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Maladaptation in Nordic agriculture

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ABSTRACT

Climatic changes are expected to pose challenges to Nordic agriculture. While some changes may provide opportunities for higher productivity, others may severely increase agricultural vulnerability. Farmers attempt to adapt or cope with these changes by taking measures to decrease vulnerability or to take advantage of potential benefits, but little is known what outcomes these adaptation measures might have. This study identifies unintended negative impacts of adaptation measures, drawing on a literature review and interviews with farmers and agricultural officials and experts in Sweden and Finland. Based on the conceptual framework of maladaptation, this study identifies outcomes that either increase the vulnerability of the implementing actor, shift the vulnerability to other actors or sectors or affect common pool resources. While a large number of adaptation measures rebound vulnerability to the implementing actor, several potential maladaptive outcomes may shift vulnerability or affect common pool resources. The findings point to the large number of trade-offs that are involved in adaptation decision-making and lead to the conclusion that raising awareness of these aspects can support future adaptation strategies.

1. Introduction

Climatic changes in the Nordic countries are projected to generate wetter and warmer conditions (IPCC, 2013; Strandberg et al., 2014). Simultaneously, periods of drought are expected to become longer and the number of days with heavy precipitation is projected to increase (ibid). These changes are expected to result in altered conditions for crop production that may pose significant challenges to Nordic agriculture in the future. Warmer and wetter conditions are associated with an increased risk of pest and weed infestations. Changes in weather extremes (increased precipitation, droughts and storms) and increasing vulnerability to heat waves and heavy precipitation are likely to have a marked effect on agriculture (Olesen and Bindi, 2002; Olesen et al., 2012). There is also a possibility that climate change may produce benefits. For example, a longer growing season offers the potential for higher yields, additional harvests, and introduction of 'new' crops. Adaptive actions are required to capture these opportunities to gain rather than lose from climate change.

Scientific literature has addressed the need for adaptation in European agriculture (Falloon and Betts, 2010; Reidsma et al., 2010; Olesen et al., 2012), highlighted some of the risks and opportunities associated with climate change, and outlined possible adaptation

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measures to address those (Iglesias et al., 2012). These adaptation measures aim either to decrease the risks associated with climate change, to increase the coping capacity or adaptive capacity of the system, or to increase the benefits that might be associated with climate change. More recently, research has focused on the degree of adaptation required within the agricultural sector, differentiating measures taken by farmers into three types, based on the degree of change, in order to determine to what extent the changes are sufficient to deal with climate risks (Howden et al 2010). Nordic farmers have mainly engaged in adapting through incremental changes to build adaptive capacity in to the future (Juhola et al., 2017).

While agriculture is often described as a sector that is used to continuous adaptation to changing conditions, the consequences of adaptive actions taken by farmers are seldom scrutinized (Hildén et al., 2005; Lemieux and Scott, 2011; Vermeulen et al., 2013; Ncube-phiri, Mudavanhu and Mucherera, 2014; Kongsager, Locatelli and Chazarin, 2016). While climate change adaptation research in the Nordic context has advanced significantly in recent years (Klein and Juhola, 2014), less work has been done on the risk of maladaptation, that is, the unintended negative consequences of adaptation policies and measures (Adger, Lorenzoni and O'Brien, 2009; Dow et al., 2013; Juhola et al., 2016; Magnan et al., 2016). According to Barnett and O'Neill (2010, p. 211), maladaptation is 'action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups'. It also includes adaptation actions with high opportunity costs that reduce the incentives to adapt or lead to unsustainable path dependencies (Barnett and O'Neill, 2010). Rather, the current adaptation literature focuses on examples of successful adaptation (Moser and Boykoff, 2013). Frequently, this literature features examples of successful adaptation as a synonym for the successful implementation of adaptation policies and measures, while not addressing to what extent actors involved in adaptation or parts of the agricultural system might experience the positive or negative effects of adaptation, nor does the literature address the geographic or temporal dimensions of these effects.

Recognizing that the outcomes of any adaptation measure do not always correspond to the intended goal, this study identifies maladaptation in Nordic agriculture by assessing unintended negative consequences. We apply an integrated analysis of the degree of adaptation (Rickards and Howden, 2012) to evaluate practices and observed or predicted maladaptive outcomes. The findings of this study can support the development of adaptation strategies so that the risks of maladaptation are already considered in the design phase. More broadly, operationalizations of the maladaptation concept, as in this study, contribute both to the theoretical development of adaptation research, as well as to an expansion of the methodological approaches and empirical knowledge on the unintended negative consequences of adaptation.

2. Analytical framework and methods

Empirical research on adaptation measures has increased significantly in the last decade, as has the conceptual basis for understanding those measures. Much effort has been expended on understanding why, how and under which conditions adaptation takes place within European agriculture (Bindi and Olesen, 2011; Bizikova et al., 2014). This study links to this literature, examining implemented or proposed adaptation measures and in particular the subsequent question regarding its consequences.

