Rimhanen *et al.*
Agricultural and Food Economics (2023) 11:31
https://doi.org/10.1186/s40100-023-00269-4

Agricultural and Food Economics

RESEARCH **Open Access**

What enhances dairy system resilience? Empirical cases in Finland and Russia

Karoliina Rimhanen[1*], Hanna Mäkinen[2], Miia Kuisma[3] and Helena Kahiluoto[2]

*Correspondence: karoliina.rimhanen@luke.fi

[1] Bioeconomy and Environment, Natural Resources Institute Finland (Luke), Latokartanonkaari 9, 00790 Helsinki, Finland
[2] Sustainability Science, LUT University, P.O. Box 20, 53850 Lappeenranta, Finland
[3] Bioeconomy and Environment, Natural Resources Institute Finland (Luke), Lönnrotinkatu 7, 50100 Mikkeli, Finland

Abstract

Dairy systems, which are the main pillars of rural livelihoods in north-eastern Europe encounter ecological, economic, and political changes in their operating environments which threaten their capacity to provide dairy supply. As uncertainty increases, there is a need to increase understanding and identify concrete tools to help food system actors manage resilience. We defined 'dairy systems' as a social-ecological system in which milk supply is the primary function, and humans and ecosystems endogenous factors. We conducted a qualitative empirical study to develop, enrich, and validate a theoretical framework, acknowledging social, economic, and ecological perspectives affecting the resilience. This paper identifies critical changes affecting the systems and key determinants of dairy system resilience, especially means actors can manage, in two socially and ecologically contrasting regions, Finland and Russia. The data consist of 26 qualitative in-depth interviews conducted in Finland and the surroundings of St Petersburg in the Leningrad Oblast. The critical changes confronting dairy system actors in both regions were especially related to prices and economics, policies, and epidemics. In Finland, possible cuts to agricultural subsidies, as well as an increasing workload, were perceived as a significant threat, whereas risks related to investors and resource adequacy were highlighted in Leningrad Oblast. Despite the socioeconomic distinctions between the countries, the determinants were similar and included ecological, economic, and social issues. However, the form of farm ownership proved decisive: for family farms in Finland, social well-being determinants were more important than economic ones; for investor-owned businesses in Leningrad Oblast, the opposite was the case. The results can be used by dairy systems actors, as well as administrators and policymakers, as a tool for understanding, assessing, and managing resilience.

Keywords: Social-ecological system, Changes, Risks, Disturbances, Adaptation, Milk production

Introduction

Global changes threaten food systems and food security (Campbell et al. 2016). In recent decades, dairy systems, which are the main pillars of rural livelihoods in north-eastern Europe, have encountered ecological, economic, and political changes in their operating environments (Barkema et al. 2015). The capacity of these systems to face such changes has rapidly grown in importance. This makes dairy system an important case for an empirical resilience study.

The changes dairy systems face include climate shocks causing yield losses (Cogato et al. 2019), the increasing market price volatility of agricultural inputs and products, and the resulting market speculation, which together complicate dairy supply (Hasegawa et al. 2018; Khabarov and Obersteiner 2017; Tadesse et al. 2014). This has influenced farmers' investment decisions (OECD 2008), retail suppliers, and consumer prices (Kahiluoto et al. 2020). Meanwhile, food scandals have shaken consumer confidence (Walker et al. 2013).

We defined resilience in a dairy farming system as the ability to resist, recover, adapt to, and transform (Carpenter et al. 2001; Folke et al. 2010; Holling 1973; Meuwissen et al. 2019) external shocks and drivers while maintaining primary functions. We defined 'dairy systems' as a social-ecological system (Berkes et al. 2000; Ericksen 2008; Paas et al. 2021; Tendall et al. 2015; Walker et al. 2012) in which milk supply is the primary function, and humans and ecosystems endogenous factors (Walker et al. 2012). The resilience literature has multiplied in recent years, but the work on what enhances and undermines resilience in food systems remains quite theoretical and few. For example, a theoretical orientation is demonstrated by a conceptual model (Tendall et al. 2015), a resilience indicator-based assessment (Jacobi et al. 2018), a livelihood resilience framework (Lecegui et al. 2022), as well as the presented dimensions of farming (Darnhofer et al. 2010; Meuwissen et al. 2019) and households (Misselhorn 2005). The same concerns studies of disaster response (Béné et al. 2016), the role of knowledge (Anderson 2015), and functional and response diversity (Hodbod and Eakin 2015), as well as a global comparison (Seekell et al. 2017). Little work has been conducted on what concrete tools help food system actors manage resilience (Rimhanen et al. 2023).

In the event of a disturbance, determinants critical for maintaining key operations, i.e. system functions such as dairy supply, are case-specific and influenced by interactions of social-ecological factors in the operating environment. In the dairy systems of north-eastern Europe, these characteristics have not previously been studied. We therefore empirically developed, enriched, and validated a theoretical framework, acknowledging social, economic, and ecological perspectives equally. We aimed to identify the critical change factors affecting the systems and the key determinants of resilience which actors could manage. We also identified the key determinants leading to dairy system collapse. Since farmers' adaptive capacity is perceived as weakest among European food supply chain actors (e.g. Himanen et al. 2016), farmers' perspectives on the dairy system were emphasised. This study provides a means for the actors of dairy systems and a model to apply, as well as an approach to follow in other cases.

We posed the following research questions:

What are the shocks and changes faced by dairy systems? Further, what enhances dairy system resilience to such shocks and changes, and on the other hand, what leads to the abandonment of dairy supply operations?

To achieve an empirical understanding of north-eastern European dairy system resilience, we conducted qualitative empirical study in two contrasting north-eastern European dairy systems in Finland and the Leningrad Oblast in Russia.

Theoretical framework

We use the concept of resilience in this study to understand social, economic, and ecological perspectives and interactions affecting the maintenance of milk supply in the event of disturbances (Cradock-Henry 2021; Meuwissen et al. 2019; Rizzo 2017; Himanen et al. 2016; Kahiluoto et al. 2014; Cabell and Oelofse 2012; Naeem et al. 2009). Resilience thinking emphasises that change is present everywhere, and it is difficult to predict, and that to maintain operations, system need to change (Darnhofer et al. 2016). Resilience can be conceptualised as the capacity of a system to cope with changes and challenges (Folke et al. 2010, 2016; Bullock et al. 2017). Resilience theory is founded on the model of the adaptive cycle, which illustrates the dynamics of social-ecological systems, distinguishing four system phases: exploitation, conservation, release and reorganisation (Gunderson and Holling 2002). A resilient system can proceed through all the system phases, requiring the capacity to buffer shocks (robustness), to adapt to changes (adaptability) and to transform (transformability) (Darnhofer et al. 2016; Meuwissen et al. 2019) for exploring and taking advantage of new opportunities (Scheffer and Westley 2007). Robustness refers to the dairy system´s capacity to resist disturbances. Dairy system needs to be able to buffer sudden price increase or unavailability of employees without changes in the supply of dairy products. Adaptability is the capacity to change inputs, production, marketing, and risk management without changing dairy system structures and feedback mechanisms. Dairy system needs to adapt to new policies, technologies or consumer habits. Transformability is the capacity to considerably change the structures and feedback mechanisms of the dairy system as a response to severe disturbances which prevent the business as usual (Meuwissen et al. 2019). The conversion from conventional to organic production is an example of such transformation, if it is linked to shifts in values, goals and social networks (Lamine 2011; Darnhofer et al. 2016). Like Himanen et al. (2016), we considered useful to identify determinants of resilience that actors can utilise in building dairy system resilience in practice. Here we adopt the relational approach to dairy system resilience, previously discussed by Darnhofer et al. (2016) and applied in dairy farmers resilience by Rizzo (2017). This approach highlights interactions of ecological and social processes, enabling the identification of different relations in different contexts to manage resilience, and enables placing the ubiquity of change in the focus of attention (Darnhofer et al. 2016).

’We developed the analytical framework employing a ‘specified’ resilience approach implying the questions ‘resilience of what, to what’ (Carpenter et al. 2001; Folke et al. 2010) but attempted to broaden the range of plausible disturbances by involving two contrasting social-ecological contexts of north-eastern dairy systems with their distinct histories. We followed the five steps of the resilience assessment by Meuwissen et al. (2019). We identified the determinants that enhanced and constrained dairy systems’ robustness, adaptability, and transformability.

