *"We see ourselves as biosphere stewards with ecosystem services as our primary product."* [quote from the farm's website].

In 2015, 67 ha of land were used on the farm to grow feed for around 100 ewes producing approximately 250 lambs per year and some bread wheat. In 2016, production of crops for direct human consumption was increased with the introduction of e.g., oats, rye, gray peas, and common beans (Table S1.1 in Supplementary Material (SM)). Through leasing, the area of land cultivated was increased to 83 ha. Instead of manure from conventional farms (which is indirectly mineral fertilizer), digestate was purchased from a biogas plant. One hectare was sown with a mixture of flowering herbs, to sustain bees and other insects throughout the season (bee forage). The owners also began building a farm shop and new barns. The oats grown in 2016 were sold to an oat drink company that made a special-edition oat drink, featuring the young farmer on the package. This was the start of a long-term collaboration between the farm and the oat drink company that involved the buyer-seller relationship and activities to discuss farm and food system sustainability.

This change towards a more diverse farm was continued in 2017-2019, by adding vegetables, landrace cereals, legumes, buckwheat, landrace beef cattle and pigs, and a small flock of laying hens. The farm gradually grew to nearly 100 ha. From 2016 onwards, all meat and vegetables and some legumes were sold directly to consumers through the farm shop, via social media and in an online store with delivery to major cities. Landrace rye was sold to a local bakery and the oats to the oat drink company. In 2018, yellow peas were sold to a major retailer, which processed them into frozen, ready-to-eat falafel. The farm opened a pop-up restaurant serving high-end local cuisine a few evenings per year, and also built a cleaning, sorting, and storage facility for grains and pulses. The farmer (son) started giving lectures, contributing to farm income. The farm aims to sell most of its crops for direct human consumption. However, in all years except 2018 (a drought year), some crops have been sold to neighboring farms as animal feed, due to lack of other sales outlets.

2.2. Assessment tools and indicators

The strength of organic farming lies in its often less intensive use of land, lower reliance on chemical pesticides and inorganic fertilizers, and more varied crop rotations, leading to less local pollution and higher biodiversity outcomes (Reganold and Wachter, 2016; Seufert et al., 2017). These aspects have been assessed previously for the case farm, using a sustainability assessment tool (Röös, 2017). A previous biodiversity assessment of the farm showed favorable outcomes, with plenty of flowering resources, no use of pesticides, and small, irregular fields (HS, undated). In the present study, we moved beyond local-based assessments to focus on the larger food system sustainability perspectives, including farm-level contribution to food security (section 2.2.1), environmental efficiency (section 2.2.2), and farm-level resilience (2.2.3).

2.2.1. Contribution to food security

We used the following indicators to capture the farm's contributions to food security: amount of food produced per ha in terms of energy (kcal), total protein, and complete protein, hence accounting for protein quality. Complete protein includes animal protein (contains all essential amino acids), and a combination of protein from legumes and cereals, which is required to get a complete protein profile. The results are also reported as number of persons fed per hectare, for ease of comparison with the Swedish average and global requirements (for more details, see SM, section S2).

2.2.2. *Environmental efficiency*

We assessed the environmental efficiency of food production on the farm by calculating the climate impact per kg for the major products produced in 2015-2019: wheat, oats, rye, peas and red meat (beef, lamb, pork) and comparing them to the climate impact of Swedish averages of corresponding products. Therefore, to enable the comparison we chose systems boundaries, emission factors and methods for calculating the emissions to be in line with these earlier studies on Swedish crop and meat production (Moberg et al., 2019; Wallman et al., 2011). The included emission sources were: emissions from land (nitrous oxide), animals (methane from enteric fermentation in ruminants), manure (in storage and excreted on land), energy use in barns, use of tractors, grain drying, and production and transport of fertilizers and fuel. Soils were assumed to be in carbon equilibrium why no emissions from soil carbon changes were included. For details on the climate impact calculations, see SM section S3. To analyze food production efficiency of the whole farm, we also calculated emissions of greenhouse gases per kcal. We limited our analysis to the climate impact, which is unaffected by where emissions take place globally. LCA also allows assessment of other impacts categories, such as eutrophication and impacts on biodiversity, but at farm level these aspects are less well-captured by LCA as they depend heavily on local conditions.

2.2.3. *Farm-level resilience*

We used the comprehensive five-step framework developed by Meuwissen et al. (2019) for assessing resilience of farming systems (for details, see SM section S5). The first step addresses the question *resilience of what?* (Fig. 1), in this case continued food production, maintained economic viability of the farm, and supporting the farmers' identity as biosphere stewards, through sustainable use of land and agency to inspire others to increase sustainable food production. In step 2, *resilience to what?* was defined in terms of three different disturbances: a) environmental events, b) changed sales opportunities, and c) risk of loss of identity as biosphere stewards (Fig. 1). In step 3, *resilience for what purpose?*, the purpose in this case was maintaining the supply of services to contribute to global food supply (tracked through yield, number of people fed and income from the delivery of services), while in step 4, *what resilience capacities*?, we considered robustness, adaptation, and transformation.