2.1. Analytical framework

Howden et al. (2010) differentiate three types of adaptation practices depending on whether the associated change is incremental, systemic or transformational. Incremental adaptation refers to practices that do not change the system itself, but merely some of its elements (e.g. changes in planting times or nutrient management). Systemic adaptation implies fundamental changes in the farm system (e.g. diversification and new crop types). Finally, transformational climate change adaptation in agriculture refers to 'major, purposeful action undertaken at the farm or supra-farm level in response to potential or actual climate change impacts and opportunities in the context of other drivers' (Rickards and Howden, 2012, p. 240). Such practices involve changing the goals or location of agricultural activities and are associated with higher complexity, costs and risk (e.g. a shift from cereal crop production to short rotation forestry) than incremental or systemic adaptation practices (Howden et al., 2010; Rickards and Howden, 2012). A related study of Nordic agricultural adaptation showed that Nordic farmers are already taking incremental measures and that there are some examples of longer-term transformative measures to capitalize on climate change impacts (Juhola et al., 2017).

So far, the outcomes of many adaptation measures remain however little known and under-researched. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) states that there is a consensus that maladaptation is to be avoided, but there is less agreement on what it is precisely (Noble et al., 2014, p. 28). There are a number of challenges related to the assessment of maladaptation, including a lack of yardsticks, varying circumstances, and the role of subjective judgment (Granberg and Glover, 2013:4). Magnan et al. (2016) point out that previous assessments of maladaptation are mainly *ex post facto* and stress the need for *ex ante* approaches to identify expected maladaptive outcomes, asking the question 'could this adaptation initiative have unintended consequences'.

This study follows up on the redefinition of the maladaptation concept by Juhola et al. (2016) and distinguishes between the three types of maladaptation according to their potential negative impact on either the targeted actor, other actors or sectors, or the common pool. The latter category refers to actors or sectors or the environment outside the farm enterprise itself. Maladaptive effects on this 'common pool' may effectively undermine sustainable development (Juhola et al., 2016).

In applying this framework to identify maladaptive outcomes as a result of farmer actions, we defined the system of interest as a particular farm with its geographical boundaries and the farmer's personal decision-making. Further, we identified examples of negative outcomes of adaptation actions, and categorized them according to the framework regarding 'for whom, where and when', based on interviews in which we asked farmers to describe potential negative outcomes. Finally, we also used cases recognized in the reviewed literature on climate adaptation in Nordic agriculture.

2.2. Methods

The two-tiered approach adopted in this study draws on material from a systematic literature review of Nordic agriculture under climate change and interviews with farmers, extension officers and agricultural decision-makers in Sweden and Finland. Examples of maladaptation, potentially maladaptive activities, and the risks of maladaptive outcomes were thematically analyzed and coded in relation to the type of maladaptive outcome.

The systematic literature review (Khan et al., 2003) comprises peer-reviewed articles and grey literature on climate change related challenges and opportunities as well as adaptation strategies for crop production in Nordic countries. The selection criteria were that the publications had to concern one or several Nordic countries, the agricultural system, climate change or climate risks, and adaptation. The search was performed[1] using the following databases: Web of Science, Environmental Sciences, Pollution Management, Scopus, Agricola, Google Scholar and Norart and publication dates between 2000 and 2017. In addition, a Google Search was performed in Finnish and Swedish. As the specific query including the search term maladaptation (maladapt*) did not provide any results, publications that covered the entire field of climate change and agriculture were included in the analysis. In an initial search, approximately 160 articles were selected based on keywords or titles. After a second reading, only 60[2] of these articles fulfilled the criteria of addressing agricultural issues in combination with climate-related impact and/or adaptation in one or several of the Nordic countries. These 60 articles were considered relevant and selected for analysis. The literature review provides a generic picture of opportunities and challenges with adaptation strategies in agriculture based on examples from the Nordic region. Each of the selected publications was assessed for examples that refer to any type of maladaptation in terms of marking a potential negative outcome or trade-off as a result of climate adaptation. These identified examples or results were then coded for what type of adaptation measures they were related to and regarding the type of maladaptive outcome.