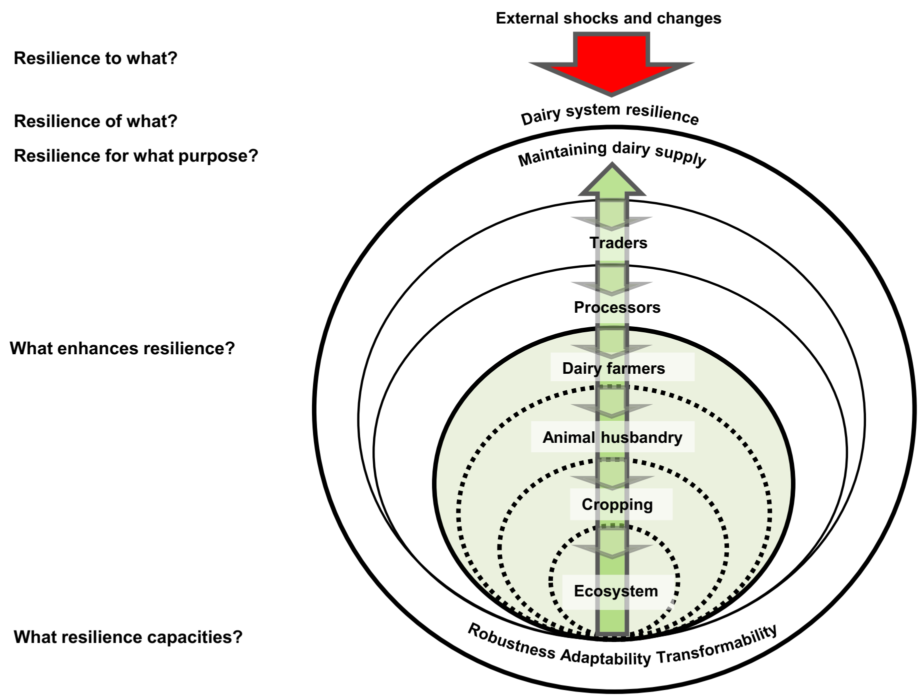

Fig. 1 System boundary of the study. The main operations of the dairy system considered are marked with solid line. Animal husbandry and cropping, marked with a dashed line were considered as key operations within the dairy farming system. Humans and the ecosystem were considered as endogenous factors, i.e. integral part of the dairy system with the interface between the social and ecological factors

1. Resilience of what?—dairy system

   In this study, the main interest is the dairy supply and the farms that produce milk. We defined the dairy farming system as including farm households, cropping, and animal husbandry. We considered the economic, ecological, and social preconditions for maintaining dairy supply. Dairy farming systems are influenced by non-farm actors interacting with the farm—namely, processing and trade (Figure 1).
2. Resilience to what?—shocks and changes
   We considered both short- and long-term economic, environmental, and social shocks and changes that had affected the operations of the dairy systems, and that were expected to affect them in the future.
3. Resilience for what purpose? —dairy supply
   The dairy system's main function is the production of milk or milk-derived products, supplemented by other food items such as meat. We identified functions that were desirable for maintaining dairy production at the farm level.
4. What resilience capacities?—robustness, adaptability, transformability
   We examined the ability of the dairy system to withstand shocks and change, adapt to change, and transform itself when required in response to change to maintain dairy production.

5. What enhances resilience?—determinants
   We identified goals and means that promoted and enabled the realisation of the resilience capacities and promoted general resilience. In addition, key determinants leading to dairy farming system collapse were identified (Gunderson and Holling 2002).

Resilience of what?

We defined 'dairy systems' as a social-ecological system (Berkes et al. 2000; Ericksen 2008; Tendall et al. 2015; Walker et al. 2012) in which dairy supply was the primary function (Fig. 1). The dairy farming system includes cropping and animal husbandry which are linked to ecosystems (soil, climate and water systems). In addition, maintaining dairy supply require acknowledging interactions with processing and retail trade. Humans and ecosystems were considered as endogenous factors, being a central part of the system, with social-ecological interface (Walker et al. 2012). Instead of considering peoples as users of the dairy system operating for securing of natural capital and ecosystem services, also dynamics of human well-being was included (Ericksen 2008; Paas et al. 2021).

The resilience of dairy systems is based on the concept of adaptive cycles, describing different stages of a system in response to change (Gunderson and Holling 2002). The concept includes the system capacity not only to buffer the change and maintain the current state of equilibrium but to adapt to change and transform functions if necessary (Walker et al. 2004; Folke et al. 2010; Meuwissen et al. 2019). Due to these capacities, the system can move along the cycle and undergo the different stages of exploitation, conservation, release, and reorganisation (Gunderson and Holling 2002; Fath et al. 2015).

By empirically identifying the critical change factors and key determinants of the resilience of dairy systems, this research advances the operationalisation, management, and assessment of resilience in food systems.

Materials and methods

Case regions

Dairy production is the most important agricultural sector and rural livelihood in north-eastern Europe, accounting for 50% and 60% of the annual agricultural gross product in Finland and the Leningrad Oblast in Russia respectively (Serova and Karlova 2010; Virkajärvi et al. 2015). Structural change in agriculture has especially affected milk production in both countries (Table 1).

Table 1 Comparison of the case regions

Characteristic	Leningrad Oblast	Finland	Literature
Share of dairy production of the annual agricultural gross product	60%	50%	Serova and Karlova (2010), Virkajärvi et al. (2015)
Development of the number of farms over the last 25 years	Decreased	Decreased	O'Brien and Wegren (2002), OSF (2020a)
Self-sufficiency rate of milk in 2014	50%	100%	Serova and Karlova (2010), Luke (2022)
Ownership of farms	Corporate-owned farms	Family farms	Hockmann et al. (2005), OSF (2020a)
Average milk yield per cow	5500 kg	9095 kg	Serova and Karlova (2010), OSF (2020a)

Before Finland joined the EU, the food sector operated in a strongly subsidised and protected environment (Jansik et al. 2014). Since EU accession in 1995, the number of dairy farms has decreased from 33,000 to approximately 5800 farms in 2019 (OSF 2020a). Nevertheless, the simultaneous increase in herd size and average milk yield have kept the volume of total milk production relatively stable; since joining the EU, it has fallen by only 3.6% (OSF 2020a). The production and consumption of dairy products are identical, the self-sufficiency for milk is almost 100% in Finland (Luke 2022). Most dairy farms are located in the Ostrobothnia regions in Western Finland and North Savo and North Karelia in Eastern Finland (Statista 2023). During the Soviet era, self-sufficient milk production was a target across all regions of the current Russian Federation (Serova and Karlova 2010). After the collapse of the Soviet Union in 1992, the liberalisation of markets resulted in the unprofitability of dairy production in certain regions, increases in consumer prices, a decrease in consumption, and an increase in imports (O'Brien and Wegren 2002). After the 1998 economic crisis, the devaluation of the rouble saw the food sector beginning to recover. Declining imports spurred on and developed the domestic dairy sector (Serova and Karlova 2010). At the time when the data was collected, in 2014, the dairy industry in Russia suffered from a milk shortage: the self-sufficiency of milk and dairy production was 50% in northwest Russia (Serova and Karlova 2010). Nowadays Russia is 82% self-sufficient in milk, aiming to achieve 100% self-sufficiency for dairy production in the next 3–4 years (Tass 2023). In the Leningrad Oblast, the intensive milk production with the highest milk yields per cow is concentrated in the northwest and central regions, close to the processing industries around St Petersburg (Serova and Karlova 2010). In 2008, there were 126 dairy farming enterprises in the Leningrad Oblast (Serova and Karlova 2010).

Farms are typically owned and managed by families in Finland. The average farm size is 74 hectares, the average number of cows is 41, and the average milk yield is 9095 kg per cow, well above the EU average of 7280 kg (OSF 2020a). Both the dairy supply and industry in Finland are cooperative, strongly intertwined, and monopolised by one major dairy supplier, accounting for 80% of milk deliveries (Arovuori et al. 2019). Of all dairy farmers, approximately 98% are owners in this cooperative (Jansik et al. 2014). In the Leningrad oblast, dairy enterprises represent mostly corporate-owned farms, privatised former sovkhozes producing about 90% of the milk and typically specialising in multiple agricultural activities (Hockmann et al. 2005). On such farms, the manager is typically hired from outside agriculture, coordinating all investment, staff, production, and marketing activities (Hockmann et al. 2005). There are usually more employees in agricultural enterprises than on family farms. In 2008, the average milk yield per cow was 5500 kg—nearly 25% less than the EU average (Serova and Karlova 2010).

Across Europe, most milk sector exports to Russia are from Finland—at more than 8000 tonnes per month—but this collapsed to zero after the embargo of imports to Russia[1] in

[1] The Russian Federation imposed countersanctions in August 2014 which banned dairy products from EU member states in response to EU sanctions against Russia in response to annexation of Crimea and the nonimplementation of the Minsk agreements. After this, EU has expanded the sanctions against Russia in response to the war against Ukraine started on 24 February 2022.