In step 5 (*what enhances resilience?*), we based our analysis on Biggs et al. (2015), who developed principles for resilience based on a thorough analysis of the literature. We used three principles from their framework that best applied to the case farm context: diversity (split into three components, see section 2.2.3.1), connectivity (see section 2.2.3.2), and governance (Fig. 1). Diversity and connectivity were assessed quantitatively, while we only reflected qualitatively on the four principles of a governance system for resilience (complex adaptive systems understanding, encouraging learning, broadening participation, and promoting polycentric governance).

2.2.3.1. Diversity. Diversity has been shown to improve food system resilience on national (Renard and Tillman, 2019; Kummu et al., 2020), regional (Sellberg et al., 2020), and farm scale (de Roest et al., 2018). In Biggs et al. (2015), diversity includes three components: a) variety (how many different elements), b) balance (how many of each element), and c) disparity (how different the different elements are from one another). We investigated these three resilience components for two elements: 1) income types (products, services, subsidies), and 2) buyers; chosen based on their relation to the threats identified in step 2) (Table 1).

2.2.3.2. Connectivity. Connectivity is defined by Biggs et al. (2015) as the manner and extent to which resources, species, or social actors disperse, migrate, or interact across ecological and social "landscapes". Landscapes may consist of components (e.g., patches, habitats, or social groupings), referred to as nodes, and the connections between them, referred to as links. The structure and strength of the links between nodes determines how they contribute to resilience. Here, connectivity aspects related to income types and buyers were captured partly by the

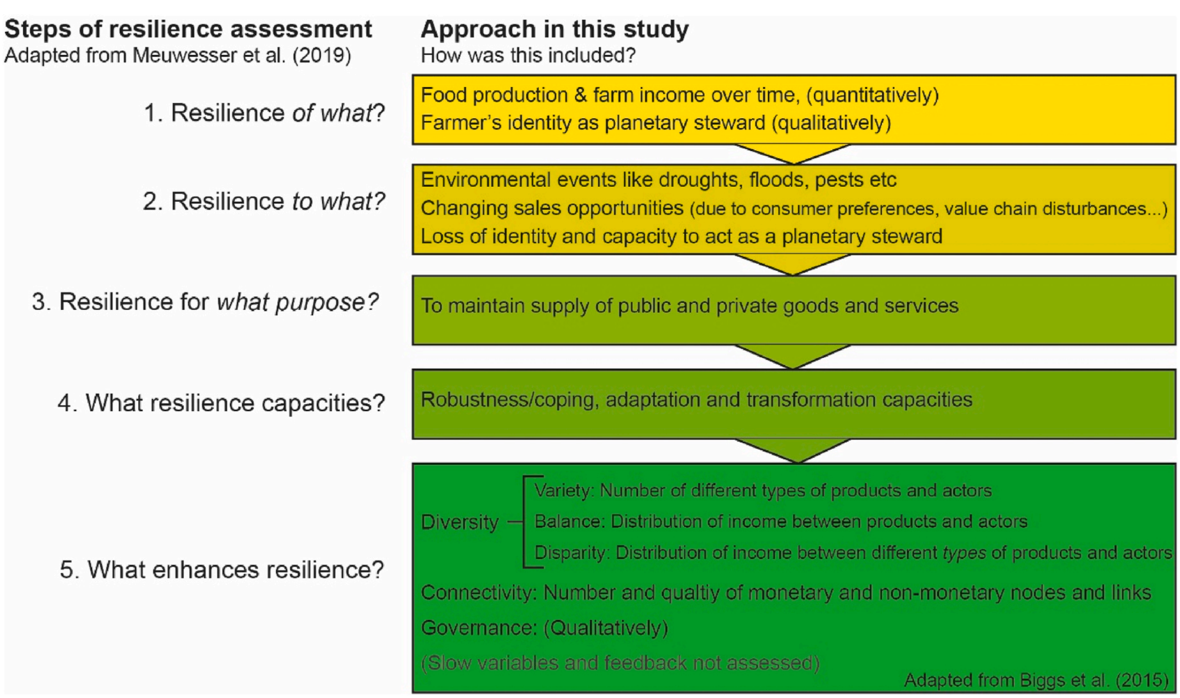

Fig. 1. Five-step resilience assessment framework, adapted from Meuwissen et al. (2019) and Biggs et al. (2015).

Table 1
Vulnerability to three threats (environmental stressors, sales opportunities, and farmer identity creation and maintenance) in terms of sources of income and type of buyers.