In order to provide more detailed information regarding adaptation measures and potential maladaptive outcomes, semi-structured interviews (Denscombe, 2007) were conducted during spring and summer of 2015 in Östergötland, Sweden and Uusimaa, Finland, two regions where climate change is already recognized as having both negative and positive impacts on agriculture. While these interviews aimed to explore further examples and perspectives on climate adaptation and potential maladaptive outcomes, the study was not designed to allow for any comparative analysis between the two regions. For the interviews, we selected Swedish stakeholders from Östergötland County and Finnish stakeholders from Uusimaa County with a specific focus on grain agriculture, and on average sized farms, cultivating mostly the main crops of the respective areas. Stakeholders included farmers and extension officers (including county officials, agricultural advisors, as well as representatives of farmers' unions). In both counties, the selection process was conducted by first using a theoretical sampling design, followed up by snowballing sampling (Warren, 2002), aiming to respect the age, gender and orientation (organic/conventional) balance of the agricultural stakeholders in the study region. The total number of stakeholders and their background is summarized in Table 1.[3]

The semi-structured interview format allowed interviewees to discuss the selected topics and also to raise additional issues during the discussion. This design was specifically selected to support the stakeholders in describing their line of thought in relation to climatic challenges and adaptation measures and the potential maladaptive outcomes without the guidance of a predefined theoretical framework. The time and place for the interviews was selected based on the stakeholders' preferences, to make them at ease in the interview situation. The interviews lasted approximately 30–60 min and were audio-recorded and transcribed. The transcripts were then analyzed for direct or indirect mentions of maladaptive outcomes of adaptation actions, and were subsequently coded for the type of adaptation action and maladaptive outcome. Both the literature excerpts and interview transcripts were subjected to a thematic analysis (Kvale and Brinkmann, 2009), using the deductive process of identifying examples of the types of maladaptation as specified by Juhola et al. (2016). We further applied the previously mentioned framework developed by Howden et al. (2010) to distinguish the degree of adaptation for each of the identified examples (see Table 2).

2.3. Study area

The Swedish region, Östergötland, has a total land area of 1 055 943 ha, of which agricultural land covers 19% (201 255 ha) and of which forested land covers 55% (Jordbruksverket, 2016). The agricultural soils are typically fertile clay/coarse silt. A wide variety of crops are grown, but winter wheat is the most important cereal in terms of yield, while table potatoes are also an important crop. Östergötland County is the third largest producer of winter wheat and the fourth largest producer of table potatoes among the Swedish counties.

Uusimaa is the county of the capital region of Finland and is thus largely urban. Nevertheless, agricultural lands cover 19% (180 825 ha) and forests 66% of the total land area (909 733 ha). The main crops, excluding fodder, are spring wheat, barley and oats, and

[1] The generic search included the following string (Agricult* OR Crop* OR farming) AND Climate AND (risk OR hazard OR stress OR impact OR vulnerability OR effect) AND (adaptation OR action OR response) AND (Nordic OR Scandinavia OR Norway OR Sweden OR Denmark OR Finland) in addition, the specific string (Agriculture* OR Crop* OR farming) AND maladaptation AND (Nordic OR Scandinavia OR Norway OR Sweden OR Denmark OR Finland) was tested but did not lead to any relevant results.

[2] For the full list of reviewed publications see Annex I.

[3] For the interview guide, please see Supplementary Material II.

Table 1
List of respondents.

	Östergötland, Sweden	Uusimaa, Finland
Extension Officers	County Officials (n = 2) Agricultural Advisors (n = 2) Representative of Farmers Union (n = 1)	County Officials (n = 2) Agricultural Advisors (n = 2) Representatives of Farmers Union (n = 2)
Farmers	Organic and Conventional Farmers, mainly wheat (n = 2) Conventional Farmers, mainly potatoes, wheat and barley/rye (n = 2) Conventional Farmer, mainly wheat and vegetables (n = 1)	Organic Farmer, mainly rye and wheat (n = 1) Conventional Farmers, mainly oat, wheat, rye and barley (n = 5) Conventional Farmer, mainly strawberries and varying grains (n = 1)

nationally Uusimaa is the second largest county to produce wheat and broad bean, and third largest producer of barley and rye. Agricultural soil in the area is mostly clayey and more than 20% of the agricultural fields have a slope of more than 5%. The region is thus classified as the highest erosion risk area in Finland (Ministry of Agriculture and Forestry, 2004). Intensification of agriculture, the erosion risk and a long coastline (1200 km) leave agriculture in Uusimaa vulnerable to the impacts of climate change.

3. Results

Examples from the Nordic countries specifically feature adaptation policies or measures that respond to challenges resulting from increased precipitation and changes in temperature, as well as measures that are aimed at grasping opportunities resulting from rising temperatures and the resulting prolonged growing season. Potential maladaptive outcomes were not explicitly addressed by respondents or in the literature but were rather implicitly described in the context of adaptation in terms of possible unintended negative effects, or trade-offs that require consideration when selecting adaptation measures. As trade-offs are frequently identified when discussing the implementation of adaptation measures, Fig. 1 suggests that possible trade-offs might be neglected in adaptation research that solely focuses on criteria and narratives for successful adaptation.

As several of the adaptation policies and measures are still in the planning stage or have only recently been implemented, the maladaptive outcomes are predominantly expressed as potential risks or single observations. These are, nevertheless, indicative of potential developments and it is important to take note of them when planning future policy interventions or guidelines.