August 2014 (Customs 2020). Nevertheless, by changing the product portfolio and finding compensatory market channels, Finland was able to cap its 2014–2015 production price decline at only 13% (OSF 2020a).

Interviews

The method followed the criteria set for coupled human–environment systems (Schröter et al. 2005), which are characterised as complex, dynamic, interconnected and integrated systems in which humans interact with natural environment (Sarkar et al. 2021), including the participation of various stakeholders. It was place-based, considering multiple interacting stresses and capacities, and both prospective and historical.

We conducted 26 interviews (Fig. 2) in Finland and the Leningrad Oblast surrounding St Petersburg (Fig. 3). Through this selection, we sought to generalise the findings beyond the regions. The interviews were performed between June 2013 and September 2014. We also included published news about the causes resulting from the abandonment of two dairy processors in Finland in the data.

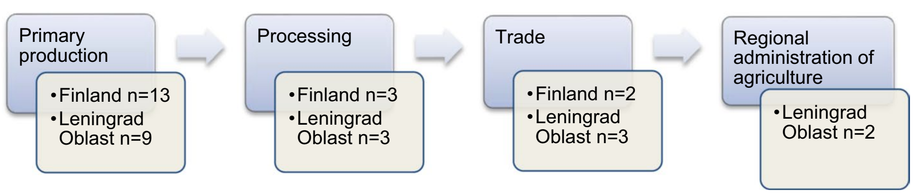

Fig. 2 The role and number of interviewees in the dairy system

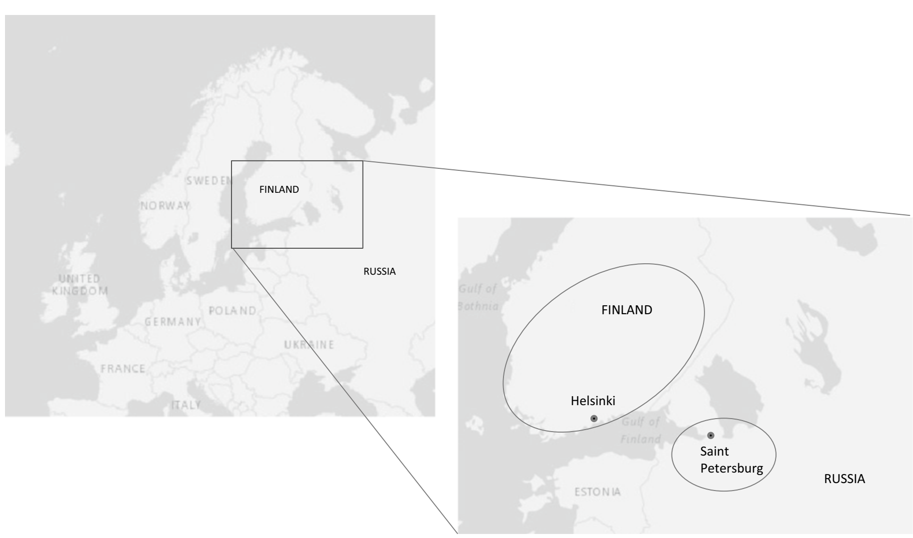

Fig. 3 The locations of the interviewees. Source: ESRI 3.4.2020

Table 2 The hypothetical determinants of resilience on the dairy farms studied (number of farms)

Hypothetically important factor	Determinant	Feature	Leningrad Oblast (*n* = 9)	Finland (*n* = 13)
Ownership	Ownership	Independent	1	10
		Cooperative, limited company	2	3
		Agroholdings	6	
Nutrient and energy economy	Plant nutrient source	Synthetic and organic fertilisers	9	8
		Organic fertilisers		5
Functional diversity in business	Line of production in addition to dairy production	Meat production (raising calves)	6	4
		Live animals (calves, breeding animals)	7	8
		Cash crops	6	3
		Direct selling of raw milk	1	2
		Milk processing	1	2
		Contracting	1	1
	Marketing channels of raw milk	One	3	8
		Several	6	5
Social networking	Level of cooperation	None–Very little	6	3
		Some–High	3	10

Regarding the farms that had stopped milk production at the time of the interview, the information concerns the period when the farm produced milk

The interviewed farmers were selected to differ in terms of farm ownership, nutrient and energy economy, diversity in business, and social networking (Table 2). Through this selection, we aimed to cover system characteristics and interactions.

In Finland, the interviewees included 12 farmers and two milk processors. Of the farmers, ten were active producers, of whom one also participated in processing; two were direct sellers of milk; and one had a position of responsibility in a cooperative. Three of the interviewees had stopped milk production between 2001 and 2012. One had continued crop production, one had started crop and meat production, and one had specialised in milk processing. Through this selection, we aimed to understand the variables leading to system transformation.

In the Leningrad Oblast, the interviewees included nine farmers or farm managers (including one family-run farm, one cooperative, and seven non-family-run agricultural enterprises), a manager of a large processing company, and two agricultural experts from the regional government.

Concerning ownership, the farms represented independent farms, run by families or other private owners, agricultural enterprises such as cooperatives and limited companies of two or more farms, or larger enterprises (agroholdings) operating in agriculture and other sectors. Concerning the nutrient and energy economy, the farms utilised commercial synthetic fertilisers or farm-residue-based recycled organic fertilisers and bioenergy. Concerning business diversity, the farms specialised in dairy production or undertaking other activities such as cash crop production, meat production, the direct

Table 3 The scale of production of the dairy farms studied

	Leningrad Oblast ($n = 9$)	Finland ($n = 13$)
Number of dairy cows		
1–25		7
26–50		2
51–100		1
101–300		3
301–1000	3	
1001–2000	6	
Milk yield, M kg a^{-1}		
0.1–0.5		10
0.6–2.0		3
2.1–5.0	2	
5.1–8.0	3	
8.1–11.0	1	
11.1–14	2	
14.1–17.0	1	
Field area, ha		
1–30		1
31–80		6
81–150		1
151–500		5
501–2000	2	
2001–4000	2	
4001–6000	5	

If the farms had stopped producing milk, the information concerns the period of dairy production

sale of raw milk, milk processing, or contracting agricultural machinery, as well as multiple marketing channels for raw milk. Concerning social networking, the farms had either no cooperation, low rates of cooperation, or high rates of cooperation in terms of joint ownership, knowledge sharing, or contracting. Farms (Table 3) were larger in the Leningrad Oblast than in Finland.

Interview guide

The questions in the semi-structured interviews were related to the functioning of the dairy system, including themes related to experienced and expected changes, impacts, mechanisms promoting robustness, adaptability and transformability, buyer–supplier relations, cooperation networks, and potential futures ("Appendix 1"). A pilot interview was conducted in both countries to test the study design. The interviews were conducted in Finnish in Finland; in Leningrad Oblast, the researcher's questions were translated from English to Russian, and the responses from Russian to English, with the aid of an interpreter. All the interviews in Finland and two in the Leningrad Oblast were tape-recorded and transcribed. The rest were recorded manually due to concerns about anonymity. The survey results are available from the author on request.

Analysis

In the analysis, we sought answers to our research questions. The unit of analysis was individual interviewees' perspectives and opinions. The data were analysed using relational content analysis (Elo et al. 2014) which explores the relationships between concepts to determine if concepts are interrelated. The transcribed data were coded and structured into the themes emerging from the data ("Appendix 2 and 3") (Creswell 2014), which formed the key goals and means of resilience. Coding and condensing were fully based on the data. The emerging themes corresponded to the change factors and key determinants in the empirical conceptual model. As a result, the emerging themes and their interactions validated and developed the empirical conceptual model.

Results and discussion

Resilience to what?