Source of income (product, service, subsidies)	Vulnerability
Crops for human consumption	Highly vulnerable to environmental events like droughts, pests, etc. Contracts with clients can be cancelled, leaving the farmer to find an alternative market at short notice.
Animal products	Animal production is vulnerable to the same risks as crop production (see above), but feed can be bought in to maintain production. For ruminants, roughage feed can be harvested later in the year or from marginal areas (e.g., during the drought in 2018 forage was harvested in autumn when the rain came).
Cultural services	Mostly unaffected by the environmental and sales opportunity threats, but highly dependent on the biosphere steward identity/capacity threats.
European Union support	Independent of the three major threats; could be subject to policy changes (CAP reforms) and political changes (as happened in the UK), but these are rather long-term.
Type of buyer	**Vulnerability**
Large processing companies	Lower prices but larger volumes, longer-term contracts, have capacity to develop personalized products from the farm
Small-scale or local companies	Higher prices but smaller volumes, higher risk of bankruptcy, build local community and networks, and contribute positively to farmer identify
Direct sales to consumers	Higher prices, gives direct feedback, sensitive to consumer relations, and interest in local and organic foods, time-consuming which might drain farmer energy and time
Restaurants	Higher prices, low volumes, direct feedback builds identity
Retailers	Intermediate prices and volumes, little risk of bankruptcy, meat becomes anonymous, which does not help build farmer identify, relatively time-consuming to deliver
Slaughterhouses	Low prices, high volumes, little time investment, high stability, no identity or capacity building

diversity analysis, which was based on monetary transactions. To further investigate aspects of connectivity, we added non-monetary nodes and links and considered the strength of the links to sustain the capacity of the farmer as a biosphere steward. To capture this aspect, we listed the major actor groups with which the farmer engaged over the years and asked him to rate these for their contribution to enabling him to act as a biosphere steward.

3. Results

3.1. Food system sustainability at farm level

3.1.1. Contribution of food security

Between 2015 and 2019, when the farm gradually increased its proportion of crops for direct human consumption; the amount of energy produced for human consumption per ha increased by 79%, the amount of total protein by 64%, and the amount of complete protein by 95% (Table 2). These large increases were a direct consequence of increased production of crops for human consumption, rather than animal feed. In 2019, the farm could feed 1.5 persons per ha in terms of edible energy, compared with 0.85 persons per ha in 2015. For total and complete protein, the corresponding values were 1.6 and 0.72 persons per ha in 2019 and 1.0 and 0.37 persons per ha in 2015.

Despite this increase, the farm is still well below the Swedish average of 4.8 persons fed per ha or the average requirement to supply the global population with food, i.e. approximately 5 persons per ha (7 billion people divided by 1.5 billion ha of cropland; FAOSTAT). This is explained by its location in the forest district of Sweden, with generally lower productivity (cereal and legume yields are between 80-95% of average yield in Sweden with large variations over the years; SBA, 2020), and its organic production, with typically lower yields (organic cereal yields in Sweden are on average approximately 50-70% of conventional yields; SBA, 2020). In the plains district of Sweden, large amounts of high-yielding cereal are produced, contributing to the high average persons fed per ha for Sweden as a whole.

Table 2
Contribution to global food security of the farm, compared with the average for the forest districts of central Sweden and for Sweden as a whole.

	2015	2016	2017	2018	2019	Swedish average 2015–2019
Number of persons the energy per hectare can feed	0.85	1.0	1.3	1.3	1.5	4.8
Number of persons the total protein per hectare can feed	1.0	1.2	1.4	1.4	1.6	4.6
Number of persons the complete protein per hectare can feed	0.37	0.92	0.72	1.0	0.72	2.4

3.1.2. Environmental efficiency

The climate impact of the farm's crops (Fig. S4.1) was similar to that of average Swedish products for cereals, but considerably higher for peas (due to crop failure in 2019, which drastically reduced yield) (Fig. 2). Emissions from fertilizer production for the farm were lower than the Swedish average, because of use of digestate instead of mineral fertilizer. However, yields were lower than the national averages (see section S3 in SM).

There are essentially two main changeable parameters that determine the climate impact per kg of a certain crop: the yield and the amount of fertilizer. With higher yield, emissions from land use, manure production, transport, and tractor diesel are divided over a greater volume of product, so emissions per unit product are lower. Greater amounts of fertilizer give rise to higher emissions from the soil (nitrous oxide) and also higher emissions from production and transport of the fertilizer itself. For meat, the case study farm caused similar emissions as the Swedish average if compared to an average of all beef production systems in Sweden, i.e. including both suckler herds and beef from the more climate efficient dairy production (as emissions are allocated on both milk and meat). If comparison was based on a Swedish average only containing suckler beef herds (which is what the case study farm has) emissions of the case study farm were slightly lower (Fig. S4.1).

The indicator 'emissions of greenhouse gases per kcal produced' showed a steady decrease as more crops for human consumption were introduced on the farm over the years (Fig. 2a), illustrating clear potential to produce more food at lower climate impact. The slight increase between 2015 and 2016 was due to introduction of cattle, which increased methane emissions, and to the wheat grown being sold as feed, since regulations on conversion to organic farming on the newly leased land prevented its sale as organic bread wheat.