The adaptation measures identified correspond predominantly to four different climate change related impacts: a longer growing

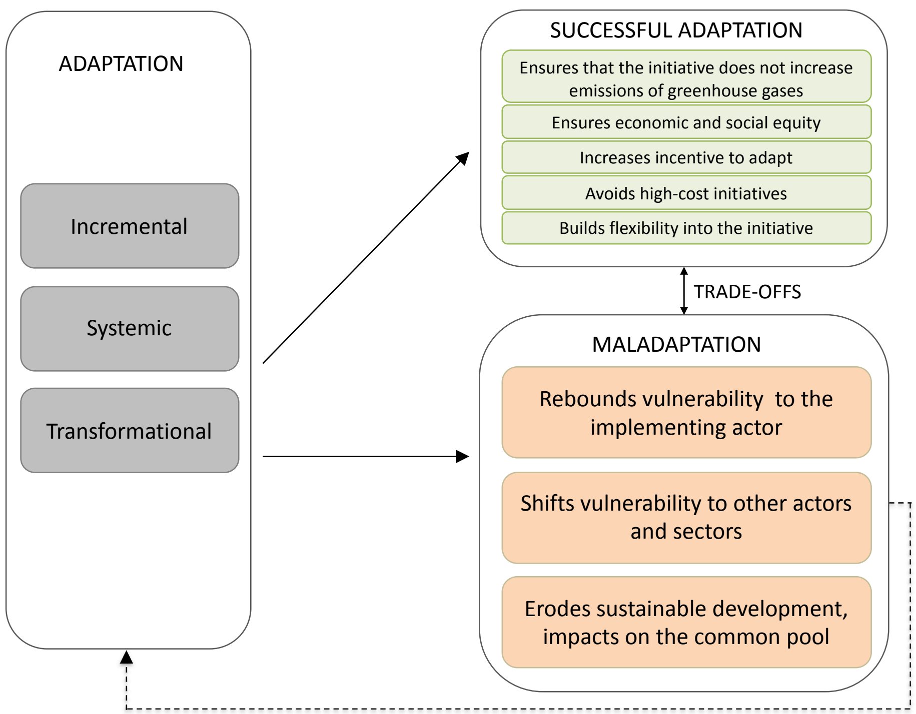

Fig. 1. Adaptation pathways based on frameworks of adaptation from Rickards and Howden (2012), maladaptation from Juhola et al. (2016) and successful adaptation from Magnan et al. (2016) in which maladaptation may lead to new adaptation actions and trade-offs between successful adaptation and potential maladaptive outcomes need to be considered.

season, increased precipitation and flooding, more pest and weed infestations, as well as rising temperatures and drought. Adaptation measures that address each of these factors were categorized as shown in Fig. 1 below.

For each of these adaptation measures, potential maladaptive outcomes that were mentioned in the reviewed literature or exemplified in the interviews were identified. The following sections describe these potential maladaptive outcomes and categorize them in accordance with the typology presented in Juhola et al. (2016). We also discuss the identified risks for maladaptive outcomes structured in accordance with the categorization of adaptation presented by Rickards and Howden (2012).

3.1. Rebounding vulnerability

The most frequently identified maladaptive outcome of adaptation measures within Nordic agricultural enterprises is an increase in costs, which in turn has a negative effect on the overall farm budget. The increased costs may be due to investment in technical equipment, to the need for more pesticides, or to infrastructural changes such as irrigation systems and drainage. Similarly, the increased use of fertilizers, either because of changing crops or because of increased use of marginal lands (see also 3.3) might affect the farm economy by creating higher costs. Common for most of these cases is that it concerns either a trade-off between the investment costs and the consequences of not implementing an adaptation measure at all. Frequently, the assessment of whether an increased cost should be considered as a maladaptive outcome of an adaptation measure relates to the time perspective in which an investment might turn into revenue or prove to decrease the risk of further losses to the farm enterprise. While increased costs may have a negative impact on the farm itself, they do not have maladaptive outcomes for other sectors or common pool resources.

Shifting from the currently grown crops to new crop types or varieties is commonly mentioned as an adaptation measure in the agricultural adaptation literature and came up repeatedly during interviews in both countries. Crops may be changed because of climate-related policies or as part of a move to optimize production efficiency in order to adapt to changing conditions or to capitalize on the potential of a longer growing season (Gregow et al., 2016). Changing crops may have a number of unintended, although not always unexpected, outcomes. Increased maize production might for instance demand a higher input of fertilizers, and increase the risk of pest and weed infestations. These infestations need to be prevented or combated either chemically or mechanically (Wivstad, 2010; Kvalvik et al., 2011), resulting in increased use of pesticides or soil compaction, which might in turn negatively affect the farm economy as well as the quality of the soil, water and food. Another potential maladaptive outcome is the risk of pests and weeds developing immunity to pesticides, a point that was raised both by Finnish respondents and in the literature (Wivstad, 2010). Such a development would influence both the implementing actor (rebounding vulnerability), as well as other actors (shifting vulnerability). Hence,