The main changes faced by the dairy systems reflected major political shifts. International relations and policies were perceived as unpredictable, constantly changing, and as threats in both countries. Current war in Ukraine is again an example of how far-reaching consequences can be. In the recent history, the most extreme examples, Finland joining the EU and the collapse of the Soviet Union—caused most of the distinctive changes (Fig. 4). They exposed the entire dairy system to the free market, and this caused

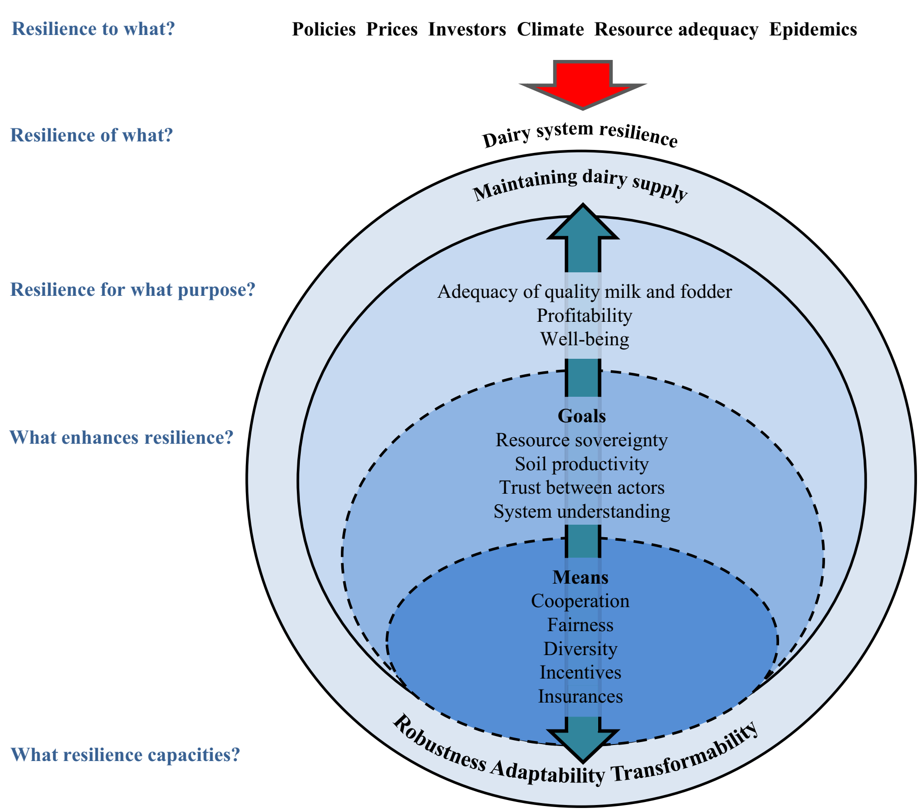

Fig. 4 The empirical conceptual model of dairy system resilience with critical change factors and key determinants, including goals and means ensuring the supply of dairy products in the event of disruptions

a decrease in the number of farms. The invasion of Crimea led to trade embargoes and a reconstruction of the dairy sector in both countries. In the Leningrad Oblast, embargoes and economic sanctions resulted in two types of opinions. They were perceived to result in a decline in dairy supply and to confuse markets, but also to provide an opportunity for an increase in domestic production. The Russian dairy system returned to increased self-sufficiency, with a narrower product selection for consumers, while a more competitive market was expected in Finland.

The reduction or ending of subsidies, especially the national northern aid in Finland and the subsidies for milk, machinery, fertilisers, and fuel in the Leningrad Oblast, was considered a threat, because they constituted a considerable share of income in both countries. A few interviewees criticised subsidies for commercial synthetic fertilisers, which directed agricultural production towards high input dependency in the Leningrad Oblast and thus accelerated the loss of soil organic matter.

Since the end of the twentieth century, the costs and volatility of inputs such as synthetic fertilisers, protein fodder, and energy, increased in both countries. Simultaneously, subsidies decreased, and producer prices remained low, decreasing profitability; these remain notably increasing future threats. In the Leningrad Oblast increased production costs were reflected as increases in market prices for food, resulting in a reduction in the consumption of dairy products during the 1998 Russian financial crisis. After the economy recovered, agricultural support from society gradually strengthened, and the purchase volume began to improve, which revived the dairy sector.

An increasing number of landowners who provided arable land for rent were reported to be investors (especially in the Leningrad Oblast, but also in Finland) or urban residents. In the Leningrad Oblast, participants voiced a fear of investors leaving the dairy sector due to dissatisfaction. Their exit from the dairy sector would considerably decrease the volume of milk produced.

Changing climate was mentioned as the major ecological change in both countries. Climate change was perceived as potentially benefiting crop production and enabling the cultivation of new crops. Longer growing season and diverse crop choices are indeed projected to bring opportunities for Northern European agriculture (Peltonen-Sainio et al. 2018, 2020), whereas rising temperature and shortage of water are expected to cause severe threats for crop production in tropics and semi-desert areas (Parker et al. 2019). However, the interviewees also worried about the impact on crop yields, prices of products, and animal health. However, none of the interviewees saw eutrophication as a threat, although agriculture in both countries is the major source of nitrogen and phosphorus runoffs to the Baltic Sea and inland water ecosystems (Räike et al. 2019). This affects agriculture through policies, and reflects the tension between top-down and bottom-up approaches to assessing resilience (Eakin et al. 2017). Actors tend to identify their immediate personal threats, excluding the interrelated environmental problems (Mäkinen et al. 2017) which affect them in the long term.

The availability of fields was considered uncertain in both case regions. Buying fields was rarely an option due to high prices and lack of supply. Particularly in the Leningrad Oblast, field prices were expected to increase further in the future. Expanding settlements were perceived as a threat to maintaining or expanding arable areas. The difficulty in finding high-quality staff was emphasised, and this was fundamental for improving the quality of milk, culminating in silage production in the Leningrad Oblast.

In Finland, animal diseases such as salmonella, EHEC, and listeria were considered threats. The participants expected epidemics to increase with globalisation and the increasing transport of animals and feed. In the Leningrad Oblast, the low quality of milk was emphasised. The lack of microbiological requirements, wide use of antibiotics, and insufficient testing in Russia were considered to benefit dairies, because it ensured the availability of milk, the quality of which was difficult for the consumer to assess organoleptically. The fact that consumers lack information about milk quality was emphasised as problematic.

Many of the identified changes such as conflicts, embargoes, and epidemics were fast, unpredictable, and abrupt, while slow changes in prices, weather volatility, and resource adequacy were observed mainly through the extremes.

Resilience for what purpose?

Despite the differing socioeconomic conditions in Finland and the Leningrad Oblast, the need for resilience was similar in both countries. Milk production and animal feeding based on fodder produced on farms were the key functions. Most highlighted external shocks and changes were directed at the farming system level. The function of the other dairy system processes mainly depended on the sufficiency of high-quality milk.

What enhances resilience?—determinants of resilience

The Finnish interviewees emphasised profitability as buffering dairy systems against shocks and change, also enabling the implementation of necessary adaptation and transformative investments, as was also found critical for dairy farmers' resilience by Rizzo (2017), agroecosystems by Cabell and Oelofse (2012), and food systems by Himanen et al. (2016). Society's commitment to supporting dairy production was considered important in both case regions. However, the interviewees perceived that the functioning of the farm should not depend too heavily on subsidies or large loans.

Well-being was emphasised as critical for overcoming shocks and changes. Financial difficulties and an accumulating workload decreased satisfaction and leisure, reducing well-being. Perrin et al. (2020) also stressed the importance of well-being and satisfaction for resilience. Growing farming sizes and workloads increased stress and fatigue, which was also the main reason for abandoning dairy production, underlining the importance of investing in well-being. Investing in employee welfare considerably reduced the number of illness days in the Leningrad Oblast. Besides the individual level, the importance of communal well-being was highlighted in both countries. Taking care of the whole surrounding community by channelling the profit from the dairy system to improve the community's welfare was considered important. The importance of communality was highlighted after an unexpected catastrophe—for example, a fire. Besides people, the interviewees emphasised that investing in animal welfare improved milk yields and milk quality and animal health and increased the average number of calves.

Positive feedback from consumers and the respect of society for dairy production increased the interviewees' self-esteem. They wished society would recognise agriculture as valuable and an opportunity, rather than merely as a source of raw materials.

In defining humans as endogenous factors of the dairy farming system (Walker et al. 2012), our study highlighted social and economic determinants (Fig. 4). Cradock-Henry (2021) also emphasises the importance of linking the social, economic, and agroecological attributes of resilience in the dairy farming context. This is in line with Ericksen (2008) and Adger et al. (2009), who underline the importance of social factors for adaptation, alongside ecological, economic, and technological factors. Such determinants are important facilitators of a fast system recovery when disturbances occur (Carpenter et al. 2012; Himanen et al. 2016). This was evident in our study in the quick help the community provided to a dairy farm after a fire, for example; the community's help enabled farming to continue without interruption.

Goals

Due to the input intensity and dependence of dairy systems, the respondents stressed the importance of resource self-sufficiency. A reduced reliance on agricultural trade was thought to increase security in the face of market volatility. Self-sufficiency in fodder and animal reproduction was critical for milk production. Having enough field resources was considered critical for the optimal balance of crop and animal production, securing silage self-sufficiency, with an adequate buffer in the event of yield losses. The interviewees supported the idea of nutrient cycling to increase nutrient self-sufficiency, soil productivity, cost reduction, and environmental benefits. However, actors had difficulties implementing nutrient cycling in practice. In the Leningrad Oblast, due to incentives for the use of synthetic fertilisers, manure management was not a primary focus. Furthermore, feed self-sufficiency was not achieved there due to the lack of integration of crop and animal production on large farms. In Finland, agricultural policy has steered crop and animal production towards regional specialisation. Manure recycling in crop farms' fields was rarely feasible or cost-effective because of high transport costs. A closed nutrient cycle would therefore require support in managing material flows.