3.2. Farm resilience

Even within the short time frame in which resilience was studied, a number of observations were made on how the farm coped with disturbances. The drought in 2018 (driest summer since 1850; SMHI, 2018) significantly reduced oat yield and income from oats (Fig. 2b and 2c). The rye grown on the farm was a landrace crop, less sensitive to drought. A pest event (birds) decimated legume (pea) yields in 2019. Meat production appeared resilient to these environmental disturbances in the

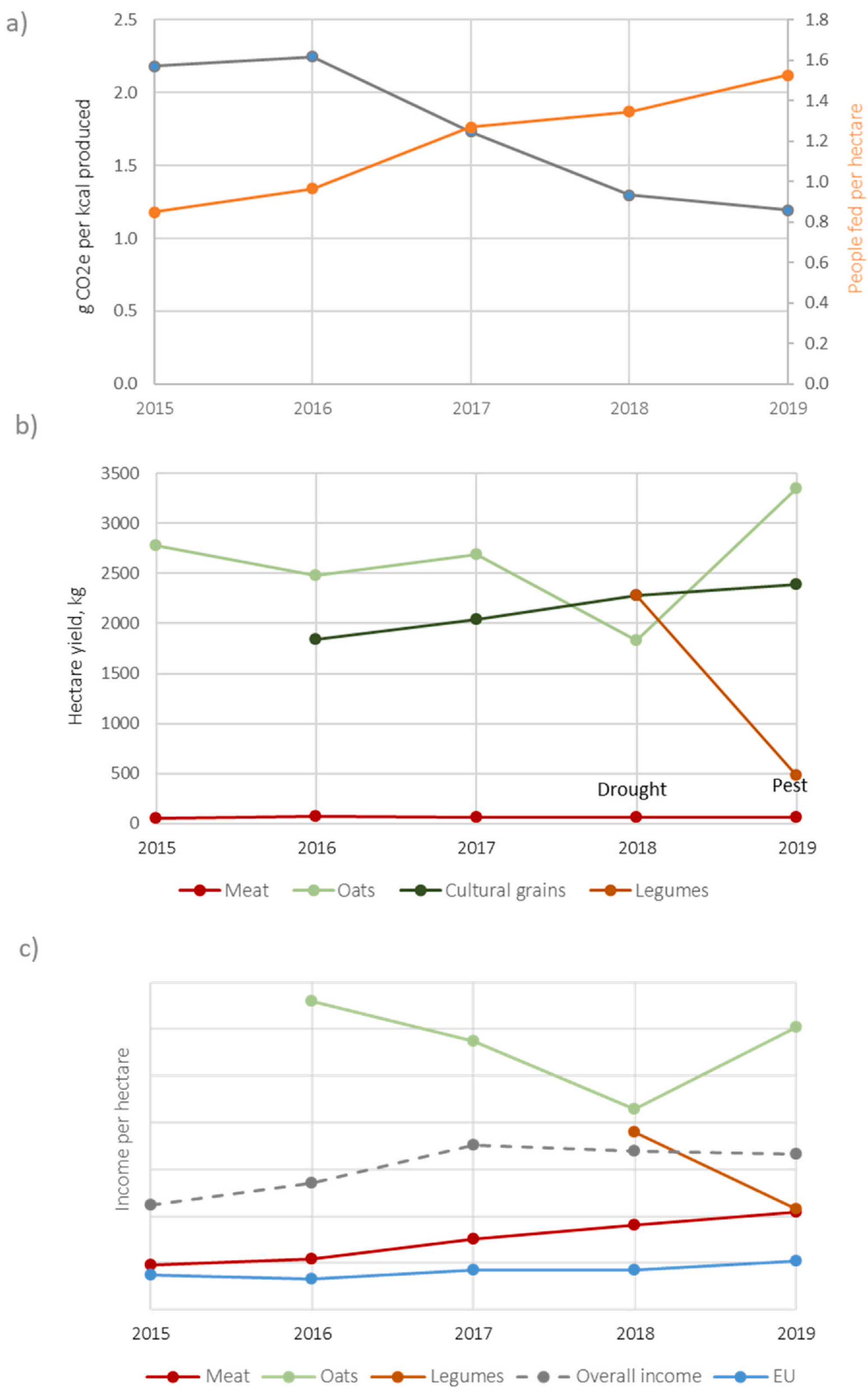

Fig. 2. a) Climate impact per kcal produced (gray) and number of persons fed per hectare (based on energy requirement) (orange), b) per-hectare yields in kg dried weight for crops (14% water content) and kg bone-free meat (2018 was an extremely dry year, in 2019 birds ate the pea crop), and c) annual income per hectare from different products. European Union (EU) support is in addition to other income. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

timeframe analyzed (Fig. 2b). (Note, however, that outbreaks of livestock diseases such as foot-and-mouth disease can lead to the loss of entire herds.) Income per ha increased slightly for meat over time (Fig. 2c), as a result of increased direct sales.