> It's a big challenge if pests become pesticide-resistant. On the other hand, our vulnerability could be increased if there are environmental restrictions on the usage of pesticides. (Finnish respondent, author's translation)

In relation to adapting to a longer growing season, Pulatov et al. (2015) discuss the trade-off between the possibility to plant and harvest potatoes in Finland up to one month earlier due to the warmer climate, which however might increase the risk of frost damage and result in a demand for investment in frost protection. Kaukoranta and Hakala (2006) draw similar conclusions in their study on sugar beets, cereals and potatoes in Finland and Eckersten et al. (2012) also discussed the potential influence of other parameters, such as water scarcity on crop yield in the Eastern parts of Sweden or varying quality for an northward extended production of silage maize. These cases exemplify the rebounding vulnerability as new challenges with growing conditions. Another commonly experimented adaptation measure among Finnish farmers is the cultivation of different winter-crops. This, however, remains risky economically-speaking for the farmer because of the fluctuating winter conditions, as many respondents had experienced and several studies have addressed (Peltonen-Sainio et al., 2009; Bergström et al., 2011; Carter, 2007).

Crop rotation is in the reviewed literature generally described as a positive measure with respect to soil structure, and was also addressed by a Finnish respondent, who pointed out that introducing a new crop is challenging in the beginning, and that planning of field work thus takes more time and effort. Similarly Himanen et al. (2016) identified a number of potential maladaptive outcomes for intercropping as an adaptation measure, including challenges in production, such as complications for crop management and harvesting, risks related to new practices, and limitations for own seed production.

Several infrastructural investments can be identified as responses to increased precipitation or more intense precipitation, as well as to the prospect of drought. Several of the examples that were discussed by farmers as well as in the literature refer to the construction or improvement of drainage systems. These are investments that affect a farm's budget. Drainage systems are also one of the recurring adaptive measures that can impact on common pool resources by increasing nutrient leakage or decreasing biodiversity (see 3.3) (Aura et al., 2006; Ministry of Agriculture and Forestry, 2012). Investment in drying equipment was mentioned by the interviewed farmers as an adaptation measure to cope with more rain at times when excessive precipitation causes management problems. However, this type of equipment can have a negative impact on the farm economy in terms of investment costs, as well as in relation to increased energy costs, and represents a buy-in to a specific technical solution (Williams et al., 2010).

> You reap the grain and transport it to a barn and blow hot air on it. (…) It takes a lot of energy, usually a fossil fuel in the form of diesel and oil, to make the drying machine work. So from one year to another, I can spend twice as much on energy and fuel for drying my grains. (Swedish respondent, author's translation)

To address the increasing occurrence of droughts during the growing season, Swedish respondents mentioned the possibility of investing in irrigation systems. Although different technical (and logistical) solutions were mentioned, the potential maladaptive outcomes discussed by the respondents were similar, featuring both high investment costs and a potential lowering of groundwater levels.

Economic losses might also occur because of measures taken to cope with heavy precipitation causing problems when harvesting. Measures that were mentioned included simply leaving the crop unharvested, reducing activities in the field to the minimum, or only tilling when necessary to avoid soil compaction. Unharvested crops are a direct economic loss, but decreased soil tillage will also increase the risk of pests and weeds, which in turn may lead to harvest loss or the need for increased pesticide use (Wivstad, 2010). On the other hand, several respondents referred to the decreased cost of energy and labor in relation to the loss of income if the crop is not harvested. One of the Finnish farmers, who left his fava bean crop unharvested because of too wet conditions, found the outcome only slightly negative because he could use the crop as green manure and save fertilizer costs in the next year.

Other potential maladaptive outcomes related to changed practices to meet the challenge of increased heavy precipitation were 'breaking the crust in spring with a harrow' when thawing was followed by heavy rainfall and subsequent 'strong sunshine', as described by a Finnish farmer, or the generic notion of increasing tillage. Both of these practices may however lead to increased soil compaction by tractors (Jordbruksverket, 2013; Uleberg et al., 2014), which leads to negative impacts on the production conditions. Similarly, the common practice of structural liming to decrease nutrient leakage may contribute to soil compaction if a tractor has to go into a wet field. Reducing the fieldwork to avoid soil compaction, for example by leaving out manure spreading, was one of the issues mentioned by a Finnish respondent, and could result in nitrogen deficiency – which in turn would be a significant maladaptive outcome on the farm level.

Another challenge raised by the respondents is the trade-off between environmental and economic goals is the implementation of buffer zones to avoid nutrient leakage in response to increased precipitation. As the implementation of this measure might lead to a loss of arable land, it could in turn affect the availability of productive land for individual farms. In the Finnish case, the policy reform of environmental subsidies for buffer zones becoming economically more beneficial increased their implementation substantially (Koppelmäki and Kaasinen, 2015).