The importance of soil productivity and health for maintaining fodder production was highlighted in both countries. The interviewees perceived that managing field drainage, liming, and increasing soil organic matter would ensure the productivity of fields during exceptional weather events, as well as in the long term.

Trust on a farm and within a family and among fellow farmers, communities, and supply chains was highlighted. On Finnish family farms, this referred to the relationship between the farming couple. Trust in permanent and substitute employees was also important to having time off from the farm. At the community level, good relations with neighbours and friends made it possible to turn to them in an hour of need. A lack of trust was considered harmful for the whole dairy sector, as it often prevented any cooperation. Collective learning, fed by trust, may incite innovation (Berkes et al. 2000; Biggs et al. 2012), which is crucial for decision making leading to adaptation and transformation (Biggs et al. 2015; Himanen et al. 2016; Polasky et al. 2011). Trust also contributes to experimentation and enables cooperation and long-term planning (Olsson et al. 2004; Walker and Salt 2006). These findings may result from the significant societal changes in recent history that have impacted dairy systems, as well as the extent to which foreign managers lead agroholdings. In Finland, the continuance of family farming from generation to generation and cooperative processing have increased long-term trust. Yet neighbourly help continues in rural areas.

It was stressed that an understanding of the needs and interactions of complex processes was important for system management. Good leadership skills, especially the ability to share responsibilities, were considered to improve the efficiency, governance, and sensitivity of the work. The findings match those of Ericksen (2008), underlining the importance of understanding complex interaction between actors and processes. The interviewees considered poor motivation and organisational skills, as well as a lack of knowledge, to be major problems in the Leningrad Oblast.

The ability to prepare for and adapt to a consistently changing operating environment requires diverse expertise, continuous learning, and adoption of new technologies. According to the interviewees in Finland, the most important knowledge came from practical skills learned in the childhood home and from colleagues. Experimenting was valued because it helped develop operations. In Finland, the interviewees emphasised the pleasure that resulted from successful experiments, which was reflected in well-being, while in the Leningrad Oblast, economic points were underlined.

Means

In relation to the resilience frameworks of farming (Meuwissen et al. 2019) and food systems (Tendall et al. 2015), our study complemented the actor toolkit with economic incentives and fairness. Trust between dairy system actors created cooperation—for example, marketing fodder and animals between farms. In Finland, where cooperation was more common, the interviewees appreciated collegial support, encouragement in decision making, and support in tackling problems. Cooperation reduced workloads and financial risks, improved outsourcing volume, and reduced costs.

Cooperation between dairy and crop farms was considered beneficial for both for marketing fodder, combining crop rotations, and manure management. Co-ownership and contracting made investment in machines possible and cheaper. Good connections with the owners of arable land could enable a longer lease period, guaranteeing the sufficiency of fodder production, and encouraging farmers to take better care of soil quality. Communication with the authorities was perceived as a channel to be better informed of new regulations.

Equal negotiation power between actors was considered to secure fairness in the dairy system. Relations between farms and dairy processing were emphasised. The opportunity to make several short-term contracts depending on price conditions maximised profits and created a strong negotiating position in the Leningrad Oblast. The equal negotiation power was obviously a result of several marketing options and short-term or no supply contracts. The negotiation position with retail was considered more difficult, resulting in large financial losses for processors. Furthermore, the perceived importance of fair compensation for work, also highlighted by (Cabell and Oelofse 2012), was the result of competition for skilled workers. Fairness was emphasised less in Finland, perhaps because milk was typically delivered to just one large farmer-owned cooperative dairy which paid the same price to each supplier and had a strong market position in the supply chain.

The resilience literature emphasises diversity as a key determinant in social-ecological systems, because it enables functionality across various circumstances (Chapin et al. 2004; Kahiluoto et al. 2014; Lin 2011; Meuwissen et al. 2019; Naeem et al. 2009; Ostrom 2009; Stirling 2007; Hertel et al. 2023; Galappaththi et al. 2021). In our study, diversity linked to functional (Moonen and Bàrberi 2008), and especially response diversity (Elmqvist et al. 2003), was emphasised, as diverse business activities that reacted differently to market changes stabilised the economy. Diversity was implemented through direct selling of raw milk, farm-level processing of milk, and the integration of the production of meat and crops. For small-scale processors, farm markets enabled forays into new markets and a diversification of activities. In Finland, diversification often meant incomes from side-lines such as machinery contracting or an external workplace.

Diverse production was considered to compensate each other's failures due to different vulnerabilities and strengths, improve the seasonality of work, and stabilise income, working as a buffer against market fluctuations. Diverse cultivation was also considered to improve long-term soil productivity. A diversity of market partners was considered to enhance flexibility during market turbulence. In the Leningrad Oblast, it was typical to have many buyers for raw milk; in Finland, a contract production for just one large-scale dairy was practised. Moreover, in the Leningrad Oblast, contracts with milk buyers were flexible; the amount of milk sold could vary monthly, which was considered positive when multiple buyers were available. This helped in price negotiations, the selling of different milk qualities, and the guaranteeing of sales if a buyer fell through. In Finland, cooperative dominance with a strong tradition of contract-based milk production and high-grade hygiene legislation limited the possibility and willingness to have multiple sale channels.

These findings support the importance of response diversity across the supply chain (Kahiluoto et al. 2020). The interviewees remarked that buildings and technology should also be flexibly planned for other purposes in changing conditions. Particularly in the Leningrad Oblast, holdings could have several activities.

Diversification strategies were implemented more in the Leningrad Oblast than in Finland. In Finland, the interviewees were aware of diversification but expended little effort on it, because it was thought to cause an additional burden on an already excessive workload. In the Leningrad Oblast, the larger size of holdings facilitated diversification; on Finnish family farms, the limited work contribution of a family was perceived as a restriction to diversification, even if no trade-off between diversity and resource use efficiency was observed (Kahiluoto and Kaseva 2016).

Incentives provided by society were seen as important for promoting nutrient cycling. At the actor level, financial and welfare-enhancing incentives were also stressed. In the Leningrad Oblast, where agroholdings employed more people, the support of employee motivation through worker benefits was emphasised. In addition to a good salary, zero-interest loans, health services, education, and recreational activities were mentioned.

Forests represented an integral part of the farming system in Finland and an important source of income. Forests were considered an insurance, as they provided capital to buffer against change and to bounce back after a disturbance, even though their average share of farm incomes in Finland was at most 7% during our study (OSF 2020b). They were also relied on when new investments were made. In the Leningrad Oblast, dairy enterprises did not manage forests.

What leads farmers to abandon dairy supply operations

Insufficient profitability and the lack of power to negotiate with retail was often a reason to abandon operations. The contamination of milk with pathogenic bacteria and the resulting costs of monitoring dairy cows and products, as well as the sterilisation of production buildings, led farmers to abandon dairy processing. The well-being and health of the farmer couple influenced such decisions. Good relations on a farm were critical for the continuity, and this was more important the smaller the farm was. On Finnish farms, this refers to the farming couple; divorce was the major reason for abandoning dairy farming. Mutual respect and shared time, values, and vision were seen as important, as work was often shared.

Generalisation

This comparison of two socioeconomically contrasting major dairy production regions—family farms and manufacture cooperatives and corporation-dominated supply chains—revealed an emphasis on whether social or economic aspects were more important for dairy system resilience. The critical changes related to climate change, market volatility, changing policies, and resource adequacy highlighted in this study are generally faced by social-ecological systems. The key determinants observed here are in line with previous research.

Conclusions

As uncertainty and disturbances are expected to increase in the future, there is a need to increase understanding of the key determinants of resilience in the dairy system which ensure the supply of dairy products in the event of disruptions. We created an empirical conceptual model of dairy system resilience with critical change factors and key determinants ensuring the supply of dairy products. Our study increases understanding of complex social-ecological interactions influencing dairy system resilience in the north-eastern Europe and provides concrete tools to help food system actors manage resilience.

Our findings highlight a diverse group of social, economic, and ecological determinants that are strongly interconnected and manifested independently of socioeconomically contrasting contexts. The implementation of means to enhance resilience in practice remains limited and requires support. There is a need for incentives, especially related to nutrient cycling and diversification. This should be promoted through national and international policy, counselling, research, and education. Projects and platforms enabling mutual learning and increasing interaction between different actors would promote the emergence of innovations. The form of farm ownership—that is, a family farm vs a corporate-owned farm—appears to determine whether social or economic aspects are more important. Social aspects on the family farm proved key to dairy supply continuity; they would therefore deserve more attention in future research. Cooperative suppliers that equalise negotiation power in a supply chain or the number of market channels available for each actor appear decisive for fairness within supply chains and should be studied more thoroughly. Further, addressing the determinants of resilience empirically in the food system across continents would provide more tools for securing the resilient futures of global food systems.