Crop yields varied between years, but crops produced considerably more food per ha than livestock, even in bad years (Fig. 2b). Peas and oats also produced higher income per ha (Fig. 2c). The diversity of products meant that the overall number of persons fed and overall income showed quite a smooth increase over time as more crops for direct human consumption were added, since the negative effect on one crop was mitigated by other products achieving normal yields.

In efforts to act as a biosphere steward, the farmers substantially increased the overall diversity of agricultural products and other services, and also the actors involved (see section 3.2.1). Diversification is a way for the farmer to care for the commons of the farmland and the biosphere at large. For example, he plants flower strips to enhance bee pollination, welcomes visitors to the farm (researchers, ministers, and journalists from Swedish Radio and the Guardian newspaper have all visited the farm), and gives talks about how farmers can contribute to sustainable landscapes. This also means substantially more work to maintain relations. As income goes up, the farm could employ more people, but the farmer constantly needs to assess whether to maintain relations or not, and terminate relations that do not improve his capacity to act as a biosphere steward. An open question is whether he will be able to cope in the long term with the increased amount of work he has created.

3.2.1. Diversity of products and actors

In 2015, the main products from the farm were sheep and lamb and, to a lesser extent income-wise, hides, wool, and breeding animals. The *variety* of products increased from five main products in 2015 to 12 in 2019 (Fig. 3). The variety of types of buyers (Table 1), increased from three (direct sales to customers, sales to a slaughterhouse, and EU support) to six (sales to retailers, restaurants, large-scale food industry, and small scale/local food companies were added, sales to the slaughterhouse ceased) between 2015 and 2016, and then remained at that level. The number of individual buyers within these groups also increased, to include several small-scale local food companies (kim-chi factory, local sourdough bakery, several restaurants).

Looking at the *balance* of products in terms of income generated, a few products dominated the income, primarily sales of sheep, lambs, and oats (Fig. 3). In terms of income, EU support (33% of income in 2015, 24-26% in 2016-2019), one large processing company (30% of income in 2016, 24% in 2017, and approximately 20% in 2018-2019), and combined direct sales to customers (variable, but 20-35% of the overall income 2016–2019) were by far the largest income sources, showing the imbalance in income from different actors. The relative importance of animal-based products increased again in 2018, to 41% of total income (compared with 32% in 2017). One reason was the drought in 2018, which reduced crop yields. Another reason was the increased diversity of animals, with pigs and cattle included since 2017 (Table S1.1).

In terms of *disparity* (distribution of income between different *types* of products and buyers), the farm substantially increased two new groups of products; crops for direct human consumption and cultural services (on-farm pop-up restaurant and income from educational activities such as talks). In terms of buyers, many of the new buyers since 2016 are very different from those in 2015. Although sales to retail, restaurants, and small-scale food industry are still relatively limited, combined they make up 9-13% of total income.

3.2.2. Connectivity

Table 3 shows the strength of links between the farmer and the main groups of actors with whom he engages. In general, it reflects an intentional change from primarily economic transactions to relations for other purposes, such as joint community building or collaborations as influencers.

The items in Table 3 are listed in order of the value placed by the farmer on different connections enabling him to act as a biosphere steward. Three of the most important actors are also financially important, i.e., customers to whom he sells directly, local and small-scale industries, and one large food industry. Direct sales were scaled up as a deliberate strategy, not only for economic reasons, but also to enable community building, where relations to customers were important to the farmer. Social media (Twitter) played an important role in recruiting these direct customers. In 2016, an important collaboration with an oat processing company was established. This was more than an economic transaction on grain sales, since they jointly developed a new product based on a cultural grain variety that the farmer had found on a neighboring farm. They also shared and developed common values, started to act as influencers for sustainable food systems in joint marketing and have, over time, engaged in research projects. More local connections are seen as important for building the local community and