3.2. Shifting vulnerability

Adaptation measures may have implications not just for the implementing actor, but also for neighboring systems and other actors or sectors. Several examples of this could be identified in the literature on Nordic climate adaptation and were described by agricultural stakeholders for their very specific contexts. Several of these examples suggest the possibility of conflicting use of resources or collisions of infrastructure, and issues related to justice and legitimacy in rural areas regarding resource use which can bring up new challenges for local policies and communal organization (Sairinen et al., 2010).

In the interviews, infrastructural measures were mentioned more frequently as having a potential negative impact on others, particularly on geographically close or neighboring farms or sectors. Several farmers discussed the risk of drainage systems shifting higher water flows to other fields and affecting arable land. Similarly, the impact of intersections with a neighbor's drainage system or other older drainage was raised as a practical issue that might increase vulnerability and these issues are also raised in the literature, for example, by the Swedish board of agriculture (Jordbruksverket, 2013). Additionally, drainage systems can have negative impacts on wetland environments. However, Swedish regulations on protecting wetlands, currently impede the implementation of new drainage systems (Jordbruksverket, 2013).

The farmers mentioned a lowering level of groundwater as a potential negative consequence of building irrigation systems. Lower groundwater levels for irrigation in combination with droughts but even agricultural irrigation with surface water may create a vulnerable situation for agricultural production, access to drinking water, and might imply conflict between different types of usage (Bastviken et al., 2015; Jordbruksverket, 2017). In those cases, it is not only the farm sector that is vulnerable, but also basic civil infrastructure (Länsstyrelsen Skåne, 2014). However, the resulting competition for groundwater between sectors was not mentioned as a current problem by the farmers. Nevertheless, Swedish farmers addressed the need for more regionally integrated plans, where a conflicting use of surface water or dams, which might affect the availability of water for other usages, is an important reason.

> I use spring runoff to fill up my irrigation dam which costs a lot more (…), instead of simply drilling a hole in the ground to a water source like they do in the south of Sweden where they now have groundwater issues. (Swedish respondent, author's translation)

Several of the examples that would affect the implementing actor also have the potential to affect others. For example, the potential maladaptive outcome of increased use of pesticides to combat increased pests and weeds could affect others as well as the implementing actor through pests and weeds developing immunity to the applied chemicals (Wivstad, 2010; see also Section 3.1). The farmers mentioned another issue resulting from less tillage to compensate for increased risk of nutrient leakage, as a result of increased rainfall, namely that pests might overwinter and then affect an entire geographic area, and not just an individual farm (Stenrød et al., 2016). Moreover, the literature suggests that the use of new plant species, such as bioenergy crops, can cause environmental impacts connected with alien invasive species (Ministry of Agriculture and Forestry, 2014). Additional maladaptive outcomes that could affect surrounding farms were mentioned by Swedish respondents. Firstly, the increase in the number of pests might lead to them being spread by the wind from organic farms to conventional fields, and secondly, the increased use of pesticides on conventional fields could lead to pesticides being spread by the wind to neighboring organic farms.

3.3. Eroding sustainable development

Maladaptive outcomes that degrade the common pool in the context of Nordic agriculture are often related to environmental degradation such as increased emission of greenhouse gases, degradation of natural resources, and leakage of pesticides or nutrients to the aquatic environment.

Fogelfors et al. (2009) address the increased cultivation of maize in response to a longer growing season as a measure that can lead to decreased humus content when grassland is replaced. Furthermore, decreasing soil organic matter can increase greenhouse gas emission and thus contribute to rising atmospheric CO_2 concentrations, as well as decreasing the capacity of a soil to retain nutrients (e.g. Corsi et al., 2012; Qin et al., 2016). This particular aspect was not addressed by the respondents, but the value of soil organic matter in terms of mitigation and adaptation was raised.

Increased leakage of nutrients is not only depicted as a direct result of climate change (Huttunen et al., 2015) but also as a potential maladaptive outcome addressed by most of the interviewed farmers in Finland and Sweden, as well as in multiple studies on Nordic agriculture. In particular, improved drainage systems, including both subsurface and open systems, have been referred to as potential causes of increased nutrient leakage. Measures like subsoil plowing to increase soil infiltration and cope with increased amounts of water on the fields and droughts, as well as increased tillage in general terms, were also associated with increasing the risk of nutrient leakage both in the interviews as well as in the literature (Fogelfors et al., 2009; Jeppesen et al., 2010).

In Finland, the shift to underground drainage has diminished the biodiversity of agricultural areas as open ditches and their banks have disappeared (Ministry of Agriculture and Forestry, 2012). Furthermore, subsurface drainage can also affect the levels of soluble phosphorus in subsurface drainage waters, which can be very high in clayey soils (Aura et al., 2006).