The conceptual model serves dairy system actors as a tool for understanding, monitoring, assessing, and managing resilience. The model can be utilised in decision-making and scenario planning as a management tool to creatively think about an alternative future. The results will be especially useful for creating and assessing possible policy interventions for mitigating the high rate of dairy farm abandonment, enhancing the viability of the weakest loop in food supply chains and thus the overall resilience of dairy and food systems. The key means of resilience give concrete measures for policymakers which should be integrated on the policies guiding agricultural and food sectors. Our findings emphasise the importance of holistic and coherent policy planning. Identified resilience means give insight into crisis prevention, adaptation and support for sustainable transformation towards future resilient food systems. It should be noted that the results of this study are based on fairly small number of interviews focusing on primary production and as a result, important issues for other dairy system actors may have been overlooked.

Appendix 1

Interview guide

1. In your own words, could you describe your farms'/company's operations and operating environment.
2. What have been the biggest changes in your farm/ the company?
3. How the changes affected your business?
4. How did you respond to the change?
5. How did you cope with the change?
6. What enhanced coping with the change?
7. What reduced coping with the change?
8. What changes threaten your operations now and in the future?
9. How do you prepare for change?

Appendix 2: critical change factors of dairy system resilience

Notes: Stepwise progress of the analysis presenting the condensed codes and themes that emerged from the interviews. Blue font represents condensed codes from Finnish data, red font from Leningrad Oblast, and black from both case regions.

Theme	Condensed codes
Policies	Agricultural policy, regulations, environmental regulations, irrational statutes, unnecessary bookkeeping, farming guidelines, directives, bureaucrats and changing rules, and changing legislation, conflicts, global political situation, state of war, threat of war, and decreasing foreign trade, embargo, Russian market, foreign trade important, confusion in the market, opportunity for Russian milk production, and good for milk business, sanctions cause problems and sanctions related to the adaptation of new legislation, Northern aid for milk production, subsidies for milk, machines, surface area, renovation of fields, underdrainage, synthetic fertilisers and fossil diesel, uncertain future, farmers' passivity, and changing supporting system, removal of milk quota, market pressure, income formation, price fluctuation, decreasing producer price of milk, and market insecurity
Prices	Increasing and fluctuating production costs, inputs, nutrients from synthetic fertilisers less expensive than manure, transport costs, lack of equipment, high wage costs, prices of energy, and fuel, decreasing producer price of milk, grain, meat, potato, vegetables, profitability, and investments, fluctuating prices, Russian market, foreign trade, no government policy, and market risk
Investors	Landowners outside agriculture, fear of investors leaving the dairy sector if dissatisfied with profit for their investment, ownership, high costs of capital, and need for investments
Climate	Weather variation, extreme weather improving production conditions, new crops, rain levels, floods, and drought insecurity, problems with plant production, success of yields abroad and effects on prices, and animals suffer from heat stress
Resource adequacy	Availability of fields, high field prices, uncertainty about renting fields, and rent field from the state, difficult to find competent staff, competition of labour, foreign labour force risky, inadequate labour, and need to hire pensioners, low quality of silage, and problems with technology
Epidemics	Salmonella, EHEC, listeria, farmers market, and foot and mouth disease, non-existent antibiotics testing, microbiological quality, no quality requirements for microbiology, and consumers do not know quality, milk quality

Appendix 3: preconditions, elements and means of dairy system resilience

Notes: Stepwise progress of the analysis presenting condensed codes and themes as they emerged from the interviews. Blue font represents condensed codes from Finnish data, red from Leningrad Oblast data, and black from both case regions.

Determinant	Theme	Condensed codes
Preconditions (Resilience for what purpose)	Adequacy of high-quality milk and fodder	Self-sufficiency of milk, milk production, milk yield, milk quality, milk quantity, increasing grazing, animal productivity, adequate field area, domestic silage, production of fodder, cow quality
	Profitability	Income, prices, implement adaptation, subsidies, farm extension, growing farm size and reduction of production costs, financial independence, continuous investments, state support for milk production, support for small-business activity, quality-based support for milk
	Well-being	Freedom, independence, enthusiasm, respect, signal from the society, joint interests, common time, meaningfulness, getting tired, stress, heavy work, giving up, overload, concern, hobby, dancing, yoga, forest walk, working hours, breaking away, social responsibility, investing in the wellbeing of employees, provision of recreation for workers, number of days lost through sickness, neighbours, villagers, employees, community, security, good salary, motivation of people, competition of labour, loans, health service, education, animal health, milk yield, quality, quantity, increasing grazing, animal productivity, animal welfare would lengthen lifetime, length of lactation period, program for heifer welfare, and good veterinary care, appreciation of agriculture, and respect from consumers, authority attitude
Elements (What enhances resilience?)	Resource sovereignty	Nutrient cycling, adequate field area, investments in domestic silage, production of fodder, cow quality, raising calves, precise fertilization, independence from purchased inputs, labour, no regulation for manure management in fields
	Soil productivity	Soil health, soil productivity, investments in domestic silage, production of fodder, field drainage, liming, soil

		organic matter, grasslands, direct area based support based on intensity of cultivation,
	Trust between actors	Connections between actors, networking with neighbour, family, friendship, common time, labour, no productional cooperation, regular meetings and discussions, knowledge sharing and planning, organisation of training and courses, loan guaranteeing, financial support from dairies to farms, respect, good relationship, friendship, informal relations, honest and reliable employees, mutual flexibility, divorce, rules of the game, distrust,
	System understanding	responsibilities, time management, sectors, employee, expert, knowledge, need to regenerate, continuum, decision-making, discussion, joint interests, quality, meaningfulness, adequate skilled staff, suitable technology, feed production, quality of fodder
Means (What enhances resilience?)	Cooperation	Knowledge sharing, common machinery and equipment, fodder supply, connections between actors, networking, experience, tradition, diverse know-how, continuous learning, excursions, consultation services, knowledge, innovations necessary to increase adaptation, organised meetings and seminars, administration advice
	Fairness	Equal negotiation power between farm and dairy, a difficult negotiation power with retail, fairness
	Diversity	Many activities, modifications and convertible buildings, farm market, options for market channels, livelihood, range of products, seasonality in production, risk aversion, financial stability, reserve funds, timing of logging, forests as insurance
	Incentives	Incentives to increase and improve fodder production, support for diversity to improve stability, support to increase self-sufficiency of fodder production, investment supports to agriculture, short-term financial support
	Insurances	Forest, source of income, reserve fund, stability

Acknowledgements
We thank Vladimir Surovtsev and Mikhail Ponomarev for helping us collect the data in the Leningrad Oblast.

Author contributions
Conceptualization, HK; Methodology, HK, KR, HM and MK; Investigation, KR and MK; Writing—Original Draft, KR; Writing—Review & Editing, KR, HM, MK, HK; Visualization, KR; Funding Acquisition, HK; Supervision, HK.

Funding
This study was funded by the Academy of Finland (ADIOSO project: Grant Number 25594, DEFORFO project: Grant Number 335648 and TREFORM project: Grant Number 339830).

Availability of data and materials
The datasets analysed during the current study are not publicly available due to it contains information that could compromise the privacy of research participants but are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors have no conflicts of interest to declare that are relevant to the content of this article.