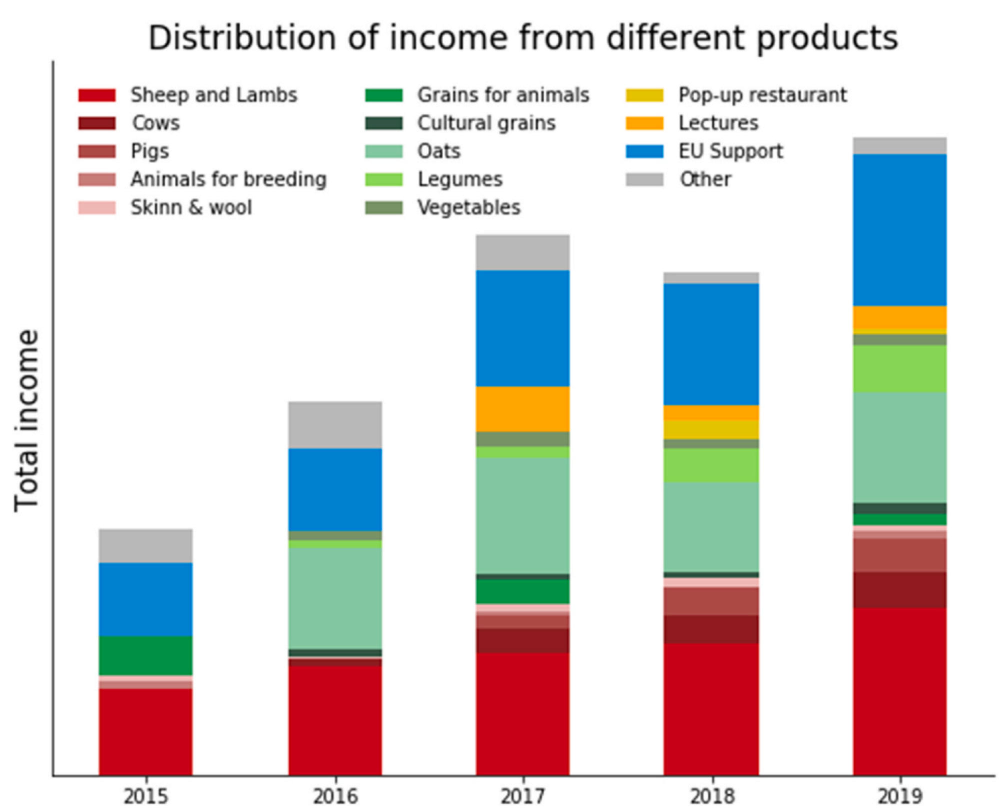

Fig. 3. Distribution of farm income from different products, 2015–2019.

Table 3
Relations and actors of financial and identity importance to the farmer (rated by him on a scale 0–3, where 3 is most important and 1 least important, 0 is not important at all).

Group	Biosphere steward-ship	Financial import-ance	Develop-ment 2015–2019	Comments from the farmer
Direct sales	3	3	Gradual increase	*"Many customers with whom strong relations are built and who come back for sales year after year".*
Small-scale or local companies	3	1-3	Substantial increase from year to year	*"Really important for a sense of building community with shared values". This category has increased and diversified over time. A few restaurants in Stockholm maintained through the period, visitors to on-farm store and pop-up restaurant from 2018, new local processors added since 2017.*
Large-scale food industry	3	3	Started 2015, a new company added 2018	*"An oat processing company has been very important here. It shared the value of biosphere stewardship, and helped spread the word in campaigns. Financially, it has been very important for enabling the transition on the farm. Very strong social and shared values".*
Farmer collaborations	3	1	Maintained	*"Important for the business and its social relations".*
Academia and knowledge	3	1	Started 2016, maintained	*"Gives me new understanding and knowledge, both theoretical and practical, which enables stronger biosphere stewardship and knowing that what I do in practice has impact. Also important to be able to get trustworthy messages out".*
NGOs	2	0	Maintained	
EU Support	1	3	Gradual increase over years	*"Financially important for me to act as a biosphere steward, but not for me to feel meaningful". Can feel shortsighted, as the funding is not dependent on the effort he makes to act sustainably. Uncertain how the future will develop.*
Slaughterhouse	1	3	Ended after 2015	*"Value added is not recognized, produce just bought in bulk. While financially important, has no value for biosphere stewardship".*
Retailers	1	1	Primarily 2016–2017	*"Value added to the produce through how I act on my farm is lost, as my experience is that the vendors are driven by shortsightedness, economic gain, and substitutability".*
Authorities	1	0	Maintained	*"Not important to feel like a biosphere steward, but for the general business and knowing the regulations I must abide by, checking these are being followed, etc."*

seeing the crops being turned into high-value products (e.g., local artisanal bread, kim-chi) and services (pop-up fine dining restaurant on the farm). The farmer also ranked collaborations with other farmers and with academia as important, even though they make very limited financial contributions.

It is also important to note that the farmer has intentionally terminated some links over the years. Most notably, relations with the slaughterhouse ended in 2016, even though it had a financially important role, and sales to retailers ceased in 2017. The farmer believed that the "*value added to the produce through how I act on my farm is lost*" in these relations, and that these actors often are driven by "*shortsightedness, economic gain, and substitutability*" (Table 3).

3.2.3. Resilience principles for governance

The farmers clearly views the farm as a complex system that can be adapted in different ways. The son also actively interacts with policy-makers and other decision-makers to form new networks of influence to enhance food system sustainability at different scales. He participates in regional and national discussions about private-public partnerships in sustainable food systems. For example, several ministers have visited the farm, and the young farmer inspires changes to sustainability on social media. He also increases consumer awareness about more sustainable produce, and develops new modes of collaboration relating to ideas and ideals, rather than produce and products. He engages in research and learning activities, strengthening his capacity to deal with the pervasive uncertainty of food system dynamics.