Mechanical measures to prevent and combat pests and weeds, which imply increased tillage (Wivstad, 2010), have a similar potential impact with regards to increased nutrient leakage. Avoiding tillage to prevent nutrient leakage from increased precipitation may result in an increased need for pesticides, in turn leading to increased emissions of pesticides to surface water and ground water (Jordbruksverket, 2008). The respondents addressed these potential consequences and discussed the challenge of decreased tillage in organic farming. A Swedish respondent expressed the concern that using aggressive pesticides on crops to cope with the effects of climate change would have negative health impacts on the consumers who eat the produce. Food quality could be affected through decreased tillage because of accumulation of pesticides in the agricultural soil.

Another potentially maladaptive outcome that might negatively affect sustainable development is the increased use of fertilizer, which would be driven by increased nutrient losses in the soil due to increased precipitation, which in turn would result in lower yields, suggesting a need for more fertilization (Eckersten et al., 2001). An increased need for fertilizer could also be caused by a shift towards more fertilizer-intensive crops such as maize (Leip et al., 2008) or by expansion of production on previously unused or marginal lands. Such increased use of fertilizer might not only raise the overall budget and contribute to nutrient leaching from agricultural production (Fogelfors et al., 2009), but could also affect the sustainable management of finite resources such as phosphorus (Neset and Cordell, 2012), and affect energy consumption related to the production and trade of chemical fertilizers. The respondents did, however, not discuss these aspects of increased use of fertilizers.

Several measures that were mentioned in the literature and raised by the respondents involved increased energy use in farm management, for example, the increased mechanical treatment of the soil as well as practices such as liming, drainage and organic farming (Ministry of Agriculture and Forestry, 2014). While these measures can be part of well-planned sustainable production, there are certain economic and environmental efficacy improvements that require consideration. However, the Nordic farmers interviewed spoke of this mainly in terms of increased costs to the farm enterprise, and thus rebounding vulnerability to the implementing actor, rather than as an environmental impact.

4. Side-stepping maladaptation in Nordic agriculture

This study has identified several potential maladaptive outcomes that need to be addressed in the near future. Although several of those outcomes have not yet been experienced, and several adaptation measures are currently only being considered as possible measures to address future changes, this assessment of unintended negative impacts provides us with a baseline for consideration and planning.

The maladaptive outcomes that were identified in this study frequently focused on their effect on the implementing actor, that is, the farmer or the farm enterprise. These outcomes often relate to increased costs, losses or impaired soil conditions. While few of the respondents reflected on outcomes that would shift vulnerability to others – whether referring to neighbors or other stakeholders or sectors, the environmental impacts of adaptation measures were more frequently discussed and exemplified.

As shown in Table 2, most of the adaptation practices or strategies for Nordic agriculture identified in the literature and interviews were incremental. This is hardly surprising since significant changes have not been recognized in Nordic agriculture so far (Juhola et al., 2017), and few climate adaptation practices have been implemented. Many of these are common practice, for example, optimizing conditions on the field or avoiding the risk of harvest losses. While significant work has been done to remove excess water from agricultural fields, less attention has been paid to the opposite effect, that is, the increased frequency of droughts. In general, incremental changes like investments in technical equipment, increased use of pesticides or fertilizer, or minor changes in practice were more prominent in the narrative of farmers and extension officers than experiences or reflections regarding systemic or transformational adaptation.

Several of the adaptation practices and strategies identified (see Table 2), have potential maladaptive outcomes of more than one type. For example, outcomes related to the use of pesticides and nutrients affect both the implementing actor in terms of increased costs and decreased soil quality (pesticides), but also common pool resources by potentially decreasing water quality and leading to eutrophication.

It is also apparent that all of the adaptation measures that may lead to negative outcomes involve some kind of trade-off between

Table 2
Description and categorization of adaptation and potential maladaptive outcomes.