Received: 1 February 2023 Revised: 29 June 2023 Accepted: 15 July 2023
Published online: 21 August 2023

References

Adger WN, Dessai S, Goulden M, Hulme M, Lorenzoni I, Nelson DR, Naess LO, Wolf J, Wreford A (2009) Are there social limits to adaptation to climate change? Clim Change 93:335–354. https://doi.org/10.1007/s10584-008-9520-z

Anderson MD (2015) The role of knowledge in building food security resilience across food system domains. J Environ Stud Sci 5(4):543–559

Arovuori K, Karikallio H, Kiviholma S, Jansik C, Niemi J, Piipponen J (2019) Structural change in the Finnish milk sector in 1995–2018. PTT Working Papers 198. p 63

Barkema HW, Von Keyserlingk MAG, Kastelic JP, Lam TJGM, Luby C, Roy J-P, LeBlanc SJ, Keefe GP, Kelton DF (2015) Invited review: changes in the dairy industry affecting dairy cattle health and welfare. J Dairy Sci 98:7426–7445. https://doi.org/10.3168/jds.2015-9377

Berkes F, Folke C, Colding J (2000) Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press, Cambridge

Béné C, Headey D, Haddad L, von Grebmer K (2016) Is resilience a useful concept in the context of food security and nutrition programmes? Some conceptual and practical considerations. Food Secur 8:123–138

Biggs R, Schlüter M, Biggs D, Bohensky EL, BurnSilver S, Cundill G, Dakos V, Daw TM, Evans LS, Kotschy K, Leitch AM, Meek C, Quinlan A, Raudsepp-Hearne C, Robards MD, Schoon ML, Schultz L, West PC (2012) Toward principles for enhancing the resilience of ecosystem services. Annu Rev Environ Resour 37:421–448. https://doi.org/10.1146/annurev-environ-051211-123836

Biggs R, Schlüter M, Schoon ML (2015) Principles for building resilience: sustaining ecosystem services in social-ecological systems. Cambridge University Press, Cambridge

Bullock JM, Dhanjal-Adams KL, Milne A, Oliver TH, Todman LC, Whitmore AP, Pywell RF (2017) Resilience and food security: rethinking an ecological concept. J Ecol 105(4):880–884

Cabell JF, Oelofse M (2012) An indicator framework for assessing agroecosystem resilience. Ecol Soc 17:13

Campbell BM, Vermeulen SJ, Aggarwal PK, Corner-Dolloff C, Girvetz E, Loboguerrero AM, Ramirez-Villegas J, Rosenstock T, Sebastian L, Thornton PK, Wollenberg E (2016) Reducing risks to food security from climate change. Glob Food Secur, 2nd International Global Food Security Conference 11:34–43. https://doi.org/10.1016/j.gfs.2016.06.002

Carpenter S, Walker B, Anderies JM, Abel N (2001) From metaphor to measurement: resilience of what to what? Ecosystems 4:765–781. https://doi.org/10.1007/s10021-001-0045-9

Carpenter SR, Arrow KJ, Barrett S, Biggs R, Brock WA, Crépin A-S, Engström G, Folke C, Hughes TP, Kautsky N, Li C-Z, McCarney G, Meng K, Mäler K-G, Polasky S, Scheffer M, Shogren J, Sterner T, Vincent JR, Walker B, Xepapadeas A, Zeeuw AD (2012) General resilience to cope with extreme events. Sustainability 4:3248–3259. https://doi.org/10.3390/su4123248

Chapin FS, Peterson G, Berkes F, Callaghan TV, Angelstam P, Apps M, Beier C, Bergeron Y, Crépin A-S, Danell K, Elmqvist T, Folke C, Forbes B, Fresco N, Juday G, Niemelä J, Shvidenko A, Whiteman G (2004) Resilience and vulnerability of northern regions to social and environmental change. AMBIO J Hum Environ 33:344–349. https://doi.org/10.1579/0044-7447-33.6.344

Cogato A, Meggio F, De Antoni MM, Marinello F (2019) Extreme weather events in agriculture: a systematic review. Sustainability 11:2547. https://doi.org/10.3390/su11092547

Customs (2020) International trade statistics. Available at: https://tulli.fi/en/statistics. Accessed 1.4.2020.

Cradock-Henry N (2021) Linking the social, economic, and agroecological: a resilience framework for dairy farming. Ecol Soc 26(1):1–19

Creswell JW (2014) Research design: qualitative, quantitative, and mixed methods approaches. Sage Publications, Thousand Oaks

Darnhofer I, Fairweather J, Moller H (2010) Assessing a farm's sustainability: insights from resilience thinking. Int J Agric Sustain 8(3):186–198

Darnhofer I, Lamine C, Strauss A, Navarrete M (2016) The resilience of family farms: towards a relational approach. J Rural Stud 44:111–122. https://doi.org/10.1016/j.jrurstud.2016.01.013

Eakin H, Connors JP, Wharton C, Bertmann F, Xiong A, Stoltzfus J (2017) Identifying attributes of food system sustainability: emerging themes and consensus. Agric Hum Values 34:757–773. https://doi.org/10.1007/s10460-016-9754-8

Elo S, Kääriäinen M, Kanste O, Pölkki T, Utriainen K, Kyngäs H (2014) Qualitative content analysis: a focus on trustworthiness. SAGE Open 4(1):2158244014522633

Elmqvist T, Folke C, Nyström M, Peterson G, Bengtsson J, Walker B, Norberg J (2003) Response diversity, ecosystem change, and resilience. Front Ecol Environ 1:488–494. https://doi.org/10.1890/1540-9295(2003)001[0488:RDECAR]2.0.CO;2

Ericksen PJ (2008) Conceptualizing food systems for global environmental change research. Glob Environ Change 18:234–245. https://doi.org/10.1016/j.gloenvcha.2007.09.002

ESRI (2020). ArcGIS Desktop 10.6.1

Fath BD, Dean CA, Katzmair H (2015) Navigating the adaptive cycle: an approach to managing the resilience of social systems. Ecol Soc 20(2):24

Folke C, Carpenter SR, Walker B, Scheffer M, Chapin T, Rockström J (2010) Resilience thinking: integrating resilience, adaptability and transformability. Ecol Soc. https://doi.org/10.5751/ES-03610-150420

Folke C, Biggs R, Norström AV, Reyers B, Rockström J (2016) Social-ecological resilience and biosphere-based sustainability science. Ecol Soc 21(3):41

Galappaththi EK, Ford JD, Bennett EM, Berkes F (2021) Adapting to climate change in small-scale fisheries: insights from indigenous communities in the global north and south. Environ Sci Policy 116:160–170. https://doi.org/10.1016/j.envsci.2020.11.009

Gunderson LH, Holling CS (eds) (2002) Panarchy: understanding transformations in human and natural systems. Island press, Washington

Hasegawa T, Fujimori S, Havlík P, Valin H, Bodirsky BL, Doelman JC, Fellmann T, Kyle P, Koopman JFL, Lotze-Campen H, Mason-D'Croz D, Ochi Y, Pérez Domínguez I, Stehfest E, Sulser TB, Tabeau A, Takahashi K, Takakura J, van Meijl H, van