Thus, while not having quantified the specific resilience principles for governance, our qualitative assessment was that the farmers scored highly on the relevant principles, including *managing the farm as a complex adaptive system*, *encouraging learning* (including modifying existing or acquiring new knowledge, behaviors, skills, values, or preferences), and *enhancing participation* (active engagement of relevant stakeholders in management and governance).

4. Discussion

The novelty of this study is the examination of a farm's contribution to global food system sustainability and resilience, moving beyond the environmental impacts at the local level, such as eutrophication of waters and local biodiversity impacts. For these environmental impacts, organic farms tend to score better than conventional farms, due to lower nitrogen fertilizer use, avoidance of pesticides, and more varied crop rotations (Röös et al., 2018). It should be noted, however, that with the current 'conventionalization' of organic farming (Darnhofer et al., 2010b) this is not always the case. The productivity of organic farming has been studied extensively, but often limited to yield gaps between organic and conventional crops (e.g., de Ponti et al., 2012; Ponisio et al., 2015) not considering what the crops are used for (feed or food), or how much is wasted, i.e., how much of the food produced that is actually consumed.

With the current global population, existing arable land world-wide needs to feed an average of five persons per ha to avoid further agricultural land expansion, and this will have to increase as the global population grows. The case study farm strongly increased its contribution to global food security between 2015 and 2019 (Table 2) from 0.9 to 1.5 persons fed per ha. However, this is lower than the global average requirement of approximately 5 persons fed per ha, and than the Swedish average of 4.8 persons fed per ha. In 2020, the farmer plans to increase crop production for human consumption by adding more legumes and oilseed rape, while slightly reducing the number of animals. With 60% of the farm's cropland used for crops for human consumption and the rest for animal feed, and with cereals and legume yields of 2-3.5 tonnes per ha, and the addition of some hectares of rapeseed the farm can meet the global average requirement of 5 persons fed per ha with only a slight decrease in animal numbers (see Table S1.1 in the SM for details). For comparison, in 2019 78% of the farm's land was used for feed crops, down from 90% in 2015.

It is however debatable whether '5 persons/ha' is an appropriate benchmark to apply at *farm level*. It may be appropriate for farms to specialize in certain products that tend to score lower, if this is compensated for by higher productivity (in terms of human nutrition) by other farms. The level at which this compensation should occur (local, national, or global) is an open, value-based question depending on e.g., the importance given to local food systems. As such, the indicator may be more appropriate as a target or benchmark for policy at the national or regional level than for an individual farm.

The indicator 'number of persons fed per ha' was however introduced because it is intuitive to understand and relatable to the absolute sustainability boundary of providing enough food for the global population. It also has the benefit that it can be used across arable, mixed and livestock farms and then captures how crops are allocated between food and feed, which is a major determinant for food security (Cassidy et al., 2013). However, like any other indicator, it cannot be the sole guiding indicator for sustainability at farm level. For example, a monoculture cereal farm would score very highly on this indicator, producing much human-edible energy and protein, but failing to deliver on local aspects such as biodiversity conservation, eutrophication, or long-term soil fertility, or on overall nutrition (De Fries, 2015). The ability to 'feed people' also depends on natural conditions such as soil quality, climate and water supply, and sunlight, so some farms will achieve a good score more easily than others. Such differences could be captured in future developments of this indicators considering also e.g. the Net Primary Production of different locations (Medková et al., 2017) and/or local crop production capacity (van Ittersum et al., 2013). However, the simple indicator used here can still be useful to give an indication of whether a farm is 'productive enough', promoting a change towards more plant-based eating and farming.

The results showed that the efficiency of the farm in terms of climate impact per kg product was similar to the Swedish average (Fig. S4.1). For the *total amount of food* leaving the farm, emissions per kcal reduced substantially (to 1.2 g CO_2e per kcal; Fig. 2a) as more crops for direct human consumption were added. Willett et al. (2019) suggest that total yearly global food system greenhouse gas emissions should be below 5 Gt CO_2e to stay within the Paris climate agreement, which gives a per kcal emissions boundary of about 0.74 g CO_2e for 2019, meaning the farm was still above this boundary despite progress. With the changes planned for 2020, the farm is predicted to deliver food with a climate impact below the boundary.

The farm scored higher on all resilience indicators analyzed (diversity, connectivity, governance) in 2019 than in 2015. The farm is now more diverse and more connected, and the farmer is engaged in learning and participation in general, using a more complex adaptive systems perspective in understanding his farm and its development. It is interesting to note that, despite year-to-year variability in crop yields, the farm produced a stable (and increasing) quantity of human-edible energy and protein. Inclusion of crops and animals that are susceptible to different stressors seemed to buffer some of the effects of disturbances within years. The farmer uses both modern crop high-yielding varieties and landraces with lower, but reliable, yields (Fig. 2a). On average over the years, the high-yielding varieties will yield more edible product than the landraces, but yield stability is also important for farmers. Meat production was more stable than crop production during the drought in 2018. Grass has a longer growing season than arable crops and was able to recover with late rain in August 2018. The farmer also used some of the crop residues from the failed crops caused by drought in 2018 and pests (legumes) in 2019 as animal feed.