Adaptation level[a]	Adaptation practice or strategy	Maladaptation	Type of maladaptive outcome[b]
Incremental	New technical equipment (e.g. drying equipment)	Negative impact on farm economy; investment cost and energy cost	Rebounding vulnerability
		GHG emissions from increased energy use	Eroding SD
	Increased fertilizer use as a result of increased precipitation and production on more marginal land	Negative impact on farm economy	Rebounding vulnerability
		Eutrophication	Eroding SD
		Increased GHG emissions	Eroding SD
	Structural liming	Soil compaction	Rebounding vulnerability
	Buffer zones to avoid nutrient leakage	Loss of agricultural area	Rebounding vulnerability
	Increased use of pesticides to combat the increased risk of pest and weeds with wetter and warmer climate	Negative impact on farm economy	Rebounding vulnerability
		Negative impact on soil quality	Rebounding vulnerability
		Negative impact on water quality	Eroding SD
		Negative impact on food quality	Rebounding and Shifting vulnerability
		Risk of immunity of pests and weeds to chemical plant protection products	Shifting vulnerability
	Reducing activities on fields to a minimum due to heavy precipitation, to reduce the risk of soil compaction and damaged crops	Negative impact on farm economy	Rebounding vulnerability
		Decreased use of labor	Shifting vulnerability
		Creates undisturbed environment for pests and weeds	Rebounding and shifting vulnerability
	Increased tillage as a measure to combat pests and weeds	Nutrient leakage, eutrophication	Eroding SD
		Soil compaction by tractors	Rebounding vulnerability
	Subsoil plowing to reduce drought sensitivity	Nutrient leakage	Eroding SD
		Soil compaction by tractors	Rebounding vulnerability
	Reduced tillage to prevent nutrient leakage from increased precipitation	Increasing the risk of pests and weeds (see also *Increased use of pesticides …*)	Rebounding and shifting vulnerability
		Negative impacts on soil drainage	Rebounding vulnerability
Systemic	New drainage system	Negative impact on farm economy	Rebounding vulnerability
		Depleting wetlands	Shifting vulnerability/ Eroding SD
		Shift of flooded area	Shifting vulnerability
		Increased nutrient leakage & GHG emissions	Eroding SD
	New irrigation system	Negative impact on farm economy	Rebounding vulnerability
		Negative impact on groundwater levels – agricultural production	Rebounding vulnerability and Shifting vulnerability
		Negative impact on groundwater levels – access to drinking water	Shifting vulnerability
	New crop types	See *Increased use of pesticides …*	
		See *Increased fertilizer use …*	
		Degrading humus content	Rebounding vulnerability
		Increased GHG emissions	Eroding SD
Transformational	Reform policies and directives for water installations which currently focus on sustainable water environments to also target sustainable food production	Negative impacts on wetlands and other valuable water environments	Shifting vulnerability
	Shift from conventional to organic production	Negative impact on farm economy	Rebounding vulnerability
		Negative impact on neighboring areas (increased use of pesticides of conventional farmers next to organic fields with increased risk of disease)	Shifting vulnerability

[a] From Howden et al. (2010).
[b] That is, Rebounding vulnerability, Shifting vulnerability, and Eroding Sustainable Development (SD) (Juhola et al., 2016).

the intended positive effect of the measure and the potential maladaptive outcome. Awareness of this trade-off and increased knowledge of the severity and additional costs or impacts that these maladaptive outcomes might involve can contribute to some degree to more informed decision-making. For example, in the case of responding to increased precipitation, an incremental measure of establishing buffer zones involve a trade-off between improving the avoidance of nutrient leakages and loosing agricultural land. On a systemic adaptation level, the implementation of new drainage systems involves a trade-off between enhancing drainage on the fields and, depending on the context, challenges in economic (investment on the drainage system), ecological (impact on nearby wetlands) or social (shifting the flooded areas to neighbor's fields) sphere. Furthermore, going beyond the local farm horizon (rebounding vulnerability) and including negative effects on other sectors and actors (shifting vulnerability), as well as effects on the common pool (eroding sustainable development) provides a basis for reflection and evaluation regarding potential trade-offs. As the knowledge base regarding adaptation practices and strategies grows with the changes experienced both in the Nordic countries and elsewhere, continuous assessments to ensure timely support for farmer's decision-making will be essential.

5. Conclusion

This study assesses the potential negative outcomes of adaptation measures that are either being implemented or considered for implementation, ranging from immediate actions to cope with sudden events to long-term planning and considerations to decrease overall vulnerability or to take advantage of potential benefits of climatic changes. While most adaptation measures that are already being implemented would be characterized as incremental, there are a number of measures that were identified that could be categorized as systemic or transformative. These measures could be associated with negative consequences that represent all three dimensions of maladaptation, where the most significant proportion of examples were negatively affecting the implementing actor (rebounding vulnerability). This finding might partly be due to economic considerations associated with any type of incremental or systemic change, or it could also indicate a lack of reflection regarding wider trade-offs that affect other actors or sectors as well as sustainable development in general, including environmental, social or economic impacts.

Our findings have implications for adaptation within agriculture, as well as adaptation research more generally. First, the results of this study contribute to the understanding of how the Nordic agricultural sector seeks to avoid unintended negative effects by implementing adaptation practices and strategies in both the short and long term. However, these limited case study findings give only a preliminary understanding of what types of unintended consequences these kinds of measure may have, and over what time periods. Day to day management decisions are important for farm level adaptation but longer terms strategies are also needed, supported by policy, and for that more empirical research on maladaptation within agriculture is necessary. Second, this study contributes to the empirical literature on the consequences of the implementation of adaptation policies and measures and to what extent it can have negative consequences and to whom. To gain a better understanding of maladaptation, it needs to be operationalized through the use of different frameworks and methods in different contexts and sectors. Eventually this may contribute to acknowledging and avoiding maladaptive outcomes in adaptation policy and planning, and provide structures for supporting and developing adaptation decision-making.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crm.2018.12.003.

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