Zeist WJ, Wiebe K, Witzke P (2018) Risk of increased food insecurity under stringent global climate change mitigation policy. Nat Clim Change 8:699–703. https://doi.org/10.1038/s41558-018-0230-x
Hertel T, Elouafi I, Tanticharoen M, Ewert F (2023) Diversification for enhanced food systems resilience. Science and innovations for food systems transformation. Springer International Publishing, Cham, pp 207–215
Himanen SJ, Rikkonen P, Kahiluoto H (2016) Codesigning a resilient food system. Ecol Soc 21:41
Hockmann H, Wandel J, Nedoborovskyy A (2005) Agroholdings in Russia: breaking the vicious circle. AgEcon Search. https://doi.org/10.22004/ag.econ.24416
Hodbod J, Eakin H (2015) Adapting a social-ecological resilience framework for food systems. J Environ Stud Sci 5:474–484
Holling CS (1973) Resilience and stability of ecological systems. Annu Rev Ecol Syst 4:1–23. https://doi.org/10.1146/annurev.es.04.110173.000245
Jacobi J, Mukhovi S, Llanque A, Augstburger H, Käser F, Pozo C, Peter MN, Delgado JMF, Kiteme BP, Rist S, Speranza CI (2018) Operationalizing food system resilience: an indicator-based assessment in agroindustrial, smallholder farming, and agroecological contexts in Bolivia and Kenya. Land Use Policy 79:433–446. https://doi.org/10.1016/j.landusepol.2018.08.044
Jansik C, Irz X, Kuosmanen N (2014) Competitiveness of Northern European dairy chains. MTT Agrifood Research Finland, Economic Research, Publications 116
Kahiluoto H, Kaseva J (2016) No evidence of trade-off between farm efficiency and resilience: dependence of resource-use efficiency on land-use diversity. PLoS ONE 11:e0162736. https://doi.org/10.1371/journal.pone.0162736
Kahiluoto H, Kaseva J, Hakala K, Himanen SJ, Jauhiainen L, Rötter RP, Salo T, Trnka M (2014) Cultivating resilience by empirically revealing response diversity. Glob Environ Change 25:186–193. https://doi.org/10.1016/j.gloenvcha.2014.02.002
Kahiluoto H, Mäkinen H, Kaseva J (2020) Supplying resilience through assessing diversity of responses to disruption. Int J Oper Prod Manag 40:271–292. https://doi.org/10.1108/IJOPM-01-2019-0006
Khabarov N, Obersteiner M (2017) Global phosphorus fertilizer market and national policies: a case study revisiting the 2008 price peak. Front Nutr 25:48. https://doi.org/10.3389/fnut.2017.00022
Lamine C (2011) Transition pathways towards a robust ecologization of agriculture and the need for system redesign. Cases from organic farming and IPM. J Rural Stud 27(2):209–219
Lin BB (2011) Resilience in agriculture through crop diversification: adaptive management for environmental change. Bioscience 61:183–193. https://doi.org/10.1525/bio.2011.61.3.4
Lecegui A, Olaizola AM, López-i-Gelats F, Varela E (2022) Implementing the livelihood resilience framework: an indicator-based model for assessing mountain pastoral farming systems. Agric Syst 199:103405
LUKE 2022. https://www.luke.fi/en/statistics/indicators/cap-indicators/ratio-between-domestic-production-and-consumption Accessed 14.6.2023
Meuwissen MPM, Feindt PH, Spiegel A, Termeer CJAM, Mathijs E, Mey Y, de Finger R, Balmann A, Wauters E, Urquhart J, Vigani M, Zawalińska K, Herrera H, Nicholas-Davies P, Hansson H, Paas W, Slijper T, Coopmans I, Vroege W, Ciechomska A, Accatino F, Kopainsky B, Poortvliet PM, Candel JJL, Maye D, Severini S, Senni S, Soriano B, Lagerkvist C-J, Peneva M, Gavrilescu C, Reidsma P (2019) A framework to assess the resilience of farming systems. Agric Syst 176:102656. https://doi.org/10.1016/j.agsy.2019.102656
Misselhorn AA (2005) What drives food insecurity in southern Africa? A meta-analysis of household economy studies. Glob Environ Chang 15(1):33–43
Moonen A-C, Bàrberi P (2008) Functional biodiversity: an agroecosystem approach. Agric Ecosyst Environ 127:7–21. https://doi.org/10.1016/j.agee.2008.02.013
Mäkinen H, Rimhanen K, Kaseva J, Himanen SJ (2017) Information needs, barriers and incentives to adopting climate change mitigation and adaptation actions in boreal agriculture. Clim Res 72:165–176. https://doi.org/10.3354/cr01462
Naeem S, Bunker DE, Hector A, Loreau M, Perrings C (2009) Biodiversity, ecosystem functioning, and human wellbeing: an ecological and economic perspective. Oxford University Press, Oxford
O'Brien DJ, Wegren SK (eds) (2002) Rural reform in post-Soviet Russia. Woodrow Wilson Center Press
OECD (2008) Rising food prices: causes and consequences. Organisation for economic co-operation and development. Paris, France
Olsson P, Folke C, Hahn T (2004) Social-ecological transformation for ecosystem management: the development of adaptive co-management of a Wetland Landscape in Southern Sweden. Ecol Soc 9:2
OSF, 2020a. Official Statistics of Finland. Structure in Agriculture and horticulture. Natural Resources Institute Finland. Available at: http://www.stat.fi/til/matira/index_en.html Accessed 7.4.2020a
OSF (2020b) Official Statistics of Finland. Statistics on regional dairy production. Available at: http://www.stat.fi/til/almaidt/index.html Accessed 7.5.2020b
Ostrom E (2009) Understanding institutional diversity. Princeton University Press
Paas W, San Martín C, Soriano B, Van Ittersum MK, Meuwissen MP, Reidsma P (2021) Assessing future sustainability and resilience of farming systems with a participatory method: a case study on extensive sheep farming in Huesca, Spain. Ecol Indic 132:108236
Parker L, Bourgoin C, Martinez-Valle A, Läderach P (2019) Vulnerability of the agricultural sector to climate change: the development of a pan-tropical Climate Risk Vulnerability Assessment to inform sub-national decision making. PLoS ONE 14(3):e0213641
Peltonen-Sainio P, Palosuo T, Ruosteenoja K, Jauhiainen L, Ojanen H (2018) Warming autumns at high latitudes of Europe: an opportunity to lose or gain in cereal production? Reg Environ Change 18(5):1453–1465. https://doi.org/10.1007/s10113-017-1275-5Returntoref2018inarticle
Peltonen-Sainio P, Sorvali J, Kaseva J (2020) Winds of change for farmers: matches and mismatches between experiences, views and the intention to act. Clim Risk Manag. https://doi.org/10.1016/j.crm.2019.100205
Perrin A, Cristobal MS, Milestad R, Martin G (2020) Identification of resilience factors of organic dairy cattle farms. Agric Syst 183:102875. https://doi.org/10.1016/j.agsy.2020.102875

Polasky S, Carpenter SR, Folke C, Keeler B (2011) Decision-making under great uncertainty: environmental management in an era of global change. Trends Ecol Evol 26:398–404. https://doi.org/10.1016/j.tree.2011.04.007
Rimhanen K, Aakkula J, Aro K, Rikkonen P (2023) The elements of resilience in the food system and means to enhance the stability of the food supply in Finland. Environ Syst Decis. https://doi.org/10.1007/s10669-022-09889-5
Rizzo F (2017) Investigating dairy farmers′ resilience under a transforming policy and a market regime: the Case of North Karelia, Finland. Quaest Geogr 36(2):85–93
Räike A, Oblomkova N, Svendsen LM, Kaspersson R, Haapaniemi J, Eklund K, Brynska W, Hytteborn J, Tornbjerg H, Kotilainen P, Ennet P, Kokorite I, Sonesten L, Plunge S, Koch D, Andresmaa E, Frank-Kamenetsky D, Pecio A, Sokolov A, Ejhed H (2019) Background information on the Baltic Sea catchment area for the Sixth Baltic Sea Pollution load compilation (PLC-6). Available at: https://helcom.fi/wp-content/uploads/2020/01/PLC-6-background-report.pdf
Sarkar P, Debnath N, Reang D (2021) Coupled human-environment system amid COVID-19 crisis: a conceptual model to understand the nexus. Sci Total Environ 753:141757. https://doi.org/10.1016/j.scitotenv.2020.141757
Scheffer M, Westley FR (2007) The evolutionary basis of rigidity: locks in cells, minds, and society. Ecol Soc 12(2):36
Schröter D, Polsky C, Patt AG (2005) Assessing vulnerabilities to the effects of global change: an eight step approach. Mitig Adapt Strateg Glob Change 10:573–595. https://doi.org/10.1007/s11027-005-6135-9
Seekell D, Carr J, Dell'Angelo J, D'Odorico P, Fader M, Gephart J, Kummu M, Magliocca N, Porkka M, Puma M, Ratajczak Z, Rulli MC, Suweis S, Tavoni A (2017) Resilience in the global food system. Environ Res Lett 12(2):025010
Serova E, Karlova N (2010) The Russian Federation: review of the dairy sector. FAO Invest. Cent. Ctry. Highlights FAO.
Statista 2023. https://www.statista.com/statistics/898166/dairy-farms-finland-by-region/#:~:text=In%202022%2C%20there%20were%204%2C891%20dairy%20farms%20in,number%20with%2022%20registered%20dairy%20farms%20in%202022. Accessed 14.6.2023
Stirling A (2007) A general framework for analysing diversity in science, technology and society. J R Soc Interface 4:707–719. https://doi.org/10.1098/rsif.2007.0213
Tass (2023) https://tass.com/economy/1565081 Accessed 14.6.2023
Tadesse G, Algieri B, Kalkuhl M, von Braun J (2014) Drivers and triggers of international food price spikes and volatility. Food Policy 47:117–128. https://doi.org/10.1016/j.foodpol.2013.08.014
Tendall DM, Joerin J, Kopainsky B, Edwards P, Shreck A, Le QB, Kruetli P, Grant M, Six J (2015) Food system resilience: defining the concept. Glob Food Secur 6:17–23. https://doi.org/10.1016/j.gfs.2015.08.001
Virkajärvi P, Rinne M, Mononen J, Niskanen O, Järvenranta K, Sairanen A (2015) Dairy production systems in Finland. In: van den Pol-van Dasselaar A et al (eds) Grassland and forages in high output dairy farming systems, vol 20. Proceedings of the 18th Symposium of the European grassland federation. Wageningen, the Netherlands
Walker B, Holling CS, Carpenter SR, Kinzig A (2004) Resilience, adaptability and transformability in social–ecological systems. Ecol Soc 9(2):5
Walker BH, Carpenter SR, Rockstrom J, Crépin A-S, Peterson GD (2012) Drivers, "Slow" Variables, "Fast" Variables, Shocks, and Resilience. Ecol Soc 17:30
Walker M, Burns M, Burns D (2013) Horse meat in beef products-species substitution 2013. J Assoc Public Anal 41:67–106
Walker B, Salt D (2006) Resilience thinking. Island Press, Washington

Publisher's Note

Dr. Karoliina Rimhanen is a Research Scientist at the Natural Resources Institute Finland (Luke), she has a PhD in agroecology from the University of Helsinki, Finland and her research focuses on the resilience of agri-food systems.