Two other aspects increased the resilience: a) the farmer earns income from services he provides, such as giving talks and engaging in expert commissions, and b) the stable income from EU Common Agricultural Policy (CAP) payments. The EU support is around 25% of overall income (decreased from 33% in 2015 to 24-26% in 2016-2019), and is thus a substantial and reliable part of annual income.

A few potential weaknesses for the farmer emerged in the resilience indicators included. First, while the diversity in terms of variety and disparity of both products and actors increased, the balance showed very high dependence on one crop (oats) and one actor (the oat processor). Further, although the farm has substantially increased its annual turnover, profit margins are still small (as for many small-scale farmers), which leaves small buffers and reduces resilience. Another potential weakness is the time spent maintaining the large number of relations needed with all the actors with whom the farmer now engages. However, the farmer has demonstrated the capacity to close down relationships and end collaborations considered not important enough for his goals.

The present analysis revealed the complexity that farmers face in the transition to sustainable and resilient farming. It may be unreasonable to expect global responsibility from individual farmers. The farmer studied here had a very strong ambition to use his land and voice to improve the sustainability in agriculture beyond the farm, and had carved out a market niche that a limited number of farmers could copy. The farmer is highly educated and have specific skills (such as direct marketing through social media) not possessed by many farmers. Most farmers have chosen a different path, one of increased specialization and intensification to achieve better economies of scale, supported by price support policies and central marketing agencies (de Roest et al., 2018).

However, diversification can be a viable economic strategy for farms. For example, de Roest et al. (2018) showed that diversified farms perform equally well or better than specialist farms and are economically more resilient, especially if they produce complementary products and are able to sell to high added value niche markets, as the farmer in our case study did. de Roest et al. (2018) identified lack of marketing skills and lack of knowledge networks as the main barriers. If more farmers undertook similar changes on their farms, they could collaborate to facilitate exchange of crops, animal feeds, and manure, but also pursue joint routes to market, knowledge exchange, and joint identity as a movement or a cooperative. In addition, if environmental, social, and economic sustainability on food system scale is to be achieved, sustainable and resilient farms need to move from being niche to becoming the norm. Most farmers would need better support and incentives to achieve the transition displayed by the farm in this case study. A positive step is that we are now seeing examples of stewardship by transnational companies, as alignment of values and goals is important for larger market shifts (Österblom et al., 2017; Folke et al., 2019). The concepts of 'stewardship' and 'global responsibility' need to be adopted not only by individual consumers and farmers, but also by other actors in the food supply chain and the policy and governance structures that surround the food system.

5. Conclusions

This paper presents a novel assessment of sustainability and resilience of a Swedish farm undertaking a transformation to enhance global biosphere stewardship, motivated by the farmer's values. A novel feature of the assessment was to go beyond local effects of the practices employed and examine the contribution of the farm to global food security. Emissions intensity in terms of greenhouse gases was also assessed, to capture aspects of environmental efficiency. A set of resilience principles, including diversity and connectivity, was applied to assess whether the farm could increase food security while maintaining or enhancing sustainability and resilience.

It proved difficult to assess the sustainability and resilience of the farm in absolute terms. The farm is not yet meeting the global average for persons fed per ha with sufficient per-capita climate efficiency. Longer timescales would be needed to draw conclusions on the resilience of the farm. However, the assessment showed that the farm is on the right path, becoming more sustainable and resilient over time. The farm showed impressive improvements in different criteria once the farmers decided to do things differently, by:

- Increasing the number of persons fed per ha by 79%, by growing more crops for human consumption.
- Significantly reducing greenhous gas emissions per calorie and unit of protein produced.
- Increased the diversity of produce and income streams, shortening supply chains, and almost doubling overall income.
- Building relations with a diversity of actors to achieve sustainability goals, and increased outreach in terms of spreading knowledge on how farmers can act to enhance biosphere stewardship

All of these changes stemmed from the farmer's desire to become a steward of his land and use the land to increase global sustainability, and his openness to trying new things and doing things differently. The key to achieving improvements was diversification into several different crops for direct human consumption and services for the community. The farmer did not react passively to changes in the market, but actively influenced change by increasing and promoting demand for products that would improve the sustainability of the farm and beyond. The farm is in many ways an exceptional case, but the analysis showed how sustainability, resilience, and food security of the global food system could be included in farm-level strategies and assessments. Similar studies on more farms would provide a better understanding of whether such assessments are useful, and whether the strategies employed ultimately lead to greater sustainability and resilience.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: In 2016, the oatdrink company Oatly cofounded (together with the research platform SLU Future Agriculture at the Swedish University of Agricultural Sciences) some of the initial work of Röös on which this paper is based. The study was set up and performed completely independently by the researchers.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gfs.2020.100487.

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